

Transtibial Centralization Using Peripheral Stabilization Suture Reduces Medial Meniscus Extrusion and Varus Progression 1 Year After Medial Meniscus Posterior Root Tear Repair

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Purpose: To evaluate the clinical and structural effects of adding peripheral stabilization suture (PSS), an additional transtibial pullout centralization technique, to conventional transtibial pullout repair for medial meniscus posterior root tears (MMPRTs).

Methods: A retrospective review was conducted of patients who underwent MMPRT repair between April 2019 and March 2024 with at least 1 year follow-up. Patients were divided into conventional pullout repair and pullout repair combined with PSS. Medial meniscus extrusion (MME) was evaluated by magnetic resonance imaging (MRI) preoperatively and at 1 year postoperatively. Radiographic parameters including hip-knee-ankle angle (HKA), mechanical axis (%MA), and Kellgren-Lawrence (KL) grade were assessed. Patient-reported outcome measures (PROMs) were also collected. Minimal clinically important difference (MCID) for MME was calculated, and the proportion of patients exceeding this threshold was compared between groups.

Results: Thirty-five patients were included. At 1 year postoperatively, the PSS group showed significantly less MME (5.3 mm vs. 3.2 mm; $P < .001$), fewer cases of varus alignment progression (12 vs. 5; $P = .018$), and less radiographic KL classification progression (11 vs. 5; $P = .044$) compared to the conventional group. The %MA remained unchanged in the PSS group but significantly shifted medially in the conventional group. PROMs improved significantly in both groups, with no significant differences between them. MCID analysis showed that the rate of clinically meaningful worsening of MME was significantly higher in the conventional group than in the PSS group (15/17 [88.2%] vs 4/18 [22.2%], $P < .001$).

Conclusions: The addition of PSS to conventional pullout repair for MMPRT effectively reduced postoperative MME and suppressed the progression of varus alignment and osteoarthritic changes at 1 year postoperatively, while both groups showed significant but comparable improvements in PROMs.

Level of Evidence: Level III, retrospective comparative study.

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A medial meniscus posterior root tear (MMPRT) is defined as a complete radial tear or a tear within 1 cm of the meniscal tibial attachment. These injuries are frequently observed in older adults with low activity levels and are closely associated with medial meniscus

extrusion (MME),¹ which reflects compromised meniscal function.² Unstable root tears disrupt circumferential fibers and eliminate hoop stress resistance, functionally resembling total meniscectomy and often requiring surgical intervention.³

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In recent years, repair techniques such as transtibial pullout repair have been widely used to restore the continuity of the posterior root. However, healing remains inconsistent,⁴ and MME often persists postoperatively,⁵ raising concerns about structural outcomes. To address these limitations, supplementary procedures such as meniscal centralization have been proposed.⁶⁻⁸

MMPRT tends to cause posteromedial extrusion during knee flexion.^{9,10} Among various augmentation techniques, the peripheral stabilization suture (PSS) method reinforces the posterior horn by performing localized transtibial pullout fixation at the high-stress posteromedial region.^{11,12}

The purpose of this study was to evaluate the clinical and structural effects of adding PSS, an additional transtibial pullout centralization technique, to conventional transtibial pullout repair for MMPRT. We hypothesized that combining PSS with pullout repair would more effectively reduce MME and suppress varus progression than pullout repair alone.

METHODS

This retrospective study protocol was approved by the Institutional Review Board of our institution. We reviewed consecutive patients who underwent pullout repair for MMPRT at our hospital between April 2019 and March 2024. Inclusion criteria were patients with symptomatic MMPRT who underwent pullout repair and had Kellgren–Lawrence (KL) grade 2 or less osteoarthritis on preoperative radiographs. There were no restrictions regarding patient age or the degree of varus alignment. Exclusion criteria included patients lost to follow-up, those with contraindications for magnetic resonance imaging (MRI) (e.g., pacemaker), and those who underwent procedures other than the PSS technique (e.g., pullout repair combined with centralization using a suture anchor). The specific indication for surgery was symptomatic MMPRT in patients who did not respond to conservative treatment and who elected surgery after receiving a thorough explanation of both surgical and nonsurgical options.

Surgical Technique

All procedures were performed by a team of orthopaedic surgeons affiliated with our institution, including the authors (S.H., T.S., R.T.), with the first author (S.H.) actively involved in every case in a supervisory capacity. From April 2019 to May 2022, patients underwent transtibial pullout repair alone (Conventional group). Beginning in May

2022, PSS was added to the procedure to enhance meniscal stability (PSS group).

