Archives of Orthopaedic and Trauma Surgery (2019) 139:1141–1147
https://doi.org/10.1007/s00402-019-03221-8

KNEE ARTHROPLASTY

Posterior condylar resections in total knee arthroplasty: current standard instruments do not restore femoral condylar anatomy

Nina Wuertele[1] · Johannes Beckmann[2] · Malin Meier[2] · Jochen Huth[2] · Wolfgang Fitz[3]

Received: 29 January 2019 / Published online: 17 June 2019

Abstract
Introduction Correct femoral rotational alignment in total knee arthroplasty (TKA) is important for femoropatellar knee kinematics as well as for the overall clinical success. The goal of the present study was to evaluate how accurately standard instruments of various manufacturers with specific rotational settings in posterior referencing restore the posterior femoral condylar anatomy and allow a rotational alignment which matches a particular anatomic rotational landmark on CT.
Methods The anatomical transepicondylar axis (aTEA) and the posterior condylar line (PCL) were identified and the angle formed by these two axes was measured on 100 consecutive CT scans of knees. A virtual posterior condylar resection was performed relative to the aTEA for femoral sizers of various manufacturers in different external rotations ranging from 3° to 7°. The resections of medial and lateral posterior condyle were calculated as well as the condylar twist angle (CTA) between PCL and aTEA.
Results The posterior condylar resection varied between 9 mm and 14 mm on the medial side and between 4 mm and 10.5 mm on the lateral side. The mean CTA was 5.5° of internal rotation (SD ± 1.9°). External femoral rotation resulted in increased resection of the medial posterior condyle and decreased resection of the lateral posterior condyle.
Conclusion Femoral sizers using a posterior referencing technique increase, with rising external rotation, medial posterior condylar resection to an extent that may exceed the implant thickness in the majority of systems. Surgeons should be aware that current standard instruments do not restore the anatomy of the posterior medial and lateral condyle and do not align the femoral component parallel to the aTEA, which may result in internal rotation of a symmetric femoral component.

Keywords TKA · Rotation · Posterior condylar referencing · Posterior condylar offset · TEA · Total knee replacement · CTA · MCO · LCO

✉ Johannes Beckmann
drjbeckmann@gmx.de

Nina Wuertele
nina.wuertele@arcor.de

Malin Meier
malin.meier@icloud.com

Jochen Huth
jochen.huth@sportklinik-stuttgart.de

Wolfgang Fitz
wfitz@partners.org

1 Klinikum Stuttgart-Olgahospital, Kriegsbergstr. 62, 70174 Stuttgart, Germany

2 Sportklinik Stuttgart Taubenheimstr. 8, 70372 Stuttgart, Germany

3 Harvard Medical School Brigham and Women'S Hospital, 75 Francis Street, Boston, MA 02115, USA

Introduction

Rotational alignment of the femoral and tibial components in total knee arthroplasty (TKA) has important implications on clinical performance and success. Femoral malrotation can result in patellar maltracking, anterior knee pain, premature wear of the polyethylene, instability, stiffness, and altered patellofemoral and tibiofemoral kinematics and can, therefore, require revision for correction [1–8].

According to several authors, femoral rotation should be based on surgical landmarks, such as the transepicondylar axis (TEA) [9], the anteroposterior trochlear axis [10], and the posterior condylar line (PCL). Some authors even recommend the evaluation of preoperative CT scans [11, 12] to measure the angle between the anatomic transepicondylar axis (aTEA) and posterior condylar line (PCL), the so-called condylar twist angle (CTA). This angle has a high variability on CT scans and, therefore, provides more accurate information to the surgeon to accurate femoral rotation [12].

To achieve a parallel alignment of the femoral component relative to the TEA, standard TKA instrumentation utilizes a "femoral sizer" (Fig. 2) to align the femoral cutting block parallel to the TEA first. This instrument allows the external rotation to be adjusted between 0 and 7° depending upon surgeon's preference and measures femoral anteroposterior height.

