Posterior Displacement of the Tibia Increases in Deep Flexion of the Knee

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Abstract

Background Deep knee flexion is important to proper function for some activities and in some cultures, although there are large posterior forces during high knee flexion. Most of what we know about posterior restraint and stability, however, has not been determined from deep flexion and without distinguishing motion in the medial and lateral compartments.

Questions/purposes We therefore evaluated (1) the difference in posterior displacement between the medial and lateral compartments at a commonly used flexion angle of 90°; (2) that of deeply flexed knees at 135°; and (3) the difference in kinematics in the medial and lateral compartments. We analyzed posterior stability in 21 normal knees using interventional open magnetic resonance imaging (MRI) system.

Results When manual posterior stress was applied, the posterior displacements of the tibia were 0.6 mm/2.1 mm (medial/lateral) at 90° and 0.6 mm/3.6 mm at 135°. The

posterior aspect of the femoral medial condyle moved 7.5 mm anteriorly with knee flexion, whereas the lateral condyle moved 1.3 mm anteriorly. The contact point of the lateral compartment moved 9.2 mm posteriorly with knee flexion, whereas the contact point of the medial compartment moved 2.3 mm anteriorly.

Conclusions Posterior displacement was larger in the lateral compartment at both flexion angles with manual posterior stress. As the knees flexed from 90° to 135°, posterior displacement became larger in the lateral compartment.

Clinical Relevance Cruciate-retaining total knee arthroplasty (TKA) or posterior cruciate ligament (PCL) reconstruction surgery should aim to achieve stability on the medial side and a few millimeters of laxity at the lateral side at 90° flexion with increasing laxity only on the lateral side in deep flexion.

Introduction

The PCL is the primary restraint to posterior tibial translation [3, 6–8, 14, 15, 19] and tension of the PCL is one of the most important factors determining outcome with PCL reconstruction surgery or TKA. Much of what we know about posterior stability has been obtained using stress radiography and arthrometry for normal knees [5, 11, 13, 23, 26, 27]. In the case of PCL reconstruction surgery, the tension of the graft is determined commonly by that of the contralateral side assessed by stress radiography or arthrometry. In the case of cruciate-retaining TKA, partial PCL release commonly is performed in knees with tight PCL in knee flexion [22]. The tension of the PCL is determined by the previously known POLO test [4, 24] or other subjective methods [1]. Posterior stability typically

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has been assessed at 25° to 90° flexion in stress radiography or arthrometry.

High flexion of the knee is essential to many activities of daily life, especially for Far Eastern and Middle Eastern populations. Many professions, including construction and agricultural work, and many hobbies and sports require high flexion of the knees. Nagura et al. reported a large tibial posterior force must be sustained at the knee during high knee flexion [17], and the PCL is assumed to play a substantial role in resisting this posterior force. The posterior stability of a deeply flexed knee also may be an important factor, and better understanding of these factors may improve the surgical technique of cruciate-retaining TKA and PCL reconstruction.

However, it is difficult to distinguish the movement of the lateral condyle from that of the medial condyle by stress radiography or arthrometry. There are substantial differences between the medial and lateral compartments, including congruity of the surfaces, stability of the collateral ligaments, and mobility of the meniscus [2]. Therefore, the kinematics and posterior stability of each compartment should differ.

Using an open MRI system, we therefore (1) assessed the difference in posterior displacement between the medial and lateral compartments at a commonly used flexion angle of 90°; (2) determined posterior displacement of deeply flexed knees at 135°; and (3) evaluated the difference in motions throughout flexion angles of 90° and 135° in the medial and lateral compartments.

Materials and Methods

We examined 21 normal knees (eight males and four females; mean age, 28.9 years; age range, 23–33 years). The subjects all were Japanese volunteers who had no knee symptoms and no history of injury. Their clinical status and MRI showed no abnormalities in their menisci, cartilages,

or ligaments. They gave informed consent and agreed to participate in this study without payment.

