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Original Article

Knee Flexion-induced Translation of Pullout Sutures Used in the Repair of Medial Meniscus Posterior Root Tears

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Medial meniscus posterior root tears (MMPRTs) have recently attracted considerable interest in orthopedics. To date, no *in vivo* human study has investigated suture translation changes in repaired MMPRTs with different degrees of knee flexion. This study examined suture translation at various degrees of knee flexion in 30 patients undergoing medial meniscus posterior root repair using the modified Mason-Allen suture technique between August 2016 and September 2017. Intraoperatively, sutures were provisionally fixed to an isometric positioner at the tibial site of the desired meniscal attachment, and the suture translation was measured at 0°, 30°, 60°, and 90° of knee flexion. The results showed significant increases in mean suture translation at the knee flexion positions from 0° to 30°, 30° to 60°, and 60° to 90° ($p < 0.01$ for all). Our findings indicate that surgeons should carefully assess the degree of knee flexion at the moment when the meniscus is refixed by surgical sutures.

Key words: medial meniscus, posterior root tear, suture translation, knee flexion, arthroscopic repair

Meniscal roots are fundamental for fastening menisci to the tibial plateau and converting axial loads into hoop stress [1,2]. Medial meniscus posterior root tears (MMPRTs) are a common occurrence in middle-aged women [3]. Left untreated, MMPRTs can rapidly lead to knee osteoarthritis due to disrupted hoop tension and progressive meniscal extrusion [4-6]. Biomechanical studies suggest that an MMPRT is functionally equivalent to a complete medial meniscectomy, which severely disrupts the contact pressure and kinematics of the knee joint [1].

Arthroscopic transtibial pullout repair of MMPRTs is currently an area of great orthopedic interest and research [4,7-12]. A cadaveric study investigating knee biomechanics after surgery showed that knee flexion and tibial rotation increased root tension [13]. This may undermine postoperative outcomes in patients undergoing MMPRT surgery. Based on second-look arthroscopic reports, the mid- to long-term success rates for this procedure may range from 0-100% [14-17]. Not surprisingly, there have been an increasing number of studies on methodologies for improving the postoperative outcomes of this procedure [18-20].

Recent studies have achieved good clinical outcomes using a novel arthroscopic meniscal root repair technique with a conventional two anterior portal approach [11,21]. This technique uses the FasT-Fix meniscal repair system and ULTRABRAID sutures (Smith & Nephew, Andover, MA, USA) to refix the torn meniscus root to the tibial plateau. To prevent meniscal extrusion during knee flexion, the sutures are pulled out from the tibial tunnel and fixed to the tibia. This technique has been reported to achieve biomechanical

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outcomes equal to or better than those of conventional root repair techniques [22]. However, no *in vivo* study has investigated the relationship between suture translation and the degree of knee flexion at the moment of meniscal refixation. Thus, the present study aimed to investigate changes in *in vivo* suture translation in repaired human MMPRTs over a range of degrees of knee flexion. We hypothesized that *in vivo* suture translation would increase with knee flexion.

Materials and Methods

Study design and patient eligibility. This study was conducted in accordance with the Declaration of Helsinki, and approved by the relevant institutional review board (approval #1857). All patients provided written consent before surgery, after all procedures were explained to them in detail. Thirty patients (5 men, 25 women: mean age: 57.4 ± 8.8 years) who underwent surgical repair of MMPRTs between August 2016 and September 2017 at our institution were retrospectively evaluated. The inclusion criteria were as follows: a diagnosis of MMPRT via magnetic resonance imaging (MRI) examinations based on characteristic findings such as a cleft, ghost, and giraffe neck sign [23, 24] and following surgical indications: (1) femorotibial angle $< 180°$, (2) mild cartilage damage (low-grade Outerbridge: I or II), (3) no necrotic lesion in the medial femoral condyle, and (4) knee osteoarthritis of Kellgren-Lawrence grade ≤ 2 on radiography. The exclusion criteria were as follows: radiographic knee osteoarthritis of Kellgren-Lawrence grade ≥ 3; previous history of meniscal or ligamental injury; or previous knee surgery. The mean duration from injury to meniscal repair surgery was 7.8 weeks (range 2-36 weeks).

