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Original article

Evaluation of joint laxity against distal traction force upon flexion in cruciate-retaining and posterior-stabilized total knee arthroplasty

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Abstract

Background. Several studies have reported varus-valgus stability in the extension position after total knee arthroplasty (TKA). However, few studies have evaluated joint laxity in the flexion position postoperatively. The purpose of the study was to evaluate joint laxity against distal traction force on flexion after cruciate-retaining and posterior-stabilized total knee arthroplasties.

Methods. A total of 44 knees (22 knees cruciate-retaining, 22 knees posterior-stabilized) in 40 patients with osteoarthritis were tested in this study. The subjects were seated at a table and their knee joints were fixed at 80° of flexion to avoid overlapping images of condyles and the femoral shaft. Tibial shafts were adjusted to be parallel to the radiographic films, and posteroanterior radiographs were obtained. Flexion stress tests were performed with a distal traction of 100 N at a neutral foot position. Radiographs were obtained at neutral and traction positions. The distance from the perpendicular line of the top of the polyethylene insert to the midpoint on the tangential line of the femoral condyle was measured (joint space distance) at each side.

Results. In the flexion-neutral position, average joint space distances were 0.1 ± 0.2 mm in cruciate-retaining (CR) TKA knees and 0.2 ± 0.3 mm in posterior-stabilized (PS) TKA knees. With flexion-traction stress tests, the average joint space distances were 0.5 ± 0.5 mm in CR TKA knees and 2.4 ± 1.2 mm in PS TKA knees. Average changes of joint space distances between the two positions were 0.3 ± 0.4 mm (CR TKA) and 2.2 ± 1.5 mm (PS TKA). The changes in joint space distances between neutral and traction positions of PS TKA knees were significantly larger than those of CR TKA knees in flexion stress tests ($P < 0.01$).

Conclusion. The posterior cruciate ligament acted as a stabilizer against distal traction force in the CR-TKA knees. However, the laxity of PS-TKA knees against distal force differed among individual cases.

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Introduction

Proper joint stability in extension and flexion positions is required to maintain good clinical results for both cruciate-retaining (CR) and posterior-stabilized (PS) total knee arthroplasty (TKA) types in the long term. Stability is obtained by creating equal and balanced extension–flexion gaps and with the proper use of prosthetic components (in terms of size and thickness).[1] However, perfect balance is not always achieved by TKA.[2]

Several research studies using fluoroscopic, stereophotogrammetric, and electrogoniometric methods[3–9] have reported knee laxity and motion analyses after TKA. A fluoroscopic study showed condylar liftoff on the coronal plane under a weight-bearing condition.[3,4] Electrogoniometry was used to measure three-dimensional knee motion and the joint reaction force during gait after CR- and PS-TKAs.[7–9] Draganich and Pottenger[10] and Stein et al.[11] studied knee laxity after TKA with a three-dimensional knee laxity system.[10,11] A KT arthrometer has been used to assess anteroposterior stability at 30° and 75° flexion of the knee and sequential change of anteroposterior stability.[12,13] Stress radiographs were used to assess posterior stability with different TKA designs.[14] The Telos arthrometer has been applied to evaluate valgus–varus stability and function of the posterior cruciate ligament.[15,16]

In the flexion position, anteroposterior, valgus–varus, and internal–external stability are critical. Moreover, proper stability is required in the distal–proximal direction after TKA. If tension is excessive in the distal–proximal direction, it causes restriction of the range of motion (ROM), breakage of the polyethylene insert, and progressive subluxation after CR-TKA.[17] If too loose, it causes posterior dislocation of the tibia on the femur after PS-TKA.[18–20] However, we found that few studies have evaluated joint laxity against distal traction force in the flexion position postoperatively.

The purpose of this study was to evaluate joint laxity using the flexion-traction test after CR- and PS-TKA to obtain further understanding of TKAs.

Materials and methods

A total of 44 knees in 40 patients diagnosed with osteoarthritis (OA) were included in this study. Consent for participation in this study was obtained from all patients. All were Japanese women, with an average age of 72.5 years (range 60–82 years) and with an average body mass index of 27.1 (range 22.2–30.6). CR-TKA was performed on 22 knees of 20 patients, and PS-TKA was performed on 22 knees of 20 patients. No cases of TKA after high tibial osteotomy and revision knee arthroplasty were included in the study.