The MRI system used in this study was an open MRI at 0.4 T (APERTO; Hitachi Medical Corporation, Tokyo, Japan). The MRI was open in the horizontal direction with a 38-cm vertical gap. We performed the test for the manual posterior drawer while each subject was beneath the gantry. The subject was placed on the table and asked to lie on the side of the knee being examined. To stabilize the trunk and leg during the procedure, we flexed the contralateral hip and knee over and anterior to the knee under examination (Fig. 1). We performed the procedures at two flexion angles of the knee: 90° (Fig. 1A) and 135° (Fig. 1B). To apply posterior force, the examiner placed his hands on the proximal tibia with the palm overlying the tibial tubercle and on the distal part of the tibia. The examiner pushed the tibial tubercle posteriorly with his palm to increase the stress. The amount of the posterior force applied to the knees was evaluated by using a KT-2000 arthrometer (MEDmetric, San Diego, CA). Because there was magnetic field influence, we were not able to measure it at the same time as we measured the posterior displacement. The examiner applied posterior force to the KT-2000 arthrometer attached to one knee in the same position as in the open MRI. The posterior force recorded on the sheet was 137.9 N at 90° flexion and 134.9 N at 135° (average of three measurements). The posterior force applied to the knees was considered to be approximately 130 N at both flexion angles which was comparable to those of the methods using arthrometers or stress radiographs [5, 13, 23, 26, 27].

The knee was scanned in the sagittal plane before and during the stress application (TR/TE, 2300 ms/112 ms; flip angle, 90°; field of view, 200 mm; thickness, 4.0 mm). When the knee was scanned under stress, the image plane was adjusted to be sagittal using Interactive Scan Control (ISC) software (Hitachi Medical Corporation, Tokyo, Japan), so the plane was the same as that for the images

Fig. 1A–B The knees were scanned at flexion angles of (A) 90° and (B) 135°.

scanned before stress was applied. ISC determines the image plane interactively on the basis of fluoroscopy images displayed on a user interface with an update time, including a scan time of 2 seconds. The user was able to change the image plane, oblique angle, phase encoding direction, and contrast parameters during the scan. The imaging pulse sequence was a balanced steady-state acquisition with a rewind gradient echo sequence (TR/TE, 5.0 ms/2.5 ms; flip angle, 90°; field of view, 260 mm; thickness, 7.0 mm). It usually took less than 3 minutes from applying stress to complete the scan, including the fine-tuning of the plane, using the ISC. First, the knee with a flexion angle of 90° was scanned and then at 135° in succession.

The position and displacement of the tibia with respect to the femur were measured in the images scanned at the center of the medial and lateral compartments. One of us (SF) used the method of Okazaki et al. [20] and Tashiro et al. [28] measuring the distance between the posterior edge of the tibial plateau and a vertical line drawn from the most posterior point of the posterior condyle of the femur (Fig. 2). At 90° flexion, it was possible to draw a tangent line on the posterior aspect of the femoral condyle, and the distance between that line and the posterior edge of the

tibial plateau was measured (Fig. 2A). At 135° flexion, the distance between the posterior edge of the tibial plateau and the most proximal point of the posterior femoral condyle was measured (Fig. 2B). We also measured the distance between the posterior edges of the tibial plateau to the most posterior point of the femoral condyle as the contact point of the femorotibial joint. The size of the femoral condyles and tibial plateau was measured. The size of the femoral condyle was defined as the maximum distance of the femoral condyle perpendicular to the anatomic axis of the distal femur. The size of the tibial plateau was defined as the distance from the anterior and posterior edges of the tibial plateau. We calculated the percentage of the contact point and posterior condylar point on the tibial plateau from the posterior edge. A positive value was assigned if the femur was anterior to the posterior edge of the tibial plateau. To measure the distance at the center of each compartment, we chose a slice that included the medial edge of the fibular head as a landmark for the center of the lateral compartment and the attachment of the medial head of the gastrocnemius for the medial compartment. The distance was measured on two adjacent images at the center of each compartment, and the average was calculated to avoid variation caused by the choice of the image. The measured distance, however, did not differ more than 1 mm between the two adjacent images, suggesting the choice of images had little influence on the results. The distance measured on the film was converted to real displacement by multiplying by a reduced scale.

