The objective of the current study is to investigate the effect of rotational alignment of the femoral and tibial components on evaluation of outcomes using The 2011 KSS.

Materials and Methods

This study includes 75 Japanese patients (92 knees) after primary posterior cruciate ligament-substituting (PS) TKA (NexGen LPS-Flex Fixed Bearing Knee system, Zimmer, Warsaw, Ind, USA, which was approved by the United States Food and Drug Administration) who answered a questionnaire containing all patient-derived components of The 2011 KSS, and who had full leg-length computed tomography (CT) scans both preoperatively and postoperatively. Patients with revision arthroplasties, patients bedridden for reasons other than knee surgery, and those who underwent another surgical procedure during the study period were preliminarily excluded. Preoperative diagnosis was osteoarthritis in all patients. This study was approved by the institutional review board. Informed consent for participation was obtained from all patients.

Summary and evaluation of the questionnaire of The 2011 KSS

The subjective score of The 2011 KSS has three questions for symptoms, five questions for satisfaction, three questions for expectations and 18 questions for functional activities (including five questions for walking and standing, six questions for standard activities, five questions for advanced activities and two questions for discretionary activities) [20,21], which can evaluate the postoperative condition much more specifically than The 1989 Knee Society Clinical Rating System [8]. Questionnaires containing all patient-derived components of The 2011 KSS were sent to the patients' home addresses. They were answered at home, without physicians, and were returned to our hospital. The minimum follow-up of all patients was one year (mean, 3.9 years; range 1.1–8.6 years). No patients were recalled specifically for this study.

All questions were scored according to values specified in The 2011 KSS and total scores in each category (symptoms, satisfaction, expectations and functional activities) were calculated. In the category of functional activities, answers about discretionary activities were completed only in 35 knees (52.2%). Therefore, the total score for functional activities was calculated excluding the score for discretionary activities in this study. In functional activities, three detailed items (walking and standing, standard activities and advanced activities) were also calculated.

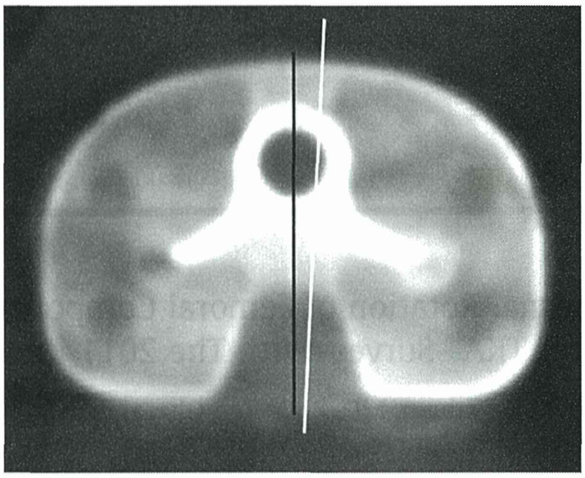

Fig. 2. Rotational alignment of the tibial component was assessed by measuring the angle between the AP axis of the tibia described by Akagi et al (white line) and the AP axis of the tibial component (black line).

Scanning procedure for CT images and measurement of the alignment of femoral and tibial components

The patients were placed in the supine position on the table and the affected knee was naturally extended without any feeling of internal or external rotation. Transverse CT scans were taken at levels ranging from the hip joint to the ankle joint at 2-mm intervals both preoperatively and postoperatively. CT images were acquired as DICOM data from the CT system server. A three-dimensional (3D) image of the lower extremity was reconstructed on the computer using the program 3D template (version 02.02.02, Japan Medical Matls. Corp., Osaka, Japan).

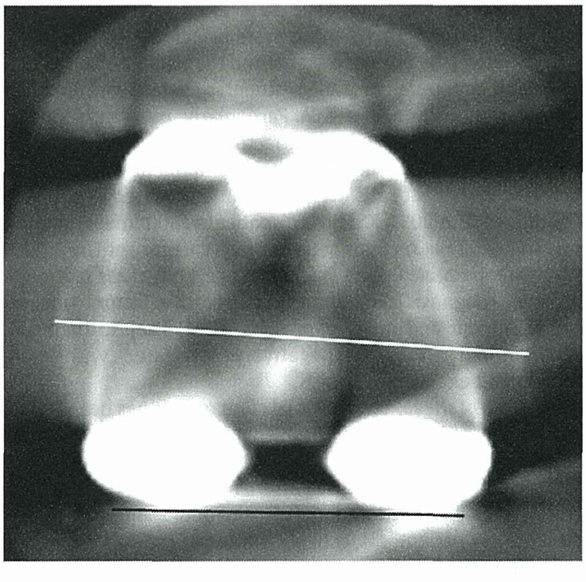

Fig. 1. Rotational alignment of the femoral component was assessed by measuring the angle between the SEA (white line) and the line joining the posterior margins of the femoral component (black line).

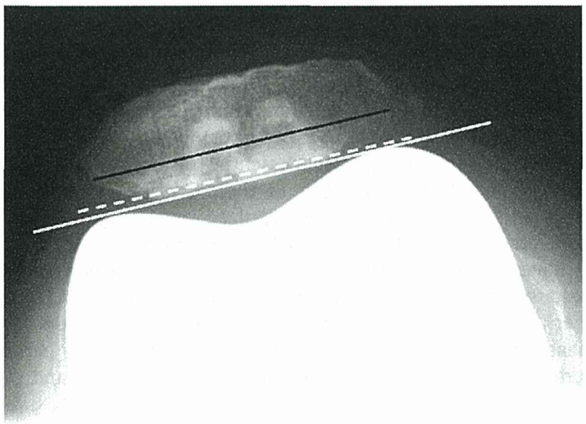

Fig. 3. The patellar component-tilting angle was defined as the angle between a line from the anterior limits of the femoral condyles (white solid line) and a line drawn through the patellar prosthesis-bone interface (white broken line). The patellar bone-tilting angle was defined as the angle between a line from the anterior limits of the femoral condyles (white solid line) and a line drawn from the posterior limits of the articular surfaces of the medial and lateral facets of the patella (black line).

Table 1
Patient Details of Groups Classified Based on the Rotational Alignments of the Femoral and Tibial Component.

