

Shallow Medial Tibial Plateau Depth is Independently Associated with Medial Meniscus Posterior Root Tear after Adjustment for Alignment and Morphological Parameters: A Multivariate Analysis

Toshiki Kohara

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Yuki Okazaki

yokazaki.okayama@gmail.com

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Takayuki Furumatsu

Japanese Red Cross Okayama Hospital

Yusuke Yokoyama

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Takaaki Hiranaka

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Koki Kawada

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Daiichiro Yokomizo

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Tomonori Tetsunaga

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Toshifumi Ozaki

Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University

Research Article

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Abstract

Purpose

Medial meniscus posterior root tears (MMPRT) have been linked to older age, female sex, varus alignment, greater medial posterior tibial slope (MPTS), and shallower medial tibial plateau depth (MTPD). However, MMPRT also occurs without these risk factors. Therefore, we aimed to identify independent predictors of MMPRT by evaluating demographic variables, coronal alignment, and sagittal osseous morphology.

Methods

This retrospective cohort study included 102 knees with acute MMPRT (Group M) and 62 control knees with meniscal tears unrelated to MMPRT (Group C) between 2016 and 2025. Both groups were limited to early-stage osteoarthritis (Kellgren–Lawrence grade ≤ 2) to minimise degenerative bias. Demographic variables (age, sex, and body mass index [BMI]) and radiographic parameters, including coronal alignment (hip–knee–ankle angle, mechanical lateral distal femoral angle, medial proximal tibial angle, and joint line-convergence angle) and sagittal osseous morphology (MPTS and MTPD), were evaluated. Multivariate logistic regression analysis was performed to identify independent predictors of MMPRT, followed by receiver operating characteristic (ROC) curve analysis.

Results

Patients with MMPRT demonstrated steeper MPTS ($P < 0.05$) and shallower MTPD ($P < 0.0001$), whereas coronal alignment parameters did not differ significantly. In multivariate logistic regression, increasing age (odds ratio [OR]: 1.14), higher BMI (OR: 1.13), and decreased MTPD (OR: 0.19) were independent predictors of MMPRT. ROC analysis demonstrated moderate discrimination for MTPD (area under the curve, 0.71) with a cutoff value of 1.92 mm.

Conclusion

A shallow MTPD was an independent predictor for MMPRT after adjustment for demographic factors, coronal alignment, and MPTS.

Level of Evidence

Level III, retrospective casecontrol study.

Introduction

Medial meniscus (MM) posterior root tears (PRTs) are increasingly recognised as a distinct meniscal pathology, typically occurring in middle-aged and older adults during low-energy activities of daily living and often accompanied by a sudden painful popping sensation [1–3]. Epidemiological studies indicate that surgical treatment for MMPRT accounts for a substantial proportion of meniscal repair procedures, reflecting its increasing clinical relevance [4, 5].

The posterior root of the MM anchors the meniscus to the medial tibial plateau (MTP), allowing conversion of axial compressive loads into circumferential hoop stress [6]. Disruption of the posterior root causes functional meniscectomy, with markedly increased peak contact pressure and reduced medial compartment contact area [7].

Previous studies reported demographic, biomechanical, and activity-related factors associated with MMPRT occurrence, including female sex, advanced age, higher body mass index (BMI), varus lower-limb alignment, low levels of sports activity, and frequent deep knee flexion [2–4]. Recent imaging studies suggest that sagittal osseous morphology, including a steeper medial posterior tibial slope (MPTS) and a shallower medial tibial plateau depth (MTPD), may predispose individuals to MMPRT [8, 9]. Contralateral MMPRT and mechanical factors, partly related to improper (often anterior) tunnel positioning in transtibial pullout repair, have been linked to both MMPRT development and inferior clinical outcomes following surgical repair [10].

Nonetheless, MMPRTs can occur in patients with neutral or valgus alignment, lower BMI, or a gentle MPTS, suggesting that current understanding of risk factors is incomplete.

We aimed to evaluate demographic, coronal-plane alignment, and sagittal-plane morphological risk factors for MMPRT using multivariable analysis. We hypothesised that sagittal osseous morphology, particularly medial tibial plateau depth, would remain independently associated with MMPRT after adjustment for patient demographics and coronal alignment.

