

Intra-operative gaps affect outcome and postoperative kinematics in vivo following cruciate-retaining total knee arthroplasty

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Abstract

Purpose The following investigation evaluates the effect of intra-operative gaps after posterior cruciate ligament-retaining total knee arthroplasty using two-dimensional/three-dimensional registration and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).

Methods Patients were divided into two groups according to their 90°–0° component gap changes using a device designed by our laboratory. The wide gap group was defined as more than 3 mm (4.3 ± 0.7 mm), and the narrow gap group was defined as less than 3 mm (1.3 ± 1.3 mm).

Results Under non-WB (weight bearing) conditions, the wide flexion gap group (N=10) showed a significant anterior displacement of the medial femoral condyle as compared with the narrow flexion gap group (N=20). Despite no significant differences observed under WB conditions, both femoral condyle positions during flexion were significantly more posterior than during extension. WOMAC of the tight gap group showed worse scores for two functional items demanding knee flexion (bending to floor and getting on/off toilet).

Conclusion The large flexion gap could influence the late rollback under non-WB conditions and better WOMAC

functional scores in the flexion items. Three to four millimetre laxity at 90°–0° component gaps may be adequate and might be necessary to carry out daily life activities.

Keywords Kinematics · Cruciate-retaining total knee arthroplasty · 2D/3D registration · Posterior cruciate ligament · Component gap · WOMAC

Introduction

One of the most important goals of total knee arthroplasty (TKA) is to relieve pain and recover knee function, resulting in normalized function. In order to do so, one must achieve a stable functional range of flexion without creating instability. To achieve normalised function, appropriate soft-tissue balancing and accurate bony alignment are important in TKA. Obtaining an accurate intra-operative gap and soft-tissue balance remains difficult. Therefore, an offset-type tensor was developed for use in TKA procedures, which enable gap and soft-tissue balance assessments throughout a range of motion (ROM) under physiological conditions, with a reduced patellofemoral joint and femoral component in place. The instrument design [1], initial intra-operative gap and soft-tissue-balance measurements [2] in TKA have been previously described. The consensus in the literature is that flexion gap is important for postoperative flexion angle [3–6].

Cruciate retaining (CR) TKA is designed for the control of both posterior cruciate and collateral ligaments. This prosthesis has an unconstrained geometry, and allows large rotation, compared with cruciate sacrificing TKA [7–11]. The in vivo kinematics of the posterior CR TKA are especially influenced by the residual competency of the posterior cruciate ligament (PCL). Komistek detected kinematic differences in knees operated on using the same CR TKA system [12]. Komistek also

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found kinematic differences between cruciate retaining and cruciate sacrificing techniques using the same CR TKA system performed by one surgeon [12]. It has not been clearly reported how PCL tension influences the postoperative kinematics in vivo during both weight-bearing and non-weight-bearing conditions.

Based on these observations, we hypothesized that the intra-operative component gap affects in vivo kinematics and outcome. The purpose of the present study was to use a two-dimensional/three-dimensional (2D/3D) registration technique to determine if there was a difference in anterior-posterior translation and axial rotation kinematics between narrow and wide component gaps (tight and loose) in posterior CR TKA under both weight-bearing and non-weight-bearing conditions. Furthermore, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) were also used to establish which group was comfortable in daily activity.

Materials and methods

A total of 30 implants in 30 patients were analysed. All patients underwent implantation of a NRG CR cementless TKA. Of the 30 patients, 24 (80 %) were women and 6 (20 %) were men. All 30 patients had primary varus osteoarthritis. The average age was 74.6 ± 6.3 years (mean \pm SD), and the average postoperative time was 23.2 ± 6.4 months. Thirty patients were selected from our historical database containing all patients who had received TKAs and were contacted for their consent to be included in this study. All subjects who underwent a successful TKA resulting in more than 90 points on the Japan Orthopaedic Association (JOA) score, without any measurable ligament laxity or pain, were chosen for this study, thus representing a sample of best performers.

Surgical technique

Surgeries were performed using a modified gap-balance technique and the cementless Scorpio NRG CR TKA system (Stryker Orthopaedics, Mahwah, NJ). An arthrotomy was performed at the middle of the vastus medialis under a tourniquet. The anterior cruciate ligament (ACL) was resected, and the PCL was preserved. A distal femoral osteotomy and then a proximal tibial osteotomy were performed perpendicular to the mechanical axes of the femur and tibia according to preoperative long-leg radiographs. The proximal tibial osteotomy was performed with 7° of posterior inclination along the sagittal plane. Next, osteophytes were removed. Ligament balance, sufficient extension gap and satisfactory alignment along the mechanical axis were assessed by placing a spacer block with the knee in extension. Additional soft tissue balancing was performed if any of these factors were deemed

suboptimal. Thereafter, the femoral component was positioned parallel to the resected proximal tibia, with each collateral ligament tensioned as equally as possible with a commercially-available tensor system, the Stryker Joint Dependent Kinematics (JDK) system, while paying attention to anatomical markers (Whiteside's line, medial/lateral epicondyles and posterior condyles) [13]. No PCL release was performed in any of these knees. Finally, we removed the osteophytes from the patella without resurfacing, and confirmed the appropriate patellar tracking. Just before final implantation and closing, the following gap measurements were performed.