	Femoral Component Rotation				Tibial Component Rotation			
	Fc ER (n = 4)	Fc NR (n = 51)	Fc IR (n = 12)	Significance	Tc ER (n = 18)	Tc NR (n = 36)	Tc IR (n = 13)	Significance
Rotational alignment	3.8° ± 0.7° external rotation	0.4° ± 1.4° internal rotation	3.7° ± 0.7° internal rotation		8.8° ± 3.5° external rotation	0.6° ± 2.7° internal rotation	8.9° ± 2.6° internal rotation	
Age (yr)	74.8° ± 2.2	75.1 ± 6.3	76.8 ± 7.1	n.s	74.9 ± 5.6	75.2 ± 7.2	76.4 ± 4.5	n.s
BMI	25.8° ± 5.6	25.1 ± 2.6	27.5 ± 4.0	n.s	25.4 ± 3.2	25.8 ± 3.5	25.3 ± 1.9	n.s
Hip-Knee-Ankle (HKA) angle	0.1° ± 2.1° valgus	0.8° ± 1.7° varus	0.3° ± 1.4° varus	n.s	0.8° ± 1.4° varus	0.6° ± 1.8° varus	0.6° ± 1.7° varus	n.s
Postoperative ROM	117.5° ± 5.0°	120.7° ± 17.0°	115.8° ± 19.4°	n.s	120.3° ± 22.5°	119.2° ± 15.0°	120.0° ± 14.0°	n.s

n.s; not significant.

First, postoperative hip–knee–ankle (HKA) angle was measured on CT images. As the postoperative varus alignment could negatively affect some categories of The 2011 KSS [22], patients with postoperative coronal malalignment more than 3° were excluded from this study [32]. Finally, 58 patients (67 knees) were included in this study.

Second, postoperative rotational alignments of femoral and tibial components were measured. On the femoral side, the rotational axis was defined as the surgical epicondylar axis (SEA), which was the line connecting the tip of the lateral epicondyle to the medial epicondylar sulcus [33,34]. In 13 knees, the medial epicondylar sulcus could not be recognized on CT scans. In these subjects, the clinical epicondylar axis (CEA) connecting the most prominent point of the medial epicondyle and the lateral epicondyle was identified, and the SEA assumed as a line rotating the CEA internally by 3° [35,36]. Rotational alignment of the femoral component (Fc) was assessed by measuring the angle between the SEA and the line joining the posterior margins of the femoral component (Fig. 1). All patients were classified into three groups based on rotational malalignment of 3°; normal rotation (Fc NR), external rotation (Fc ER) and internal rotation (Fc IR) [37]. On the tibial side, the rotational axis was defined as the anteroposterior (AP) axis of the tibia described by Akagi et al, which was the line connecting the middle of the PCL at the tibial attachment to the medial border of the patellar tendon at the attachment level [38,39]. As the middle of the PCL at the tibial attachment could not be identified on the postoperative CT, the AP axis of the tibia was identified on the preoperative CT and projected accurately to the postoperative CT. Rotational alignment of the tibial component (Tc) was assessed by measuring the angle between the AP axis of the tibia and the AP axis of the tibial component (Fig. 2). Barrack et al described that there was a highly significant difference in tibial component rotation between the two groups with the patients with anterior knee pain averaging 6.2° internal rotation compared with 0.4° external rotation in the control group [40]. Therefore, all patients were classified into three groups based on rotational malalignment of 5°; normal rotation (Tc NR), external rotation (Tc ER) and internal rotation (Tc IR). All the angles were measured in the computer program 3D template and the program allowed one decimal. Whether the rotational malalignment of each component affects each category of The 2011 KSS was identified.

Measurement of the postoperative PF alignment

The PF joints were evaluated in skyline view radiographs taken with the knees at approximately 60° of flexion [41]. Postoperative PF alignment was evaluated at final follow-up measuring the patellar component-tilting angle and the patellar bone-tilting angle (Fig. 3) [42,43]. The patellar component-tilting angle was defined as the angle between a line from the anterior limits of the femoral condyles and a line drawn through the patellar prosthesis–bone interface. The patellar bone-tilting angle was defined as the angle between a line from the anterior limits of the femoral condyles and a line drawn from the posterior limits of the articular surfaces of the medial and lateral facets of the patella. Whether the rotational malalignment of each component affects postoperative PF alignment was identified.

Statistical analysis

All the measurement procedures were repeated three times at least a week apart by one examiner (SK) for all patients and the average of three measurements was adopted as the data. Preoperative factors including age and BMI, postoperative factors including HKA angle and ROM, and scores of each category of The 2011 KSS were compared among the groups of femoral and tibial component malrotation, respectively, using ANOVA with a Tukey–Kramer post hoc test. JMP 9.0 (SAS Institute Inc, Cary, NC, USA) was used to analyze the data. Significance was set at a P value of < 0.05.

To evaluate intraobserver and interobserver reproducibility, the measurements were performed three times by one examiner (SK) and once by two examiners (HN, SO) on 10 knees randomly selected from the study group. The intraclass correlation coefficient and the interclass correlation coefficient were 0.89 and 0.75 for measurement of the femoral component rotational angle, 0.92 and 0.88 for measurement of the tibial component rotational angle, 0.91 and 0.85 for measurement of the patellar component-tilting angle, and 0.90 and 0.81 for measurement of the patellar bone-tilting angle.

Results

The preoperative and postoperative parameters for each group are shown in Table 1. None of them was significantly different.

Table 2
Scores of Each Category of The 2011 KSS Between Groups Classified Based on the Rotational Alignments of the Femoral and Tibial Component.

	Femoral Component Rotation				Tibial Component Rotation			
	Fc ER (n = 4)	Fc NR (n = 51)	Fc IR (n = 12)	Significance	Tc ER (n = 18)	Tc NR (n = 36)	Tc IR (n = 13)	Significance
Symptoms (25)	17.0 ± 5.9	20.3 ± 4.7	17.3 ± 5.7	n.s	18.6 ± 5.9	20.3 ± 4.6	19.4 ± 4.4	n.s
Satisfaction (40)	21.0 ± 3.8	24.8 ± 6.4	19.8 ± 5.6	n.s	21.9 ± 5.1	25.5 ± 6.7	21.1 ± 6.1	n.s
Expectations (15)	8.7 ± 2.5	10.8 ± 2.1	10.0 ± 3.3	n.s	10.6 ± 2.7	10.4 ± 2.1	11.3 ± 3.0	n.s
Functional activities (85) (except discretionary activities)	45.0 ± 17.2	52.4 ± 17.7	36.7 ± 13.0	NR > IR ($P = 0.029$)	50.8 ± 16.0	49.5 ± 19.8	48.3 ± 14.9	n.s

n.s; not significant.

Table 3
Scores of Each Detail of Functional Activities (85) Between Groups Classified Based on the Rotational Alignments of the Femoral and Tibial Component.

