Kinematic factors affecting postoperative knee flexion after cruciate-retaining total knee arthroplasty

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Abstract

Purpose The purpose of this study was to investigate kinematic factors affecting postoperative knee flexion after cruciate-retaining (CR) total knee arthroplasty (TKA) by analysing pre- and postoperative knee kinematics.

Methods We retrospectively analysed 58 patients with osteoarthritis who received the same implant series. Pre- and postoperative kinematics were measured intraoperatively using a navigation system. As a clinical outcome, we measured the knee flexion angle before and one year after surgery. Correlations among pre- and postoperative kinematics and postoperative flexion were analysed using simple linear regression analyses.

Results Preoperative knee kinematics, including tibial internal rotation and anterior translation ($R=0.87$, $P<0.001$; $R=0.53$, $P<0.001$, respectively), were significantly correlated with postoperative kinematics. Preoperative varus–valgus movements improved significantly postoperatively; however, tibial internal rotation remained unchanged. Furthermore, postoperative knee flexion angle was significantly correlated with postoperative tibial internal rotation ($R=0.45$, $P<0.001$).

Conclusions Preoperative knee kinematics were unchanged even after CR-TKA. Postoperative tibial internal rotation is one of the most important factors affecting postoperative knee flexion.

Introduction

Total knee arthroplasty (TKA) is a successful technique for treating painful osteoarthritic knees. It is important to achieve tibiofemoral alignment in TKA because optimal knee kinematics can help achieve a better functional outcome [1–3]. In recent years, a navigation system was developed for TKA, which is useful for accurate preoperative tibiofemoral alignment and kinematics [4, 5]. However, some postoperative kinematic analyses have shown that abnormal knee kinematics associated with osteoarthritis have not been fully restored by TKA [6, 7] and that these abnormal kinematics may be associated with patient dissatisfaction. Consequently, the number of kinematic studies after TKA has increased, and several different methods for kinematic measurement, such as navigation systems [8], fluoroscopy [9], and point cluster [10], have been used.

The method for analysing knee kinematics can change depending on the conditions. In weight-bearing conditions, point cluster and fluoroscopy are useful techniques and can provide information under functional activity [9]. However, it is difficult to minimise the dispersion caused by inconstant muscle forces and the local environment. On the other hand, in non-weight-bearing conditions, kinematic analysis using a navigation system can provide more consistent information; however, measurement is practicable only in limited movement, such as passive knee flexion under anaesthesia [7]. In addition, a navigation system allows high reproducibility of intraoperative measurement of the mechanical axes of the lower limb [11]. A number of studies have used a navigation system to assess knee kinematics [7, 12].

Range of motion (ROM) is one of the most important clinical outcomes and is associated with postoperative patient satisfaction [13]. Many studies have reported that postoperative knee flexion is influenced by preoperative clinical conditions, such as ROM and tightness of hip extension

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[14–16]. However, the effect of preoperative factors on postoperative knee flexion has not been fully elucidated, and even the correlation between pre- and postoperative knee kinematics is only partially understood. Seon and colleagues reported that preoperative knee kinematics, including posterior femoral rollback and external femoral rotation, affect postoperative knee kinematics [17]. However, in that article, the relationship between pre- and postoperative kinematics and postoperative clinical outcome was not well documented. Therefore, we investigated intraoperative passive knee kinematics before and after cruciate-retaining (CR) TKA using a navigation system and analysed the relationship among pre- and postoperative knee kinematics and pre- and postoperative knee flexion.

