

**The distance between the tibial tunnel aperture and meniscal root attachment is correlated with
meniscal healing status following transtibial pullout repair for medial meniscus posterior root tear**

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Abbreviations

AC, Attachment center; AUC, Area under curve; CT, Computed tomography; ICC, Intra-class correlation
coefficient; KOOS, Knee Injury and Osteoarthritis Outcome Score; MM, Medial meniscus; MMPRT, MM

- 1 posterior root tear; MTE, Medial tibial eminence; MTP, Medial tibial plateau; QOL, Quality of life; RP,
- 2 Reference point; TC, Tunnel center; TSS, Two simple stitches; VAS, Visual analog scale
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1. Introduction

Posterior root tear of the medial meniscus (MM) can lead to loss of hoop tension resulting in a condition equivalent—in biomechanical terms—to total meniscectomy [1]. Restoration of tibiofemoral contact areas and pressures following the MM posterior root tear (MMPRT) can be achieved via MM posterior root repair by anchoring the MM posterior root and horn [2]. Several repair techniques have been developed [3-6], and transtibial pullout has become the gold standard for repair of MMPRT. Some biomechanical studies have demonstrated that MMPRT should be repaired anatomically, because non-anatomical repair does not restore the tibiofemoral contact pressure or area sufficiently [7, 8]. We have previously developed aiming guides to create the tibial tunnel for anatomical posterior root attachment [9, 10]; however, it is unclear whether creation of an anatomical tibial tunnel improves meniscal healing after transtibial pullout repair. To investigate this, we examined the location of the tibial tunnel aperture by three-dimensional (3D) computed tomography (CT) and evaluated meniscal healing through second-look arthroscopy using an arthroscopic scoring system (the meniscal healing score) [11]. Using this information, the aim of the present study was to investigate the relationship between location of the tibial tunnel aperture and the meniscal healing score after pullout repair. We hypothesized that a shorter distance between the tibial tunnel aperture and the meniscal root attachment is correlated with improved meniscal healing.

2. Methods

2.1. Patients

We recruited all patients who underwent transtibial pullout repair for MMPRT between October 2016 and July 2018 (Table 1). Exclusion criteria were radiographic knee osteoarthritis with Kellgren-Lawrence grade III or higher, previous meniscus injury, obesity (body mass index of over 30 kg/m²), or type I root tear [12].

2.2. Surgical procedure

A standard anterolateral portal was used for arthroscopic visualization using a 30° arthroscope (Smith & Nephew, Andover, MA, USA), and a standard anteromedial portal used for the instruments. We used two repair techniques which we have published previously [6, 13]. From October 2016 to February 2018, the modified Mason-Allen suture technique was performed on 19 knees using the FasT-Fix all-inside suture

device (Smith & Nephew, Andover, MA, USA) combined with Ultrabraid for a stronger repair (Fast-Fix-Modified Mason-Allen technique, F-MMA) [6]. From March 2018 to July 2018, we developed the previous surgical technique, and a new simple-fixation technique using two simple stitches (TSS) [13] was performed on six knees. For all tear types, the tibial tunnel was created at the root attachment using a custom-made posterior-root-aiming device (PRT guide, Smith & Nephew) [9].

2.3. Three-dimensional computed tomography-based measurements

All patients underwent CT examination 1 week after surgery. Images were obtained with an Asteion 4 Multislice CT System (Toshiba Medical Systems, Tochigi, Japan) operated at 120 kVp and 150 mA with a 1-mm slice thickness. The 3D reconstruction of tibial condyles in the axial plane [14] was carried out using 3D-volume-rendering software (AZE Virtual Place software; AZE Ltd., Tokyo, Japan). The 3D CT image was rotated to visualize the superior aspect of the proximal tibia, adjusting internal/external rotation until the most posterior articular margins of both the medial and lateral tibial plateaus were placed at the horizontal level. The location of a critical point was determined by two coordinates (one on an anteroposterior axis and the other on a mediolateral axis).