	Femoral Component Rotation				Tibial Component Rotation			
	Fc ER (n = 4)	Fc NR (n = 51)	Fc IR (n = 12)	Significance	Tc ER (n = 18)	Tc NR (n = 36)	Tc IR (n = 13)	Significance
Walking and standing (30)	18.8 ± 7.9	20.4 ± 9.7	16.6 ± 8.9	n.s	19.4 ± 9.9	19.4 ± 10.0	20.8 ± 7.6	n.s
Standard activities (30)	20.3 ± 5.9	22.1 ± 5.4	16.1 ± 6.2	NR > IR (P = 0.004)	20.7 ± 6.3	21.4 ± 5.9	19.7 ± 6.1	n.s
Advanced activities (25)	6.0 ± 5.4	10.3 ± 6.5	5.0 ± 3.7	NR > IR (P = 0.028)	10.8 ± 4.9	9.1 ± 7.3	6.8 ± 4.7	n.s

n.s; not significant.

Scores of each category of The 2011 KSS are shown in Table 2. In the category of functional activities, the score of the Fc IR group was significantly lower than that of the Fc NR group ($P = 0.029$). In the category of satisfaction, the score of the Fc IR group was slightly lower than that of the Fc NR group, but not significantly different ($P = 0.062$). In the categories of symptoms and expectations, scores were not significantly different among groups for femoral component malrotation. In all categories of The 2011 KSS, scores were not significantly different among groups for tibial component malrotation.

Scores for each detail of functional activities are shown in Table 3. In the categories of standard activities and advanced activities, the scores of the Fc IR group were significantly lower than those of the Fc NR group ($P = 0.004$ and $P = 0.028$, respectively). In the categories of walking and standing, the scores were not significantly different among groups for femoral component malrotation. In all categories of functional activities, scores were not significantly different among groups of tibial component malrotation.

The patellar component-tilting angle and the patellar bone-tilting angle are shown in Table 4. None were significantly different among groups for femoral or tibial component malrotation.

Discussion

Patient satisfaction has been focused on the quality of life after TKA [14,16]. Expectations of postoperative activities by younger and more active patients have been higher, and their activities more diverse [19]. The 2011 KSS was developed as a new scoring system to better characterize the satisfaction, expectations, and physical activities of patients who underwent TKA [20,21]. Surgeons should know which factors related to their surgical techniques affect patients' subjective outcomes. As far as we know, there is no literature on the effect of rotational alignment of the femoral or tibial components on patient satisfaction or functional activities in daily life. In this study, we investigated the effect of rotational alignment of the femoral and tibial components on evaluation of outcomes using The 2011 KSS.

The score of the Fc IR group was significantly lower than that of Fc NR group in the category of functional activities. Thompson et al used a forward-dynamic computer model of a simulated squatting motion to perform a parametric study of the effects of variations in component rotational alignment in TKA [44]. Internally rotated femoral components required the highest forces of the quadriceps in deep flexion. For each detail of functional activities, the scores of the Fc IR group were significantly lower than those of the Fc NR group in the categories of standard activities and advanced activities, which would need relatively more quadriceps force at mid to deep flexion of the knee. On the contrary, the score was not significantly different among groups of femoral component malrotation in the categories of walking and standing, which would need relatively little quadriceps force at extension or mild flexion of the knee. Briefly, the decrease of quadriceps efficiency by the internal rotation of the femoral component might be a major cause of the disability of functional activities.

In the category of satisfaction, the score of the Fc IR group was slightly but not significantly lower than that of the Fc NR group. Our preliminary study investigating the correlation between the patient satisfaction score and the functional activities score in The 2011 KSS revealed that there was moderate correlation between patient satisfaction and either "walking and standing", "standard activities" or "advanced activities" (data in preparation). Therefore, internal rotation of femoral component would have a risk to affect adversary on the patient satisfaction although the current study did not show the statistical significance. In all categories of The 2011 KSS, scores were not significantly different between the Fc NR group and the Fc ER group. To sum up results of the femoral side, surgeons should avoid internal rotation of the femoral component to preserve functional activities and improve postoperative satisfaction.

In the category of symptoms, scores were not significantly different among groups of femoral component malrotation. Moreover, patellar alignment was not significantly different among groups of femoral component malrotation. Though PF problems like pain or congruity by malrotation of the femoral component have been reported [24,31], the rotational error was not very large in most cases in either the Fc ER or Fc IR groups. Consequently, this might be a major reason why the malrotation of the femoral component did not significantly affect symptoms or patellar alignment.

In all categories of The 2011 KSS, scores were not significantly different among groups of tibial component malrotation. As the polyethylene surface used in this study has rotational tolerance of 12°, some rotational malalignment of the tibial component might be allowed. However, in our fluoroscopic study analyzing the loading of knees after TKA, the rotational malalignment of the tibial component caused the rotational mismatch between the femoral and tibial components (data in preparation). Tibial component malrotation of 5°–10° might have no effect on a patient's subjective discomfort.

There are several limitations to this study. First, this study included only one implant design, and all surgeries were PS TKA. Therefore, the results of this study are not necessarily applicable to other implant

Table 4
PF Alignment Between Groups Classified Based on the Rotational Alignments of the Femoral and Tibial Component.

	Femoral Component Rotation				Tibial Component Rotation			
	Fc ER (n = 4)	Fc NR (n = 51)	Fc IR (n = 12)	Significance	Tc ER (n = 18)	Tc NR (n = 36)	Tc IR (n = 13)	Significance
Patellar component-tilting angle	2.6 ± 1.5º	2.1 ± 3.8º	0.9 ± 3.9º	n.s	2.9 ± 3.7º	2.2 ± 3.4º	−0.1 ± 3.9º	n.s
Patellar bone-tilting angle	4.3 ± 4.1º	4.8 ± 3.8º	4.5 ± 5.7º	n.s	5.4 ± 3.2º	4.9 ± 4.4º	3.1 ± 4.5º	n.s

n.s; not significant.

designs or PCL retaining (CR) TKA. Second, we did not evaluate patient expectations and functional activities before surgery. Postoperative changes in functional activities should be evaluated in future studies. However, patient details in each group were not significantly different, and so results from this study are still informative and valid. Third, the score for discretionary activities was excluded in this study. Answers about discretionary activities were completed by only half of the patients and this might be one of the limitations of the patient-derived score. Fourth, the patellar alignment was evaluated only at mid-flexion of the knee. Patellar shift and tilt would be larger at deep knee flexion and should be evaluated at deep knee flexion in future studies. Last, we controlled preoperative and postoperative parameters that have been known to affect each category of The 2011 KSS in this study, however, there may be other variables potentially affecting it except malrotation of the femoral component.