The clinical rating system of the Knee Society was applied to evaluate clinical results. The high-tech CR knee implant has a flat-on-flat surface, and the PS type has 3° of medial inclination and 2° of lateral inclination on the coronal plane (Nakashima Medical, Okayama, Japan). CR and PS types have femoral components of the same radii on the sagittal plane, and the aspect ratios — anteroposterior/mediolateral (AP/ML) — of femoral components were 0.86. Both tibial plates of the CR and PS types have 5° of posterior inclination (Fig. 1).

All surgeries were performed by a single senior surgeon (H.M.). The surgical technique involved approaching the knee through a medial parapatellar incision and then performing an arthrotomy. The condition and function of the posterior cruciate ligament (PCL) were assessed using magnetic resonance imaging (MRI) and a posterior drawer test with a Telos arthrometer (Medizinisch-Techniche, Griesheim, Germany) preoperatively; and the CR type was selected only when the PCL was intact anatomically and functionally. In some cases, type selection was changed from CR to PS during the operation because dysfunction of the PCL appeared after cutting the femoral and tibial bones.

After sizing the anteroposterior dimensions of the distal femur, the distal femoral cutting guide was aligned along the transepicondylar axis, and the distal femur was cut by the anterior reference method. The proximal tibia was cut perpendicular to the axis of the tibial shaft. Before the final implantation, trial components were set. The ligament balance for knee extension and flexion was confirmed manually, although no quantitative analysis was performed. Posterior capsulotomy was not performed in all the cases, but posterior femoral osteophytes were removed. The femoral, tibial, and patellar components were fixed without cement. The average interval between surgery and examination of stress radiography was 29.0 months (range 24–40 months).

Flexion stress radiography was performed with the flexion stress system (Nakashima Medical, Okayama, Japan). The subjects were seated at a table and their knee joints were fixed at 80° of flexion to avoid overlapping images of condyles and the femoral shaft. Rotation of the femur was restricted by the examiners with a rubber band. Tibial shafts were adjusted to be parallel to the radiographic films, and posteroanterior radiographs were obtained. Flexion stress tests were per-

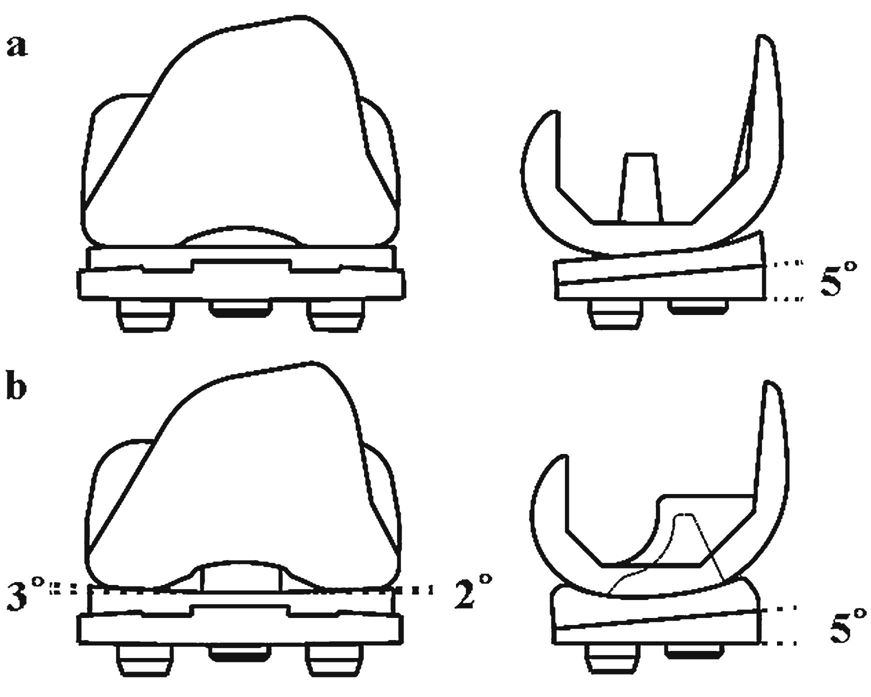

Fig. 1. Patterns of total knee joints. **a** Cruciate-retaining type **b** Posterior-stabilized type