Our novel gap measurement device

The offset tensor consists of three parts: an upper see-saw plate, a lower platform plate with a keel, and an extra-articular main body, as previously reported [7]. Both plates are connected to the extra articular main body by the offset connection arm throughout the medial parapatellar arthrotomy, which allows for reduction of the patellofemoral joint while performing measurements (Fig. 1). The upper plate has a proximal, convex-shaped centralizer which fits into the intercondylar space. The lower tibial plate is placed at the intended position of the tibial component after tibial keel preparation. This tensor mechanism controls the tibiofemoral position in both coronal and sagittal planes according to the PCL tension, and allows for the reproduction of joint balance and alignment after implantation of individual components.

The device was designed to allow surgeons to measure the ligament balance and the gap between the centre of the joint and the component while applying a constant distraction force. A distraction force between 30 lbs and 80 lbs (133.4–355.8 N) (13.6–36.3 kg) can be exerted between plates through a specially-constructed torque driver, which can change the applied force value. After sterilization, the driver is placed on a rack which contains a pinion mechanism along the extra-articular main body, and the appropriate torque is applied to generate the designated distraction force. Once distracted, the angle between the plates and the distance (mm) between the midpoint of the upper surface of the proximal plate and the proximal tibial cut were measured under a constant joint distraction force. We were thus able to determine the ligament balance and gaps between the centre of the joint and the applied component.

After the bony resection and soft-tissue release, we fixed the tensor to the proximal tibia, and fitted the trial femoral component. The joint distraction force was set at 40 lbs (177.9 N/18.1 kg) in all patients. We selected this distraction force because it created a gap in the joint in full extension with the trial femoral component in place, that corresponded to the thickness of the insert derived from our preliminary clinical studies. We measured the femorotibial gap (mm) with the knee

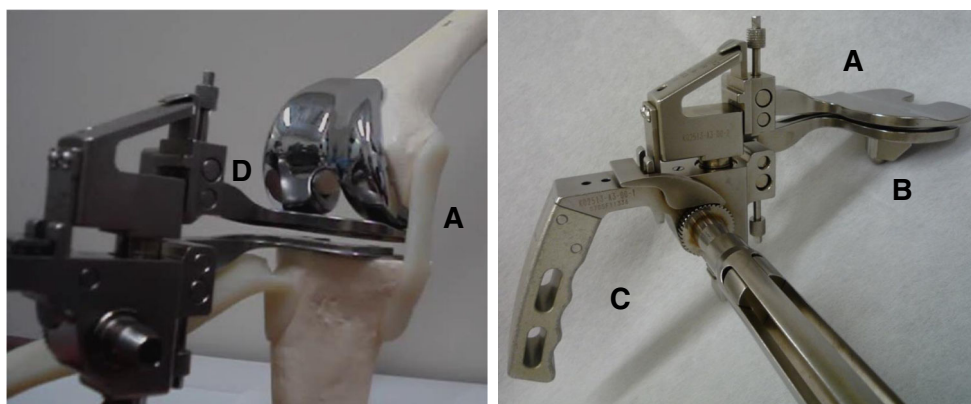


Fig. 1 Photograph showing that the tensor used in cruciate-retaining total knee replacement consists of three parts: an upper see-saw plate (a), a lower platform plate with a keel (b), and an extra-articular main body (c). The two plates are connected to the extra-articular main body by the offset

connection arm (d) throughout a medial parapatellar arthrotomy, which allows for reduction of the patellofemoral joint while performing measurements. Note that the femoral trial component is attached to the femur during measurement

at 0 degrees (full extension), 45 degrees (mid-range flexion), 90 degrees, and 135 degrees (deep flexion) of flexion. These measurements were made with the patella reduced while applying stitches both proximally and distally to the connection arm of the tensor. During each measurement, the thigh, knee, and tibia were aligned in sagittal, coronal, and horizontal planes in order to eliminate the external load on the knee at each angle of flexion [14, 15].

In vivo kinematic analysis

Each patient was asked to perform sequential deep knee bends from the extended position and full extension from the flexed position under both weight-bearing and non-weight-bearing conditions. Both motions from full extension to maximum flexion and from maximum flexion to full extension were monitored fluoroscopically in the sagittal plane. For the non-weight-bearing condition, the patient sat on a chair and was asked to perform active knee bending and extension. The sequential motion was recorded as digital X-ray images (1024 × 1024 × 12 bits/pixel, 7.5-Hz serial spot images as a DICOM file) using a 17-inch flat panel detector system (C-vision Safire L; Shimadzu, Kyoto, Japan). To estimate the spatial position and orientation of the TKA, a 2–3-dimensional (2D/3D) registration technique was used [16, 17]. This technique was based on a contour-based registration algorithm using single-view fluoroscopic images and three-dimensional computer-aided design models. Estimation accuracy of the relative motion between metal components was 0.5° or less in rotation and 0.4 mm or less in translation.