In all cases, the posterior root of the medial meniscus was sutured using the modified Mason–Allen technique.¹³ To improve the arthroscopic working space, the superficial medial collateral ligament was percutaneously trephinated at several points using an 18-gauge needle while a gentle valgus force was applied. UltraTape (Smith & Nephew, London, UK) was passed through the posterior root of the medial meniscus using a single cinch loop, and the Fast-Fix device (Smith & Nephew, London, UK) was anchored in the posterior capsule, passing through the UltraTape cinch loop to secure the posterior root (Figure 1A). A 4.5-mm transtibial tunnel was created using an MMPRT guide, referencing landmarks such as the remnant tissue and the medial tibial eminence, and both the UltraTape and Fast-Fix were retrieved and pulled into the tibial tunnel. Pullout fixation was performed with an EndoButton (Smith & Nephew, London, UK) through the tibial tunnel.

For the PSS technique, a single Ultrabraid was passed through the posteromedial edge of the medial meniscus in a looped fashion, such that both limbs of the suture exited on the tibial side (Figure 1B). A 2.4-mm tibial tunnel was then created at the edge of the medial tibial plateau near the suture site and at the apex of the posterior horn of the medial meniscus. The 2 suture limbs were retrieved and secured transtibially using the pullout technique¹¹ (Figure 1C).

To avoid excessive centralization, we first fixed the root portion, followed by fixation with PSS. After fixation, arthroscopic evaluation was performed through a range of motion from 0° to 90° to confirm that appropriate tension was achieved and that no excessive tightness occurred during knee flexion (Figure 1D). In cases where partial-thickness cartilage defects corresponding to Outerbridge grade 4 were observed, microfracture was performed.

Postoperative Management

After MMPRT repair, all patients followed a structured rehabilitation program. In both groups, full weight-bearing was allowed starting at 6 weeks postoperatively; however, patients in the convention group remained nonweight-bearing until then, whereas those in the PSS group were permitted partial weight-bearing beginning at 2 weeks. Range of motion was limited to 0°–90° until 4 weeks postoperatively, then increased to 120° at 6 weeks, and unrestricted after 8 weeks. Immobilization was achieved using a hybrid splint until 4 weeks postoperatively, followed by the use of a hinged valgus knee brace for 4 months. Rehabilitation was supervised by a physical therapist for

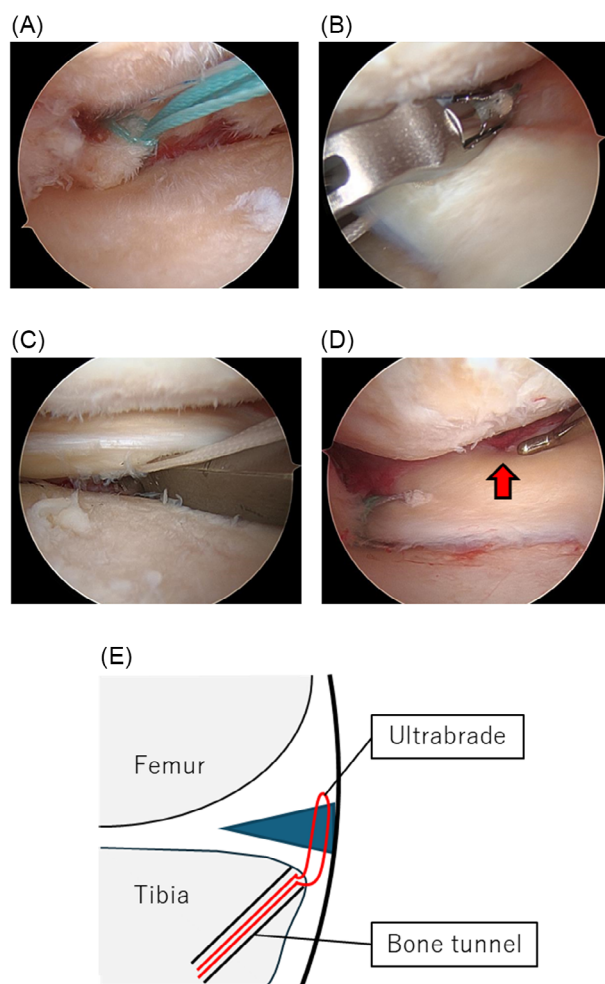


FIGURE 1 Arthroscopic images of the PSS technique in MMPRT repair of a right knee, with schematic illustration. (A) Modified Mason-Allen technique; UltraTape was passed through the posterior root of the medial meniscus using a single cinch loop, and the Fast-Fix device was anchored in the posterior capsule just behind the medial meniscus posterior root, passing through the UltraTape cinch loop (viewed from the lateral portal, right knee). (B) Peripheral stabilization suture (PSS) technique: a strong suture was looped around the apex of the posterior root of the medial meniscus, with both ends exiting on the tibial side (viewed from the medial porta, right knee). (C) A 2.4-mm tibial tunnel is created at the posteromedial edge (viewed from the lateral portal, right knee). (D) Final fixation of the meniscal root and PSS (arrow indicates the PSS fixation site; viewed from the lateral portal, right knee). (E) Schematic illustration of the PSS technique. (MMPRT, medial meniscus posterior root tear; PSS, peripheral stabilization suture.)