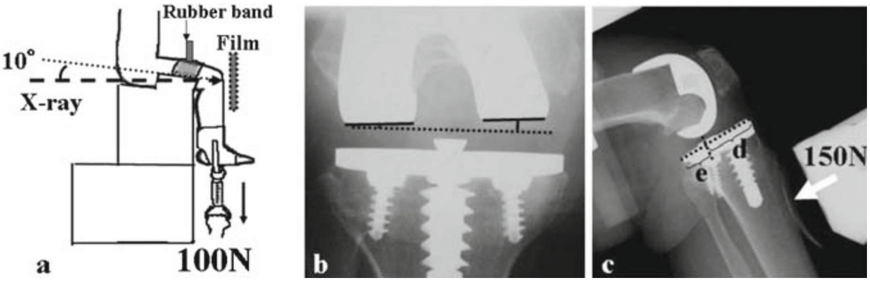

Fig. 2. Measuring methods. **a** Flexion-traction stress test. **b** Joint space distance: distance from the perpendicular line from the top of the polyethylene insert to the midpoint on the tangential line of the femoral condyle was measured at both sides. **c** Posterior stability: $d/(d + e) \times 100$; normal is >45

formed with a distal traction of 100 N (using a spring scale) at a neutral foot position (Fig. 2). Radiographs were obtained at neutral and traction positions. The distance from the perpendicular line of the top of the polyethylene insert to the midpoint on the tangential line of the femoral condyle was measured (joint space distance) at each side (Fig. 2b). The real joint space distance was obtained by correcting the radiographic magnification.

These flexion tests were examined by two orthopedic surgeons (Y.T., J.M.) in 10 cases. The average errors of joint space distance between the two examiners were 0.1 ± 0.2 mm in the neutral and traction positions ($r^2 = 0.97$, $P < 0.01$).

Valgus and varus stress tests in the knee extension position, along with a posterior drawer test, were performed at 150 N using a Telos arthrometer. Valgus and varus stability in the extension position were calculated by measuring the angle formed by tangential lines of the femoral condyles and the tibial metal plate. Posterior stability at 90°of knee flexion was evaluated using the midpoint method,[10] in which the proportion of the anterior distance from the average closest points between both condyles and the tibial plate to the sagittal tibial diameter is determined. A ratio under 45% suggests posterior instability.[21] The femorotibial angle (FTA) was assessed as the lateral angle between tibial and femoral axes on an anteroposterior view radiograph in the weight-bearing condition, preoperatively and postoperatively. The change of posterior condylar offset was defined as the subtraction from the preoperative posterior condylar offset to the postoperative one, when measuring the distance between the line tangential to the posterior cortex of the femur and the lowest point of the posterior condyle in the lateral view radiograph.[22] The change of joint line was evaluated using the method described by Figgie et al. on lateral radiographs of the knee.[23] The change to the proximal position was defined as positive.

Statistical analysis was performed using the Wilcoxon signed rank test and the Mann-Whitney U-test. Correlations were analyzed by Pearson's correlation coefficient or Spearman's rank correlation, as appropriate. The significance level was set at 0.05.

Results

The average knee scores were 91.7 ± 3.4 after CR-TKA and 91.6 ± 7.1 after PS-TKA. The average function scores were 81.8 ± 12.8 after CR-TKA and 80.0 ± 8.1 after PS-TKA. There were no significant differences between CR-TKA and PS-TKA in either the knee score or the function score. The average maximum flexion angles were 116.3° ± 11.0° after CR-TKA and 118.9° ± 11.2° after PS-TKA, with no significant difference. Preoperative FTAs were 187.3° ± 4.2° after CR-TKA and 194.5° ± 7.6° after PS-TKA. There was a significant difference between the preoperative FTAs ($P < 0.01$). Postoperative FTAs were 174.6° ± 1.4° after CR-TKA and 176.4° ± 2.9° after PS-TKA. The average insert thicknesses were 8.3 ± 1.8 mm after CR-TKA and 9.3 ± 2.3 mm after PS-TKA. The average changes in the joint line were 0.8 ± 1.5 mm after CR-TKA and 1.5 ± 1.5 mm after PS-TKA, with no significant difference (Table 1).

The joint angles of the extension-valgus test were 3.0° ± 1.1° after CR-TKA and 4.1° ± 1.8° after PS-TKA. The joint angles of the extension-varus test were 2.9° ± 1.6° after CR-TKA and 2.6° ± 2.1° after PS-TKA. The posterior drawer test results were 53.6% ± 6.6% after CR-TKA and 64.6% ± 2.1% after PS-TKA (Table 2).

