

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

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21 Abbreviations

22 AC, Attachment center; AUC, Area under curve; CT, Computed tomography; ICC, Intra-class correlation

23 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

3

1 **1. Introduction**

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

18  
19 **2. Methods**

20 **2.1. Patients**

21 We recruited all patients who underwent transtibial pullout repair for MMPRT between October 2016 and  
22 July 2018 (Table 1). Exclusion criteria were radiographic knee osteoarthritis with Kellgren-Lawrence  
23 grade III or higher, previous meniscus injury, obesity (body mass index of over 30 kg/m<sup>2</sup>), or type I root  
24 tear [12].

25 **2.2. Surgical procedure**

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

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

### 6 **2.3. Three-dimensional computed tomography-based measurements**

7 All patients underwent CT examination 1 week after surgery. Images were obtained with an Asteion 4  
8 Multislice CT System (Toshiba Medical Systems, Tochigi, Japan) operated at 120 kVp and 150 mA with a  
9 1-mm slice thickness. The 3D reconstruction of tibial condyles in the axial plane [14] was carried out  
10 using 3D-volume-rendering software (AZE Virtual Place software; AZE Ltd., Tokyo, Japan). The 3D CT  
11 image was rotated to visualize the superior aspect of the proximal tibia, adjusting internal/external  
12 rotation until the most posterior articular margins of both the medial and lateral tibial plateaus were  
13 placed at the horizontal level. The location of a critical point was determined by two coordinates (one on  
14 an anteroposterior axis and the other on a mediolateral axis).

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

### 25 **2.4. Clinical scores**

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

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

#### 4 **2.5. Evaluation of meniscal healing**

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

#### 11 **2.6. Statistical analysis**

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

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

### 24 **3. Results**

25 We retrospectively analyzed data of 48 patients who underwent pullout repair for MMPRT. Twelve  
26 patients were excluded following application of exclusion criterion and 11 patients were excluded due to  
27 lack of data. We enrolled 25 patients (20 women and 5 men, mean age: 62.5 years) who underwent  
28 transtibial pullout repair for MMPRT within the study period. Type 2 tears were identified in 23 knees  
29

1 (2a, two knees; 2b, 17 knees; 2c, four knees) and type 4 in two knees. There were no knees with type 3 or  
2 type 5 tears. The second-look arthroscopy was performed approximately one year postoperatively. The  
3 inter-observer and intra-observer reliabilities were high, with mean ICC values of 0.82 and 0.85,  
4 respectively. The mean AC-TC and RP-TC distances were  $5.9 \pm 2.0$  mm and  $5.2 \pm 1.0$  mm, respectively.  
5 All tibial tunnels were created toward the antero-medial direction (mean distance of  $5.5 \pm 1.9$  mm  
6 anteriorly and  $2.1 \pm 0.6$  mm medially) from the AC. A significant association was observed between AC-  
7 TC distance and meniscal healing score ( $R^2 = 0.342$ ;  $p = 0.002$ ; Fig. 2), with the linear regression line ( $y =$   
8  $-0.42x + 9.48$ ) confirming increased AC-TC distance to be correlated with worse meniscal healing. There  
9 were no statistically significant associations between RP-TC distance and meniscal healing score ( $R^2 =$   
10  $0.030$ ;  $p = 0.408$ ; Fig. 3), with the linear regression line ( $y = -0.24x + 8.21$ ). A significant correlation was  
11 observed between AC-TC distance and RP-TC distance ( $R^2 = 0.264$ ;  $p = 0.009$ ; Fig. 4), with the linear  
12 regression line ( $y = 0.26x + 3.60$ ).

13 The optimal AC-TC distance for improved meniscal healing (defined by a score of  $\geq 7$  points) was 5.8  
14 mm according to ROC analysis, with a sensitivity of 100% and specificity of 53% (Figure 5).

15 We used this cut-off to categorize participants into two groups based an AC-TC distance,  $\leq 5.8$  mm and  
16  $> 5.8$  mm. The mean meniscal healing score was 7.4 among patients with an AC-TC distance of  $\leq 5.8$  mm,  
17 compared with 6.3 among patients with an AC-TC distance of  $> 5.8$  mm ( $p < 0.001$ ) (Table 2). The mean  
18 AC-TC distances in the  $\leq 5.8$ -mm and  $> 5.8$ -mm groups were 4.5 and 7.7 mm, respectively ( $p < 0.001$ ).

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

23 In patients who underwent the TSS repair ( $n=6$  patients), the average meniscal healing score was 7.0  
24 points. AP-TC distances tended to be associated with meniscal healing score with the linear regression  
25 line ( $y = -0.42x + 8.92$ ), but a significant difference was not demonstrated ( $R^2 = 0.179$ ;  $p = 0.402$ ). There  
26 were no statistically significant associations between RP-TC distances and meniscal healing scores ( $R^2 =$   
27  $0.126$ ;  $p = 0.489$ ). There was no significant difference in meniscal healing score between two repair  
28 techniques.