5 months, focusing on progressive muscle strengthening, range-of-motion exercises, and gait training.

Imaging Evaluation

MRI scans were routinely obtained preoperatively and at 1 year postoperatively in both groups. Additionally, in

the PSS group, MRI was performed at 1 week, 3 months, and 6 months postoperatively as a supplementary observation to assess the temporal changes in MME. MRI was used to evaluate MME and to assess the status of the posterior root repair (Figure 2A). MME was defined as the horizontal distance, parallel to the joint line, between a line drawn along the medial edge of the tibial plateau excluding osteophytes and a line tangential to the outer margin of the medial meniscus. Measurements were performed on coronal images corresponding to the midpoint of the medial femoral condyle in the sagittal plane, as described by Costa et al.¹⁴ (Figure 2B).

Postoperative computed tomography (CT) was routinely obtained at 1 week in all patients (Figure 2C). The CT shows a tibial bone tunnel created near the apex of the posterior horn. In addition, the positions of the posterior root tunnel and the PSS tunnel were evaluated using the 3D-CT method¹⁵ and expressed as anterior-to-posterior and medial-to-lateral percentages of the tibial plateau. (Figure 2D). Plain radiographs were used to assess the grade of osteoarthritis, hip-knee-ankle angle (HKA), and % mechanical axis (%MA) (Figure 2E). The radiographic grade of osteoarthritis was determined using the KL classification on standing anteroposterior knee radiographs. HKA and %MA were measured on full-length, standing anteroposterior radiographs of the lower limbs. HKA was measured, with positive values indicating varus alignment and negative values indicating valgus alignment. Longitudinal changes in these parameters were evaluated using radiographs obtained preoperatively and at 1 year postoperatively.

Clinical Outcomes

Subjective outcomes were evaluated using the International Knee Documentation Committee (IKDC) subjective score, the Lysholm score, and the Knee injury and Osteoarthritis Outcome Score (KOOS). The KOOS includes five subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation Function, and Knee-related Quality of Life (QOL). These scores were routinely collected at our institution, obtained preoperatively and at 1 year postoperatively, and changes over time were analyzed for each outcome measure.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 29 (IBM, Armonk, NY, USA). The normality of distribution for continuous variables was