In conclusion, internal rotation of the femoral component significantly decreased the score in the category of functional activities. Decrease of quadriceps efficiency might be a major cause of the disability of functional activities. Surgeons should avoid internal rotation of the femoral component to preserve functional activities and improve the postoperative satisfaction of patients.

References

1. Devers BN, Conditt MA, Jamieson ML, et al. Does greater knee flexion increase patient function and satisfaction after total knee arthroplasty? J Arthroplasty 2011;26:178.
2. Harmer AR, Naylor JM, Crosbie J, et al. Land-based versus water-based rehabilitation following total knee replacement: a randomized, single-blind trial. Arthritis Care Res 2009;61:184.
3. Miner AL, Lingard EA, Wright EA, et al. Knee range of motion after total knee arthroplasty. How important is this as an outcome measure? J Arthroplasty 2003;18:286.
4. Bourne RB, Chesworth B, Davis A, et al. Comparing patient outcomes after THA and TKA: is there a difference? Clin Orthop Relat Res 2010;468:542.
5. Brander V, Gondek S, Martin E, et al. Pain and depression influence outcome 5 years after knee replacement surgery. Clin Orthop Relat Res 2007;464:21.
6. Elson DW, Brenkel IJ. Predicting pain after total knee arthroplasty. J Arthroplasty 2006;21:1047.
7. Scott CE, Howie CR, MacDonald D, et al. Predicting dissatisfaction following total knee replacement: a prospective study of 1217 patients. J Bone Joint Surg Br 2010;92:1253.
8. Insall JN, Dorr LD, Scott RD, et al. Rationale of the Knee Society clinical rating system. Clin Orthop Relat Res 1989;248:13.
9. Bellamy N, Buchanan WW, Goldsmith CH, et al. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 1988;15:1833.
10. Conaghan PG, Emerton M, Tennant A. Internal construct validity of the Oxford Knee Scale: evidence from Rasch measurement. Arthritis Rheum 2007;57:1363.
11. Tugwell P, Bombardier C, Buchanan WW, et al. The MACTAR Patient Preference Disability Questionnaire—an individualized functional priority approach for assessing improvement in physical disability in clinical trials in rheumatoid arthritis. J Rheumatol 1987;14:446.
12. McHorney CA, Haley SM, Ware Jr JE. Evaluation of the MOS SF-36 Physical Functioning Scale (PF-10): II. Comparison of relative precision using Likert and Rasch scoring methods. J Clin Epidemiol 1997;50:451.
13. Ware Jr JE, Sherbourne CD. The MOS 36-item Short-Form health survey (SF-36). I. Conceptual framework and item selection. Med Care 1992;30:473.
14. Bourne RB, Chesworth BM, Davis AM, et al. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 2010;468:57.
15. Roos EM, Roos HP, Lohmander LS, et al. Knee Injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. J Orthop Sports Phys Ther 1998;28:88.
16. Kwon SK, Kang YG, Kim SJ, et al. Correlations between commonly used clinical outcome scales and patient satisfaction after total knee arthroplasty. J Arthroplasty 2010;25:1125.
17. Bullens PH, van Loon CJ, de Waal Malefijt MC, et al. Patient satisfaction after total knee arthroplasty: a comparison between subjective and objective outcome assessments. J Arthroplasty 2001;16:740.
18. Khanna G, Singh JA, Pomeroy DL, et al. Comparison of patient-reported and clinician-assessed outcomes following total knee arthroplasty. J Bone Joint Surg Am 2011;93:e117.1.
19. Healy WL, Sharma S, Schwartz B, et al. Athletic activity after total joint arthroplasty. J Bone Joint Surg Am 2008;90:2245.
20. Noble PC, Scuderi GR, Brekke AC, et al. Development of a new Knee Society scoring system. Clin Orthop Relat Res 2012;470:20.
21. Scuderi GR, Bourne RB, Noble PC, et al. The new Knee Society knee scoring system. Clin Orthop Relat Res 2012;470:3.
22. Matsuda S, Kawahara S, Okazaki K, et al. Postoperative alignment and ROM affect patient satisfaction after TKA. Clin Orthop Relat Res 2013;471:127.
23. Akagi M, Matsusue Y, Mata T, et al. Effect of rotational alignment on patellar tracking in total knee arthroplasty. Clin Orthop Relat Res 1999;366:155.
24. Berger RA, Crossett LS, Jacobs JJ, et al. Malrotation causing patellofemoral complications after total knee arthroplasty. Clin Orthop Relat Res 1998;356:144.
25. Matsuda S, Miura H, Nagamine R, et al. 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;14:152.
26. Anouchi YS, Whiteside LA, Kaiser AD, et al. The effects of axial rotational alignment of the femoral component on knee stability and patellar tracking in total knee arthroplasty demonstrated on autopsy specimens. Clin Orthop Relat Res 1993;287:170.
27. Nagamine R, Whiteside LA, White SE, et al. Patellar tracking after total knee arthroplasty. The effect of tibial tray malrotation and articular surface configuration. Clin Orthop Relat Res 1994;304:262.
28. Lewis P, Rorabeck CH, Bourne RB, et al. Posteromedial tibial polyethylene failure in total knee replacements. Clin Orthop Relat Res 1994;299:11.
29. Wasielewski RC, Galante JO, Leighty RM, et al. Wear patterns on retrieved polyethylene tibial inserts and their relationship to technical considerations during total knee arthroplasty. Clin Orthop Relat Res 1994;299:31.
30. Su EP, Su SL, Della Valle AG. Stiffness after TKR: how to avoid repeat surgery. Orthopedics 2010;33:658.
31. Verlinden C, Uvin P, Labey L, et al. The influence of malrotation of the femoral component in total knee replacement on the mechanics of patellofemoral contact during gait: an in vitro biomechanical study. J Bone Joint Surg Br 2010;92:737.
32. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. J Bone Joint Surg Br 1991;73:709.
33. Berger RA, Rubash HE, Seel MJ, et al. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res 1993;286:40.
34. Moreland JR, Bassett LW, Hanker GJ. Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am 1987;69:745.
35. Akagi M, Yamashita E, Nakagawa T, et al. Relationship between frontal knee alignment and reference axes in the distal femur. Clin Orthop Relat Res 2001;388:147.
36. Yoshino N, Takai S, Ohtsuki Y, et al. Computed tomography measurement of the surgical and clinical transepicondylar axis of the distal femur in osteoarthritic knees. J Arthroplasty 2001;16:493.
37. Mizu-uchi H, Matsuda S, Miura H, et al. The evaluation of post-operative alignment in total knee replacement using a CT-based navigation system. J Bone Joint Surg Br 2008;90:1025.
38. Akagi M, Mori S, Nishimura S, et al. Variability of extraarticular tibial rotation references for total knee arthroplasty. Clin Orthop Relat Res 2005;436:172.
39. Akagi M, Oh M, Nonaka T, et al. An anteroposterior axis of the tibia for total knee arthroplasty. Clin Orthop Relat Res 2004;420:213.
40. Barrack BL, Schrader T, Bertot AJ, et al. Component rotationand anterior knee pain after total knee arthroplasty. Clin Orthop Relat Res 2001;392:46.
41. Laurin CA, Le'vesque HP, Dussault R, et al. The abnormal lateral patellofemoral angle: a diagnostic roentgenographic sign of recurrent patellar subluxation. J Bone Joint Surg Am 1978;60:55.
42. Fukagawa S, Matsuda S, Mizu-uchi H, et al. Changes in patellar alignment after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2011;19:99.
43. Kawano T, Miura H, Nagamine R, et al. Factors affecting patellar tracking after total knee arthroplasty. J Arthroplasty 2002;17:942.
44. Thompson JA, Hast MW, Granger JF, et al. Biomechanical effects of total knee arthroplasty component malrotation: a computational simulation. J Orthop Res 2011;29:969.