Materials and Methods

Study Design and Patient Selection

We reviewed 164 knees, including 102 that underwent transtibial pullout repair for MMPRT (Group M) and 62 that underwent knee surgery for conditions unrelated to MMPRT (Group C, control) between January 2016 and June 2025. Group M included patients with acute MMPRT with a clearly documented onset. Surgical indications for MMPRT repair were as follows: % mechanical axis $> 30\%$, hip–knee–ankle angle (HKAA) $\leq 5^\circ$ of varus, Kellgren–Lawrence (KL) grade ≤ 2 , International Cartilage Repair Society cartilage lesion grade ≤ 2 , and subchondral insufficiency fracture of the knee grade ≤ 2 [11]. Group C included patients who underwent surgery for knee pathologies not involving MMPRT, such as MM tears or lateral meniscal tears (Table 1). Because full-length standing radiographs cannot be ethically obtained from asymptomatic individuals, surgically treated patients without MMPRT were used as a practical control group for alignment-based analyses.

Table 1
Surgical Procedures in Group C (Control: non-MMPRT surgery group)

Injury	n (%)
Medial meniscus injury	46 (74.2%)
Lateral meniscus injury	8 (12.9%)
Discoid lateral meniscus	8 (12.9%)
Total	62 (100%)
Values are presented as numbers (%).	
Abbreviation: MMPRT, medial meniscus posterior root tear.	

The exclusion criteria were: KL grade ≥ 3 , a history of anterior cruciate ligament (ACL) injury, lower-extremity fracture, prior ipsilateral knee surgery, skeletal immaturity, or chronic MMPRT with unknown onset. To minimise selection bias and limit the influence of degenerative changes, only knees with early-stage OA (KL ≤ 2) were included. Demographic data, including age, sex, height, and body weight, were obtained from medical records, and BMI was calculated. Time from injury to plain radiography was recorded only in Group M.

Radiographic and Magnetic Resonance Imaging (MRI) Evaluation

. Coronal alignment was evaluated on standing full-length anteroposterior radiographs obtained with the patellae oriented anteriorly. HKAA, mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), and joint line-convergence angle (JLCA) were measured (Fig. 1a and b). Sagittal morphology was assessed using MPTS and MTPD. MPTS was measured on true lateral knee radiographs as the angle between a line perpendicular to the proximal tibial anatomical axis and a line connecting the most proximal anterior and posterior margins of the medial tibial plateau, as previously described [12]. The proximal tibial anatomical axis was defined by connecting the midpoints between the anterior and posterior cortices at two levels distal to the tibial tubercle (Fig. 1c). MTPD was measured on MRI on the slice demonstrating the deepest concavity of the MTP, as previously described [8]. Depth was defined as the perpendicular distance from a line connecting the anterior and posterior subchondral bone margins, excluding cartilage, to the deepest point of the concavity (Fig. 1d). MPTS and MTPD were recorded to the second decimal place.

Statistical Analysis

Continuous variables were tested for normality and presented as means with standard deviations. Groups were compared using independent t-tests or Mann–Whitney *U* tests, and categorical variables using the chi-squared test. Univariate logistic regression assessed associations between MMPRT and

demographic, coronal, and sagittal parameters. Stepwise multivariable logistic regression included all variables, with selection based on the Akaike information criterion (AIC). Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Independently associated factors identified in multivariate analysis were further assessed by receiver operating characteristic (ROC) curve analysis to determine optimal cutoff values, based on the Youden index and clinical relevance. Statistical significance was set at $P < 0.05$. Analyses were performed using GraphPad Prism (GraphPad Software, USA) and EZR (Saitama Medical Center, Jichi Medical University).

Measurements of the MPTS and MTPD were independently performed by two observers and repeated after 8 weeks. Intra- and interobserver reliability were assessed using intraclass correlation coefficients (ICCs), with ICCs > 0.80 indicating excellent reliability.

Results

Patient Demographics

Table 2 shows demographic and radiographic characteristics. Group M exhibited a significantly higher proportion of female patients than did Group C ($P < 0.01$). The mean age at surgery was significantly higher in Group M (64.2 ± 9.8 years) than in Group C (48.8 ± 16.1 years; $P < 0.0001$). BMI did not differ significantly between groups.