To evaluate the reproducibility of this method, the whole procedure was repeated three times for the same knee and the procedure was repeated on the same day. The repeated procedure was performed by the same examiner or by different examiners to evaluate intraexaminer and interexaminer reproducibility, respectively. The procedure was performed three times by one examiner on the first 10 knees. The first examiner performed it once and another examiner performed it twice on the other 11 knees. The displacement of the tibia with respect to the femur was measured in each scan, and the difference among the three examinations was assessed. An interclass correlation coefficient was used to test the reproducibility. We performed an ANOVA under the general linear model procedure to calculate the intraclass and interclass correlation coefficients. In the first 10 knees, the intraclass correlation coefficient was calculated from the data of three measurements of one of the observers (YT). In the other 11 knees, the intraclass correlation coefficient was calculated from the data of two measurements of the other observer (SF), and the interclass correlation coefficient was calculated from the data of the measurement of one of the observers (YT) and the average of the two measurements of the other observer (SF). The reproducibility of this

Fig. 2A–B MR images show the medial compartment knee when stress was applied at (A) 90° and (B) 135°. Line F = a vertical line drawn from the most posterior point of the posterior condyle of the femur; Line C = a vertical line drawn from the contact point; Line anterior = a vertical line drawn from the posterior edge of the tibial plateau; Line posterior = a vertical line drawn from the anterior edge of the tibial plateau. (a) The distance between the posterior edge of the tibial plateau and a line drawn from the most posterior aspect of the femoral condyle (Line F to posterior). (b) The distance between the posterior edge of the tibial plateau and the contact point (Line C to posterior). (c) The length of the tibial plateau (line anterior to posterior). The positions of the posterior aspect of the femur and contact point are shown by the length (mm) and the percentage on the tibial plateau ($a/c\%$ and $b/c\%$).

method was assessed by repeating all procedures in the same knee. The intraclass correlation coefficient among the three measurements conducted by the same examiner (YT) in the first 10 knees was 0.99 for measurement of the distance between the posterior edge of the tibial plateau and the posterior aspect of the femoral condyle and 0.99 for measurement of the distance between the posterior edge of the tibial plateau and the contact point. In the other 11 knees, the intraclass correlation coefficient between the two measurements conducted by the same examiner (SF) was 0.99 for measurement of the distance between the posterior edge of the tibial plateau and the posterior aspect of the femoral condyle and 0.94 for measurement of the distance between the posterior edge of the tibial plateau and the contact point. When stress was applied by different examiners, the interclass correlation coefficient between the measurement of one of the examiners (YT) and the average of the measurements of the other examiner (SF) was 0.95 for measurement of the distance between the posterior edge of the tibial plateau and the posterior aspect of the femoral condyle and 0.92 for measurement of the distance between the posterior edge of the tibial plateau and the contact point (Table 1).

We used the following methods to confirm the validity of the sample size. Standard error (SE) is estimated by the standard deviation (SD) divided by the square root of the sample size.

$$SE = SD/n^{-1}$$

To set the SE to less than 1 mm, the sample size should be greater than 14.44 with a maximum SD in this study of 3.8 (the position of the posterior edge of the tibia with respect to the contact point in the lateral compartment, with posterior stress, at 135°). Therefore, 21 knees was the number of adequate cases in this study.

We correlated posterior displacement of the tibia and size of the femoral condyles and tibial plateau using Pearson's correlation coefficients. The data were analyzed using JMP software (Version 7.0; SAS Institute, Cary, NC).

Results

In the knees with 90° flexion, the positions of the posterior edge of the tibia with respect to the posterior aspect of the femoral condyle were almost at the same level in both

Table 1. Assessment of intraobserver and interobserver reproducibility

Knees	Examiner	Reproducibility	Interclass correlation coefficient
The positions of the posterior edge of the tibia with respect to the posterior aspect of the femoral condyle			
1 to 10	Y.T. × 3	Intraobserver YT × 3	ICC (1.3) 0.99
11 to 21	Y.T. × 1, S.F. × 2	Intraobserver SF × 2	ICC (1.2) 0.99
		Interobservers YT and SF	ICC (2.2) 0.95
The positions of the posterior edge of the tibia with respect to the contact point			
1 to 10	Y.T. × 3	Intraobserver YT × 3	ICC (1.3) 0.99
11 to 21	Y.T. × 1, S.F. × 2	Intraobserver SF × 2	ICC (1.2) 0.94
		Interobservers YT and SF	ICC (2.2) 0.92

ICC = interclass correlation coefficient.