Knee Surg Sports Traumatol Arthrosc (2014) 22:1070–1075
DOI 10.1007/s00167-013-2468-1

KNEE

Medial sixth of the patellar tendon at the tibial attachment is useful for the anterior reference in rotational alignment of the tibial component

Shinya Kawahara · Ken Okazaki · Shuichi Matsuda · Hiroaki Mitsuyasu · Hiroyuki Nakahara · Shigetoshi Okamoto · Yukihide Iwamoto

Received: 2 September 2012 / Accepted: 25 February 2013 / Published online: 12 March 2013

Abstract
Purpose The anteroposterior (AP) axis connecting the middle of the posterior cruciate ligament to the medial border of the patellar tendon at its attachment has been introduced as a reproducible and reliable reference perpendicular to the surgical epicondylar axis in healthy knees. A recent literature has reported that the AP axis of the tibia is, on average, almost perpendicular to the surgical epicondylar axis also in varus and valgus knees and can be used as a tibial rotational reference to minimize the risk for rotational mismatch between the femoral and tibial components in total knee arthroplasty (TKA). However, it is difficult to identify the AP axis after tibial resection. The purpose of the current study was to determine a modified AP axis that runs parallel to the AP axis and passes through the centre of the cut surface in osteoarthritic knees.
Methods Preoperative computed tomography scans on 30 varus and 30 valgus knees undergoing TKA were studied using a three-dimensional software. The modified AP axis that runs parallel to the AP axis and passes through the centre of the cut surface was drawn. We investigated where the modified AP axis crossed the patellar tendon at its tibial attachment.
Results The modified AP axis passed through the medial 1/6 of the patellar tendon (4 mm from medial edge) at its attachment in both varus and valgus knees.
Conclusions The AP axis of the tibia is useful as a tibial rotational reference in cutting the proximal tibia, but it is difficult to identify the AP axis after tibial resection. The clinical relevance of this study is that medial 1/6 of the patellar tendon at its attachment would be a useful landmark in aligning the tibial component.
Level of evidence IV.

Keywords Total knee arthroplasty (TKA) · Surgical epicondylar axis (SEA) · Anteroposterior (AP) axis of the tibia

S. Kawahara · K. Okazaki (✉) · S. Matsuda · H. Mitsuyasu · H. Nakahara · S. Okamoto · Y. Iwamoto
Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan
e-mail: okazaki@med.kyushu-u.ac.jp

Introduction

Proper femoral and tibial component rotational positioning is essential for successful total knee arthroplasty (TKA). Positioning is a key as consequences of malrotation may produce patellofemoral problems [1, 4, 5, 16, 20], flexion instability [4], wear of ultra-high-molecular-weight polyethylene [14, 20, 28], stiffness [23] and abnormal gait patterns [27].

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 [6, 15, 17, 18, 29]. In contrast to the femur, several references have been used to determine tibial rotational orientation, such as the medial 1/3 of the tibial tubercle [12], the posterior condylar line of the tibia [19], the midsulcus of the tibial spine [7, 21], the transcondylar line of the tibia [8, 30], the intermalleolar axis of the ankle and the axis of the second metatarsal bone. The AP axis connecting the middle of the posterior cruciate ligament (PCL) at the tibial attachment to the medial border of the patellar tendon at its attachment has been introduced as a reproducible and reliable reference perpendicular to the SEA in healthy knees [2, 3, 24].

A recent study has reported that the AP axis of the tibia is, on average, almost perpendicular to the SEA also in varus and valgus knees [13]. The AP axis can be used as a tibial rotational reference to minimize the risk for rotational mismatch between the femoral and tibial components. However, it is difficult to identify the centre of the PCL attachment after tibial resection. The tibial component generally would be set at the centre of the cut surface; therefore, a modified line that runs parallel to the AP axis and passes through the centre of the cut surface would be useful in aligning the tibial component. For this reason, it is important to anatomically identify the location of the anterior landmark of the modified AP axis on the patellar tendon at the tibial attachment or on the cut surface.

The objective of the current study was to measure the medial percentage width of the patellar tendon at its tibial attachment and on the cut surface at which the modified AP axis crosses in osteoarthritic knees.

Materials and methods

This study was approved by the institutional review board (Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan, No. 24–25). Informed consent for participation was obtained from all patients. We obtained preoperative knee CT scans on 30 patients with primary varus osteoarthritis and on 30 patients with primary valgus osteoarthritis undergoing TKA. Postoperative knees displaying intra-articular osteosynthesis, high tibial osteotomies and unicompartmental knee arthroplasties were excluded from the study. The patients were all Japanese. Patient details of varus and valgus groups are described in Table 1.

The patients were placed in the supine position on the scanning table, and the affected knee was naturally extended without any feeling of internal or external rotation. Transverse CT scans were taken at levels ranging from the hip joint to the ankle joint at 2-mm intervals. CT images were acquired as DICOM data from the CT system server. A three-dimensional (3D) image of the lower extremity was reconstructed on the computer using the program 3D template (version 02.02.02, Japan Medical Materials Corp., Osaka, Japan). An axial plane was defined perpendicular to the tibial mechanical axis.