Table 2
Patient demographics and radiographic characteristics

Number of patients	Group M	Group C	P value
	102	62	
Age (years)	64.2 ± 9.8	48.8 ± 16.1	< 0.0001 [§]
Sex, female (%)	81 (79.4%)	37 (56.5%)	< 0.01 [§]
Height (m)	1.57 ± 0.08	1.64 ± 0.09	< 0.0001 [§]
Weight (kg)	64.2 ± 13.7	67.2 ± 13.5	0.17
Body mass index (kg/m ²)	25.8 ± 4.1	25.0 ± 4.7	0.25
Hip-knee-ankle angle (°, varus positive)	2.7 ± 2.6	2.6 ± 3.2	0.73
Mechanical lateral distal femoral angle (°)	87.5 ± 1.6	87.3 ± 2.0	0.38
Medial proximal tibial angle (°)	86.1 ± 2.2	85.9 ± 2.3	0.66
Joint line-convergence angle (°)	1.2 ± 1.2	1.2 ± 1.3	0.97
Medial posterior tibial slope (°)	9.5 ± 3.0	8.6 ± 2.9	0.0495 [§]
Medial tibial plateau depth (mm)	1.4 ± 0.6	1.9 ± 0.7	< 0.0001 [§]
Values are presented as means ± standard deviations or numbers (%).			
Group M: patients who underwent medial meniscal posterior root repair; Group C: control group.			
[§] Significant differences were determined using independent t-tests.			

Radiographic Characteristics

The mean interval from injury to plain radiography was 33.1 days. Reliability analyses of MPTS and MTPD measurements revealed excellent intra and interobserver reproducibility, with ICC values > 0.90. In the sagittal-plane, the mean MPTS was greater in Group M (9.5 ± 3.0°) than in Group C (8.6 ± 2.9°), with a significant difference (P = 0.0495). Conversely, MTPD was significantly smaller in Group M (1.4 ± 0.6 mm) than in Group C (1.9 ± 0.7 mm; P < 0.0001). No significant differences were observed between groups in coronal-plane alignment parameters, including HKAA, mL DFA, MPTA, or JLCA.

Logistic Regression Analysis

In univariate logistic regression, increasing age (odds ratio [OR]: 1.10; 95% confidence interval [CI]: 1.07–1.15; P < 0.000001), female sex (OR: 2.98; 95% CI: 1.49–5.96; P < 0.01), and decreased MTPD were significantly associated with MMPRT. MPTS showed a trend toward significance in the univariate

analysis. Other variables assessed, including BMI and coronal-plane alignment parameters, were not significantly associated with MMPRT (Table 3). AIC-based stepwise selection retained age, BMI, JLCA, MPTS, and MTPD in the final multivariable model. In this model, increasing age (odds ratio [OR]: 1.14; 95% confidence interval [CI]: 1.08–1.20; $P < 0.00001$), higher BMI (OR: 1.13; 95% CI: 1.02–1.26; $P = 0.021$), and decreased MTPD (OR: 0.19; 95% CI: 0.085–0.41; $P < 0.0001$) remained independent predictors of MMPRT. JLCA and MPTS were retained in the final model but were not independently associated with MMPRT (Table 4).

Table 3

Univariate logistic regression analysis for medial meniscus posterior root tear Dependent variable: Presence of MMPRT (MMPRT = 1, non-MMPRT = 0)

Variables	Odds ratio	95% CI	<i>P</i> value
Age (years)	1.10	1.07–1.15	$< 0.000001^{\boxtimes}$
Female sex	2.98	1.49–5.96	$< 0.01^{\boxtimes}$
BMI (kg/m ²)	1.05	0.97–1.13	0.25
HKAA (°)	1.02	0.91–1.14	0.73
mLDFA (°)	1.08	0.91–1.30	0.38
MPTA (°)	1.03	0.90–1.19	0.66
JLCA (°)	1.00	0.78–1.29	0.99
MPTS (°)	1.12	1.00–1.25	0.052
MTPD (mm)	0.26	0.15–0.47	$< 0.00001^{\boxtimes}$
Abbreviations: BMI, body mass index; HKAA, hip-knee-ankle angle; mLDFA, mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; JLCA, joint line-convergence angle; MPTS, medial posterior tibial slope; MTPD, medial tibial plateau depth.			
[⊗] Significant values.			