Narrow and wide gap groups

These 30 patients were divided into two groups according to a discriminatory threshold of 3 mm intra-operative 90°–0° gap measurement (90° component gap subtracted by 0°

component gap) using our original device. Twenty knees were in the narrow gap group (1.3 ± 1.3 mm), and ten knees were in the wide gap group (4.3 ± 0.7 mm). The average femerotibial gaps were 11.7 ± 1.3, 14.1 ± 2.2, 12.9 ± 1.4 and 12.0 ± 1.2 mm for the narrow gap group, 12.1 ± 1.5, 16.7 ± 2.3, 16.4 ± 1.6 and 14.4 ± 1.1 mm for the wide gap group, at 0, 45, 90 and 135° of knee flexion, respectively (Fig. 2). Significant differences were detected at 45, 90 and 135° between the narrow and wide gap groups.

No significant difference was detected between groups with respect to demographics i.e. age, postoperative age, gender, and the pre-operative and postoperative knee flexion and extension angle.

All components were well-fixed according to radiographic evaluations during the postoperative follow-up. In this study, we chose exact postoperative anteroposterior (AP) and lateral X-ray films. Regarding the posterior slope (PTS), Han et al. [18] reported that the PTS is measured against the fibular shaft, and that the angle between the tibial anatomical axis and the fibular shaft axis was 3.0 degrees. This angle between

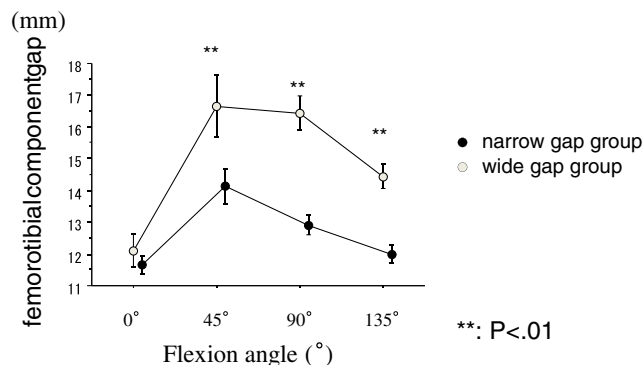


Fig. 2 Kinematics of the femerotibial component gap. The average femerotibial component gaps were 11.7, 14.1, 12.9 and 12.0 mm for the narrow gap group, 12.1, 16.7, 16.4 and 14.4 mm for the wide gap group, at 0°, 45°, 90° and 135° of knee flexion, respectively (Fig. 2)

the fibular shaft and the tibial component was measured, and the PTS angle was defined as the measured angle plus 3.0 degrees. The PTS of the narrow gap group was $5.4 \pm 3.6^\circ$, and that of the wide gap group was $7.9 \pm 3.5^\circ$. No significant difference was detected between groups.

The preoperative posterior condylar offset (PCO) of the narrow gap group was 27.9 ± 3.3 mm and that of the wide gap group was 28.0 ± 3.0 mm. The postoperative PCO of the narrow gap group was 26.5 ± 3.7 mm and that of the wide gap group was 24.3 ± 3.3 mm. Despite significant differences between groups between the pre- versus post-surgical values ($P < 0.0001$), there was no significant difference between narrow and wide gap groups in regard to preoperative and postoperative PCO.

Hip-knee-ankle (HKA) angles were also evaluated between the two groups. The pre-operative HKA angle of the narrow gap group was $189.2 \pm 5.5^\circ$ and that of the wide gap group was $189.7 \pm 4.5^\circ$. The postoperative HKA angle of the narrow gap group was $180.1 \pm 3.2^\circ$ and that of the wide gap group was $181.7 \pm 2.5^\circ$. Despite significant differences between groups in pre- versus post-surgical values ($P < 0.0001$), there was no significant difference between narrow and wide gap groups in regard to pre-operative and postoperative HKA angles.

The contact point measurement was carried out to evaluate posterior cruciate ligament function [19]. The contact ratio of the wide gap group was 46.9 ± 6.6 % and that of the narrow gap group was 56.0 ± 5.9 . A significant difference was detected between the groups ($P < 0.001$).

Statistical analysis

All data in the text are expressed as means \pm SD, and as means \pm standard error of the mean (SEM) in figures. We utilized a statistical software package (Statview, Abacus Concepts Inc, Berkeley, CA) to analyse data. We used the Wilcoxon test for comparisons between flexion and extension movements, and the Mann-Whitney test between wide and narrow gap groups. P-values less than 0.05 were considered statistically significant.