Table 2. Posterior stability in the knee with 90° flexion*

Side	Without stress	With posterior stress	Displacement
The positions of the posterior edge of the tibia with respect to the posterior aspect of the femoral condyle			
Medial	0.6 ± 1.6 mm (−3.4 to 3.1) [1.2% ± 3.4% (−8.1 to 6.1)]	1.2 ± 1.7 mm (−2.8 to 4.0) [2.5% ± 3.6% (−6.6 to 5.5)]	0.6 ± 0.7 mm (−1.2 to 2.3) [1.3% ± 1.5% (−2.8 to 4.5)]
Lateral	−0.7 ± 2.4 mm (−4.3 to 5.0) [−1.6% ± 5.6% (−10.9 to 10.8)]	1.4 ± 2.7 mm (−3.6 to 8.5) [3.3% ± 6.2% (−9.0 to 18.8)]	2.1 ± 1.2 mm (−0.1 to 4.4) [4.9% ± 2.9% (−0.2 to 10.8)]
The positions of the posterior edge of the tibia with respect to the contact point			
Medial	16.3 ± 2.0 mm (12.2 to 19.7) [33.9% ± 3.7% (26.1 to 40.2)]	17.1 ± 2.0 mm (14.1 to 20.8) [35.7% ± 3.3% (30.5 to 41.6)]	0.8 ± 1.1 mm (−1.8 to 2.6) [1.8% ± 2.5% (−3.7 to 6.3)]
Lateral	17.1 ± 2.4 mm (12.5 to 22.3) [39.1% ± 5.0% (28.8 to 48.2)]	18.9 ± 2.5 mm (12.8 to 25.4) [43.2% ± 6.0% (32.1 to 56.3)]	1.8 ± 1.5 mm (−0.7 to 5.2) [4.1% ± 4.0% (−1.3 to 13.9)]

* Mean ± SD (range).

Table 3. Posterior stability in the knee with 135° flexion*

Side	Without stress	With posterior stress	Displacement
The positions of the posterior edge of the tibia with respect to the posterior aspect of the femoral condyle			
Medial	8.1 ± 3.0 mm (2.8 to 14.0) [16.4% ± 5.9% (6.0 to 27.2)]	8.7 ± 2.9 mm (4.3 to 13.3) [17.7% ± 5.7% (7.8 to 27.1)]	0.6 ± 0.5 mm (−2.0 to 5.0) [1.3% ± 3.0 (−3.8 to 10.4)]
Lateral	0.6 ± 2.3 mm (−3.4 to 4.2) [1.5% ± 5.5% (−7.8 to 9.7)]	4.2 ± 3.7 mm (−2.6 to 9.8) [10.0% ± 8.7% (−5.7 to 24.1)]	3.6 ± 2.1 mm (0.2 to 8.0) [8.4% ± 4.9% (0.3 to 18.3)]
The positions of the posterior edge of the tibia with respect to the contact point			
Medial	18.6 ± 3.0 mm (14.5 to 24.2) [37.4% ± 5.0% (31.1 to 47.6)]	19.6 ± 3.1 mm (14.9 to 25.3) [39.6% ± 5.3% (32.2 to 52.7)]	1.0 ± 1.3 mm (−1.9 to 3.6) [2.2% ± 2.6% (−3.0 to 6.8)]
Lateral	7.9 ± 3.2 mm (2.6 to 15.7) [18.8% ± 7.4% (6.3 to 34.1)]	11.4 ± 3.8 mm (3.3 to 16.7) [26.6% ± 9.3% (8.0 to 41.0)]	3.5 ± 3.1 mm (−0.6 to 10.6) [7.8% ± 7.5% (−2.1 to 24.5)]

* Mean ± SD (range).

Fig. 3A–B The positions of the posterior aspect of the (A) femur and (B) contact point on the tibial plateau at 90° and 135° flexion are shown. Lat = lateral; Med = medial.

compartments without stress. Posterior displacements in the lateral compartment were approximately 2 mm, which were larger than those in the medial compartment, less than 1 mm at both reference points (Table 2). The sizes of the femoral condyle were 59.2 ± 4.0 mm (range, 51.7–66.4 mm) in the medial side and 62.6 ± 4.0 mm (range, 57.0–71.9 mm) in the lateral side. The sizes of the tibial plateau were 48.1 ± 3.5 mm (range, 41.9–54.4 mm) in the medial side and 43.8 ± 3.1 mm (range, 39.5–49.7 mm) in the lateral side. We observed no correlation ($r^2 = 0.00$ – 0.09 ; $p = 0.14$ – 0.92) between those sizes and posterior displacement.

In the knees with 135° flexion, posterior displacements in the lateral compartment were approximately 4 mm, which also were larger than those in the medial compartment, less than 1 mm (Table 3). There was no correlation ($r^2 = 0.00$ – 0.07 ; $p = 0.23$ – 0.86) between the size of the femoral condyle or tibial plateau and posterior displacement.

