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Basic Science

Influence of Medial Collateral Ligament Release for Internal Rotation of Tibia in Posterior-Stabilized Total Knee Arthroplasty: A Cadaveric Study

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ABSTRACT

Background: Previous studies suggested that changes in kinematics in total knee arthroplasty (TKA) affected satisfaction level. The aim of this cadaveric study was to evaluate the effect of medial collateral ligament (MCL) release by multiple needle puncture on knee rotational kinematics in posterior-stabilized TKA.
Methods: Six fresh, frozen cadaveric knees were included in this study. All TKA procedures were performed with an image-free navigation system using a 10-mm polyethylene insert. Tibial internal rotation was assessed to evaluate intraoperative knee kinematics. Multiple needle puncturing was performed 5, 10, and 15 times for the hard portion of the MCL at 90° knee flexion. Kinematic analysis was performed after every 5 punctures. After performing 15 punctures, a 14-mm polyethylene insert was inserted, and kinematic analysis was performed.
Results: The tibial internal rotation angle at maximum knee flexion without multiple needle puncturing was significantly larger (9.42°) than that after 15 punctures (3°). Negative correlation (Pearson $r = -0.715$, $P < .001$) between tibial internal rotation angle at maximum knee flexion and frequency of puncture was observed. The tibial internal rotation angle with a 14-mm insert was significantly larger (7.25°) compared with the angle after 15 punctures.
Conclusion: Tibial internal rotation during knee flexion was reduced by extensive MCL release using multiple needle puncturing and was recovered by increasing of medial tightness. From the point of view of knee kinematics, medial tightness should be allowed to maintain the internal rotation angle of the tibia during knee flexion which might lead to patient satisfaction.

Total knee arthroplasty (TKA) is a procedure with successful long-term outcomes, including pain relief and functional restoration [1,2]. Despite favorable long-term implant survival after TKA, patient-reported outcomes did not indicate satisfaction levels that were comparable with those reported after total hip arthroplasty. Bourne et al [3] reported that nearly 1 in 5 patients remained unhappy after TKA, which was otherwise perceived by the surgeon as successful. This dissatisfaction could be explained partly by changes in kinematics after TKA [4]. The kinematic pattern in a normal knee is well known to have a medial pivot motion with internal rotation of the tibia in flexion [5]. Several studies investigating the kinematic pattern after TKA showed a paradoxical motion that was different from a normal knee [6,7]. Some previous studies emphasized that tibial internal rotation increased during deep flexion kneeling after TKA [8,9]. Moreover, Nishio et al [10] reported that intraoperative medial pivot kinematic patterns with femoral external rotation relative to the tibia resulted in larger flexion angles and better patient-reported outcomes. Therefore, from the point of view of kinematics, the surgical technique to maintain the medial pivot motion in TKA is important to increase the patient satisfaction.

On the other hand, for varus knee with late-stage osteoarthritis (OA), TKA often involves release of the medial structures, especially the medial collateral ligament (MCL), to realign the leg and achieve soft tissue balance; a couple of previous studies reported that the

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maneuver was necessary in 76%-88% of OA varus knees [11-13]. Although incorrect soft tissue balancing can result in a number of complications, the standard intraoperative soft tissue balancing technique has not been established. Thus, performance of soft tissue balancing is left to the discretion of the surgeon. However, Lee et al [14] described that a surgeon's subjective view of the technical quality of a procedure did not predict postoperative knee scores.

Consequently, we hypothesized that medial release affects the rotational kinematics in TKA, which may also influence the patient outcome. The aim of this cadaveric study was to evaluate the effect of MCL release by multiple needle puncturing on knee rotational kinematics in posterior-stabilized (PS) TKA.

Material and Methods

After obtaining approval from the institutional review board of our hospital, 6 fresh, frozen cadavers stored at −20°C were included in this study. There were 5 male specimens and 1 female specimen; the mean age was 82.0 years (range, 61-91 years). The bodies were complete in all specimens and were macroscopically intact without gross evidence of prior surgery. A PS-type prosthesis (NexGen LPS-Flex, Zimmer Biomet, Warsaw, IN) was used for each specimen using an image-free knee navigation system (Stryker Navigation, version 1.0; Stryker, Kalamazoo, MI), infrared cameras, and light-emitting diodes.