Results

Comparison of narrow and wide gap groups' kinematics under non-weight-bearing conditions

Kinematics under non-weight-bearing conditions were examined from 0° to 100° of flexion from the extended position (Fig. 3a, b, c). At 0° of knee flexion, the average nearest medial point of the narrow gap group was -1.2 ± 1.6 mm. The average nearest medial point moved 5.3 mm anteriorly to reach 4.1 ± 2.5 mm at 70° of knee flexion. From 70° to 100° ,

the average nearest medial point moved 5.1 mm posteriorly and reached -1.0 ± 3.3 mm at 100° of knee flexion (Fig. 3a). At 0° of knee flexion, the average nearest medial point of the wide gap group was 0.3 ± 1.4 mm. The average nearest medial point moved 6.0 mm anteriorly to reach 6.3 ± 2.9 mm at 70° of knee flexion. From 70° to 100° , the average nearest medial point moved 5.9 mm posteriorly and reached 2.4 ± 4.4 mm at 100° of knee flexion. The medial side of the wide gap group was positioned significantly more anteriorly at the 0° extended position ($P < 0.05$) and at 80° and 90° flexion ($P < 0.01$) (Fig. 3a).

At 0° of knee flexion, the average nearest lateral point of the narrow gap group was -4.3 ± 2.9 mm. Under non-weight-bearing conditions from 0° to 70° , the average nearest lateral point remained constant. Subsequently, the nearest lateral point moved 6.8 mm posteriorly from 70° to 100° , and reached -11.1 ± 3.8 mm at 100° of knee flexion (Fig. 3b). The average nearest lateral point of the wide gap group moved in the same way (Fig. 3b). No significant difference was detected between groups.

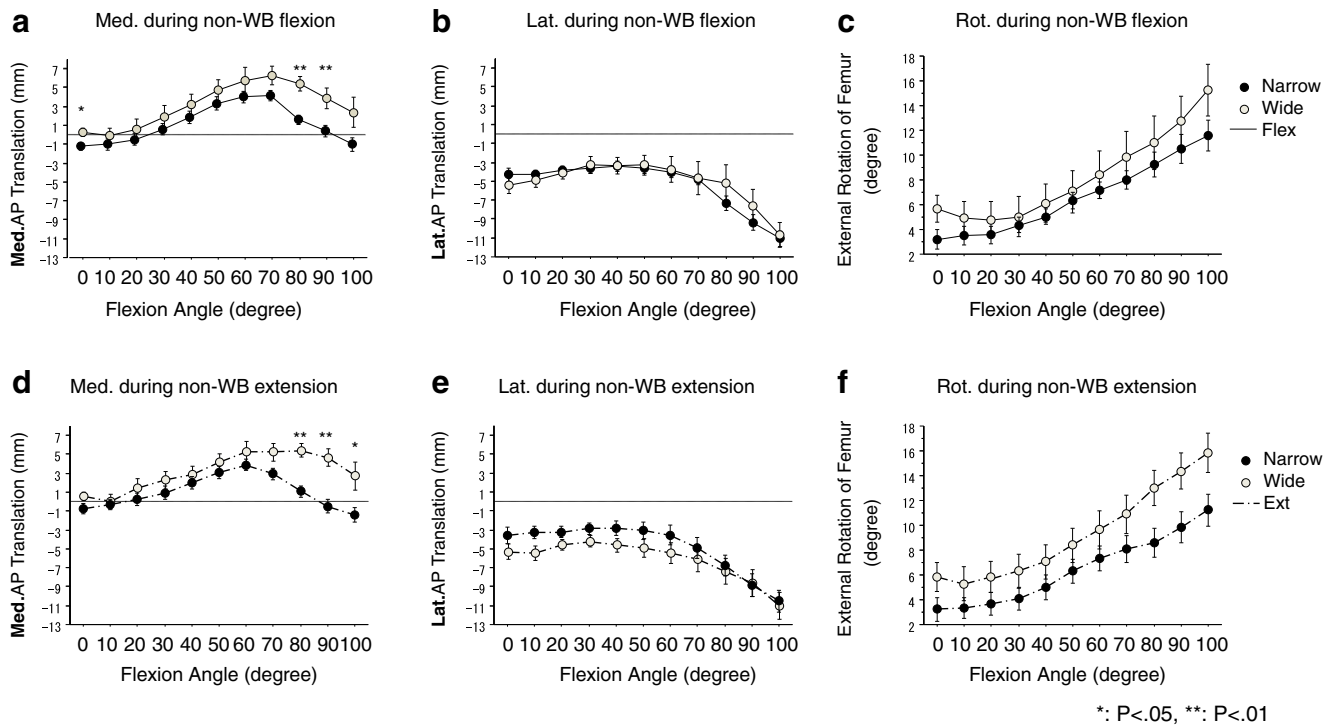
With regard to the axial rotation of the femoral component relative to the tibial component of the narrow gap group, the mean axial rotation was $3.5^\circ \pm 3.4$ at 0° , and the femoral component exhibited gradual external rotation and reached $11.6^\circ \pm 5.7^\circ$ at 100° of knee flexion (Fig. 3c). The mean axial rotation of the wide gap group was $5.7^\circ \pm 3.2$ at 0° , $4.8^\circ \pm 4.4^\circ$ at 20° , and $15.2^\circ \pm 5.9^\circ$ at 100° of knee flexion. The femoral component initially exhibited internal rotation from 0° to 10° and gradual external rotation from 10° to 100° , with mean axial rotation during the knee flexion cycle of 6.8° (Fig. 3c). No significant difference was detected between groups.