In the flexion-neutral position, average joint space distances were 0.1 ± 0.2 mm after CR-TKA and 0.2 ± 0.3 mm after PS-TKA. In flexion-traction stress tests, the average joint space distances were 0.5 ± 0.5 mm after CR-TKA and 2.4 ± 1.2 mm after PS-TKA. Average changes in joint space distances between the two positions were 0.3 ± 0.4 mm after CR-TKA and 2.2 ± 1.5 mm after PS-TKA. The changes in joint space distances between neutral and traction positions of PS-TKA were significantly larger than those of CR-TKA in flexion stress tests ($P < 0.01$) (Table 3). The joint space distances of all cases after CR-TKA were <2 mm in the flexion-traction stress test, but joint space distances of <2 mm were found in only 10 cases (45.5%) after PS-TKA. Three cases (13.6%) that changed from CR type to PS type due to dysfunction of the PCL after cutting bones showed distances >4 mm in the flexion-traction stress test (Table 4). The average posterior condylar offsets showed a decrease of 3.6 ± 2.9 mm after CR-

Table 1. Demographics of patients with cruciate-retaining type TKA and those with posterior-stabilized type TKA

Parameter	CR type	PS type
No. of knees	22	22
Diagnosis	Osteoarthritis	Osteoarthritis
Age (years)	72.5 ± 7.3	72.5 ± 3.9
Sex	Female	Female
Body mass index (kg/m^2)	26.9 ± 2.4	27.3 ± 4.4
Knee score (points)	91.7 ± 3.4	91.6 ± 7.1
Function score (points)	81.8 ± 12.8	80.0 ± 8.1
Flexion angle	116.3° ± 11.0°	118.9° ± 11.2°
FTA (preoperative)	187.3° ± 4.2°*	194.5° ± 7.6°
FTA (postoperative)	174.6° ± 1.4°	176.4° ± 2.9°
Insert thickness (mm)	8.3 ± 1.8	9.3 ± 2.3
AP/ML of femoral component	0.86	0.86
Change in joint line (mm)	0.8 ± 1.5	1.5 ± 1.5
Change in posterior condylar offset (mm)	3.6 ± 2.9	4.3 ± 4.3

Results are the mean ± SD
CR, cruciate-retaining; PS, posterior-stabilized; FTA, femorotibial angle; AP/ML, anteroposterior/mediolateral aspect ratio
* $P < 0.01$

Table 2. Results of extension stress test

	Extension stress test		
Group[a]	Valgus	Varus	Posterior Drawer Test (%)
CR-TKA	3.0° ± 1.1°	2.9° ± 1.6°	53.6 ± 6.6 *
PS-TKA	4.1° ± 1.8°	2.6° ± 2.1°	64.6 ± 2.1 *

Mean ± S.D., * $P < 0.05$
[a]There were 22 patients in each group

TKA and a decrease of 4.3 ± 4.3 mm after PS-TKA, with no significant difference between the two. There were no significant correlations between the decrease of posterior condylar offsets and the change of joint space distance in the flexion stress test (Table 1).

In the relations of the flexion and extension stress tests to the Knee Society score and ROM, there were no significant correlations.

Discussion

Matsuda et al. reported that 4° laxity in the coronal direction was considered acceptable regarding mobile weight-bearing ligament balance in the extension position with low contact stress, as measured with a Telos arthrometer.[15] In the present study, the joint angles of valgus and varus tests were within 4.1° in both CR- and PS-TKAs, and stability in the extension position was assumed to be good in our series.

Mihalko and Krackow reported that posterior cruciate ligament sacrifice caused movement of the joint line cephalad in a cadaveric study of a normal knee.[24] However, Cope et al. showed that theoretical elevation of the joint line did not occur after sacrifice of the PCL when comparing 28 CR-TKAs with 28 PS-TKAs.[25] In the current study, the average change in the joint line after PS-TKA was 1.5 ± 1.5 mm, which tended to be larger than that after CR-TKA, although there were no significant differences.

Tanzer et al. reported that good clinical results were achieved with both CR- and PS-TKAs using a skillful surgical technique.[26] In their study, the posterior drawer tests showed acceptable stability of the posterior cruciate ligament after CR-TKA and good function of the post-cam mechanism after PS-TKA. Knee scores, function scores, flexion angles, and postoperative FTAs similarly indicated good clinical results of CR- and PS-TKAs. However, the flexion stress tests revealed different aspects. The average joint space distances after CR-TKA were 0.1 ± 0.2 mm in flexion-neutral position and 0.5 ± 0.5 mm in flexion-distraction position. The joint space distances of all cases after CR-TKA were <2 mm in the flexion-traction stress test. Although Kleinbart et al. reported histological degeneration of the posterior cruciate ligament in osteoarthritic knees,[27] the results of this study showed that the posterior cruciate ligament works as a stabilizer against distal traction force. On the other hand, average joint space distances after PS-TKA were 0.2 ± 0.3 mm in the flexion-neutral position and 2.4 ± 1.2 mm in the flexion-traction position. Average changes in the joint space distances between the two positions were 0.3 ± 0.4 mm after CR-TKA and 2.2 ± 1.5 mm after PS-TKA. The changes in the joint space distance after PS-TKA were significantly larger than those after CR-TKA. Joint space distances of >2 mm were found in 12 cases (55.5%) after PS-TKA. In general, the decrease in posterior condylar offset