Methods

We studied 58 patients—[50 women, eight men; average age, 73.4 [standard deviation (SD)] 7.3 years; age range, 52–89 years; average body mass index (BMI), 26.8 (SD, 5.1)—from the same implant series who were diagnosed with osteoarthritis with varus deformity and underwent primary TKA between 2005 and 2009. The average femorotibial angle on standard weight-bearing anteroposterior radiographs was $186.2^{\circ} \pm 4.5$ preoperatively. Exclusion criteria for this study were valgus deformity, severe bony defect requiring bone graft or augmentation, revision TKA, active knee-joint infection, bilateral TKA, posterior-stabilised TKA, and TKA without the use of a tensor or navigation system. Our institution's internal review board approved this study, and informed consent was obtained from all patients. All procedures were performed by three senior doctors using CR-TKA (e.motion; B. Braun Aesculap, Tuttlingen, Germany) with an image-free navigation system (Orthopilot; B. Braun Aesculap).

Navigation registration procedure

After attaching passive optical reference frames from the navigation system onto the medial side of the distal femur and proximal tibia with screws and inflating the tourniquet with the knee flexed, the knee joint was exposed by a medial parapatellar approach. The standard registration procedure was conducted according to the system's instructions. The centre of the knee and ankle were registered by a landmark-based technique, whereas the centre of the hip was registered by the circular motion of the femur around the centre of hip rotation. Femoral and tibial axes in the sagittal and coronal planes were calculated using software based on the acquired data. The respective calculation methods have been described previously [11].

Upon completion of the registration procedure, the system provided flexion, varus, and rotation angle and tibial anterior translation of the knee.

Kinematic measurements of the knee and clinical outcome

During surgery, after registration by the navigation system following a medial parapatellar arthrotomy, the surgeon manipulated the knee using three repetitions from extension to flexion to record preoperative kinematic data. The extension movement initially began with heel support to record the position of maximum flexion. While supporting the heel with an open palm and touching the thigh with the opposite hand, the surgeon gently flexed the hip and knee to the final points as gravity flexed the knee. The reverse procedure was used to extend the knee. During this motion, the navigation system recorded the position and orientation of the knee. The operations were performed with the tibia first-gap technique, as reported previously [18]. First, a tibial osteotomy was performed perpendicular to the tibial axis in the coronal and sagittal planes, ensuring that the posterior cruciate ligament (PCL) attachment was preserved as a bony island. In order to obtain a balanced extension gap, the medial collateral ligament and soft-tissue releases were added, if required. Following measurement of the extension and flexion gaps with the tensor and the navigation system, distal and posterior femoral osteotomies were performed to create an acceptable rectangular extension and flexion gap. In this procedure, a residual lateral laxity of under three degrees was allowed. Postoperative kinematic data were collected after the prosthesis was fixed with cement, the patella was reduced, and the capsule was sutured. The pre- and postoperative kinematic measurement procedures were the same. To determine clinical outcome, we measured the knee flexion angle using a two-arm goniometer with the patient in the supine position before surgery, and at one year after surgery in the outpatient clinic.

Data calculation

Considering that the PCL begins to function physiologically at around 60° in CR-TKA, and based on a recent report that the PCL functions during mid- to deep knee flexion after CR-TKA [19], we defined tibial internal rotation and tibial anterior translation as the differences of the value at 60° and at maximum knee flexion angle, respectively. From the navigation kinematic data obtained during the motion cycles, we calculated the total varus–valgus movement, tibial internal rotation after 60° of knee flexion, and the amount of tibial anterior translation after 60° of knee flexion before and after surgery. Then, we evaluated the correlation between the pre- and postoperative values. In addition, the correlation between the maximum flexion angle at one year

after surgery and parameters of kinematic data were determined.

All measurements were expressed as mean $\pm$ standard error of the mean (SEM). An unpaired, two-tailed Student's *t* test was used to compare differences between two values. Data analyses were performed using a statistical software package (Statview 5.0; Abacus Concepts Inc., Berkeley, CA, USA). Correlations among pre- and postoperative knee kinematics and postoperative knee flexion angle were analysed using simple linear regression models and Pearson's correlation coefficient. A statistical power analysis was performed prior to the study, which was expected to require a power of 0.8 based on a prespecified significance level of $\alpha < 0.05$ and assuming a medium effect size (effect size $f^2 = 0.15$) using G power 3 [20]. The estimated sample size was 55 patients. *P* values < 0.05 were considered statistically significant.