Under non-weight-bearing conditions from 100° to 0° of extension from the flexed position, the narrow and wide gap groups exhibited the same kinematics as under non-weight-bearing conditions from 0° to 100° of flexion from the extended position (Fig. 3d, e, f). Significant differences in medial points at 80° , 90° , and 100° of knee flexion were detected between groups (Fig. 3d).

Comparison of the narrow and wide gap groups' kinematics under weight-bearing conditions

Under weight-bearing conditions from 0° to 100° of flexion from the extended position, the average nearest medial point was constant for both the narrow (between -1.3 mm and -0.3 mm) and wide gap groups (between -1.7 mm and -0.0 mm) (Fig. 4a). No significant difference was detected between groups.

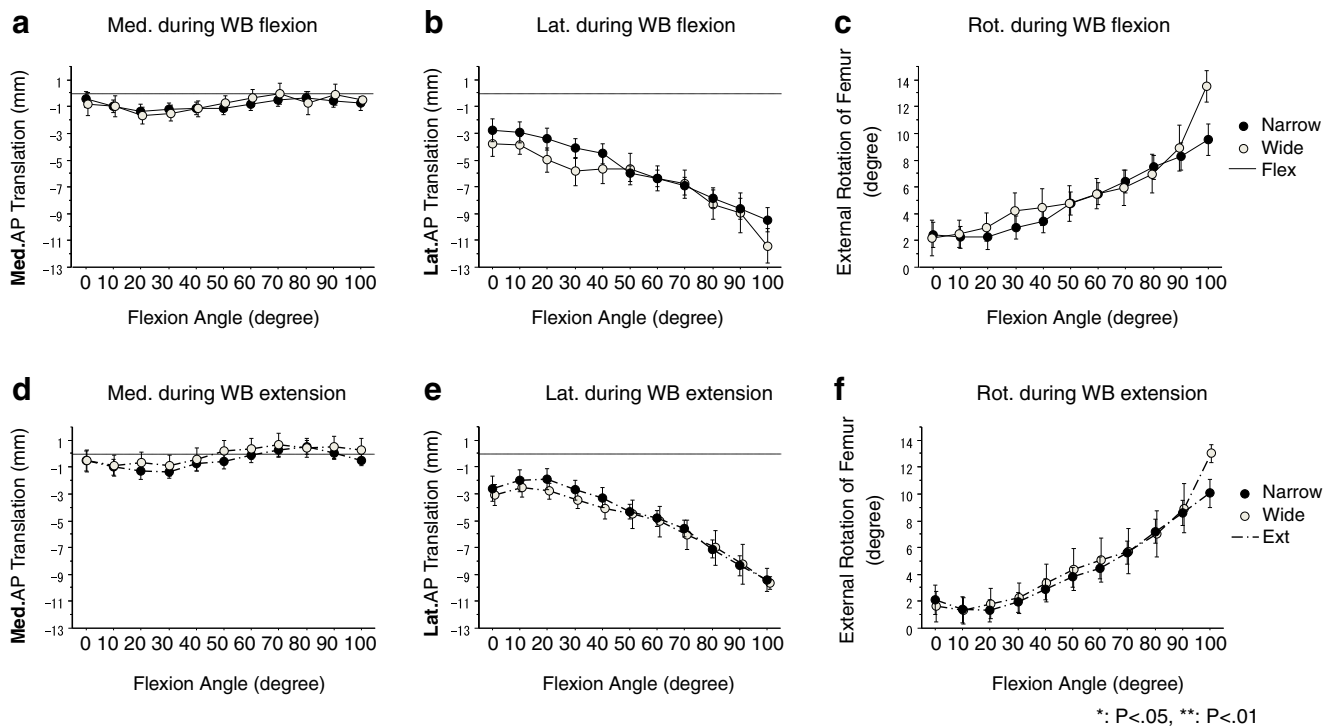
At 0° of knee flexion, the average nearest lateral point of the narrow gap group was -2.7 ± 3.6 mm. The average nearest lateral point of the narrow gap group moved 6.8 mm posteriorly from 0° to 100° , and reached -9.5 ± 3.3 mm at 100° of knee flexion. The average nearest lateral point of the wide gap



*: $P < .05$, **: $P < .01$

Fig. 3 Comparison between the narrow and wide gap groups during flexion from an extended position (a, b, c) and during extension from a flexed position (d, e, f) under non-weight-bearing conditions. The average nearest medial point of the wide gap group was significantly

more anterior than that of the narrow gap group during both flexion from an extended position (a) and extension from a flexed position (d). There was no significant difference regarding the average nearest the lateral point and external rotation



*: $P < .05$, **: $P < .01$

Fig. 4 Comparison between narrow and wide gap groups during flexion from an extended position (a, b, c) and during extension from a flexed position (d, e, f) under weight bearing conditions. No significant differences were detected between narrow and wide gap groups during both flexion from an extended position (a, b, c) and extension from a

flexed position (d, e, f) under weight bearing conditions detected between narrow and wide gap groups during both flexion from an extended position (b, c) and extension from a flexed position (e, f) under non-weight-bearing conditions

moved in the same way (Fig. 4b). No significant difference was detected between groups.