The goal of the present study was to evaluate how accurately standard instruments of various manufacturers with specific rotational settings in posterior referencing restore the posterior femoral condylar anatomy and allow a rotational alignment which matches a particular anatomic rotational landmark on CT.

The first hypothesis of the present study is that the use of different manufacturer's standard instruments with specific rotational settings in posterior referencing allows to restore, despite various degrees of external rotation, both the posterior medial condylar offset (MCO) and the posterior lateral condylar offset (LCO) in TKA. Furthermore, the second hypothesis is that using different manufacturer's instruments does not lead to any major difference. The third hypothesis is that the resections do not result in internal rotation of the femoral component relative to the aTEA.

Materials and methods

Computerized tomographic (CT) scans of 100 consecutive patients undergoing custom-made primary TKA were retrieved. This cohort included 57 women and 43 men with an average age of 63.9 years (42–84 years). Weight-bearing anteroposterior long leg radiographs showed 79 cases of varus and 21 cases of valgus alignment.

Measurements of the distal femur were performed on CT scans according to Berger's method [9] using Centricity Enterprise Web (GE Medical Systems, Chicago Ill, USA). Measurements were done on a transverse plane displaying both medial and lateral epicondyles. For each image, the PCL and the aTEA were identified. The surgical TEA (sTEA) was identified for only 72% of the images. Therefore, the aTEA was used for further calculations. After identifying the PCL and the aTEA, the resulting CTA, as the angle between these two axes, was calculated.

The distances between the aTEA and the PCL on the medial and lateral side were measured and defined as the posterior medial condylar offset (MCO) and posterior lateral condylar offset (LCO) (Fig. 1).

Six different femoral sizers of standard TKA instrumentation (Attune®, DePuySynthes, Warsaw, IN, USA; PFC Sigma®, DePuySynthes, Warsaw, USA; Genesis II®, Smith&Nephew, Memphis, TN USA; Triathlon® Stryker, Michigan, ILL, USA; NexGen®, Zimmer, Warsaw, IN, USA; Persona®, Zimmer, Warsaw, IN, USA) were included. The pivot of all examined femoral sizers is located at the half distance between the pin holes. Since the distances between pin holes and posterior condyle line vary between the different sizers, the pivot varies. For each sizer, an external rotation setting of 3°, 5°, and 7° was selected and the resulting bone resections of posterior medial and lateral condyles were calculated (Fig. 2): For each femoral sizer, the distances between the pin holes and the feet of the femoral sizer were measured with the setting of 0° external rotation (indicated as black line) and then repeated for 3°, 5°, and 7° of external rotation. The red line in Fig. 2 exemplary indicates the distance between the pin holes and the feet