Surgical technique. For each participant, the surgical procedure involved the following. The patient was placed in a supine position on the operating table and a standard arthroscopic examination of the knee joint was performed using a 4 mm diameter 30° arthroscope (Smith & Nephew) through the anteromedial and anterolateral portals. A probe introduced through the anteromedial portal was used to evaluate MMPRT severity. Each patient was determined to have a type 2 MMPRT under the LaPrade classification system [25]. In patients with a tight medial compartment, we used the outside-in pie-crusting technique and released the medial collateral ligaments using a standard 18-gauge (1.2×40 mm) hypodermic needle (Terumo, Tokyo, Japan).

The needle was percutaneously inserted at the level of the tibial plateau with the knee in the valgus-extension position. After confirming the expansion of the medial compartment, we used a rasp to detach the posterior meniscal periphery. We used a suture passer (Knee Scorpion; Arthrex, Naples, FL, USA) to pass a non-absorbable suture (no. 2 ULTRABRAID; Smith & Nephew) vertically through the meniscal tissue and tensioned it through the anterolateral portal. A meniscal repair system (FasT-Fix 360; Smith & Nephew) was then inserted through the anteromedial portal through the superior surface of the posterior horn of the medial meniscus (MM). Two anchors were advanced across the ULTRABRAID in a horizontal mattress suture pattern using a modified Mason-Allen configuration (F-MMA; Fig. 1) [21].

After removing the needle, we fastened the sliding knot of the inserted anchor and retrieved the uncut free end of the suture through the anterolateral portal. After confirming the attachment of the MM posterior root, we placed a custom-made posterior root-aiming device (MMPRT guide; Smith & Nephew) [26] at the center of the attachment area. A 2.4 mm guide pin was inserted into the articular surface at a 55° angle using the aiming device, and a 4.5 mm cannulated drill was used for overdrilling. The free ends of the sutures were pulled out through the tibial tunnel using a suture manipulator. Mild tension (5-10 N) was applied to the sutures until the posterior horn reached its tibial attachment area. After recording all target measurements, tibial fixation was performed using a double-spike plate and screw (Meira, Aichi, Japan). At this time, the knee was in 45° flexion and an initial 20 N was being applied to the suture [1, 21].

Measurements of suture translation. An isometric positioner was used to measure suture translation in each patient. This syringe-like device has an outer barrel (marked with scales), an inner plunger, and a coiled spring between the plunger and the end of the barrel (Fig. 2A) [27]. Transosseous sutures were provisionally tethered to the spring, and the point of the barrel was inserted into the tibial cortex (Fig. 2B). By sliding the plunger through the barrel, we obtained measurements of suture translation during the knee range of motion: our suture translation values were based on the changes in spring length.

To accurately position the knee for this purpose, we held the lower leg and foot in 0° dorsal ankle flexion with the second metatarsal bone positioned vertically [28]. Knee flexion angles of 0°, 30°, 60°, and 90° were measured using a goniometer composed of two steel arms (proximal and distal), with the ends affixed to a semicircular protractor. The maximum flexed angle was set at 90° to prevent suture cut-out. The proximal arm was held parallel to the femoral shaft; the center of the goniometer was aligned with the center of the knee joint (Fig. 2C). We applied light tension (about 5-10 N) to the suture (to avoid suture elongation in the knee-extended position) and then tethered the suture to the plunger (set at baseline for suture tension). In no case did our measurements reach the upper limit of the isometric positioner's range. After all measurements, curves of knee flexion angles and suture translation were generated (Fig. 3). All intraoperative measurements were taken and recorded by an experienced surgeon or assistant surgeons. All measurements were taken twice, and the average results were calculated.

Statistical analysis. Data were reported as means ± standard deviations. Statistical analysis and power calculations were performed using EZR software (Saitama Medical Center, Jichi Medical University, Tochigi, Japan) [29]. Differences in measured values or patient demographics were evaluated using the Mann-Whitney *U*-test or one-way analysis of variance (ANOVA) with the post-hoc Tukey honest significant difference test. Statistical significance was set at $p < 0.05$. Interobserver and intraobserver reliabilities were assessed using the intraclass correlation coefficient (ICC). ICC values > 0.9 were considered excellent, ICC values between 0.8 and 0.9 were considered good, and ICC values < 0.8 were considered poor.