For the AP axis of the tibia, the centre of the PCL at its tibial attachment and the medial border of the patellar tendon at its attachment (Fig. 1a) were identified. In varus knees, axial planes 6, 8 and 10 mm distal to the centre of the tibial lateral plateau were defined as tibial cut planes. In valgus knees, axial planes 3, 5 and 7 mm distal to the centre of the tibial medial plateau were defined as tibial cut planes to avoid laxity of the medial soft tissues [22]. The centre of the tibial cut plane, dividing the mediolateral (ML) dimension of the tibial cut plane in half, was defined as the geometric centre (Fig. 1b). The line that runs parallel to the AP axis and passes through the geometric centre was defined as the modified AP axis.

Firstly, the point where the modified AP axis crossed the patellar tendon at its tibial attachment was investigated (Fig. 1a). The patellar tendon width (l) and the width medial to the crossing point (m) were measured, and the medial percentage width ($m/l \times 100$) was calculated.

Then, the point where the modified AP axis crossed the patellar tendon on the tibial cut plane was investigated (Fig. 1b). In a method similar to the first measurement, the patellar tendon width (l') and the width medial to the crossing point (m') were measured and the medial percentage width ($m'/l' \times 100$) was calculated.

Statistical analysis

All measurements were repeated three times at least a week apart by one examiner (S.K.) for all patients, and the average of these three measurements was adopted as the data. To evaluate the intraobserver and interobserver reproducibility, the measurements were performed three times by one examiner (S.K.) and once by two examiners (H.N., S.O.) on 10 knees randomly selected from the study group. The intraclass correlation coefficient and the interclass correlation coefficient were 0.85 and 0.84 for measurement of the medial percentage width of the patellar tendon at its tibial attachment.

Table 1 Patient details of varus and valgus groups

	Varus group ($n = 30$)	Valgus group ($n = 30$)
Age (years)[a]	74.4 ± 7.7	70.9 ± 9.3
Gender	Male 4 knees	Male 8 knees
	Female 26 knees	Female 22 knees
Side (Rt/Lt)	Rt 14 knees/Lt 16 knees	Rt 16 knees/Lt 14 knees
Body mass index (BMI)[a]	25.5 ± 3.6	25.0 ± 4.0
Hip–knee–ankle angle (HKA)[a]	11.3 ± 7.0° varus	7.1 ± 5.7° valgus

[a] The value is given as the mean and SD

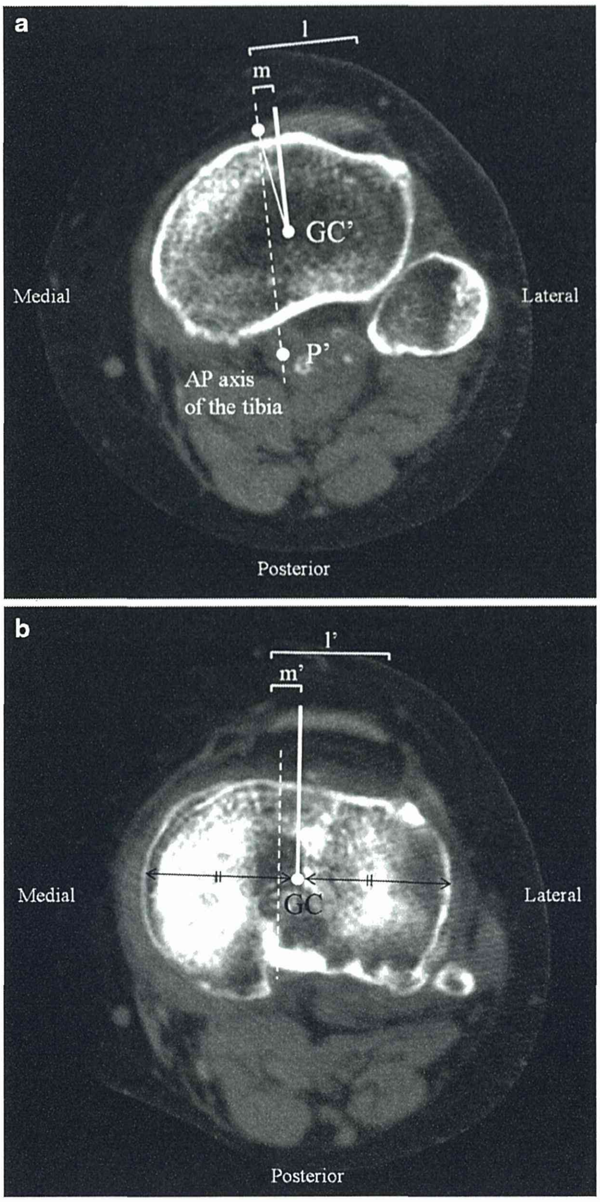

Fig. 1 **a** The axial plane at the level of the attachment of the patella tendon. *P'* projected centre of the PCL, *GC'* projected geometric centre, *l* patellar tendon width. The AP axis (*broken line*) connecting the medial border of the patellar tendon and P' was drawn. The modified AP axis (*solid line*) that runs parallel to the AP axis and passes through GC' was drawn. The tendon width (m) medial to the point where the modified AP axis and the patellar tendon intersect was measured, and the medial percentage width (m/l × 100) was calculated. **b** The axial plane at the level of the tibial cut. *GC* geometric centre, *l'* patellar tendon width. The AP axis (*broken line*) and the modified AP axis (*solid line*) were projected to this plane. The tendon width (m') medial to the point where the modified AP axis and the patellar tendon intersect was measured, and the medial percentage width (m'/l' × 100) was calculated

Results

The medial percentage width (m/l) and the medial width (m) of the patellar tendon at its tibial attachment were 15.5–16.5 % and 3.7–3.9 mm, respectively, in the varus group and 16.5–18.5 % and 4.1–4.5 mm, respectively, in the valgus group (Tables 2, 3). There were no great distinctions according to varus–valgus alignment of the knee or thickness of the tibial cut. Calculated based on all data in Tables 2 and 3, the medial percentage width and the medial width of the patellar tendon at its tibial attachment were 1/6 (16.7 ± 5.9 %) the width of the tendon and 4.0 ± 1.4 mm from medial edge. The medial percentage width (m'/l') and the medial width (m') of the patellar tendon on the tibial cut plane were the medial 1/4–1/3 of the tendon and approximately 7.0 mm in the varus group and the medial 1/5–1/4 and 5.8 mm in the valgus group.