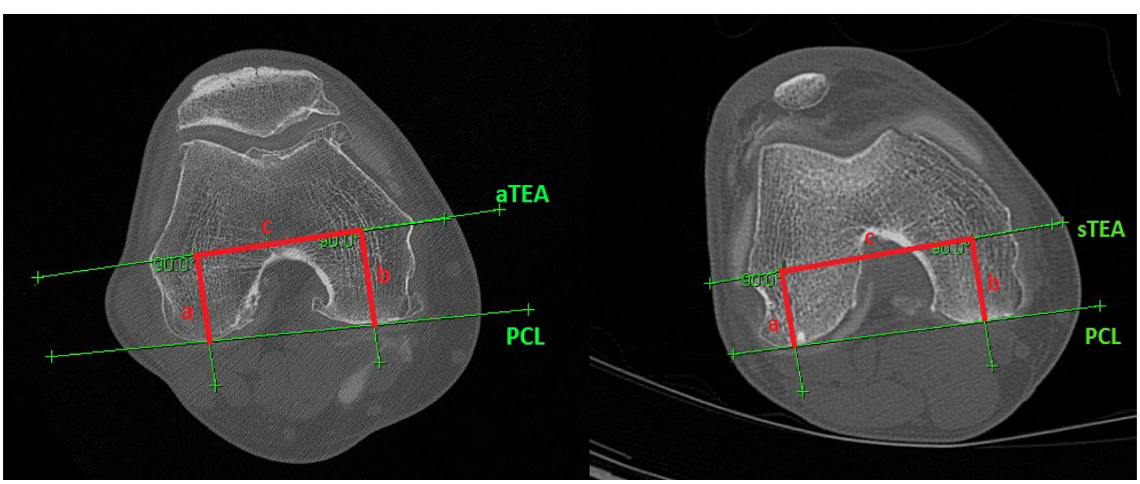

Fig. 1 On each Ct scan the aTEA (left) and sTEA (right) axes and the posterior condylar line (PCL) were identified and the resulting angle between these two axes was calculated. The differences between the aTEA and the PCL on the medial and lateral side were measured and defined as the medical condylar offset (MCO) and lateral condylar offset (LCO)

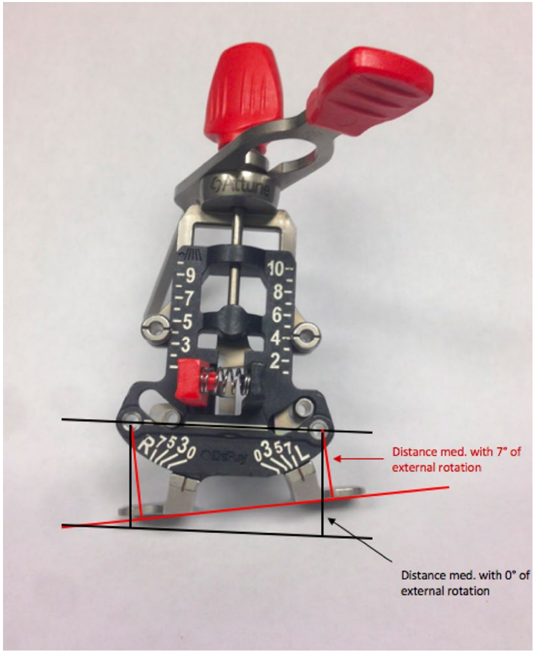

Fig. 2 Exemplary femoral sizer (Attune®, DePuy Synthes, Warsaw, IN, USA), set for a left knee. For each femoral sizer, the distances between the pin holes and the feet of the femoral sizer were measured with the setting of 0° external rotation (indicated as black line) and then repeated for 3°, 5°, and 7° of external rotation. The red line in Fig. 2 exemplary indicates the distance between the pin holes and the feet with a setting of 7° external rotation. The various distances between the each medial and lateral pin hole and the medial and posterior condyle represent the resulting bone resections

with a setting of 7° external rotation. The various distances between each the medial and lateral pin hole and the medial and posterior condyle represent the resulting bone resections. Statistical analyses of various measurements and results were performed using the SPSS software (IBM SPSS Statistics, Ehningen, IBM Deutschland GmbH, version 21). For comparing the CTA and MCO and LCO between men and women and also between varus and valgus alignment, the Mann–Whitney *U* test was performed. For comparing the CTA and also the MCO and LCO before and after implantation, the Wilcoxon Matched-Pairs Signed-Ranks Test was used. A p value < 0.05 was considered to be significant in both tests.

Results

The mean CTA was 5.5° (SD ± 1.9°, 0.8° to 9.9°), reflecting an internal rotation of the PCL relative to the aTEA. CTA was larger in women compared to men and larger in valgus deformities compared to varus. The differences were significant between men and women, but not between varus and valgus (Table 1).

The overall mean LCO was 25.7 mm and the overall mean MCO was 30.5 mm. The LCO was smaller in women and smaller in valgus deformities compared to men and varus, respectively. Differences were significant for gender and varus/valgus.

Using the measured distances of the different sizers, the rotation of the sizer relative to the aTEA was calculated. All investigated sizers lead approximately to their predicted rotation (3°, 5° and 7°). The mean deviation between the predicted and the calculated rotation was 0.2°, p value 0.96.