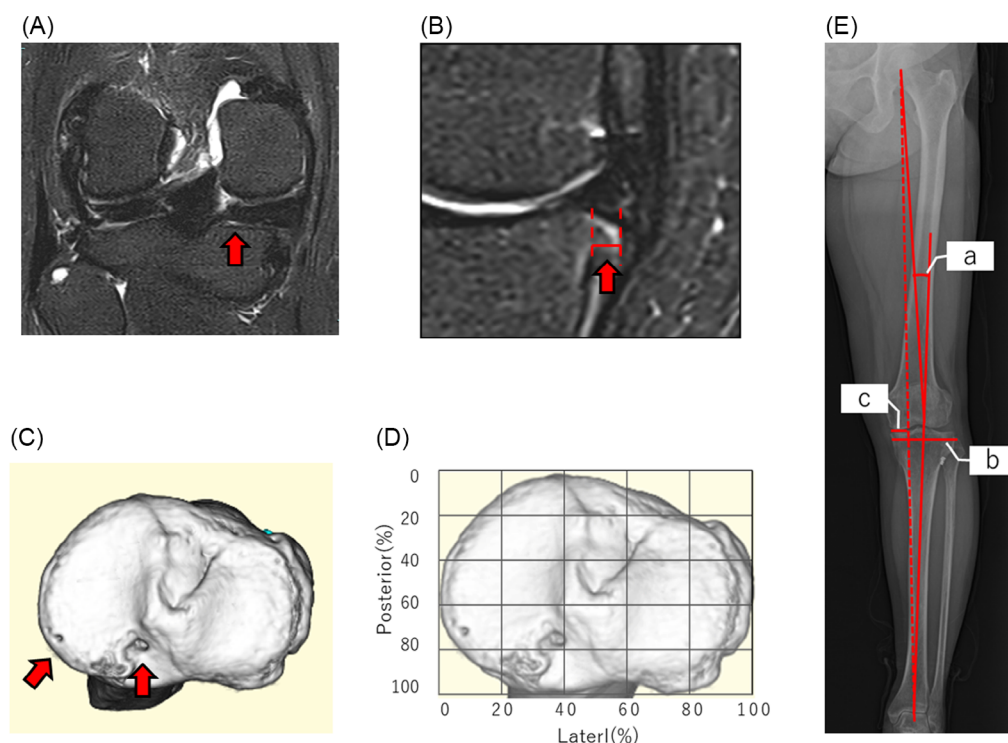


FIGURE 2 Representative images illustrating measurement methods. (A) Representative coronal MRI at 1 year postoperatively in a patient from the PSS group, showing the repaired medial meniscus posterior root. (Arrow indicates the medial posterior root, right knee). (B) On the coronal slice corresponding to the midpoint of the medial femoral condyle in the sagittal plane, MME was measured as the distance from the medial tibial margin to the outer margin of the medial meniscus (arrow, right knee). (C) A representative postoperative CT image at 1 week (arrows indicating the posterior root tunnel and the PSS tunnel, right knee). (D) The position of the PSS tunnel and posterior root tunnel was evaluated as a percentage from the anterior and medial edges of the tibial plateau. (E) (a) indicates the HKA. %MA was calculated as (c)/(b). (CT, Computed Tomography; MME, medial meniscal extrusion; MRI, magnetic resonance imaging; PSS, peripheral stabilization suture.)

assessed using the Shapiro–Wilk test. Data with a normal distribution were presented as mean $\pm$ standard deviation. Paired t-tests were used to compare continuous variables, while categorical variables were presented as numbers (percentages) and compared using the chi-square test. Paired t-tests were used to compare preoperative and postoperative values within each group. For the minimal clinically important difference (MCID) analysis, the MCID for MME was defined as 0.5 times the standard deviation of the change from baseline to 1 year (Δ MME) in each group. Patients whose Δ MME exceeded the MCID threshold were considered to have experienced clinically meaningful worsening, and the proportion of such patients was compared between groups using the chi-square test. Two-tailed tests were applied, and a P -value of $<.05$ was considered statistically significant. The required sample size was calculated using G*Power software based on MME. With an $\alpha = 0.05$, a power = 0.80, an MCID of 1.6 mm for MME, and a standard deviation of 1.4 mm,¹⁶ the minimum sample size was determined to be 11 patients per group.

RESULTS

Five patients were lost to follow-up, one patient had a pacemaker and could not undergo MRI, and one patient underwent a procedure other than the PSS technique (pull-out repair combined with centralization using a suture anchor). Thus, 35 patients (17 in the conventional group and 18 in the PSS group) were included in the final analysis (Figure 3). The mean follow-up period, based on the final follow-up visit, was 35.1 months (range, 13–74 months). Table 1 presents the baseline characteristics. There were no significant differences between groups in age, sex, BMI, operative side, or Time from injury to surgery.

Preoperative MME was comparable between the conventional (3.2 ± 1.0 mm) and PSS (3.3 ± 1.0 mm) groups. At 1 year postoperatively, the PSS group showed significantly less MME (3.2 ± 1.1 mm vs. 5.3 ± 1.9 mm; $P < .001$; Post-hoc power analysis showed a power of 0.988). Within-group analysis revealed a significant increase in MME in the conventional group ($P < .001$), while no significant change was observed in the PSS group

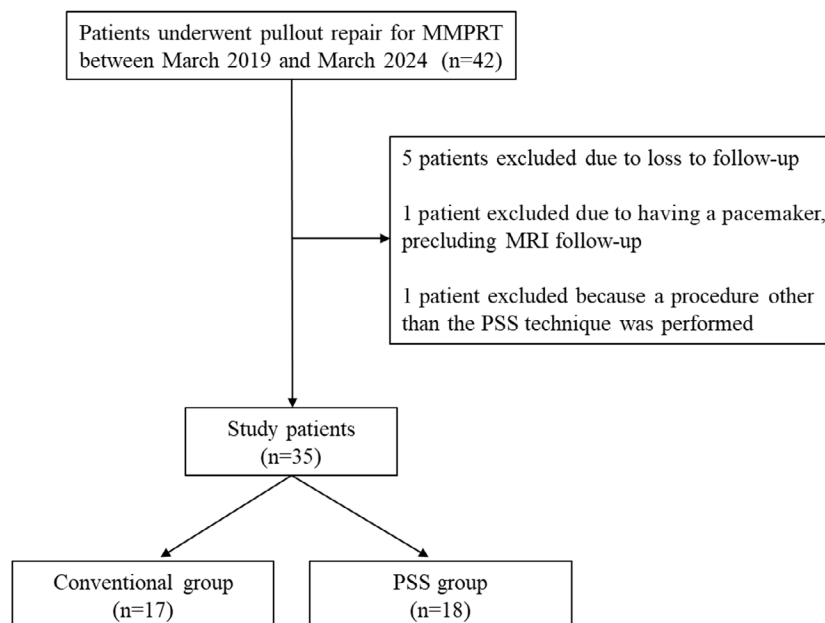


FIGURE 3 Patient selection flow chart. (MMPRT, medial meniscus posterior root tear; MRI, magnetic resonance imaging; PSS, peripheral stabilization suture.)