Results

Range of motion

Mean pre- and postoperative extension angle, flexion angle, and ROM were $-2.5^\circ \pm 1.1^\circ$ and $-3.5^\circ \pm 0.5^\circ$; $122.2^\circ \pm 1.7^\circ$ and $124.2^\circ \pm 1.3^\circ$; and $119.7^\circ \pm 2.1^\circ$ and $120.7^\circ \pm 1.3^\circ$, respectively. Preoperative extension angle, flexion angle, and ROM did not improve significantly after surgery. Pre- and postoperative knee flexion angle showed a significant positive correlation ($R=0.51$, $P<0.001$; Fig. 1a).

Varus–valgus movement

Mean preoperative minimum, maximum, and magnitude of varus–valgus movement were $3.7^\circ \pm 0.5^\circ$, $11.8^\circ \pm 0.6^\circ$, and $8.1^\circ \pm 0.5^\circ$, respectively (Fig. 1b). These values decreased

Fig. 1 Correlation between clinical outcome and kinematic measurements before and after total knee arthroplasty (TKA). **a** Regression analysis revealed that preoperative knee flexion was positively correlated with postoperative knee flexion ($R=0.51$, $P<0.001$). **b** Mean preoperative minimum, maximum, and magnitude of varus–valgus movement (positive value in varus ligament balance) improved

significantly postoperatively ($P<0.001$). **c** Regression analysis revealed that preoperative tibial internal rotation was positively correlated with postoperative tibial internal rotation ($R=0.87$, $P<0.001$). **d** Regression analysis revealed that preoperative anterior tibial translation was positively correlated with postoperative anterior tibial translation ($R=0.53$, $P<0.01$)

significantly after surgery ($-1.1^\circ \pm 0.3^\circ$, $4.8^\circ \pm 0.3^\circ$, and $5.9^\circ \pm 0.3^\circ$, respectively). In addition, there was no significant correlation between pre- and postoperative magnitude of varus–valgus movement.

Tibial internal rotation

Mean pre- and postoperative tibial internal rotation were $22.8^\circ \pm 1.7^\circ$ and $21.6^\circ \pm 2.1^\circ$, respectively; there was no significant difference. All the cases showed positive tibial internal rotation after 60° of knee flexion preoperatively; however, the amount of tibial internal rotation was widely distributed from: 2° to 55° preoperatively, and from -6° to 66° postoperatively. There was a significant strong correlation between pre- and postoperative tibial internal rotation after 60° of knee flexion ($R=0.87$, $P<0.001$; Fig. 1c).

Tibial anterior translation

Mean pre- and postoperative tibial anterior translation were 7.5 ± 0.6 mm and 5.9 ± 0.6 mm, respectively; there was no significant difference. There was a significant correlation between pre- and postoperative tibial anterior translation after 60° of knee flexion ($R=0.53$, $P<0.001$; Fig. 1d).

Pre- and postoperative knee flexion angle

There was a significant correlation between preoperative knee flexion angle and preoperative tibial internal rotation and tibial anterior translation ($R=0.41$, $P<0.01$; $R=0.31$, $P<0.05$, respectively; Fig. 2a). There also was a significant correlation between postoperative knee flexion angle and postoperative tibial internal rotation ($R=0.45$, $P<0.001$; Fig. 2b).