With increasing external rotation, all femoral sizers increased the medial and decreased the lateral posterior condylar bone resection. Medial resections increased to a mean medial resection of 10.8 mm for 3°, 11.1 mm for 5° and 12.2 mm for 7° rotation, respectively. On the lateral condyle, the mean resection was 8.4 mm for 3°, 7.3 mm for 5°, and 6.4 mm for 7° rotation, respectively (Table 2).

Modern implants have a thickness ranging from 7 to 9 mm. Therefore, the posterior condyles are not restored: the larger medial resection decreases the posterior condylar offset of up to 5 mm and increases the lateral posterior condyle of up to 5 mm (Table 2).

Table 2 compares values of mean CTA, medial and lateral resection resulting from different settings of the different femoral sizers. The setting of 3° resulted in internal rotation in 90.1% of cases studied and the setting of 5° resulted in internal rotation in 81.2% of cases studied. The setting of 7° resulted in external rotation in 72.4% of cases studied with only an amount of 0.74°–1.9°. The medial posterior condyle is overresected and the lateral posterior condyle is under-resected compared to implant thicknesses (Table 2).

Discussion

The most important finding of this study is that the posterior medial and lateral condylar offset are not restored using standard instrumentation of different manufacturers. Standard femoral sizers decrease in posterior referencing technique the medial posterior condylar offset and increase the posterior condylar lateral offset with increased external rotation. Furthermore, the medial posterior condylar resection exceeds the implant thickness in most cases (Table 3).

Therefore, the present study's hypotheses have to be rejected: first, increased femoral external rotation decreases medial posterior condylar offset and increases lateral posterior condylar offset. Second, bony resections vary between the different instrumentation systems, and third, the femoral rotation is not restored. The second most important finding is

Table 1 Measurement of CT scans

Measurement	Mean value (± SD, min–max)	p value
Condylar Twist Angle (CTA)		
Overall	5.5° (± 1.9°, 0.8–9,9)	
Men	4.5° (± 1.8°, 0.8–8.5)	< 0.001
Women	6.2° (± 1.7°, 2.2–9.9)	
Varus	5.3° (± 1.9°, 0.8–9.9)	0.08
Valgus	6.3° (± 1.9°, 3.1–9.7)	
Posterior lateral condylar offset (LCO)		
Overall	25.7 mm (± 2.9, 19.8–35.5)	
Men	27.9 mm (± 2.7, 22.3–35.5)	< 0.001
Women	24.0 mm (± 1.8, 19.8–28.5)	
Varus	26.1 mm (± 2.9, 21.3–35.5)	0.01
Valgus	24.3 mm (± 2.9, 19.8–31.6)	
Posterior medial condylar offset (MCO)		
Overall	30.5 mm (± 2.8, 24.2–39.1)	
Men	32.3 mm (± 2.5, 27.3–39.1)	< 0.001
Women	29.2 mm (± 1.9, 24.2–33.5)	
Varus	30.8 mm (± 2.6, 24.2–39.1)	0.06
Valgus	29.6 mm (± 2.7, 25.4–36.5)	

Table 2 Various sizers resect various amounts of posterior condyles with different degrees of femoral rotation