Regarding axial rotation of the femoral component relative to the tibial component, the mean axial rotation of the narrow gap group was $2.4^\circ \pm 3.8^\circ$ at 0° of knee flexion, $2.2^\circ \pm 4.2^\circ$ at 10° of knee flexion, and $9.5^\circ \pm 4.3^\circ$ at 100° of knee flexion. The femoral component exhibited gradual external rotation from 10° of knee flexion to 100° . The mean axial rotation of the wide gap group moved in the same way (Fig. 4c). No significant difference was detected between groups.

Under weight-bearing conditions from 100° to 0° of extension from the flexed position, the average nearest medial point was also constant for both groups.

At 100° of knee flexion, the average nearest lateral point of the narrow gap group was -9.4 ± 3.2 mm. The average nearest lateral point of the wide gap group moved in the same way (Fig. 4e). No significant difference was detected between groups.

In regards to axial rotation of the femoral component relative to the tibial component, the femoral component initially exhibited internal rotation from 100° to 20° and gradual external rotation from 10° to 0° , and the mean range of axial rotation during the knee extension cycle was 8.8° . The mean axial rotation in the wide gap group moved in the same way (Fig. 4f). No significant difference was detected between groups.

Comparison of flexion and extension kinematics under weight-bearing conditions

In regards to the narrow gap group under weight-bearing conditions, the average nearest medial point of flexion from the extended position was significantly more posteriorly located at 50° , 60° , 70° , 80° , 90° , and 100° than those of extension from the flexed position (Fig. 5a). The average nearest lateral point of flexion from the extended position was also significantly more posteriorly located at 10° , 20° , 30° , 40° , 50° , 60° , 70° , and 80° than those of extension from the flexed position (Fig. 5b). Regarding axial rotation of the femoral component relative to the tibial component, significant differences were detected at 10° , 20° , 30° , 50° , 60° , and 70° (Fig. 5c).

With respect to the wide gap group, the average nearest medial point of flexion from the extended position was also significantly more posteriorly located at 80° than those of extension from the flexed position (Fig. 5d). The average nearest lateral point of flexion from the extended position was significantly more posteriorly located at 0° , 10° , 20° , 30° , and 60° than those of extension from the flexed position similarly (Fig. 5e). Regarding axial rotation of the femoral component relative to the tibial component, significant differences were detected at 10° , 20° , and 30° (Fig. 5f).

WOMAC

The clinical evaluation was also carried out using the Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) [20]. The pain, stiffness, and functional subtotal scores suggested a trend toward superior results for the wide gap group compared to narrow gap group. Significant differences were detected for two functional items (bending to floor and getting on/off toilet) (Table 1). These items require comfortable moderate knee flexion.

Discussion

We examined knee kinematics in 30 knees with narrow and wide flexion gap TKA under both weight-bearing and non-weight-bearing conditions to evaluate gap effects on kinematics. Consistent with our hypothesis, intra-operative joint gaps influenced kinematics. Under non-weight-bearing conditions, the medial condyle of the wide flexion gap group was more anteriorly positioned than that of the narrow flexion gap group (posterior translation of tibia relative to femur due to gravity) and significant differences were detected around 80 – 100° of knee flexion, beginning to rollback. Under weight-bearing conditions, flexion from an extended position showed more posterior position of both medial and lateral condyles of the two groups compared with extension from a flexed position. In contrast, no significant difference between groups was detected regarding medial and lateral condyle positions and the axial rotation of the femur component relative to the tibia component.

Component gap differences between extended and flexed positions were examined in this study. Both extension and flexion gaps can be influenced by many factors during the operation (osteophytes, ligament tension, ligament release, alignment, implant size and position, etc.) [21]. Our preliminary study revealed that flexion gap was strongly affected by PCO and PTS [3]. In this study, we evaluated the PCO and PTS and confirmed no significant difference between the narrow and wide flexion groups. Previous literature reported that the PCL strongly influences the flexion gap [21, 22]. The contact point measurement was also carried out to evaluate posterior cruciate ligament function [19]. The contact ratio of the wide gap group was significantly more posterior than that of the narrow gap group ($P < 0.001$). Therefore, we speculate that the PCL tension of the wide flexion gap group in this study was less than the PCL tension in the narrow flexion group. This PCL tension could have strongly influenced the kinematic differences in this study.