Discussion

The purpose of this study was to clarify the relationship between pre- and postoperative knee kinematics and postoperative knee flexion. We found that pre- and postoperative knee flexion was positively correlated; however, knee ROM did not increase after TKA. This correlation is supported by the findings of previous reports [14, 15]. In addition, the mean preoperative minimum, maximum, and magnitude of varus–valgus movement improved significantly after surgery, and there was no correlation between pre- and postoperative values. These results indicate that varus movements throughout flexion before surgery were reduced by TKA; they also confirm that our surgical procedure of ligament balancing was performed properly. On the other hand, pre- and postoperative tibial internal rotation accompanied by knee flexion over 60° did not show a significant difference, which is consistent with the results of a previous study on posterior-stabilised TKA with mobile insert [21]. Tibial anterior translation tends to be reduced after TKA, as has been reported previously [22]. The results may be due to the fact that mobile bearing has anterior mobility and that this mobility was substituted for the motion of tibial anterior translation. In contrast, pre- and postoperative tibial internal rotation and pre- and postoperative tibial anterior translation showed a significant correlation. These results suggest that tibial internal rotation and tibial anterior translation were not corrected completely by TKA, especially as preoperative tibial internal rotation was maintained even after TKA. Seon and colleagues reported the same relationship as the one we found, which is the correlation between pre- and postoperative knee kinematics, including posterior femoral rollback and external femoral rotation [17]. In their report, tibial internal rotation was significantly reduced and tibial anterior

Fig. 2 Correlation between pre- and postoperative knee flexion angle and tibial internal rotation. **a** Regression analysis revealed that preoperative knee flexion angle was positively correlated with tibial internal

rotation ($R=0.41$, $P<0.01$). **b** Regression analysis revealed that postoperative knee flexion angle was positively correlated with tibial internal rotation ($R=0.45$, $P<0.001$)

translation was not, which differed from our results, even though the same type of implant was used. We presume this was due to the difference in the definition of rotation and translation in the kinematic measurement. We defined the kinematic measurements as over 60° of knee flexion, as, in the early phase of knee flexion, abnormal kinematics including tibial external rotation may occur after TKA [6] and the PCL functions during mid- to deep-knee flexion after CR-TKA [19]. In the previous study, the authors defined tibial rotation and translation as the difference between the value from 10° to 120° flexion of the knee in the kinematic measurement [17], which is different from the 60° to maximum knee flexion used in our study. The authors concluded that pre- and postoperative kinematic correlations may explain why preoperative ROM influences ROM after TKA [17]. However, the correlation between ROM and kinematic measurement has not been documented.

In one clinical outcome study, it was reported that patient satisfaction improved with the gain of postoperative knee flexion in a Japanese population [13]. Many studies report that postoperative knee flexion is influenced by preoperative clinical conditions, such as ROM and tightness of hip extension [14–16]. However, preoperative kinematic factors that affect postoperative knee flexion are not fully understood. In our study, there was a significantly strong correlation between pre- and postoperative tibial internal rotation after 60° of knee flexion; furthermore, there was a significant correlation between postoperative knee flexion angle and postoperative tibial internal rotation. Therefore, these results indicate that maintaining preoperative tibial internal rotation after TKA is related to postoperative knee flexion. In fact, preoperative tibial internal rotation was significantly correlated with postoperative knee flexion angle ($R=0.39$, $P<0.01$).

In 2D and 3D registration analyses, it has been reported that tibial internal rotation and tibial anterior translation are observed in deep-knee flexion of the normal knee and even the osteoarthritic knee [15, 19]. In our study, preoperative knee flexion was significantly correlated with preoperative kinematics, including tibial internal rotation and tibial anterior translation. These results are consistent with a previous report [17] and indicate that our procedures of kinematic measurement were performed properly. When achieving high flexion after TKA, some studies emphasise that an increase in postoperative tibial internal rotation is observed during knee flexion, even in normal knees [23, 24]. Considering previous reports [23, 24] and our results, we believe postoperative tibial internal rotation is the most important factor for gaining postoperative knee flexion.

There are some limitations to our study. It was a retrospective analysis, implant type was limited to CR-TKA, and conditions during measurement were limited to the use of anaesthesia. Another limitation was the method of kinematic

measurement, including measurement definition. Kinematic values using a navigation system tend to be larger than those using fluoroscopic analysis [6, 25], and, in the registration, mechanical axis is different from fluoroscopic measurement.