Type of prosthesis	Predicted rotation by sizer	Mean post-op. CTA by implant	Resection MCO (mm)	Resection LCO (mm)	Difference of post-op. MCO (mm)	Difference of post-op. LCO (mm)
DePuySynthes Attune	3°	2.1°*,§	11.0	8.0	− 3.0	0
	5°	1.0°*,§	12.0	8.0	− 4.0	0
	7°	− 1.3°*,§	13.0	7.0	− 5.0	+ 1.0
DePuySynthes P.F.C. Sigma	3°	3.2°*,§	12.0	10	− 4.0	− 2.0
Smith&Nephew Genesis II	3°	2.1°*,§	9.0	6.0	0	+ 3.0
	5°	0.4°*,§	9.5	5.0	− 0.5	+ 4.0
	7°	− 1.9°*,§	10.5	4.0	− 1.5	+ 5.0
Stryker Triathlon	3°	3.2°*,§	9.5	7.5	− 1.5	+ 0.5
	4.5°	2.7°*,§	9.0	6.5	− 1.0	+ 1.5
	6°	− 0.2°*,§	10.5	5.5	− 2.5	+ 2.5
Zimmer NexGen	3°	3.2°*,§	12.0	10.0	− 3.0	− 1.0
	5°	1.0°*,§	13.0	9.0	− 4.0	0
	7°	− 1.3°*,§	14.0	8.0	− 5.0	+ 1.0
Zimmer Persona	3°	3.2°*,§	11.0	9.0	− 2.0	0
	5°	1.0°*,§	12.0	8.0	− 3.0	+ 1.0
	7°	− 0.74°*,§	13.0	7.5	− 4.0	+ 1.5

*Standard deviation: 1.8°, §p value < 0.001 [mean postoperative CTA to mean preoperative rotation (5.5°)], positive values: internal rotation of CTA, negative values: external rotation of CTA

the fact that even 3° and 5° of external rotation of the femoral component relative to the PCL result in internal rotation relative to the aTEA seen on CT scan.

This study cannot precisely predict how the over-resection of the medial condyle and the under-resection of the lateral posterior condyle affects knee kinematics. However, altered posterior condylar offsets do result in clinical relevant changes [13]. In general, the lateral flexion gap is looser which allows lateral roll-back of the femur [14]. A tighter lateral flexion gap decrease lateral condylar rollback [15] and a looser medial flexion gap might be the cause of the paradoxical anterior translation [16] and to lift-off while

Table 3 Postoperative rotation relative to aTEA for different rotations and sizers (mean)

	Mean pre-op. CTA (± SD)	Predicted rotation by sizer	Mean post-op- CTA (± SD) by degree
Overall	5.5° (±1.9°)	3°	2.9° (±0.6°)
		5°	1.2° (±0.9°)
		7°	− 1.1° (±0.6°)
Men	4.5° (±1.8°)	3°	2.1° (±0.5°)
		5°	0.6° (±0.8°)
		7°	− 1.4° (±0.6°)
Women	6.2° (±1.7°)	3°	3.4° (±0.6°)
		5°	1.6° (±0.9°)
		7°	− 0.8° (±0.7°)
Varus	5.3° (±1.9°)	3°	2.7° (±0.6°)
		5°	1.0° (±0.8°)
		7°	− 1.2° (±0.6°)
Valgus	6.3° (±1.9°)	3°	3.6 (±0.6°)
		5°	1.8° (±0.9°)
		7°	− 0.6° (±0.7°)

aTEA anatomic transepicondylar axis, *CTA* condylar twist angle (between aTEA and PCL) differences between men and women and varus and valgus deformities are for each degree of external rotation within more or less 1°

walking [17] and might be a cause for decreased patient satisfaction [18]. Furthermore, it was reported that a more anatomic reconstruction of the medial posterior condyle resulted in improved knee kinematics [19]. Matziolis et al. [20] observed that an anatomic reconstruction of both posterior condyles occurs only in 3% in a cohort of patients undergoing computer assisted surgery and they concluded that a restoration of the posterior condyles within 2 mm is necessary to avoid midflexion instability. Minoda et al. [21] confirmed the present study's observation that every added degree of external rotation results in increased medial femoral resection. Minoda et al. calculated the posterior resection for each instrument using the production drawings of each manufacturer. In contrast, in the present study, each resection amount was measured directly off the femoral sizers for different external rotational degrees. It was noticed that all femoral sizers have a pivot point for external rotation. Furthermore, a comparison of different degrees of external rotation to the true patient-specific anatomic CTA and aTEA for each sizer was done with the finding that current practice of adding 3° or 5° still places the femoral component in internal rotation relative to the aTEA.