Table 3. Joint space distance in flexion stress test

Group	Neutral			Traction (100 N)			Difference between joint space distances in neutral and traction positions
	Medial	Lateral	Mean	Medial	Lateral	Mean	Traction-Neutral
CR-TKA	0.1 ± 0.2	0.1 ± 0.3	0.1 ± 0.2	0.5 ± 0.7]*	0.5 ± 1.0]*	0.5 ± 0.5]*	0.3 ± 0.4]*
PS-TKA	0.2 ± 0.3	0.3 ± 0.5	0.2 ± 0.3	2.2 ± 1.3	2.6 ± 1.2	2.4 ± 1.2	2.2 ± 1.5

Results are the joint space distance (in millimeters)
Neutral, neutral position; Traction, 100 N traction position; Medial, medial side of knee; Lateral, lateral side of knee; Mean, mean value of the medial and lateral sides
* $P < 0.01$

Table 4. Distribution of joint space distances in flexion-traction stress test

Parameter	No. within each range of joint space distance (0–5 mm) in the flexion-traction stress test					
	≥0 to <1	≥1 to <2	≥2 to <3	≥3 to <4	≥4 to <5	Total
CR-TKA	16 (72.7%)	6 (27.3%)	0	0	0	22 (100%)
PS-TKA	2 (9.1%)	8 (36.4%)	5 (22.7%)	4 (18.2%)	3 (13.6%)	22 (100%)

increases the flexion gap, and changes of posterior condylar offset in the study showed no significant differences between CR- and PS-TKAs. Sacrifice of the PCL influences the increase in joint space distance. However, the average preoperative FTA after PS-TKA was significantly larger than that after CR-TKA in the current study. There was a possibility that the tension of other secondary soft tissues (e.g., gastrocnemius and pes tendons, iliotibial band, joint capsule) was loose in a severely deformed knee and caused a larger increase in the flexion gap. PS-TKA produced a larger range of laxity than CR-TKA in the flexion position, and the clinical results of PS-TKA were good at the 2-year follow-up. Nevertheless, this laxity might cause a high rate of condylar liftoff and increase the motions of components, leading to high compressive stresses at the polyethylene insert and the trabecular bone in the long term.

Mihalko and Krackow revealed that loss of the PCL led to an average increase of 6.4 mm in flexion gap with manual distraction in a cadavaric study.[24] Kadoya et al. stated that the flexion gap increased 4.8 mm on the medial side and 4.5 mm on the lateral side after resection of the PCL.[28] In their study, the increase in the flexion gap seemed to be smaller than those reported in cadavaric and intraoperative studies.[24,28] In an vivo postoperative study, the tests for CR- and PS-TKAs could not be examined in the body of the same individual, and stiffness of soft tissues varies among individuals. These two factors affect differences between postoperative data and cadaver or intraoperative data.

In the case of a larger-than-expected increase in the flexion gap, additional distal femoral cutting and use of a thicker polyethylene insert might decrease the joint space distance in a flexion stress test, and this procedure might cause the higher elevation of the joint line. In three cases (13.6%) changed from the CR-type to the PS-type TKA due to dysfunction of the PCL after cutting femoral and tibial bones, the procedure was performed but the joint space distances remained >4 mm in the flexion traction stress test. Therefore, the intraoperative change from the CR-type to the PS-type TKA is not recommended, especially after cutting both femoral and tibial bones. An alternative is to select an artificial joint with a different radius for the femoral component on the sagittal plane. However, it is difficult to obtain a preoperative estimate of the increase of flexion gap for severely deformed knees.

There are some limitations to the current study. Our study was a statistical analysis of laxity against a distal force at 80° flexion, performed at one point between 24 and 40 months after TKA. It is necessary to evaluate the sequential change because the function of the PCL might change. Moreover, it is not clear whether the displacement (joint space distance) of the flexion-traction test relates to the intraoperative tension of the knees because extension and flexion gaps were not measured in the current study. The combination of flexion stress test with intraoperative measurement of gaps could be effective for evaluating knee stability.

The study revealed that the PCL kept the knee stable against distal traction force in the flexion position, and sacrifice of this ligament caused joint laxity in different ranges. The increases in the flexion gap after resection of the PCL varied among individuals. Therefore, careful attention is required for adjustment of gap when performing PS-TKA on severely deformed knees.

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