In conclusion, we showed that preoperative knee kinematics, including tibial internal rotation and anterior translation, were significantly correlated with postoperative kinematics. Preoperative varus-valgus movements improved significantly postoperatively; however, internal tibial rotation remained unchanged. Furthermore, postoperative knee flexion was significantly correlated with postoperative internal tibial rotation. Thus, postoperative internal tibial rotation is one of the most important factors affecting postoperative knee flexion.

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References

1. Dennis DA, Komistek RD, Scuderi GR, Zingde S (2007) Factors affecting flexion after total knee arthroplasty. *Clin Orthop Relat Res* 464:53–60. doi:10.1097/BLO.0b013e31812f785d
2. Yoshiya S, Matsui N, Komistek RD, Dennis DA, Mahfouz M, Kurosaka M (2005) In vivo kinematic comparison of posterior cruciate-retaining and posterior stabilized total knee arthroplasties under passive and weight-bearing conditions. *J Arthroplast* 20(6):777–783. doi:10.1016/j.arth.2004.11.012
3. Moro-oka TA, Muenchinger M, Canciani JP, Banks SA (2007) Comparing in vivo kinematics of anterior cruciate-retaining and posterior cruciate-retaining total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 15(1):93–99. doi:10.1007/s00167-006-0134-6
4. Jenny JY, Clemens U, Kohler S, Kiefer H, Konermann W, Miehke RK (2005) Consistency of implantation of a total knee arthroplasty with a non-image-based navigation system: a case-control study of 235 cases compared with 235 conventionally implanted prostheses. *J Arthroplast* 20(7):832–839. doi:10.1016/j.arth.2005.02.002
5. Martin A, Wohlgenannt O, Prenn M, Oelsch C, von Strempel A (2007) Imageless navigation for TKA increases implantation accuracy. *Clin Orthop Relat Res* 460:178–184. doi:10.1097/BLO.0b013e31804ea45f
6. Dennis DA, Komistek RD, Mahfouz MR, Walker SA, Tucker A (2004) A multicenter analysis of axial femorotibial rotation after total knee arthroplasty. *Clin Orthop Relat Res* 428:180–189
7. Siston RA, Giori NJ, Goodman SB, Delp SL (2006) Intraoperative passive kinematics of osteoarthritic knees before and after total knee arthroplasty. *J Orthop Res* 24(8):1607–1614. doi:10.1002/jor.20163
8. Klein GR, Parvizi J, Rapuri VR, Austin MS, Hozack WJ (2004) The effect of tibial polyethylene insert design on range of motion: evaluation of in vivo knee kinematics by a computerized navigation system during total knee arthroplasty. *J Arthroplast* 19(8):986–991
9. Dennis DA, Komistek RD, Hoff WA, Gabriel SM (1996) In vivo knee kinematics derived using an inverse perspective technique. *Clin Orthop Relat Res* 331:107–117
10. Ngai V, Wimmer MA (2009) Kinematic evaluation of cruciate-retaining total knee replacement patients during level walking: a comparison with the displacement-controlled ISO standard. *J Biomech* 42(14):2363–2368. doi:10.1016/j.jbiomech.2009.06.030