Paradoxical anterior femoral slides have been described in many studies [9, 23–25]. In this study, two types of anterior translation were observed. The first type was a larger anterior translation (about 3–4 mm) of both medial and lateral

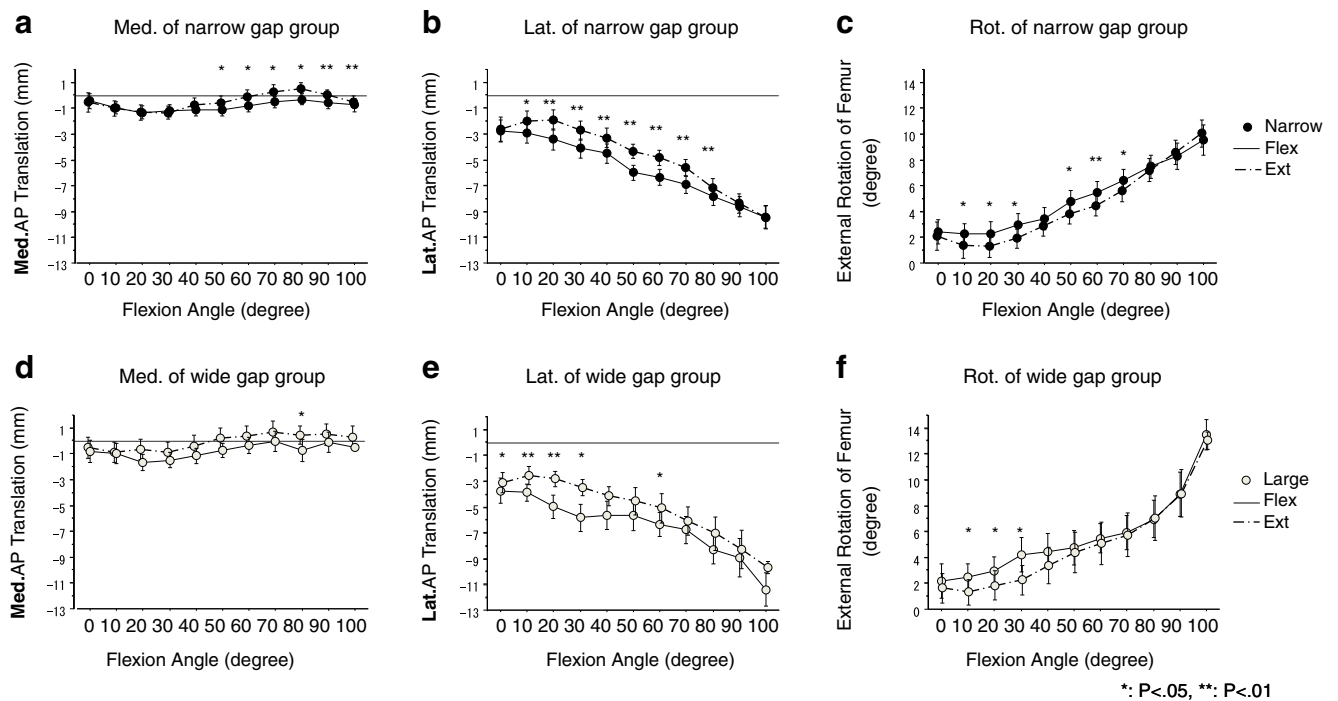


Fig. 5 Narrow gap group (a,b,c) and wide gap group (d,e,f) comparisons between flexion from an extended position and extension from a flexed position under weight bearing conditions. The average nearest medial and lateral point of both the narrow and wide gap groups during flexion was

significantly more posterior than that observed during extension (a,b,d,e). The average external rotation of narrow and wide gap groups during flexion from an extended position was significantly larger than that during extension from a flexed position (c)

condyles during non-weight bearing, and the second type was a small anterior translation (average 1–2 mm) of the medial and lateral femoral condyle between flexion and extension during weight bearing (the flexion from the extended position is continuously translated posteriorly). The first type of anterior translation observed during non-weight bearing is not observed in the anterior cruciate ligament (ACL)-deficient knees without axial load between the femur and tibia. We propose an explanation for this mechanism. Gravity produces a posterior force on the tibia relative to the femur, and the tibia is likely to translate posteriorly (sagging) due to mid flexion joint laxity. The medial femoral condyle of the wide flexion gap group will translate more anteriorly than that of the narrow flexion gap group (Fig. 3). Rollback starts around 70–110° and is regulated by PCL tension. The wide flexion gap group showed consistently more anterior medial condyle position compared with the narrow gap group. In other words, the wide flexion gap group showed greater sagging and a later start in rollback. This first type of anterior translation observed during non-weight bearing could be mainly related to PCL laxity.

The second type of small anterior translation occurred under weight-bearing conditions likely due to ACL deficiency. Sliding and rolling mechanisms are regulated by the ACL and PCL. The medial femoral condylar position of posterior CR TKA was first translated posteriorly from 0° of extension to 30° of flexion. The medial femoral condyle then moved

anteriorly from 30 to 80 degrees of flexion. This early, small posterior translation of the femur is most likely a result of the ACL deficiency phenomenon. During flexion in the weight bearing condition, the medial femoral condyle of a CR TKA was forced to translate posteriorly from 0 to 30 degrees as would occur in an ACL deficient knee. Subsequent small anterior translations of the medial condyle from 30 to 80 were compensation for the ACL deficiency.