Surgical Procedure and Evaluation of Intraoperative Kinematics

Each surgery was performed using the standard medial parapatellar approach. Soft tissue release was not performed except for portions that required osteotomy. Registration of the navigation system was done for each case, following the manufacturer's protocol. Measured resection technique was used for bone resection. The anterior cruciate ligament and posterior cruciate ligament were sacrificed. Using the navigation system, the distal femur and proximal tibia were resected perpendicular to the mechanical axis on the coronal plane. On the sagittal plane, the femoral flexion angle and tibial posterior slope were set as 3° and 5°, respectively. The amount of cut bone was set as component thickness. To determine femoral rotation as parallel to the surgical epicondylar axis, posterior condylar angle was used which was measured from preoperative CT. Tibial rotational alignment was directed along a line from the medial border of the tibial tubercle to the middle of the posterior cruciate ligament [15]. The patella was not resurfaced. A 10-mm polyethylene insert was appropriate in all knees. After the trial component was assembled, intraoperative kinematic analysis was performed to evaluate the knee.

A multiple needle puncturing technique, which was described by Bellemans et al [16], was used to release the MCL. The amount of MCL release was classified into the following 4 steps. Using an 18-G needle, puncturing was performed 5 times, 10 times, and 15 times on the hard portion of the MCL at 90° knee flexion. Kinematic analysis was performed at each stage of medial release. After 15 times of multiple needle puncturing, it became possible to place a 14-mm polyethylene insert. Kinematic analysis was also performed with a 14-mm insert.

During evaluation of intraoperative kinematics, the dissected fascia was closed with 2 forceps. For each knee, kinematic analysis was performed once by the same examiner using the navigation system. The knee was flexed by placing the specimen's heel on the examiner' open palm to allow for freedom of tibial rotation while the other hand of the examiner was placed beside the specimen's knee for support [17]. Care was taken to avoid intentional rotation of the knee throughout flexion. The navigation system automatically recorded the rotation angle of the tibia at maximum extension, 30°, 60°, 90°, 120°, and maximum flexion during passive knee motion; internal rotation was designated as positive.

Statistical Analysis

To evaluate the differences in the internal rotation angle of the tibia at maximum knee flexion at each stage of MCL pie crusting, 1-way analysis of variance was used followed by the Tukey's multiple comparison tests. Correlation between tibial internal rotation angle at maximum knee flexion and frequency of needle puncturing was also assessed. Data after 15 times of pie crusting were compared with those after placement of a 14-mm insert using Student t test. All statistical analyses were performed using IBM SPSS statistical software (SPSS, version 21.0, for Mac OS X). A power analysis of the study and effect size were performed in relation to the internal rotation angles of the tibia at maximum knee flexion in each status of the knee. An effect size of 0.47 and power of 0.95 were obtained, which was considered adequate.

Results

The results of the internal rotation angle of the tibia during knee flexion are summarized in Figure 1. The mean values for tibial internal rotation angle at maximum knee flexion were 9.42° in PS knees without multiple needle puncturing and 3° in PS knees after 15 times of multiple needle puncturing. Tukey's 1-way analysis of variance revealed that there was significant difference (F [3, 20] = 7.186, P = .002) in PS knees between before and after multiple needle puncturing (Fig. 2). The internal rotation angle of the tibia on deep knee flexion tended to decrease as the number of multiple needle puncturing increased. Tibial internal rotation angle at maximum knee flexion was observed to be correlated with the frequency of needle puncturing (Pearson's r = 0.715, P < .001).

The changes in the internal rotation angle of the tibia due to insert thickness are summarized in Figure 3. The mean internal rotation angle of the tibia with a 14-mm insert was 7.25°; this was significantly larger compared with the mean angle in MCL-released knees at maximum knee flexion (t [9.957] = −3.248, P = .009).

Discussion

To our knowledge, this study was the first to report on the relationship between quantity of medial release and tibial internal rotation in TKA using a navigation system. Our results had 2 major findings. First, MCL release reduced the internal rotation angle of the tibia in deep knee flexion. Second, increasing the insert thickness increased the internal rotation of the tibia during knee flexion. Our results support the hypothesis that medial release affects the rotational kinematics in TKA and also indicate that medial tightness is needed to rotate the tibia internally during knee flexion.