11. Jenny JY, Boeri C, Picard F, Leitner F (2004) Reproducibility of intra-operative measurement of the mechanical axes of the lower limb during total knee replacement with a non-image-based navigation system. *Comput Aided Surg* 9(4):161–165. doi:[10.3109/10929080500095517](https://doi.org/10.3109/10929080500095517)
12. Casino D, Zaffagnini S, Martelli S, Lopomo N, Bignozzi S, Iacono F, Russo A, Marcacci M (2009) Intraoperative evaluation of total knee replacement: kinematic assessment with a navigation system. *Knee Surg Sports Traumatol Arthrosc* 17(4):369–373. doi:[10.1007/s00167-008-0699-3](https://doi.org/10.1007/s00167-008-0699-3)
13. Matsuda S, Kawahara S, Okazaki K, Tashiro Y, Iwamoto Y (2012) Postoperative Alignment and ROM Affect Patient Satisfaction After TKA. *Clin Orthop Relat Res*. doi:[10.1007/s11999-012-2533-y](https://doi.org/10.1007/s11999-012-2533-y)
14. Harvey IA, Barry K, Kirby SP, Johnson R, Elloy MA (1993) Factors affecting the range of movement of total knee arthroplasty. *J Bone Joint Surg Br* 75(6):950–955
15. Lizaaur A, Marco L, Cebrian R (1997) Preoperative factors influencing the range of movement after total knee arthroplasty for severe osteoarthritis. *J Bone Joint Surg Br* 79(4):626–629
16. Matsumoto T, Tsumura N, Kubo S, Shiba R, Kurosaka M, Yoshiya S (2005) Influence of hip position on knee flexion angle in patients undergoing total knee arthroplasty. *J Arthroplast* 20(5):669–673. doi:[10.1016/j.arth.2005.01.011](https://doi.org/10.1016/j.arth.2005.01.011)
17. Seon JK, Park JK, Jeong MS, Jung WB, Park KS, Yoon TR, Song EK (2011) Correlation between preoperative and postoperative knee kinematics in total knee arthroplasty using cruciate retaining designs. *Int Orthop* 35(4):515–520. doi:[10.1007/s00264-010-1029-1](https://doi.org/10.1007/s00264-010-1029-1)
18. Matsumoto T, Muratsu H, Kubo S, Matsushita T, Ishida K, Sasaki H, Oka S, Kurosaka M, Kuroda R (2012) Soft tissue balance using the tibia first gap technique with navigation system in cruciate-retaining total knee arthroplasty. *Int Orthop* 36(5):975–980. doi:[10.1007/s00264-011-1377-5](https://doi.org/10.1007/s00264-011-1377-5)
19. Yue B, Varadarajan KM, Rubash HE, Li G (2012) In vivo function of posterior cruciate ligament before and after posterior cruciate ligament-retaining total knee arthroplasty. *Int Orthop* 36(7):1387–1392. doi:[10.1007/s00264-011-1481-6](https://doi.org/10.1007/s00264-011-1481-6)
20. Faul F, Erdfelder E, Buchner A, Lang AG (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 41(4):1149–1160. doi:[10.3758/BRM.41.4.1149](https://doi.org/10.3758/BRM.41.4.1149)
21. Casino D, Martelli S, Zaffagnini S, Lopomo N, Iacono F, Bignozzi S, Visani A, Marcacci M (2009) Knee stability before and after total and unicondylar knee replacement: in vivo kinematic evaluation utilizing navigation. *J Orthop Res* 27(2):202–207. doi:[10.1002/jor.20746](https://doi.org/10.1002/jor.20746)
22. Bull AM, Kessler O, Alam M, Amis AA (2008) Changes in knee kinematics reflect the articular geometry after arthroplasty. *Clin Orthop Relat Res* 466(10):2491–2499. doi:[10.1007/s11999-008-0440-z](https://doi.org/10.1007/s11999-008-0440-z)
23. Kanekasu K, Banks SA, Honjo S, Nakata O, Kato H (2004) Fluoroscopic analysis of knee arthroplasty kinematics during deep flexion kneeling. *J Arthroplast* 19(8):998–1003
24. Nakamura E, Banks SA, Tanaka A, Sei A, Mizuta H (2009) Three-dimensional tibiofemoral kinematics during deep flexion kneeling in a mobile-bearing total knee arthroplasty. *J Arthroplast* 24(7):1120–1124. doi:[10.1016/j.arth.2008.08.008](https://doi.org/10.1016/j.arth.2008.08.008)
25. Komistek RD, Dennis DA, Mahfouz M (2003) In vivo fluoroscopic analysis of the normal human knee. *Clin Orthop Relat Res* 410:69–81. doi:[10.1097/01.blo.0000062384.79828.3b](https://doi.org/10.1097/01.blo.0000062384.79828.3b)