As the knees flexed from 90° to 135°, the posterior aspect of the femoral condyle on the tibial plateau moved 7.5 mm anteriorly in the medial compartment and 1.3 mm anteriorly in the lateral compartment (Fig. 3A). The contact point on the tibial plateau moved 9.2 mm posteriorly in the lateral compartment and 2.3 mm anteriorly in the medial compartment (Fig. 3B).

Discussion

Despite the existence of a substantial body of literature dedicated to assessing posterior displacement with stress radiography or arthrometry, rotational movement resulting from posterior stress or posterior displacement in deeply flexed knees has yet to be evaluated. With this information deficiency as an impetus, we therefore (1) assessed the difference in posterior displacement between the medial and lateral compartments at a commonly used flexion angle of 90°; (2) assessed posterior displacement of deeply flexed knees at 135°; and (3) evaluated the difference in kinematics in the medial and lateral compartments.

There are some limitations in this study. First, because force was applied manually, it would be subject to some inconsistency. The degree of displacement would vary depending on the stress and direction of the force and may be influenced by the position of the examiner and body mass index of the leg being examined. We therefore assessed reproducibility of this method by repeating the whole procedure in the same knee. The interclass correlation coefficient in all measurements was 0.98 with an interexaminer and 0.99 with an intraexaminer. Therefore, we consider the reproducibility of this method is acceptable and believe the stress was reasonably consistent. Second, the degree of displacement may vary depending on the choice of images to measure. Although the scanning plane was set to be the same by the ISC system, it was not

perfectly identical among the subjects. We chose two images at the center of the compartments and averaged them to minimize the variation of images to be assessed. Third, all subjects were Japanese in this series. The Japanese population has greater varus alignment compared with the Caucasian population [10]. However, knee alignment is considered to have little influence on knee laxity because it is determined mainly by the ligaments and soft tissues. Our subjects, young people without abnormalities in their physical and MRI findings, are appropriate subjects for evaluation of knee laxity although they have varus alignment. Additional studies are needed to investigate whether the medial tightness may be associated with the prevalence of osteoarthritis. Fourth, only two flexion angles, 90° and 135°, were evaluated. Additional studies involving more flexion angles are needed to evaluate posterior stability and kinematics of the normal knees.

Our data showed the posterior stability of the knee and relative position of the femur and tibia. We observed similar stability at 90° flexion as reported by others using the arthrometry and stress radiographic techniques [5, 23] (Table 4). However, the rotatory movement we report was not detected with the radiographic techniques used by others. Logan et al. compared the kinematics of PCL-deficient knees with normal knees using a vertical open MRI system [12]. They reported 0.5 mm medial and 1.9 mm lateral displacement with manual posterior stress in six intact knees, the contralateral side of the PCL-deficient knees, at a flexion angle of 90°. Our results were similar to theirs. We examined a larger number of knees and also assessed the reproducibility of the methods, so we

believe our data are reliable. Some knees experienced anterior displacement in the unilateral compartment with posterior drawer stress. Those knees showed rotating movement rather than posterior movement, and large posterior displacement in the lateral (or medial) compartment and slight anterior displacement in the medial (or lateral) compartment.

In the knees with 135° flexion, we observed mean posterior displacements of the tibia of 0.6 mm in the medial and 3.6 mm in the lateral compartments, indicating posterior displacements were almost six times larger in the lateral compartment than in the medial side. The knees with 90° flexion also showed the same tendency; posterior displacements in the lateral compartment were larger than in the medial side. In comparing laxity between 90° and 135°, posterior displacement of the lateral compartment of 135° was larger than that of 90°, whereas posterior displacement of the medial compartment did not change during flexion from 90° to 135°. Papannagari et al. reported the length of the PCL increased with flexion from 0° to 120° and decreased beyond 120° [21]. They found the length of the PCL was almost the same at 90° flexion and at 135° flexion, but the sagittal elevation angle of the PCL increased as the knee flexed from 0° to 135°. This presumably explains why the knee became unstable at 135°. In comparing laxity between both compartments, the constraint was stronger in the medial compartment because the PCL was attached to the medial side of the femur. In addition, external rotation of the tibia reportedly is limited by the posterolateral structure [8, 9]. We were not able to evaluate isolate function of the posterolateral structure in