The expected anatomic center of the MM posterior root attachment was determined as the center of a virtual circle which contacted three sides of the triangular footprint of the MM posterior root (the anterior border of the posterior cruciate ligament tibial attachment, the lateral margin of the medial tibial plateau, and the retro-eminence ridge) [10] and was defined as the root attachment center (AC). The tibial tunnel center (TC) was determined as the central point of the circular or oval tunnel aperture. We calculated the AC-TC distance as the minimum distance between AC and TC on the transverse view of the tibial plateau (Figure 1a). We also calculated the TC height from a reference point (RP) on the posterior view of the proximal tibia and defined it as the RP-TC distance (Figure 1b). The RP was set as the midpoint between the joint line of the tibial plateau and the lowest point of MM posterior root attachment from the posterior view, because it was difficult to identify the AC point in this view (Figure 1b).

2.4. Clinical scores

Clinical evaluations were performed at primary surgery and during second-look arthroscopy. We evaluated the clinical outcomes using the Lysholm knee score, Tegner activity score, pain score, visual analog scale (VAS), International Knee Documentation Committee (IKDC) subjective knee evaluation form, and the Japanese Knee Injury and Osteoarthritis Outcome Score (KOOS). The KOOS consists of

five subscales: pain, symptoms, activities of daily living, sport and recreation function (Sport/Rec), and knee-related quality of life (QOL). The pain intensity of the knee was assessed using a 100-mm VAS, ranging from 0 mm (no pain) to 100 mm (worst possible pain).

2.5. Evaluation of meniscal healing

We assessed the healing status of the MM following transtibial pullout repair by second-look arthroscopy using a previously reported scoring system which involved three evaluation criteria: (i) anteroposterior width of the bridging tissues between the MM posterior horn and root attachment, (ii) stability of the repaired MM posterior root, and (iii) synovial coverage of the sutures [11]. Meniscal healing was scored on a scale from 0 to 10 points. Second-look arthroscopy was performed, on average, at 15 months postoperatively.

2.6. Statistical analysis

Statistical analysis was performed using EZR (Saitama Medical Center Jichi Medical University, Saitama, Japan). Separate univariate linear regression models were used to determine the association between AC-TC distance and meniscal healing score, RP-TC distance and meniscal healing score, AC-TC distance and RP-TC distance, and clinical and meniscal healing scores. A paired t-test was used to compare preoperative and postoperative clinical scores. The optimal AC-TC or RP-TC distance cut-off associated with improved postoperative MM healing score (≥ 7 points) was determined using receiver operating characteristic (ROC) analysis and calculating the Youden index (J).

The level of significance for all analyses was determined a priori at $p \leq 0.05$. Two orthopedic surgeons (Y.O. and S.M.) independently measured the location of the expected AC and TC. Each observer performed each measurement twice, at least 2 weeks apart. The inter-observer and intra-observer reliabilities were assessed with the intra-class correlation coefficient (ICC). An ICC of >0.80 was considered to represent a reliable measurement.

3. Results

We retrospectively analyzed data of 48 patients who underwent pullout repair for MMPRT. Twelve patients were excluded following application of exclusion criterion and 11 patients were excluded due to lack of data. We enrolled 25 patients (20 women and 5 men, mean age: 62.5 years) who underwent transtibial pullout repair for MMPRT within the study period. Type 2 tears were identified in 23 knees