TABLE 1 Baseline Characteristics of Patients Undergoing MMPRT Repair

	Conventional Group	PSS Group	P Value
Age, year	58.1 ± 7.4	62.7 ± 9.0	.113
Sex, female/male	16/1	14/4	.338
BMI	26.2 ± 4.0	27.2 ± 4.3	.478
Operative side, right/left	8/9	7/11	.738
Time from injury to surgery, days	115.4 ± 45.9	97.4 ± 54.8	.286

BMI, body mass index; MMPRT, medial meniscus posterior root tear; PSS, peripheral stabilization suture.

(Table 2, Figure 4A,B). The rate of clinically meaningful worsening in MME, defined as a change greater than the MCID, was significantly higher in the conventional group than in the PSS group (15/17 [88.2%] vs 4/18 [22.2%], $P < .001$). In the PSS group, temporal changes in MME showed a marked improvement at 1 week postoperatively, followed by an increase at 3 months, and then a gradual increase thereafter, reaching a plateau at 6 months (Figure 4C).

Regarding alignment parameters, the PSS group showed significantly greater baseline varus deformity, with a larger HKA angle ($P = .025$), and smaller %MA

($P < .001$). At 1 year, group differences in HKA was no longer significant. However, within-group analysis showed significant varus progression in the conventional group (HKA, $P = .02$), whereas the PSS group remained stable. %MA in the PSS group showed no significant change from pre- to postoperative values, whereas the conventional group exhibited a significant medial shift postoperatively ($P < .001$) (Table 2).

Table 3 summarizes radiographic progression. Varus progression (HKA-based) occurred in 12 patients in the conventional group and 5 in the PSS group ($P = .018$). K-L grade progression was observed in 11 and 5 patients, respectively ($P = .044$), suggesting that PSS helped mitigate structural deterioration at short-term follow-up.

Patient-reported outcomes (IKDC, Lysholm, KOOS subscales) improved significantly postoperatively in both groups ($P < .001$ for all). However, no significant between-group differences were observed preoperatively or at 1-year follow-up (Table 4).

Table 5 and Figure 5 show the evaluation of the posterior root tibial tunnel positions. There were no significant differences between the conventional and PSS groups in any of the measured parameters: anterior-to-posterior percentage ($74.0\% \pm 5.7\%$ vs $75.1\% \pm 5.5\%$), medial-to-lateral percentage ($38.9\% \pm 5.1\%$ vs $39.4\% \pm 3.9\%$), or the distance between the tunnel center and the anatomic position (2.9 ± 1.7 mm vs 2.3 ± 1.5 mm). The mean tunnel position of PSS was located at $69.5\% \pm 8.9\%$ in the anterior-to-posterior direction and $8.1\% \pm 2.9\%$ in the medial-to-lateral direction of the tibial plateau.

TABLE 2 Pre- to Postoperative Changes and Group Comparisons of Structural and Radiologic Outcomes at 1-Year Follow-up

		Conventional Group	PSS Group	P Value
MME, mm	Pre	3.2 ± 1.0	3.3 ± 1.0	.559
	Post	5.3 ± 1.9	3.2 ± 1.1	<.001
	P value	<.001	.314	
HKA, °	Pre	2.1 ± 1.8	4.3 ± 3.6	.025
	Post	3.0 ± 1.7	4.5 ± 3.2	.112
	P value	.002	1.000	
%MA, %	Pre	43.9 ± 5.3	29.8 ± 15.1	<.001
	Post	37.4 ± 8.6	27.3 ± 13.7	.024
	P value	<.001	.133	
KL classification, 0/1/2/3/4	Pre	5/7/5/0/0	2/5/11/0/0	.146
	Post	1/3/10/2/1	1/4/10/3/0	0.859

HKA, hip-knee-ankle angle; KL, Kellgren–Lawrence; MME, medial meniscus extrusion; PSS, peripheral stabilization suture.

DISCUSSION

At 1 year postoperatively, the PSS group showed significantly less medial meniscus extrusion and fewer cases of varus alignment progression and KL grade progression compared with the conventional pullout repair group. Patient-reported outcomes improved similarly in both groups. These results indicate that adding PSS provides superior structural preservation without compromising clinical recovery.