The MCL is always released to some extent during initial anteromedial arthrotomy. Release of the deep MCL and posteromedial capsule is usually sufficient to correct a mild varus deformity [18-20]. The superficial MCL is often released to correct any residual varus deformity [21-23]. However, Hunt et al [24] reported that there remains a lack of consensus on quantification of medial release; therefore, interpretation of surgical procedures remains difficult. To quantify releasing, a pie-crusting technique for posterolateral release using scalpel blade was described by Mihalko and Krackow [25]. Some previous studies have also suggested pie-crusting release of MCL [26,27]. However, Meneghini et al [28] reported that MCL pie crusting was likely technique dependent since failure may occur within the ligament itself. On the other hand, the multiple needle puncturing technique is also a quantitative method for MCL release. Bellemans et al described that the procedure which

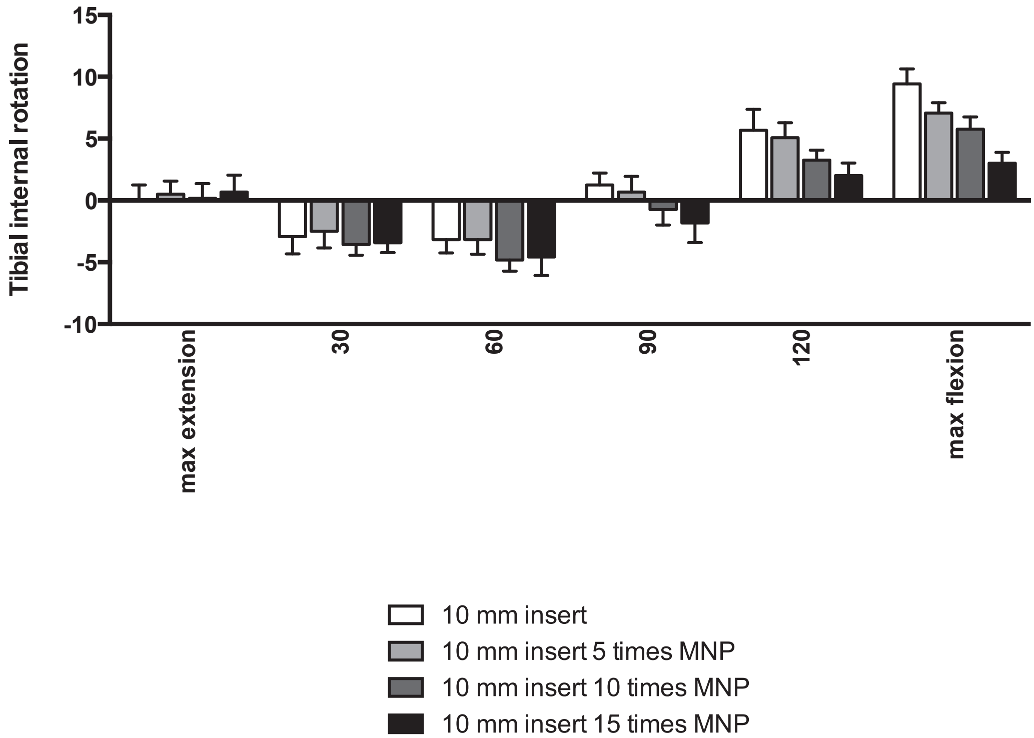

Fig. 1. Internal rotation of the tibia during knee flexion in each stage of MNP. Error bars indicate standard error. MNP, multiple needle puncturing.

was considered successful for correction of medial tightness was present to such an extent that mediolateral joint line opening measuring 2-4 mm during extension and 2-6 mm during flexion. Instability due to over-release was seen in 1 of 35 knees [16]. In addition, in present study, the multiple needle puncturing was to contribute to the quantitative assessment of the MCL release. Nevertheless, concerning with our results, additional MCL release for correction of medial tightness reduces internal rotation angle of tibia during deep knee flexion. From the point of view of knee kinematics, medial tightness might be allowed instead of the additional release of MCL.

A previous cadaveric study indicated that medial release influenced a laxity of the knee joint. Matsueda et al [29] evaluated medial soft tissue release with calipers and stated that an increase in coronal angulation and medial gap occurred after the release of anteromedial sleeves 8 cm from the medial joint line. Whiteside et al [13] reported that complete MCL release, regardless of the fibers, increased the laxity in flexion and extension. Crottet et al [30] assessed the contact force of the knee joint and stated that the medial contact force was reduced by 20% and 46% after minor and major collateral ligament releases, respectively. Iizawa et al [31] reported a significant increase in valgus and rotatory instability after deep MCL and posterior oblique ligament release in TKA. In the present study, the internal rotation angle of the tibia during knee flexion tended to decrease as the number of needle punctures on the MCL increased. Furthermore, the decrease in the internal rotation angle of the tibia after MCL release during knee flexion significantly recovered after placement of 14-mm insert. This result indicated that recovery of medial tightness increased the internal rotation angle of the tibia during knee flexion.