Discussion

The most important findings of the present study were that the modified AP axis parallel to the tibial AP axis described by Akagi et al. passed through the geometric centre of the tibial cut surface to the medial 1/6 of the patellar tendon at its tibial attachment, which is approximately 4.0 mm from the medial edge of the patellar tendon attachment. Howell et al. [10] virtually placed the tibial component on the magnetic resonance image (MRI) data of osteoarthritic knees and measured the distance from the AP axis of the tibial component to the medial border or the medial 1/3 of the tibial tubercle. They reported that the AP axis of the tibial component was located 3 ± 3 mm lateral to the medial border and 4 ± 2 mm medial to the medial 1/3 of the tibial tubercle. Since the AP axis of the tibial component divided the distance between the medial border and the medial 1/3 of the tibial tubercle approximately in half, our results were consistent in this respect. The position of the modified AP axis would be affected by differences of varus–valgus alignment of the knee or thickness of the tibial cut; however, these differences were not considered in their study. Our results were consistent regardless of these differences. Therefore, the medial 1/6 of the patellar tendon at its attachment would be useful for an anterior reference point in aligning the tibial component and sufficiently reliable.

The medial percentage width of the patellar tendon on the tibial cut plane was also measured, composed of the medial 1/5–1/3 of the tendon, variable among varus and valgus knees. Moreover, some surgeons align the tibial

Table 2 Results in varus knees

	Thickness of the tibial cut (centre of the tibial lateral plateau)		
	6 mm	8 mm	10 mm
Medial percentage width of the patellar tendon (%)[a] (at the tibial attachment)	15.5 ± 6.7	15.5 ± 6.5	16.5 ± 6.8
Medial width of the patellar tendon (mm)[a] (at the tibial attachment)	3.7 ± 1.7	3.7 ± 1.6	3.9 ± 1.7
Medial percentage width of the patellar tendon (%)[a] (on the tibial cut plane)	27.9 ± 8.0	26.7 ± 7.5	25.0 ± 7.8
Medial width of the patellar tendon (mm)[a] (on the tibial cut plane)	7.3 ± 2.1	7.0 ± 2.2	6.4 ± 2.0

[a] The value is given as the mean and SD

Table 3 Results in valgus knees

	Thickness of the tibial cut (centre of the tibial medial plateau)		
	3 mm	5 mm	7 mm
Medial percentage width of the patellar tendon (%)[a] (at the tibial attachment)	16.5 ± 5.5	17.9 ± 4.9	18.5 ± 5.0
Medial width of the patellar tendon (mm)[a] (at the tibial attachment)	4.1 ± 1.3	4.4 ± 1.0	4.5 ± 1.0
Medial percentage width of the patellar tendon (%)[a] (on the tibial cut plane)	21.1 ± 9.4	22.4 ± 9.7	22.7 ± 9.7
Medial width of the patellar tendon (mm)[a] (on the tibial cut plane)	5.6 ± 2.6	5.8 ± 2.5	5.8 ± 2.3

[a] The value is given as the mean and SD

component with patellar eversion. Therefore, the reference point at the attachment of the patellar tendon is more consistent and useful for clinical use than that on the tibial cut plane. It would be technically important to choose the patellar tendon at just the tibial attachment level intraoperatively not to be affected by the patellar eversion or subluxation.

Several references have been used to determine tibial rotational orientation, such as the medial 1/3 of the tibial tubercle [12], the posterior condylar line of the tibia [19], the mid-sulcus of the tibial spine [7, 21], the transcondylar line of the tibia [8, 30], the intermalleolar axis of the ankle and the axis of the second metatarsal bone. The tibial tubercle has a broad base and both ends are hard to specify. In addition, a previous publication reported that the medial 1/3 of the tibial tuberosity might be too externally rotated in aligning the tibial component [7, 25]. The posterior condylar line of the tibia, the midsulcus of the tibial spine and the transcondylar line of the tibia would be susceptible to osteophyte and bone loss of the tibial articular surface [19]. The intermalleolar axis of the ankle and the axis of the second metatarsal bone would be susceptible to deformities of ankle and feet caused by osteoarthritis or rheumatoid arthritis, while on the other hand, the AP axis shown by Akagi et al. would not be influenced by articular deformity, and it would be perpendicular to the SEA in both healthy knees [2, 3, 24] and osteoarthritic knees [13]. Therefore, the AP axis would be useful as a tibial rotational reference in cutting the proximal tibia, and the modified AP axis connecting the centre of the cut surface to the medial 1/6 of the patellar tendon at its attachment would be useful in aligning the tibial component because it would be difficult to identify the AP axis after tibial resection.

A line drawn from the projected geometric centre to the medial border of the patellar tendon at its attachment was internally rotated relative to the AP axis in all knees. Since the anterior reference of AP axis is the medial border of the patellar tendon at its attachment, some surgeons may mistakenly use it as an anterior reference point not only in cutting the proximal tibia but also in aligning the tibial component. In this case, the tibial component would be aligned internally rotated relative to the AP axis [10]. The tibial component should be aligned in the same direction of the proximal tibial cut from the aspect of rotational alignment, and in addition, it could also have an effect on the coronal alignment of the knee when the tibia is prepared with some degree of posterior slope. If the rotational position of the tibial component varies from the rotational direction of the tibial cutting procedure, the component would be malaligned in varus or valgus due to posterior slope [11].

There are several limitations to this study. First, we evaluated a limited number of varus and valgus knees. However, the standard deviations of the measurements were all small enough to use the medial 1/6 of the patellar tendon at its attachment as the anterior reference point in aligning the tibial component. Secondly, the study population was limited to Japanese subjects. The study described by Akagi et al. also included Japanese subjects, and our study is in agreement with their study in this respect. However, it is possible that the data included in the current study would be typical only for knees of Japanese subjects, and therefore, there would be anatomic differences from the Caucasian population [9, 24, 26]. Thus, the results of this study should be interpreted cautiously. Thirdly, the modified AP axis of our study may not be appropriate for aligning all types of tibial components. As we defined the geometric centre as the centre of the tibial cut surface, the modified AP axis would be useful under assumption of aligning the symmetrical tibial component on the centre of the tibial cut surface. Therefore, we should take care in aligning the asymmetrical component. Finally, we have not examined the relationship between the SEA and the modified AP axis of the tibia in this study. The AP axis shown by Akagi et al. is useful to be referred when cutting the proximal tibia, but not when aligning the tibial component. The modified AP axis of this study is useful when aligning the tibial component, but not when cutting the tibia because the geometric centre of the tibial cut surface is not visible before cutting the tibia. As several studies suggest that Akagi's AP axis is reliably perpendicular to the SEA in both healthy knees [2, 3, 24] and osteoarthritic knees [13], we propose to use Akagi's AP axis when cutting the tibia and use the modified AP axis of this study when aligning the component which is parallel to Akagi's AP axis. However, there would be a variation between Akagi's AP axis and the SEA and between the modified AP axis of this study and Akagi's AP axis. Therefore, there might be a variation between the modified AP axis of this study and the SEA, as well.