MMPRT is one of the major causes of MME. Once the meniscus is extruded, the loss of the “hoop stress” function accelerates joint degeneration, highlighting the critical importance of accurate repair of MMPRT.^{17,18} Previous studies have shown that medial meniscus root repair significantly improves subjective clinical symptoms in most patients. A prior meta-analysis also showed that root repair significantly improved patient-reported outcome scores, delayed the progression of osteoarthritis compared with partial meniscectomy, total meniscectomy, or nonoperative treatment, and reduced the likelihood of future knee arthroplasty, functioning as a cost-saving intervention.^{19,20} However, a recent prospective study reported that the mean MME measured on MRI increased from 3.6 mm preoperatively to 5.0 mm at 2 years postoperatively, indicating that root repair alone does not significantly reduce meniscal extrusion.²¹ Consistent with these findings, the current study also showed that conventional root repair alone failed to significantly improve MME.^{22,23}

To address these suboptimal structural outcomes following isolated root repair, several techniques have been introduced to enhance meniscal stabilization, including the centralization technique.^{6–8} Krych et al. reported that centralization of the extruded medial meniscus using suture anchors significantly reduced meniscal extrusion and improved meniscal positioning on postoperative MRI. Specifically, the MME decreased from a preoperative average of 3.2 to 1.6 mm postoperatively, indicating a substantial improvement in meniscal alignment.⁸ Zhou et al. reported that MME at two years postoperatively was 4.0 mm in the conventional pullout repair group, whereas it improved to 2.7 mm in the group that underwent centralization using suture anchors.²⁴ Although such studies have shown the efficacy of anchor-based centralization techniques, no previous reports have evaluated the outcomes of transtibial centralization techniques such as PSS. In our study, we showed that the addition of PSS significantly improved MME compared to conventional pullout repair alone, achieving results comparable to those reported with anchor-based centralization. Furthermore, the PSS group showed less progression of varus alignment and osteoarthritic changes in the short term. Although it remains unclear whether anchor-based or transtibial techniques are superior for centralization, Boksh et al. reported in a porcine model that transtibial fixation was the most effective in improving MME and contact mechanics.^{25,26}

Accurate placement of the tibial tunnel is considered crucial for restoring meniscal function after arthroscopic MMPRT.