This study had some limitations. First, we assessed only the internal rotation angle of the tibia during flexion. There is a lack of kinematic data on anteroposterior, mediolateral, and superoinferior dimensions because knee kinematics included 6 degrees of

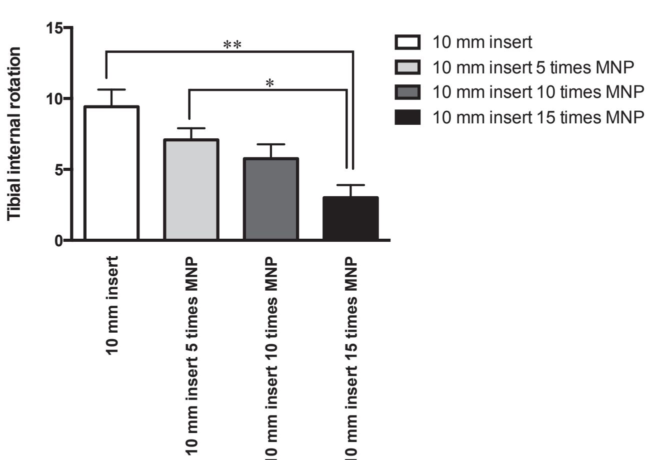

Fig. 2. Comparison of tibial internal rotation at maximum knee flexion during each stage of MNP. Error bars indicate standard error. $^{*}P < .05$, $^{**}P < .01$.

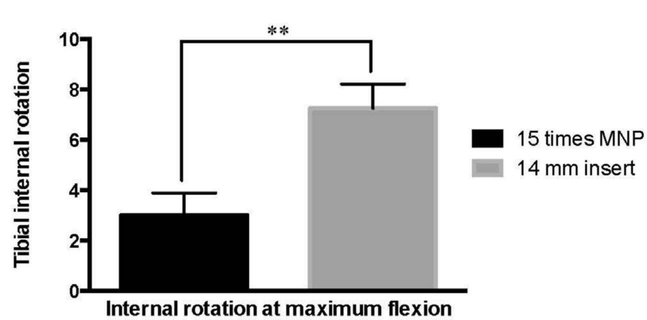

Fig. 3. Comparison of tibial internal rotation at maximum knee flexion after 15 times of needle puncturing and with a 14-mm insert. Error bars indicate standard error. $^{**}P < .01$.

freedom. Especially, anterior–posterior translation should be examined to evaluate knee flexion kinematics; unfortunately, this could not be assessed in our navigation system. Second, the condition during assessment of tibial internal rotation was not weight bearing. Many previous studies on intraoperative nonweight-bearing kinematics evaluation stated this limitation; however, a recent study reported that femoral external rotation with intraoperative medial pivot motion was associated with postoperative deep knee flexion angle [10]. Therefore, even in a nonweight-bearing kinematics situation, tibial internal rotation was an important parameter of postoperative knee flexion. Although this study was a cadaveric study using a whole body, our conditions were similar to those of clinical studies of patients under anesthesia. Third, cadaveric normal knees were used to assess intraoperative kinematics in the present study. Our data from normal knees might be different from those with OA. This issue should be examined in navigation-assisted TKA of OA cases. Fourth, the reproducibility of kinematic analysis was not evaluated and may be questionable because the analysis was performed manually. Nevertheless, our previous study revealed that intraoperative kinematic analysis had high reproducibility [17]. Therefore, we believe that the present data, which were assessed by the same method, had sufficient reproducibility. Finally, the ideal medial tightness has not been revealed, and the procedure to quantitatively evaluate medial tightness has not been developed. Although our data indicated that recovery of medial stability increased the internal rotation angle of the tibia during knee flexion, further study is needed to determine the appropriate medial stability and insert thickness.

In conclusion, extensive MCL release by multiple needle puncturing reduced tibial internal rotation during knee flexion. This decrease in the internal rotation angle of the tibia after MCL release during knee flexion significantly recovered after placement of a 14-mm insert, which increased the medial tightness. Recovery of medial tightness increased the internal rotation angle of the tibia during knee flexion. Therefore, from the point of view of knee kinematics, medial tightness might be allowed instead of the additional release of MCL.

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