(2a, two knees; 2b, 17 knees; 2c, four knees) and type 4 in two knees. There were no knees with type 3 or type 5 tears. The second-look arthroscopy was performed approximately one year postoperatively. The inter-observer and intra-observer reliabilities were high, with mean ICC values of 0.82 and 0.85, respectively. The mean AC-TC and RP-TC distances were 5.9 ± 2.0 mm and 5.2 ± 1.0 mm, respectively. All tibial tunnels were created toward the antero-medial direction (mean distance of 5.5 ± 1.9 mm anteriorly and 2.1 ± 0.6 mm medially) from the AC. A significant association was observed between AC-TC distance and meniscal healing score ($R^2 = 0.342$; $p = 0.002$; Fig. 2), with the linear regression line ($y = -0.42x + 9.48$) confirming increased AC-TC distance to be correlated with worse meniscal healing. There were no statistically significant associations between RP-TC distance and meniscal healing score ($R^2 = 0.030$; $p = 0.408$; Fig. 3), with the linear regression line ($y = -0.24x + 8.21$). A significant correlation was observed between AC-TC distance and RP-TC distance ($R^2 = 0.264$; $p = 0.009$; Fig. 4), with the linear regression line ($y = 0.26x + 3.60$).

The optimal AC-TC distance for improved meniscal healing (defined by a score of ≥ 7 points) was 5.8 mm according to ROC analysis, with a sensitivity of 100% and specificity of 53% (Figure 5). We used this cut-off to categorize participants into two groups based on AC-TC distance, ≤ 5.8 mm and > 5.8 mm. The mean meniscal healing score was 7.4 among patients with an AC-TC distance of ≤ 5.8 mm, compared with 6.3 among patients with an AC-TC distance of > 5.8 mm ($p < 0.001$) (Table 2). The mean AC-TC distances in the ≤ 5.8 -mm and > 5.8 -mm groups were 4.5 and 7.7 mm, respectively ($p < 0.001$).

In patients who underwent the F-MMA repair ($n=19$ patients), the average meniscal healing score was 6.9 points. A significant association was observed between the AC-TC distance and meniscal healing score ($R^2 = 0.413$; $p = 0.003$), with the linear regression line ($y = -0.41x + 9.59$). There were no statistically significant associations between the RP-TC distance and meniscal healing score ($R^2 = 0.072$; $p = 0.265$).

In patients who underwent the TSS repair ($n=6$ patients), the average meniscal healing score was 7.0 points. AP-TC distances tended to be associated with meniscal healing score with the linear regression line ($y = -0.42x + 8.92$), but a significant difference was not demonstrated ($R^2 = 0.179$; $p = 0.402$). There were no statistically significant associations between RP-TC distances and meniscal healing scores ($R^2 = 0.126$; $p = 0.489$). There was no significant difference in meniscal healing score between two repair techniques.

The preoperative and postoperative clinical characteristics are shown in Table 3. All clinical scores were significantly improved at one year postoperatively. There were no significant correlations between postoperative subjective outcome scores and meniscal healing scores.

4. Discussion

This study demonstrates that increased AC-TC distance is associated with a reduction in meniscal healing score. An AC-TC distance of 5.8 mm was determined to be the threshold for unfavorable meniscal healing score. Thus, our results confirm the hypothesis that a shorter distance between tibial tunnel aperture and meniscal root attachment is correlated with improved meniscal healing status. Anatomical repair is therefore advisable to achieve optimal postoperative meniscal healing.

Several biomechanical studies have investigated the effect of the location of MM posterior root attachment to the articular cartilage. A 3-mm displacement of the MM posterior root attachment has been shown to induce cartilage deformation by decreasing meniscal hoop tension in a porcine model of meniscus root tear [7]. A cadaveric study demonstrated that non-anatomic repair 5-mm posteromedial to the native MM posterior root attachment did not restore the tibiofemoral contact area and pressure [8]. A study on the function of meniscal allografts has reported that a medial meniscal transplant placed 5 mm medially to the native posterior root attachment resulted in increased tibiofemoral maximum contact pressures in human cadaveric knees [15]. From these studies, anatomic repair of the MM posterior root appears to be critical for restoring biomechanical function of the MM. However, there have been no studies on the relationship between tibial tunnel location and postoperative meniscal healing status following MM posterior root repair. In the present study, we evaluated the relationship between displacement from AC and postoperative meniscal healing status from second-look arthroscopy. We found a positive correlation between AC-TC distance and meniscal healing score, with AC-TC distance cut-off for predicting better meniscal healing score (≥ 7) being 5.8 mm.