Table 4

Multivariate logistic regression analysis for medial meniscus posterior root tear Dependent variable: Presence of MMPRT (MMPRT = 1, non-MMPRT = 0)

Variables	Odds ratio	95% CI	P value
Age (years)	1.14	1.08–1.20	< 0.001 [§]
BMI (kg/m ²)	1.13	1.02–1.26	0.021 [§]
JLCA (°)	0.69	0.47–1.01	0.060
MPTS (°)	1.12	0.97–1.30	0.13
MTPD (mm)	0.19	0.085–0.41	< 0.001 [§]
Abbreviations: BMI, body mass index; JLCA, joint line-convergence angle; MPTS, medial posterior tibial slope; MTPD, medial tibial plateau depth.			
[§] Significant values.			

ROC Curve Analysis

ROC curve analysis demonstrated that MTPD had moderate discriminatory ability for MMPRT, with an area under the curve of 0.7138 (95% CI: 0.6306–0.7970) (Fig. 2). An MTPD cutoff of 1.92 mm provided 74.19% sensitivity and 58.06% specificity for distinguishing MMPRT from non-MMPRT knees (Fig. 2).

The sensitivity and specificity were 74.19% and 58.06%, respectively, when the MTPD cutoff value was set at 1.92 mm (red point)

Figure 3 Radiological findings of an atypical case of medial meniscus posterior root tear in a 51-year-old woman (body mass index, 24.8)

Lower-limb alignment was relatively neutral (hip-knee-ankle angle, 2.0° valgus) (a), with a mild medial posterior tibial slope of 6.0° (b), and a shallow medial tibial plateau depth of 0.8 mm (c)

Discussion

MTPD remained independently associated with MMPRT after adjustment for demographic, coronal, and sagittal parameters, suggesting that tibial sagittal morphology may contribute to MMPRT susceptibility beyond conventional alignment factors. Previous studies have reported an association between sagittal-plane morphology and MMPRT, particularly increased MPTS and shallow MTPD [8, 9, 13–15]. Here, MPTS was significantly greater in the MMPRT group in univariate analysis; nonetheless, it did not retain independent significance after multivariable adjustment. Therefore, MPTS may contribute to MMPRT development, but its effect could be influenced by other factors, including age-related tissue degeneration and tibial plateau morphology. In contrast, the persistent association of MTPD after

multivariable adjustment suggests that plateau depth may provide information that is not captured by tibial slope or coronal alignment alone.

Biomechanically, a steep MPTS increases anterior tibial translation and shear forces on the MM posterior horn, a secondary stabilizer against anterior translation [16–18]. The MM posterior root may be susceptible to repetitive mechanical stress because of its firm attachment to the tibial plateau and limited mobility [19]. These anatomical characteristics may predispose the posterior root to degenerative changes. Previous studies reported that anterior cruciate ligament degeneration is a risk factor for MMPRT, suggesting that increased anterior tibial translation may similarly be involved in its pathogenesis [16]. A direct association between decreased MTPD and MMPRT has been reported only by Karalar et al. and Okazaki et al. [8, 9]. Anatomically, the medial tibial plateau is concave, whereas the lateral tibial plateau is convex [20]. This concavity, together with surrounding soft tissues, contributes to medial compartment stability during knee flexion. A shallow MTPD may reduce this passive constraint, allowing increased translation of the MFC and a reduced contact area. These changes could increase stress concentration at the MM posterior root, predisposing it to degenerative tearing.

ROC analysis showed moderate discrimination (AUC, 0.714). An MTPD threshold of 1.92 mm yielded 74.2% sensitivity and 58.1% specificity but should not be considered diagnostic; MTPD may instead complement age, BMI, symptoms, and imaging findings in risk stratification.

Unlike sagittal-plane parameters, no coronal-plane alignment parameter was identified as an independently associated factor for MMPRT. This contrasts with previous reports linking varus lower-limb alignment to MMPRT [4, 15, 21, 22]. However, varus alignment in this MMPRT cohort was relatively mild. Previous MMPRT cohorts have reported mean HKAA of approximately 2.9°–4.5° varus [4, 15, 23]. Another study reported a mean femorotibial angle of 177.3° in patients with MMPRT, corresponding to an estimated HKAA of approximately 3.3° varus [24]. The MMPRT group had a mean varus alignment of 2.7°, likely reflecting selection bias because repair was limited to patients with an HKAA ≤ 5° varus. Imaging was performed approximately 30 days after onset, before substantial deformity progression. The inclusion of early-stage OA only (KL grade ≤ 2), and the predominance of female patients, who have been shown to exhibit less constitutional varus alignment than males, may have also contributed to the mild alignment. Therefore, the absence of a significant association between coronal alignment and MMPRT in this cohort does not necessarily negate a potential role but suggests that coronal alignment alone may be insufficient to explain MMPRT, particularly in patients without marked varus deformity.