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

#### 4 5 **4. Discussion**

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

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

25 Previous studies have demonstrated MM posterior root attachment to form an oval or triangular shape  
26 [16, 17], with the anatomic center being 4–5 mm on 3D CT images [10]. In the present study, the mean  
27 radius of the virtual circle was 4.7 mm. When the AC-TC distance is  $\leq 5.8$  mm, this would place this  
28 measurement within the meniscal root attachment which may contribute to regaining native regulation of  
29 meniscal movement and hoop tension during knee motion, resulting in improved meniscal healing. Newly

1 developed aiming guides can help create the tibial tunnel at the optimal location, with an AC-TC distance  
2 of approximately 4 mm [9, 10].  
3 In the present study, an AC-TC distance of >5.8 mm brought the TC near to the medial tibial eminence  
4 (MTE) apex, which is located 9.6 mm anteriorly to the AC [2, 18]. We found AC-TC distance to be  
5 positively correlated with RP-TC distance, which may be attributed to the fact that the MTE apex slopes  
6 downward toward the AC. This confirms that if the tibial tunnel is created more anterior than the AC,  
7 around the MTE apex, AC-TC distance and RP-TC distance increase, resulting in an increase in the  
8 distance from the root attachment. A large displacement from AC will reduce meniscal healing, possibly  
9 because the tensile force applied to the repaired meniscus is higher compared with anatomical repair [7].  
10 The present study has several limitations which should be acknowledged. First, the sample size was  
11 small; further studies involving larger sample sizes are required to draw firm conclusions. Second, the  
12 AC-TC and RP-TC distances will depend on the individual and be affected by tibial plateau size. Third, it  
13 is possible that the ideal location for the tibial tunnel might differ from the expected anatomic center on  
14 3D CT images. Fourth, two surgical techniques were utilized in this study, and we did not consider the  
15 influence of differences in repair technique on the meniscal healing score. There was no significant  
16 difference in meniscal healing scores between the two repair techniques. In addition, similar findings  
17 were obtained in patients who underwent the F-MMA and TSS repair techniques. Fifth, CT scans as a  
18 gold standard for evaluating the tibial tunnel aperture expose the patient to significant radiation. Though  
19 MRI has the advantage in terms of no radiation exposure; however, the longer acquisition time increases  
20 the risk of motion artifacts, and 3D MRI is not always available in every institute including ours. Finally,  
21 considering individual tibial plateau size, we did not evaluate the location of the tibial tunnel aperture  
22 relative to the tibial plateau. Further investigation into the location of points of interest on the tibial  
23 surface are required, utilizing percentage-dependent methods as per previous reports [9, 10, 14].

24

## 25 **5. Conclusions**

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

29



1

2 **Declarations of interest**

3 None

4

5 **Informed consent and ethical information**

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

9

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13

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15

1 **Figure legends**

2

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

4 tomography images.

5 a) Distance from the posterior root attachment center to tibial tunnel center (yellow line) on the transverse

6 view of the tibial plateau. The red dashed circle contacts three sides of the triangular footprint of the

7 medial meniscus posterior (anterior border of the posterior cruciate ligament, lateral margin of the medial

8 tibial plateau, and retro-eminence ridge). The center of the red dashed circle represents the posterior root

9 attachment center. The blue dashed circle is the tibial tunnel aperture and the center is defined as tibial

10 tunnel center.

11 b) Distance from the reference point to tibial tunnel center (green line) on the posterior view of the tibial

12 plateau. The reference is set as the midpoint between the joint line of the medial tibial plateau and the

13 lowest point of the medial meniscus posterior root attachment on the posterior view. Abbreviations: AC,

14 root attachment center; TC, tibial center; RP, reference point; MTE, medial tibial eminence; MTP, medial

15 tibial plateau.

16

17 **Fig. 2** Correlation analysis between posterior root attachment center to tibial tunnel center distance and

18 meniscal healing score. A significant correlation is observed ( $y = -0.42x + 9.48$ ,  $R^2 = 0.342$ ;  $p = 0.002$ ).

19 Abbreviations: AC-TC, distance from posterior root attachment center to tibial center.

20

21 **Fig. 3** Correlation analysis between reference point to tibial tunnel center distance and meniscal healing

22 score. No significant correlation is observed ( $y = -0.24x + 8.21$ ,  $R^2 = 0.030$ ;  $p = 0.408$ ). Abbreviations:

23 RP-TC, distance from reference point to tibial center.

24

25 **Fig.4** Correlation analysis between posterior root attachment center to tibial tunnel center distance and

26 reference point to tibial tunnel center distance. A significant correlation is observed ( $y = 0.26x + 3.60$ ,  $R^2$

27  $= 0.264$ ;  $p = 0.009$ ).

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

29 from reference point to tibial center.

1

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.

5

1 Table 1. Patient demographics and clinical characteristics

	<b>Total study population (n = 25)</b>
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 <sup>2</sup> )	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

2

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

1 **Table 2.** Comparisons of characteristics of patients with a distance from the root attachment center to the  
 2 tibial tunnel center of  $\leq 5.8$  mm or  $>5.8$  mm

	AC-TC distance $\leq 5.8$ 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 $\pm$ 8.6	64.6 $\pm$ 8.3	n.s.
Height (m)	1.55 $\pm$ 0.08	1.58 $\pm$ 0.09	n.s.
Weight (kg)	62.8 $\pm$ 10.1	63.6 $\pm$ 10.8	n.s.
Body mass index (kg/m <sup>2</sup> )	25.9 $\pm$ 2.5	25.1 $\pm$ 2.3	n.s.
AC-TC distance (mm)	4.5 $\pm$ 0.7	7.7 $\pm$ 1.5	<0.001*
Meniscal healing score (points)	7.4 $\pm$ 1.1	6.3 $\pm$ 1.5	<0.001*

3  
 4 Continuous data are presented as mean  $\pm$  standard deviation, categorical data are presented as number.

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

6 \*p < 0.05.

7

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

	<b>Preoperative</b>	<b>Postoperative</b>	<b>P value</b>
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 <sup>a</sup>		7.0 ± 1.4	

2

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. <sup>a</sup> Meniscal healing  
 6 score at second-look arthroscopy (total, 10 points). \*p < 0.05.

7