Conclusion

The modified AP axis runs parallel to the tibial AP axis and passes through the geometric centre of the bony cut surface, intersecting the medial 1/6 of the patellar tendon at its tibial attachment. The clinical relevance of this study is that medial 1/6 of the patellar tendon at its attachment would be useful in the anterior referencing and alignment of the tibial component.

References

1. Akagi M, Matsusue Y, Mata T, Asada Y, Horiguchi M, Iida H, Nakamura T (1999) Effect of rotational alignment on patellar tracking in total knee arthroplasty. Clin Orthop Relat Res 366:155–163
2. Akagi M, Mori S, Nishimura S, Nishimura A, Asano T, Hamanishi C (2005) Variability of extraarticular tibial rotation references for total knee arthroplasty. Clin Orthop Relat Res 436:172–176
3. Akagi M, Oh M, Nonaka T, Tsujimoto H, Asano T, Hamanishi C (2004) An anteroposterior axis of the tibia for total knee arthroplasty. Clin Orthop Relat Res 420:213–219
4. Anouchi YS, Whiteside LA, Kaiser AD, Milliano MT (1993) The effects of axial rotational alignment of the femoral component on knee stability and patellar tracking in total knee arthroplasty demonstrated on autopsy specimens. Clin Orthop Relat Res 287:170–177
5. Berger RA, Crossett LS, Jacobs JJ, Rubash HE (1998) Malrotation causing patellofemoral complications after total knee arthroplasty. Clin Orthop Relat Res 356:144–153
6. Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS (1993) Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res 286:40–47
7. Dalury DF (2001) Observations of the proximal tibia in total knee arthroplasty. Clin Orthop Relat Res 389:150–155
8. Eckhoff DG, Johnston RJ, Stamm ER, Kilcoyne RF, Wiedel JD (1994) Version of the osteoarthritic knee. J Arthroplasty 9:73–79
9. Hovinga KR, Lerner AL (2009) Anatomic variations between Japanese and Caucasian populations in the healthy young adult knee joint. J Orthop Res 27:1191–1196
10. Howell SM, Chen J, Hull ML (2012) Variability of the location of the tibial tubercle affects the rotational alignment of the tibial component in kinematically aligned total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-012-1987-5
11. Insall JN, Easley ME (2001) Surgical techniques and instrumentation in total knee arthroplasty. In: Insall JN, Scott WN (eds) Surgery of the knee, 3rd edn. Churchill livingstone, New York, pp 1553–1620
12. Insall JN (1993) Surgical techniques and instrumentation in total knee arthroplasty. In: Insall JN, Windsor RE, Scott WN, Kelly M, Aglietti P (eds) Surgery of the knee, 2nd edn. Churchill livingstone, New York, pp 739–804
13. Kawahara S, Matsuda S, Okazaki K, Tashiro Y, Mitsuyasu H, Nakahara H, Iwamoto Y (2012) Relationship between the tibial anteroposterior axis and the surgical epicondylar axis in varus and valgus knees. Knee Surg Sports Traumatol Arthrosc 20:2073–2077
14. Lewis P, Rorabeck CH, Bourne RB, Devane P (1994) Posteromedial tibial polyethylene failure in total knee replacements. Clin Orthop Relat Res 299:11–17
15. Mantas JP, Bloebaum RD, Skedros JG, Hofmann AA (1992) Implications of reference axes used for rotational alignment of the femoral component in primary and revision knee arthroplasty. J Arthroplasty 7:531–535
16. Matsuda S, Miura H, Nagamine R, Urabe K, Hirata G, Iwamoto Y (2001) 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 14:152–156
17. Miller MC, Berger RA, Petrella AJ, Karmas A, Rubash HE (2001) Optimizing femoral component rotation in total knee arthroplasty. Clin Orthop Relat Res 392:38–45
18. Moreland JR, Bassett LW, Hanker GJ (1987) Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am 69:745–749
19. Moreland JR (1988) Mechanisms of failure in total knee arthroplasty. Clin Orthop Relat Res 226:49–64
20. Nagamine R, Whiteside LA, White SE, McCarthy DS (1994) Patellar tracking after total knee arthroplasty. The effect of tibial tray malrotation and articular surface configuration. Clin Orthop Relat Res 304:262–271
21. Sahin N, Atıcı T, Kurtoğlu U, Turgut A, Ozkaya G, Ozkan Y (2012) Centre of the posterior cruciate ligament and the sulcus between tubercle spines are reliable landmarks for tibial component placement. Knee Surg Sports Traumatol Arthrosc. doi: 10.1007/s00167-012-2120-5
22. Schnurr C, Csécsei G, Nessler J, Eysel P, König DP (2011) How much tibial resection is required in total knee arthroplasty? Int Orthop 35:989–994

23. Su EP, Su SL, Della Valle AG (2010) Stiffness after TKR: how to avoid repeat surgery. Orthopedics 33:658
24. Tao K, Cai M, Li SH (2010) The anteroposterior axis of the tibia in total knee arthroplasty for Chinese knees. Orthopedics 33:799
25. Uehara K, Kadoya Y, Kobayashi A, Ohashi H, Yamano Y (2002) Bone anatomy and rotational alignment in total knee arthroplasty. Clin Orthop Relat Res 402:196–201
26. Urabe K, Mahoney OM, Mabuchi K, Itoman M (2008) Morphologic differences of the distal femur between Caucasian and Japanese women. J Orthop Surg 16:312–315
27. Verlinden C, Uvin P, Labey L, Luyckx JP, Bellemans J, Vandenneucker H (2010) The influence of malrotation of the femoral component in total knee replacement on the mechanics of patellofemoral contact during gait: an in vitro biomechanical study. J Bone Joint Surg Br 92:737–742
28. Wasielewski RC, Galante JO, Leighty RM, Natarajan RN, Rosenberg AG (1994) Wear patterns on retrieved polyethylene tibial inserts and their relationship to technical considerations during total knee arthroplasty. Clin Orthop Relat Res 299:31–43
29. Yoshioka Y, Siu D, Cooke TD (1987) The anatomy and functional axes of the femur. J Bone Joint Surg Am 69:873–880
30. Yoshioka Y, Siu DW, Scudamore RA, Cooke TD (1989) Tibial anatomy and functional axes. J Orthop Res 7:132–137