Recently, Bonnin et al. [22] confirmed the present study's findings. They investigated 110 preoperative CT scans and 14 different TKA models and the posterior lateral and medial condyles were resected parallel 10 mm anterior to the posterior condylar line seen of CT scan. They used different resection levels in their study, whereas in the present study, actual femoral sizers of various manufacturers were used. Their calculations might be somewhat overestimating the restoration of medial and lateral condylar offset. Furthermore, the asymmetric resection and reconstruction leads to lateral overhang and may hereby lead to an impingement of the soft tissues such as the popliteal tendon.

Bellemans et al. found that for every 2 mm decrease in posterior condylar offset, the maximal obtainable flexion was reduced by a mean of 12.2° [23]. However, they did not differentiate between medial and lateral condylar offset, since measurements were based on lateral X-rays and not on CT scans.

Recently, a more anatomic reconstruction of the femoral posterior condyles using a shape matching or kinematically aligned technique has shown clinical improvements compared to a traditional mechanically aligned surgical technique. In this technique, the amount of resected bone and cartilage of both condyles matches the prosthetic implant thickness. In a randomized controlled trial of 88 patients, the kinematically aligned arm showed better flexion, better pain relief, and better function [24]. However, Woon et al., who compared patient-reported outcome scores following TKA between kinematic alignment using patient-specific instrumentation (PSI-KA) and mechanical alignment (MA), reported that pain and functional improvements were similar between the two techniques studied [25].

The present study confirms that current standard surgical techniques with femoral sizers offered by various manufacturers do not restore the anatomic posterior condylar offset of both condyles.

The present study's data show that a parallel alignment of the femoral implant to the aTEA is only possible if sizers are adjusted to a rotation of at least 5°. This is contrary to common practice, since most surgeons use only 3°. Current practice of 3° of external rotation leads to an internal rotation of the femoral implant which may result in patellofemoral malrotation, impacting negatively the clinical outcome [26]. The present study showed that even though the setting of 3° of external rotation was leading to an internal rotation of the femoral implant, the medial condyle was overresected in an amount that may exceed the implant thickness, which would result in a loose medial flexion gap and may, therefore, result in flexion instability. Newer studies have shown that a change as little as 2 mm of posterior condylar offset results in midflexion instability [20].

The present study has several limitations: CT scans were used to calculate the virtual resection instead of the actual resection. However, Kinzel et al. [27] could demonstrate that the visual identification of the TEA intraoperatively is imprecise and should, therefore, not be used as the only reference. The CT-based measurements could be seen as a strength of this study, though. Furthermore, it has been shown that the accuracy of CT is high and that measured angles on CT scans are transferrable to intra-operative support correct femoral rotation [28, 29]. Similarly, Victor et al. described the accuracy of CT scans and found that inter- and intra-observer variabilities are very low, and especially, the measurements for the PCL and the aTEA are very precise [12]. In addition, Michaut et al. [11] used CT measurement to determine femoral rotation to increase accuracy of femoral rotation: postoperative rotation was observed to be within 2° of the objective in 77% of the cases. A further limitation of the present study is the fact that CT does not display cartilage thickness which varies between 1 and 6 mm with a mean of 2 mm [30] on the posterior condyles, which would change the present study's results. However, the findings in the present study question surgeon's routine to follow manufacturers' recommendation of various degrees of external rotation applied to femoral sizers. Furthermore, in knees with varus alignment, the cartilage thickness of the medial condyle is usually less than the cartilage thickness of the lateral condyle and would, therefore, strengthen the fact that the medial posterior condyle is over resected and the lateral posterior condyle under resected. Furthermore, cartilage wear, depleted on either posterior condyle, would require additional rotational adjustments.