Previous studies have demonstrated MM posterior root attachment to form an oval or triangular shape [16, 17], with the anatomic center being 4–5 mm on 3D CT images [10]. In the present study, the mean radius of the virtual circle was 4.7 mm. When the AC-TC distance is ≤ 5.8 mm, this would place this measurement within the meniscal root attachment which may contribute to regaining native regulation of meniscal movement and hoop tension during knee motion, resulting in improved meniscal healing. Newly

developed aiming guides can help create the tibial tunnel at the optimal location, with an AC-TC distance of approximately 4 mm [9, 10].

In the present study, an AC-TC distance of >5.8 mm brought the TC near to the medial tibial eminence (MTE) apex, which is located 9.6 mm anteriorly to the AC [2, 18]. We found AC-TC distance to be positively correlated with RP-TC distance, which may be attributed to the fact that the MTE apex slopes downward toward the AC. This confirms that if the tibial tunnel is created more anterior than the AC, around the MTE apex, AC-TC distance and RP-TC distance increase, resulting in an increase in the distance from the root attachment. A large displacement from AC will reduce meniscal healing, possibly because the tensile force applied to the repaired meniscus is higher compared with anatomical repair [7].

The present study has several limitations which should be acknowledged. First, the sample size was small; further studies involving larger sample sizes are required to draw firm conclusions. Second, the AC-TC and RP-TC distances will depend on the individual and be affected by tibial plateau size. Third, it is possible that the ideal location for the tibial tunnel might differ from the expected anatomic center on 3D CT images. Fourth, two surgical techniques were utilized in this study, and we did not consider the influence of differences in repair technique on the meniscal healing score. There was no significant difference in meniscal healing scores between the two repair techniques. In addition, similar findings were obtained in patients who underwent the F-MMA and TSS repair techniques. Fifth, CT scans as a gold standard for evaluating the tibial tunnel aperture expose the patient to significant radiation. Though MRI has the advantage in terms of no radiation exposure; however, the longer acquisition time increases the risk of motion artifacts, and 3D MRI is not always available in every institute including ours. Finally, considering individual tibial plateau size, we did not evaluate the location of the tibial tunnel aperture relative to the tibial plateau. Further investigation into the location of points of interest on the tibial surface are required, utilizing percentage-dependent methods as per previous reports [9, 10, 14].

5. Conclusions

This study demonstrates that AC-TC distance is significantly correlated with postoperative meniscal healing status. Anatomic repair within 5.8 mm of the AC is desirable to achieve improved meniscal healing.

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Declarations of interest

None

Informed consent and ethical information

This study and its protocols were approved by our Institutional Review Board (approval no. 1857), and was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments. Written informed consent was obtained from all participants.

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Figure legends

Fig. 1 Distance from the root attachment to the tibial tunnel center on three-dimensional computed tomography images.

a) Distance from the posterior root attachment center to tibial tunnel center (yellow line) on the transverse view of the tibial plateau. The red dashed circle contacts three sides of the triangular footprint of the medial meniscus posterior (anterior border of the posterior cruciate ligament, lateral margin of the medial tibial plateau, and retro-eminence ridge). The center of the red dashed circle represents the posterior root attachment center. The blue dashed circle is the tibial tunnel aperture and the center is defined as tibial tunnel center.

b) Distance from the reference point to tibial tunnel center (green line) on the posterior view of the tibial plateau. The reference is set as the midpoint between the joint line of the medial tibial plateau and the lowest point of the medial meniscus posterior root attachment on the posterior view. Abbreviations: AC, root attachment center; TC, tibial center; RP, reference point; MTE, medial tibial eminence; MTP, medial tibial plateau.

Fig. 2 Correlation analysis between posterior root attachment center to tibial tunnel center distance and meniscal healing score. A significant correlation is observed ($y = -0.42x + 9.48$, $R^2 = 0.342$; $p = 0.002$). Abbreviations: AC-TC, distance from posterior root attachment center to tibial center.