Table 4. Comparison of published studies of mean posterior displacement

Method	Study	Flexion angle	Posterior force	Distance from posterior aspect of the femoral posterior condyle to posterior edge of tibial plateau			Posterior displacement		
				Overall	Medial	Lateral	Overall	Medial	Lateral
Arthrometry	Shultz et al. [26]	25°	133 N	—	—	—	5.2 mm	—	—
	Steiner et al. [27]	25°	89 N	—	—	—	3.0 mm	—	—
	Eakin and Cannon [5]	25°	133 N	—	—	—	3.4 mm	—	—
		90°	177 N	—	—	—	2.5 mm	—	—
Stress radiography	Margheritini et al. [13]	25°	89 N	2.7 mm	—	—	—	—	—
		90°	89 N	3.6 mm	—	—	—	—	—
	Schulz et al. [23]	90°	150 N	1.3 mm	—	—	—	—	—
Open MRI	Logan et al. [12]	90°	Manual	—	—	—	—	0.5 mm	1.9 mm
	Current study	90°	Manual	—	1.2 mm	1.4 mm	—	0.6 mm	2.1 mm
		135°	Manual	—	8.7 mm	4.2 mm	—	0.6 mm	3.6 mm

our study, but it would have some influence on stability at lateral compartment. In the case of cruciate-retaining TKA, surgeons must determine the appropriate tension of the PCL. Partial PCL release commonly is performed in knees with tight PCLs in knee flexion [22]. Proper release would improve the maximum flexion angle and maintain AP stability without causing undesirable changes in kinematics, whereas excessive resection of the PCL causes unfavorable AP instability [1]. Some reports have included indices of the tension of the PCL during cruciate-retaining TKA, but their methods were relatively subjective. Chmell and Scott introduced the POLO (pull-out, lift-off) test to evaluate tension of the PCL [4, 24]. Arima et al. reported partial release of the PCL could improve the maximum flexion angle and maintain AP stability [1]. Our data suggest normal knees have very high posterior stability. The kinematics of the knee change after TKA and undoubtedly are influenced by the implant design, size, and implant positioning. Therefore, although not applicable to every knee, our data can be used as an index of the tension of the PCL during cruciate-retaining TKA. We believe surgery should aim to achieve stability on the medial side and a few millimeters of laxity at the lateral side at 90° flexion with increasing laxity only at the lateral side in deep flexion.

Nakagawa et al. reported flexion from greater than 90° to active maximum flexion was accompanied by backward movement of the medial femoral flexion facet center (2 mm) and by backward movement laterally (13 mm) [18]. We found all knees experienced posterior femoral translation of the lateral condyle and minimal change in position of the medial condyle with knee flexion. Our results agree with those of previous reports showing large posterior translation in the lateral side and little movement in the medial side [16, 18]. Our data consist of only two flexion angles, but these contact point results were similar to what we expected. This large AP motion of the lateral condyle is accompanied by movement of the lateral meniscus (the meniscus moves with the femur relative to the tibia as the knee flexes and rotates). However, on the medial side, the posterior (but not the anterior) horn is fixed to the tibia [2], so movement of the medial side is restricted. We also assessed movement of the posterior aspect of the femoral condyle. The posterior aspect of the femoral condyle on the tibial plateau moved 7.5 mm anteriorly in the medial compartment and 1.3 mm anteriorly in the lateral compartment as the knees flexed from 90° to 135°. In the normal knee, sliding is reportedly the main movement in the medial compartment and rolling is the main movement in the lateral compartment [25]. Our findings, that the contact position stayed at the same position and the posterior aspect moved largely anteriorly in the medial and that the contact position moved posteriorly and the posterior aspect stayed at the same position

in the lateral, agreed with the previously known phenomena. Our results suggest these sliding/rolling phenomena also occur in deeply flexed knees.

We assessed posterior stability of the normal knee using an open MRI system. Posterior displacement was larger in the lateral compartment at a flexion angle of 90° with manual posterior stress. At 135° flexion, all knees experienced posterior femoral translation of the lateral condyle and minimal change in position of the medial condyle with knee flexion. Posterior displacement also was larger in the lateral compartment at a flexion angle of 135° with manual posterior stress. The posterior displacement became larger as the knee flexed in the lateral compartment, whereas that in the medial compartment was less than 1 mm at flexion angles of 90° and 135°. Our data reflect the tension of the PCL during the procedure of cruciate-retaining TKA or reconstruction surgery.

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