Our WOMAC outcomes revealed that the wide gap group gained significantly better scores in two functional items (bending to the floor and getting on/off toilet). This result might indicate that a small amount of laxity is indispensable for daily activities. Both the aforementioned activities are carried out under weight bearing conditions with deep knee flexion. Our weight-bearing results at full extension (0°) through mid-flexion (100°) did not detect significant differences between the two groups. Further biomechanical evaluations involving deep flexion might explain this result. In contrast, this anterior sliding of the femoral component on the tibial polyethylene surface could risk accelerated polyethylene wear. Blunn et al. [26], in a laboratory evaluation of polyethylene wear, found dramatically increased polyethylene wear with cyclic sliding as compared with compression or rolling, because of increased surface shear stresses. Therefore, a smaller flexion-extension gap difference might be desirable, as long as it does not limit postoperative terminal flexion and daily activity, or induce excessive rollback and adverse wear of

Table 1 The results of the Western Ontario and McMaster Universities osteoarthritis Index (WOMAC)

Measure		Narrow gap group	Wide gap group	P-value
Pain	1. Walking	0.6±0.8	0.8±0.7	0.438
	2. Stair Climbing	1.0±0.8	0.8±0.7	0.4785
	3. Nocturnal	0.8±0.6	0.3±0.5	0.0965
	4. Rest	0.5±0.7	0.4±0.5	>0.9999
	5. Weight bearing	0.8±0.8	0.6±0.5	0.4708
	Subtotal	3.7±2.9	2.9±2.5	0.7182
Stiffness	1. Morning stiffness	0.8±0.6	0.3±0.5	0.0965
	2. Stiffness occurring later in the day	0.7±0.8	0.2±0.4	0.1809
	Subtotal	1.4±1.2	0.6±0.9	0.0509
Physical function	1. Descending stairs	1.7±0.1	1.9±1.1	0.6499
	2. Ascending stairs	1.2±1.0	1.4±1.0	0.5157
	3. Rising from sitting	1.0±1.2	0.9±0.6	0.8419
	4. Standing	0.8±1.0	0.8±0.1	0.8784
	5. Bending to floor	1.9±1.3	0.3±0.5	0.0085**
	6. Walking on flat surface	0.8±1.0	0.6±0.5	0.8766
	7. Getting in / out of car	1.1±1.0	0.7±0.9	0.284
	8. Going shopping	1.2±0.9	1.2±1.2	0.7506
	9. Putting on socks	1.0±0.9	1.2±1.0	0.5635
	10. Lying in bed	1.0±0.9	1.2±1.0	0.5635
	11. Talking off socks	1.2±0.7	0.8±0.7	0.2113
	12. Rising from bed	0.5±0.8	0.6±0.7	0.2732
	13. Getting in/out of bath	1.5±1.0	1.1±0.6	0.3435
	14. Sitting	0.7±0.8	0.2±0.4	0.1809
	15. Getting on/off of toilet	0.6±0.6	0.1±0.3	0.0487*
	16. Heavy domestic duties	1.9±1.0	2.0±1.2	0.9805
	17. Light domestic duties	1.5±1.0	1.4±1.0	0.8416
Subtotal	19.4±11.7	16.4±5.6	0.6535	
Total	22.2±13.8	17.3±6.4	0.4223	

*P<0.05, **P<0.01

polyethylene due to high shear and compressive forces [26, 27]. Adequate laxity should be determined in the future.

As with every study, strengths and weaknesses exist. The small size of the study (30 knees) is a limitation. It was difficult to evaluate the in vivo kinematics in all of our patients. In the future, we hope to increase the number of patients assessed after a CR TKA, including those with poor clinical outcomes, so that new insights into in vivo kinematics after a TKA can be explored. Flexion of the femoral component and the PTS did not reflect the angle between femoral and tibial shafts. We only evaluated the angle between femoral and tibial components, which is a limitation of the present study. One should bear in mind that several degrees of difference exist between the component angle and the femoral-tibial shaft angle. The choice of our patient sample and methods of evaluation of patient satisfaction also include limitations. JOA and WOMAC scores are not significant between the two groups. Only basic knee motions were evaluated in this study. Other

daily motions, such as slow/fast gait, and ascending/descending stairs, were not examined. It is still unclear whether any difference would be detected between the two groups.

In conclusion, we investigated the in vivo mid-flexion kinematics of the CR TKA under weight-bearing and non-weight-bearing conditions, and evaluated the effects of joint gap. Under non-weight-bearing conditions, the medial condyle of the wide flexion gap group was more anteriorly positioned compared with that of the narrow flexion gap group especially around 80–100° of knee flexion. In other words the wide flexion gap group showed a late start in rollback. Under weight-bearing conditions of the two groups, both medial and lateral condyles during the flexion from the extended position moved posteriorly as compared with the extension from the flexed position. The excessive wide flexion gap might influence the late rollback observed under non-weight-bearing conditions, and anterior-posterior instability observed under weight-bearing conditions. On the other hand, a tight flexion

gap could interfere with daily activity, and adequate laxity might be necessary for comfortable daily activity. This study also indicates that 3–4 mm laxity at 90°–0° component gaps may be adequate and might be necessary to carry out daily life activities.

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

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