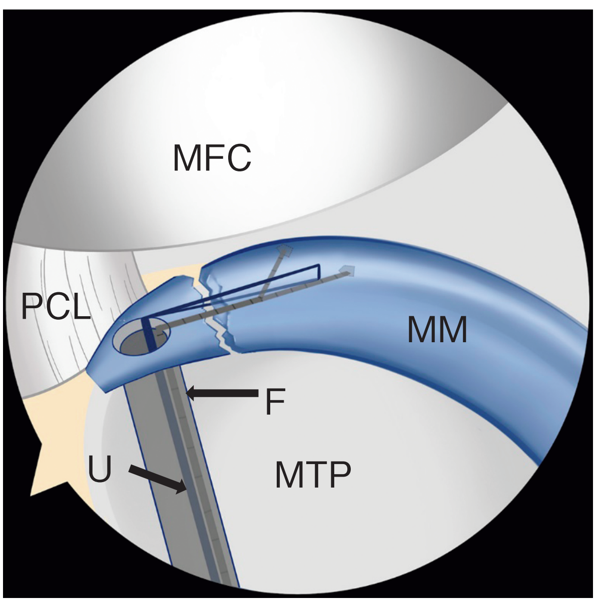

Fig. 1 A schematic figure of the modified Mason-Allen suture method using the FasT-Fix combined with ULTRABRAID. MM, medial meniscus; MFC, medial femoral condyle; MTP, medial tibial plateau; PCL, posterior cruciate ligament; U, ULTRABRAID; F, FasT-Fix.

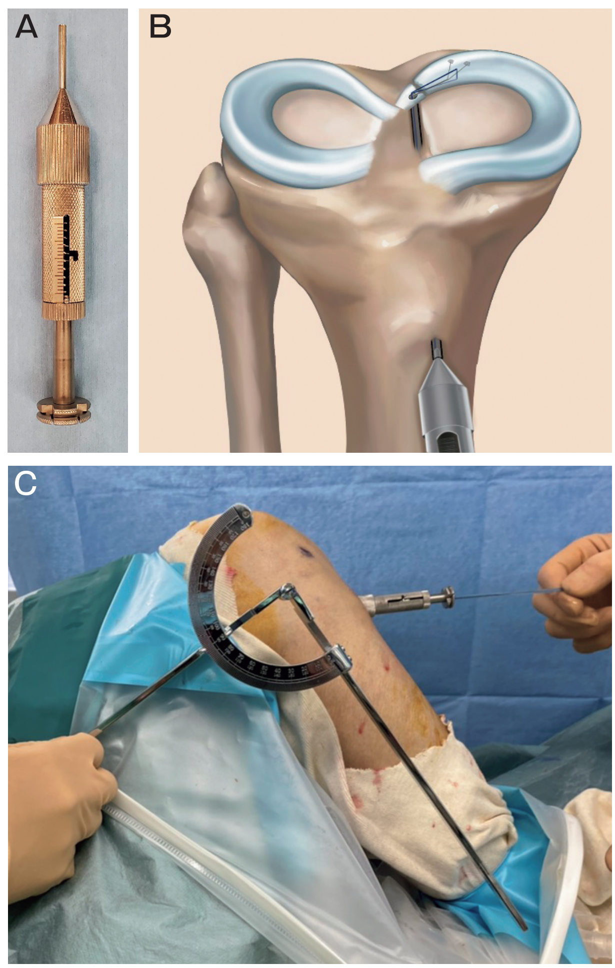

Fig. 2 The isometric positioner and intraoperative measurement setup. A, The custom-made isometric positioner; B, A schematic figure of the isometric positioner installation; C, Intraoperative setup of measurement at 90° knee flexion.

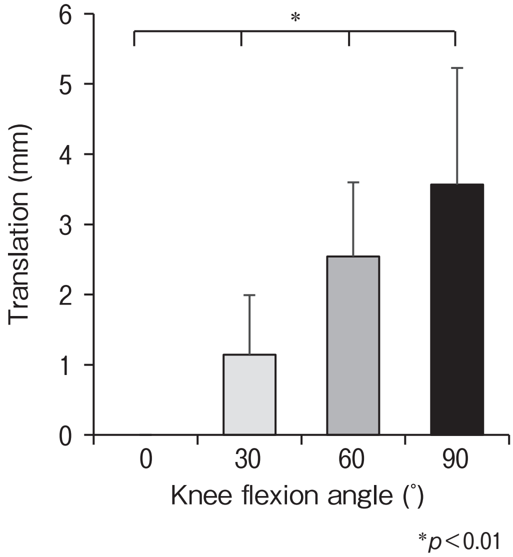

Fig. 3 Variation in suture translation between 0° and 90° knee range of motion. The knee flexion angle-suture translation of the repaired medial meniscus posterior root. $*p<0.01$.