Another limitation is the fact that only the aTEA was used for the calculations, since the medial epicondylar sulcus could not be identified in 28% of patients due to arthritic changes. Other authors noticed similar findings: Yoshino et al. [31] compared the aTEA and sTEA in CT scans of 96 knees for preoperative planning. They were able to detect the medial sulcus of the medial epicondyle which is highly influenced by the progression of the arthritis in only 20%. On the other hand, the aTEA is probably the most used reference used intraoperatively.

This study cannot answer the question whether an anatomic reconstruction of the posterior condyles has clinical significance. However, this study should make surgeons aware of the non-anatomic reconstruction of the posterior femoral condyles with current standard instrumentations. This research may initiate future studies to determine better femoral rotation with a more anatomic reconstruction of the posterior condyles.

Conclusion

Femoral sizers using a posterior referencing technique increase, with rising external rotation, medial posterior condylar resection to an extent that may exceed the implant thickness in the majority of systems. A high amount of femoral internal rotation using standard femoral sizers and current techniques were observed. Surgeons should be aware that current standard instruments do not restore the anatomy of the posterior medial and lateral condyle and do not place the femoral component parallel to the aTEA, but likely in internal rotation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Akagi M, Matsusue Y, Mata T et al (1999) Effect of rotational alignment on patellar tracking in total knee arthroplasty. Clin Orthop Relat Res 366:155–163
2. Barrack RL, Schrader T, Bertot AJ et al (2001) Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop Relat Res 392:46–55
3. Bédard M, Vince KG, Redfern J, Collen SR (2011) Internal rotation of the tibial component is frequent in stiff total knee arthroplasty. Clin Orthop Relat Res 469:2346–2355. https://doi.org/10.1007/s11999-011-1889-8
4. Bell SW, Young P, Drury C et al (2014) Component rotational alignment in unexplained painful primary total knee arthroplasty. Knee 21:272–277. https://doi.org/10.1016/j.knee.2012.09.011
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. Nicoll D, Rowley DI (2010) Internal rotational error of the tibial component is a major cause of pain after total knee replacement. J Bone Jt Surg Br 92:1238–1244. https://doi.org/10.1302/0301-620X.92B9.23516
7. Laskin RS (1995) Flexion space configuration in total knee arthroplasty. J Arthroplasty 10:657–660
8. Sharkey PF, Hozack WJ, Rothman RH et al (2002) Insall Award paper Why are total knee arthroplasties failing today? Clin Orthop Relat Res 404:7–13
9. Berger RA, Rubash HE, Seel MJ et al (1993) Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop Relat Res 286:40–47
10. Whiteside LA, Arima J (1995) The anteroposterior axis for femoral rotational alignment in valgus total knee arthroplasty. Clin Orthop Relat Res 321:168–172
11. Michaut M, Beaufils P, Galaud B et al (2008) Rotational alignment of femoral component with computed-assisted surgery (CAS) during total knee arthroplasty. Rev Chir Orthop Reparatrice Appar Mot 94:580–584. https://doi.org/10.1016/j.rco.2008.03.038
12. Victor J, Van Doninck D, Labey L et al (2009) How precise can bony landmarks be determined on a CT scan of the knee? Knee 16:358–365. https://doi.org/10.1016/j.knee.2009.01.001
13. Tokuhara Y, Kadoya Y, Nakagawa S et al (2004) The flexion gap in normal knees. An MRI study. J Bone Jt Surg Br 86:1133–1136
14. Dennis DA, Mahfouz MR, Komistek RD, Hoff W (2005) In vivo determination of normal and anterior cruciate ligament-deficient knee kinematics. J Biomech 38:241–253. https://doi.org/10.1016/j.jbiomech.2004.02.042
15. Pinskerova V, Johal P, Nakagawa S et al (2004) Does the femur roll-back with flexion? J Bone Jt Surg Br 86:925–931