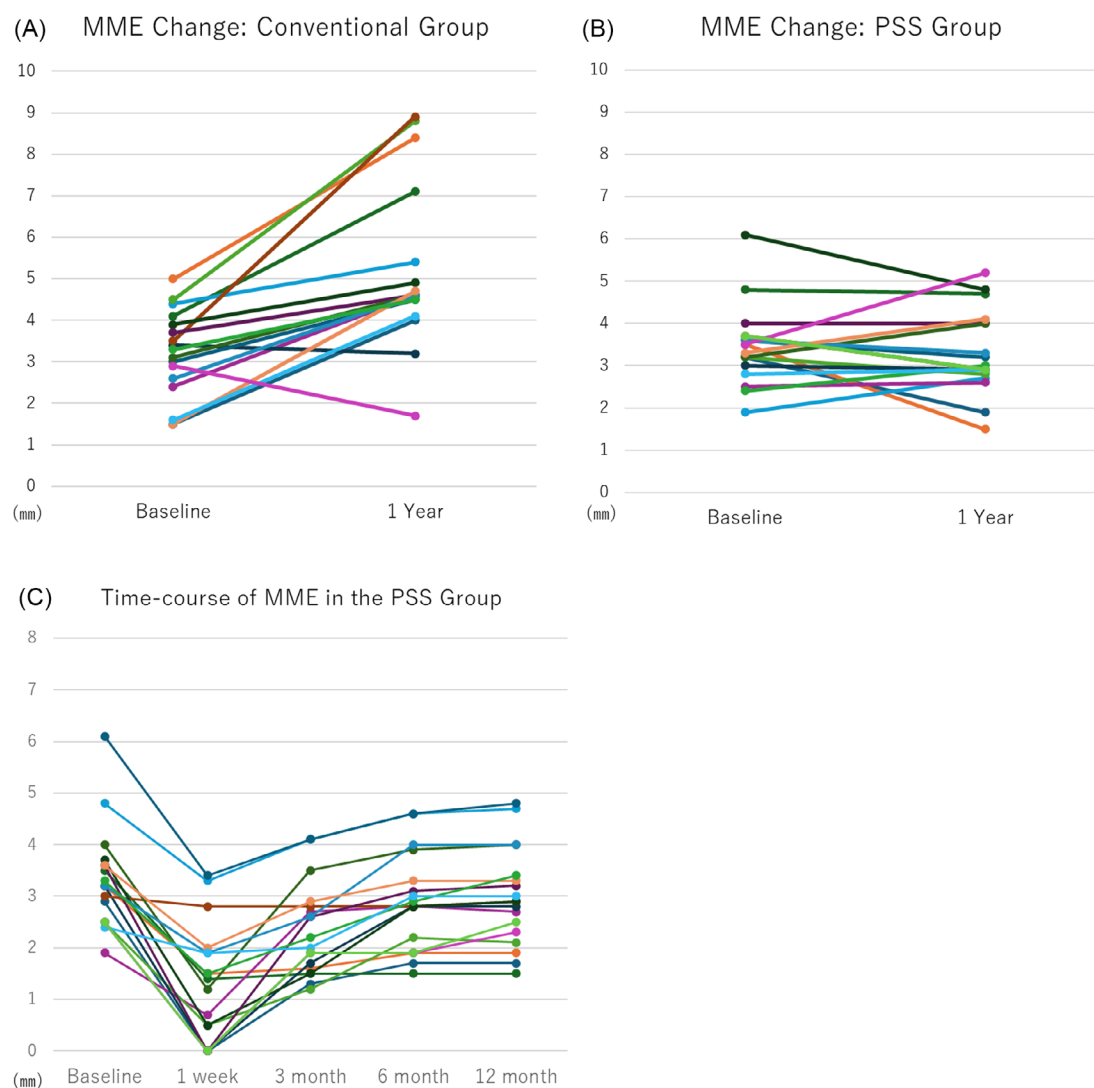


FIGURE 4 Changes in MME in the Conventional Group and the PSS Group. Line graphs showing changes in MME from preoperative to 1-year postoperative assessments in (A) the conventional group and (B) the PSS group. Each line represents an individual patient. (C) MME was measured at baseline (preoperative), 1 week, 3 months, 6 months, and 1 year postoperatively in the PSS group. (MME, medial meniscus extrusion; PSS, peripheral stabilization suture.)

TABLE 3 Comparison of Postoperative Changes in Alignment and Osteoarthritic Grade Between Groups at 1 Year

	Conventional Group	PSS Group	P Value
Progression of varus alignment (HKA), n (%)	12 (71%)	5 (28%)	.018
Progression of KL classification, n (%)	11 (65%)	5 (28%)	.044

HKA, hip-knee-ankle angle; KL, Kellgren–Lawrence; PSS, peripheral stabilization suture.

repair.²⁷ The attachment site of the medial meniscus posterior root is located within a triangular area bordered by the lateral edge of the medial tibial plateau, the posterior cruciate ligament, and the posterior intercondylar eminence.²⁸ Anatomically, the posterior root attachment lies approximately 9.6 mm posterior and 0.7 mm lateral to the apex of the medial tibial eminence.^{28,29} 3D CT analysis using the Tsukada method¹⁵ places the anatomic center of the MM posterior root at 78.5% posterior and 39.4% lateral within this region.³⁰ Although the surgical technique differed between time periods in this study, the tunnel positions of the posterior root were similar in both groups and were generally well placed. This consistency supports that the observed

TABLE 4 Pre- to Postoperative Changes and Group Comparisons of Patient-Reported Outcomes at 1-Year Follow-up

		Conventional Group	PSS Group	P Value
IKDC	Pre	38.9 ± 12.5	32.1 ± 12.4	.141
	Post	66.9 ± 14.5	63.9 ± 11.5	.502
	P value	<.001	<.001	
Lysholm	Pre	48.8 ± 20.8	49.1 ± 22.3	.961
	Post	86.6 ± 15.5	83.2 ± 18.4	.572
	P value	<.001	<.001	
KOOS				
Symptoms	Pre	57.4 ± 15.9	55.8 ± 20.7	.812
	Post	80.5 ± 15.1	80.4 ± 13.7	.982
	P value	<.001	<.001	
Pain	Pre	55.7 ± 15.4	51.4 ± 16.1	.442
	Post	85.6 ± 12.4	82.4 ± 15.4	.502
	P value	<.001	<.001	
Function, daily living	Pre	66.4 ± 17.1	59.9 ± 14.8	.266
	Post	89.9 ± 10.9	83.6 ± 15.1	.165
	P value	<.001	<.001	
Function, sports and recreational activities	Pre	27.5 ± 19.1	18.4 ± 18.1	.179
	Post	66.4 ± 20.6	58.6 ± 17.1	.228
	P value	<.001	<.001	
Quality of Life	Pre	30.5 ± 14.2	23.5 ± 14.7	.179
	Post	66.9 ± 19.5	63.9 ± 22.8	.676
	P value	<.001	<.001	