Results

Suture translation values. The suture translation values were as follows: 1.1 ± 0.9 mm at 30° knee flexion, 2.5 ± 1.1 mm at 60°, and 3.6 ± 1.7 mm at 90°. There were statistically significant increases in mean translation at knee flexion from 0° to 30°, 30° to 60°, and 60° to 90° ($p<0.01$ for all, Fig. 3). The maximum translation detected in the suture was 7.5 mm at 90° knee flexion. In 3 of 30 patients, there was no change in tension or translation between 0° and 30° knee flexion. None of the patients exhibited a significant difference between our first and second sets of measurements. The analysis of our measurements for intra- and interobserver reliability yielded an ICC of 0.93/0.91.

Discussion

The most important finding of the present study was that suture translation increased with flexion of the knee joint when the pullout suture technique was used for MMPRTs. MMPRTs have attracted considerable interest in the field of knee joint disorders due to recent revelations that they can lead to rapid osteoarthritis. Several surgical techniques have been developed for repairing MMPRTs [10, 12, 21]. In the conventional repair technique, one or 2 posterior portals are needed for 2 purposes: the passage of sutures to the MM posterior root, and the insertion of the suture anchor into the tibial attachment of this root. However, there are potential problems associated with additional posterior portals, including the risk of neurovascular injury.

To resolve this problem, Fujii *et al.* developed a repair technique, the F-MMA suture [21], that is less invasive and requires less operative time. In a previous study involving swine menisci, the tensile strength of the F-MMA suture was compared with that of the conventional Mason-Allen suture, and no significant difference was observed [22]. In earlier reports, Furumatsu *et al.* compared short-term clinical outcomes and meniscal healing between the F-MMA and transtibial pullout repair using only the FasT-Fix device and observed superior results in the F-MMA group [11]. We consider the technique used in the present study to be a good suturing method that is safe, simple, and efficient.

No suture translation was observed between 0° and 30° knee flexion in 3 cases. Although we could not determine the underlying reason for this phenomenon, various factors might have played a role, including individual differences, meniscal degeneration/swelling, and the bone tunnel position. A normal meniscus moves posteriorly with knee flexion due to the rollback motion of the femur [30]. In a previous report, MRI in the knee-flexed position was used to confirm posterior translation and displacement of the MM in knees with MMPRTs [31]. Loss of posterior root continuity further increases the posterior extrusion of the menisci during knee flexion, thereby leading to a reduced femorotibial contact area and increased contact force [32]. The results of our study are in accordance with those of previous studies where severe MM posterior extrusion was observed, especially at 90° knee flexion in MMPRT knees, and where the sutures forced the MM posterior root to stay in the repaired position, thereby preventing MM posterior extrusion [31, 33].

By applying Hooke's Law, the stiffness coefficient of the coiled spring in the isometric positioner is defined as k (in newtons/meters [N/m]). When the length of the spring is changed by x (in m), the force exerted on the suture, F (in N), is explained by the following equation: $F=k \times x$. From this law and the results of our study, we can easily postulate that suture tension increases with knee flexion. Due to the posterior movement of the MM during knee flexion, there may be too much suture tension if the sutures are fixed while the knee is fully extended, whereas the sutures may be too loose during extension if fixed while the knee is in deep flexion. Given these factors (along with general postoperative loosening of suture thread), orthopedic surgeons should carefully consider the degree of knee flexion when the reparative suture is initially fixed. Based on previous reports, tibial fixation has generally been performed at 20-30° knee flexion in our institution [1,6,13,18,34].

During postoperative rehabilitation, deep flexion should probably be avoided: knee flexion should probably stay within 30-45° angles when the meniscus is sutured; this may be advantageous when standing, walking, or bearing weight, and may also improve long-term outcomes.

The present study had some limitations. The sample size was small, and the interval between each patient's injury and surgery was not considered. The effects of anterior-posterior translation and axial rotational torque could not be completely eliminated during measurements. In addition, detailed suture tension could not be evaluated by the isometric positioner. Further, only 4 flexion angles from 0° to 90° were evaluated. An increased translation may occur at a more deeply flexed position due to femoral rollback movement [30]. To prevent a cut-out of the MM, the tension we applied to the sutures was not strong [35]. Moreover, the influence of the tibial tunnel position was not considered. Further research is needed to evaluate the tunnel position and its influence on suture tension and translation.

In conclusion, suture translation increased with flexion of the knee joint when the pullout suture technique was used for MMPRTs. These results suggest that surgeons should carefully assess the degree of knee flexion at the moment the meniscus is refixed by surgical suture.

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