Fig. 3 Correlation analysis between reference point to tibial tunnel center distance and meniscal healing score. No significant correlation is observed ($y = -0.24x + 8.21$, $R^2 = 0.030$; $p = 0.408$). Abbreviations: RP-TC, distance from reference point to tibial center.

Fig. 4 Correlation analysis between posterior root attachment center to tibial tunnel center distance and reference point to tibial tunnel center distance. A significant correlation is observed ($y = 0.26x + 3.60$, $R^2 = 0.264$; $p = 0.009$).

Abbreviations: AC-TC, distance from posterior root attachment center to tibial center. RP-TC, distance from reference point to tibial center.

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2 **Fig. 5** Threshold for posterior root attachment center to tibial tunnel center distance for improved
3 meniscal healing score. The calculated cut-off value (5.8 mm) has a sensitivity of 100% and specificity of
4 53% for improved meniscal healing score. Abbreviations: AUC, area under curve.

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1 Table 1. Patient demographics and clinical characteristics

	Total study population (n = 25)
Gender (male/female)	5/20
Age (years)	62.5 ± 8.5
Height (m)	1.57 ± 0.09
Weight (kg)	63.6 ± 10.8
Body mass index (kg/m ²)	25.8 ± 72.4
Femorotibial angle (°)	176.8 ± 1.3
Duration from injury to operation (days)	86.5 ± 72.9
Preoperative Kellgren-Lawrence grade (0/1/2/3/4)	6/12/7/0/0

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3 Continuous data are presented as mean ± standard deviation, categorical data are presented as number.

Table 2. Comparisons of characteristics of patients with a distance from the root attachment center to the tibial tunnel center of ≤ 5.8 mm or >5.8 mm

	AC-TC distance ≤ 5.8 mm (n = 15)	AC-TC distance >5.8 mm (n = 10)	p value
Gender (male/female)	2/13	3/7	n.s.
Age (years)	61.4 ± 8.6	64.6 ± 8.3	n.s.
Height (m)	1.55 ± 0.08	1.58 ± 0.09	n.s.
Weight (kg)	62.8 ± 10.1	63.6 ± 10.8	n.s.
Body mass index (kg/m ²)	25.9 ± 2.5	25.1 ± 2.3	n.s.
AC-TC distance (mm)	4.5 ± 0.7	7.7 ± 1.5	$<0.001^*$
Meniscal healing score (points)	7.4 ± 1.1	6.3 ± 1.5	$<0.001^*$

Continuous data are presented as mean \pm standard deviation, categorical data are presented as number.

Abbreviations: AC-TC, distance from root attachment center to tibial tunnel center; n.s., not significant.

* $p < 0.05$.

1 **Table 3.** Preoperative and postoperative clinical characteristics

	Preoperative	Postoperative	P value
KOOS			
Pain	60.5 ± 23.6	89.0 ± 8.8	< 0.001*
Symptoms	67.9 ± 22.4	81.8 ± 14.3	0.023*
ADL	73.6 ± 16.4	91.8 ± 6.5	< 0.001*
Sport/Rec	34.1 ± 28.5	68.3 ± 20.5	< 0.001*
QOL	37.3 ± 21.3	69.5 ± 18.2	< 0.001*
Lysholm knee score	63.4 ± 12.6	87.4 ± 7.7	< 0.001*
IKDC score	45.6 ± 15.7	70.5 ± 9.6	< 0.001*
Pain score (VAS)	31.9 ± 24.2	5.5 ± 4.9	< 0.001*
Arthroscopic score ^a		7.0 ± 1.4	

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3 KOOS, Knee Injury and Osteoarthritis Outcome Score. ADL, activities of daily living. Sport/Rec, sport and
4 recreation function. QOL, knee-related quality of life. IKDC, International Knee Documentation
5 Committee. VAS, visual analog scale. Data are displayed as mean ± standard deviation. ^a Meniscal healing
6 score at second-look arthroscopy (total, 10 points). *p < 0.05.

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