IKDC, International Knee Documentation Committee score; KOOS, Knee injury and Osteoarthritis Outcome Score; PSS, peripheral stabilization suture,

TABLE 5 Location of Tibial Tunnel Center

	Conventional Group	PSS Group	P Value
Posterior, %	74.0 ± 5.7	75.1 ± 5.5	.566
Lateral, %	38.9 ± 5.1	39.4 ± 3.9	.727
Distance between tunnel center and anatomic position, mm	2.9 ± 1.7	2.3 ± 1.5	.262

differences in outcomes between the PSS and conventional groups reflect the effect of the PSS itself. Furthermore, although the PSS group was allowed earlier weight-bearing during rehabilitation, patient-reported outcomes remained comparable, while MME and progression of varus deformity

were better controlled, highlighting the clinical relevance of PSS in structural preservation.

Limitations

This study has several limitations. First, it was a retrospective, nonrandomized study in which surgical techniques were determined by the period of treatment, which may have introduced selection bias. Second, the follow-up period was relatively short, and longer-term outcomes remain to be clarified. Third, although the required sample size was met by power analysis, the overall number of patients was small, which may limit generalizability. Fourth, postoperative rehabilitation protocols varied between groups. Fifth, patients in the PSS group had more severe preoperative varus deformities, potentially introducing selection bias. Finally, the study cohort mainly consisted of female patients, which reflects the

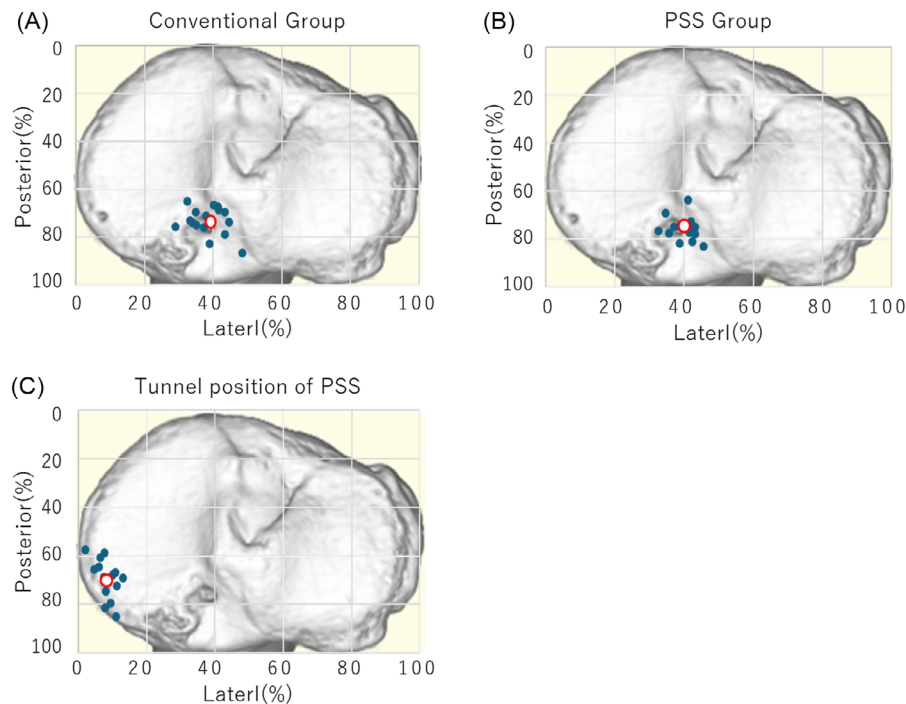


FIGURE 5 Tibial bone tunnel positions projected onto the right tibial plateau. (A) Root tunnel position in the conventional pullout repair group. (B) Root tunnel position in the PSS group. (C) PSS tunnel position in the PSS group. (PSS, peripheral stabilization suture.)

characteristics of Asian populations with MMPRTs,³¹ but also resulted in a sex imbalance that precluded sex-disaggregated analyses.

CONCLUSIONS

The addition of PSS to conventional pullout repair for MMPRT effectively reduced postoperative MME and suppressed the progression of varus alignment and osteoarthritic changes at 1 year postoperatively, while both groups showed significant but comparable improvements in patient-reported outcome measure.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used OpenAI's ChatGPT to improve readability and language quality. After using the tool, the authors reviewed and edited the content as needed and take full responsibility for the final content of the publication.

DISCLOSURES

The authors (S.H., T.S., R.T., H.K., T.O., H.C.) declare that they have no known competing financial interests

or personal relationships that could have appeared to influence the work reported in this article.

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