16. Stiehl JB, Komistek RD, Dennis DA et al (1995) Fluoroscopic analysis of kinematics after posterior-cruciate-retaining knee arthroplasty. J Bone Jt Surg Br 77:884–889
17. Fehring TK (2000) Rotational malalignment of the femoral component in total knee arthroplasty. Clin Orthop Relat Res 380:72–79
18. Azukizawa M, Kuriyama S, Nakamura S et al (2018) Intraoperative medial joint laxity in flexion decreases patient satisfaction after total knee arthroplasty. Arch Orthop Trauma Surg 138:1143–1150. https://doi.org/10.1007/s00402-018-2965-2
19. Fitz W, Sodha S, Reichmann W, Minas T (2012) Does a modified gap-balancing technique result in medial-pivot knee kinematics in cruciate-retaining total knee arthroplasty? A pilot study. Clin Orthop Relat Res 470:91–98. https://doi.org/10.1007/s11999-011-2121-6
20. Matziolis G, Brodt S, Windisch C, Roehner E (2017) Changes of posterior condylar offset results in midflexion instability in single-radius total knee arthroplasty. Arch Orthop Trauma Surg 137:713–717. https://doi.org/10.1007/s00402-017-2671-5
21. Minoda Y, Mizokawa S, Ohta Y et al (2016) Posterior reference guides do not always maintain the size of posterior femoral condyles in TKA. Knee Surg Sports Traumatol Arthrosc 24:2489–2495. https://doi.org/10.1007/s00167-015-3706-5
22. Bonnin MP, Saffarini M, Nover L et al (2017) External rotation of the femoral component increases asymmetry of the posterior condyles. Bone Jt J 99:894–903. https://doi.org/10.1302/0301-620X.99B7.BJJ-2016-0717.R1
23. Bellemans J, Banks S, Victor J et al (2002) Fluoroscopic analysis of the kinematics of deep flexion in total knee arthroplasty. Influence of posterior condylar offset. J Bone Jt Surg Br 84:50–53
24. Dossett HG, Estrada NA, Swartz GJ et al (2014) A randomised controlled trial of kinematically and mechanically aligned total knee replacements: two-year clinical results. Bone Jt J 96:907–913. https://doi.org/10.1302/0301-620X.96B7.32812
25. Woon JTK, Zeng ISL, Calliess T et al (2018) Outcome of kinematic alignment using patient-specific instrumentation versus mechanical alignment in TKA: a meta-analysis and subgroup analysis of randomised trials. Arch Orthop Trauma Surg 138:1293–1303. https://doi.org/10.1007/s00402-018-2988-8
26. Narkbunnam R, Electricwala AJ, Huddleston JI et al (2019) Suboptimal patellofemoral alignment is associated with poor clinical outcome scores after primary total knee arthroplasty. Arch Orthop Trauma Surg 139:249–254. https://doi.org/10.1007/s00402-018-3073-z
27. Kinzel V, Ledger M, Shakespeare D (2005) Can the epicondylar axis be defined accurately in total knee arthroplasty? Knee 12:293–296. https://doi.org/10.1016/j.knee.2004.09.003
28. Hirschmann MT, Konala P, Amsler F et al (2011) The position and orientation of total knee replacement components: a comparison of conventional radiographs, transverse 2D-CT slices and 3D-CT reconstruction. J Bone Jt Surg Br 93:629–633. https://doi.org/10.1302/0301-620X.93B5.25893
29. Jazrawi LM, Birdzell L, Kummer FJ, Di Cesare PE (2000) The accuracy of computed tomography for determining femoral and tibial total knee arthroplasty component rotation. J Arthroplasty 15:761–766. https://doi.org/10.1054/arth.2000.8193
30. Clarke HD (2012) Changes in posterior condylar offset after total knee arthroplasty cannot be determined by radiographic measurements alone. J Arthroplasty 27:1155–1158. https://doi.org/10.1016/j.arth.2011.12.026
31. Yoshino N, Takai S, Ohtsuki Y, Hirasawa Y (2001) Computed tomography measurement of the surgical and clinical transepicondylar axis of the distal femur in osteoarthritic knees. J Arthroplasty 16:493–497. https://doi.org/10.1054/arth.2001.23621