Although activity-related factors were not evaluated, epidemiological studies have shown that MMPRT frequently occurs during stair descent [2] and in individuals engaged in occupations involving frequent squatting [3]. Biomechanical and finite element studies demonstrated that shear stress on the MM posterior root rises substantially with greater loaded knee flexion, particularly during stair descent, compared with level walking [25]. In robotic biomechanical studies, under anterior tibial loading, the MM posterior root experienced one of the highest forces after the ACL at higher flexion angles [18]. Repetitive mechanical stress may promote posterior-root degeneration and rupture, suggesting that

MMPRT is multifactorial. Shallow MTPD may represent an underrecognized risk factor, even without marked varus alignment or a steep posterior tibial slope.

From a clinical perspective, MTPD may serve as an imaging-based morphological marker that helps identify patients at an increased risk of MMPRT. In patients with shallow MTPD who present with posteromedial knee symptoms, particularly in the presence of additional risk factors such as older age or higher BMI, clinicians may consider MMPRT in the differential diagnosis and pay attention to activities that impose repetitive mechanical loading on the posterior root, including stair descent, deep squatting, and kneeling. When MMPRT is clinically suspected, MRI may be considered to evaluate meniscal pathology and to characterise sagittal tibial morphology. However, these applications remain hypothesis-generating. Further studies should determine whether MTPD can be reliably assessed or screened using plain radiographs and whether MTPD-based risk stratification or activity modification can improve clinical outcomes or prevent MMPRT development.

This study had some limitations. First, the control group consisted of surgically treated patients rather than asymptomatic volunteers and predominantly included patients with non-root medial meniscal pathology. Therefore, these findings should not be generalised to the broader or asymptomatic population. Obtaining full-length standing radiographs in healthy individuals is ethically challenging; thus, using a surgical control group without MMPRT was a pragmatic approach adopted in this and previous alignment studies. Second, postoperative radiological and clinical outcomes were not evaluated because the analysis focused on MMPRT occurrence and associated factors. Third, activity level, specific daily activities, and sex-specific subgroup analyses were not assessed. Excluding patients with ACL injuries may have reduced the representation of knees with extremely steep MPTS.. Even if MPTS had been independently significant, the main conclusion would remain that sagittal-plane morphology, particularly MTPD, contributes to MMPRT development beyond coronal alignment alone. Finally, MTPD was measured from subchondral bone morphology without including articular cartilage. Although this may not fully reflect true joint-surface geometry, subchondral morphology can be assessed using standard imaging modalities and may provide a clinically relevant measure for risk assessment..

Conclusions

Lower MTPD, older age, and higher BMI were independently associated with MMPRT. Although MPTS was higher in patients with MMPRT, it was not an independent predictor after multivariable adjustment. Conversely, coronal-plane alignment parameters were not associated with MMPRT in this cohort. These findings suggest that even in the absence of marked varus alignment or a steep MPTS, MTPD may play a role in MMPRT pathogenesis and contribute to tear development.

Declarations

Author Contribution

T.K.: Methodology, Formal analysis, data curation, writing, and original draftY.O.: Conceptualization, Methodology, Writing the original draft, writing the review, and editing.T.F.: Data curation and supervision.Y.Y.: Data curationT.H.: Data curationK.K.: Formal analysisD.Y.: Data curationT.T.: Supervision, writing the review, and editing.T.O.: SupervisionAll the authors have read and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

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Figures



Figure 1

Radiological measurements of lower limb parameters in the coronal and sagittal planes

(a) and (b). Measurements of the hip-knee-ankle, mechanical lateral distal femoral, medial proximal tibial, and joint line-convergence angles using standing full-length anteroposterior radiographs.

(c). Measurement of medial posterior tibial slope (MPTS) on true lateral knee radiographs. MPTS was defined as the angle between a line perpendicular to the proximal tibial anatomic axis and a line connecting the most proximal points of the anterior and posterior margins of the medial tibial plateau.

(d). Measurement of medial tibial plateau depth (MTPD) on magnetic resonance imaging. MTPD was measured on the slice demonstrating the deepest concavity of the medial tibial plateau. Depth was defined as the perpendicular distance from a line connecting the anterior and posterior subchondral bone margins (excluding cartilage) to the deepest point of the concavity

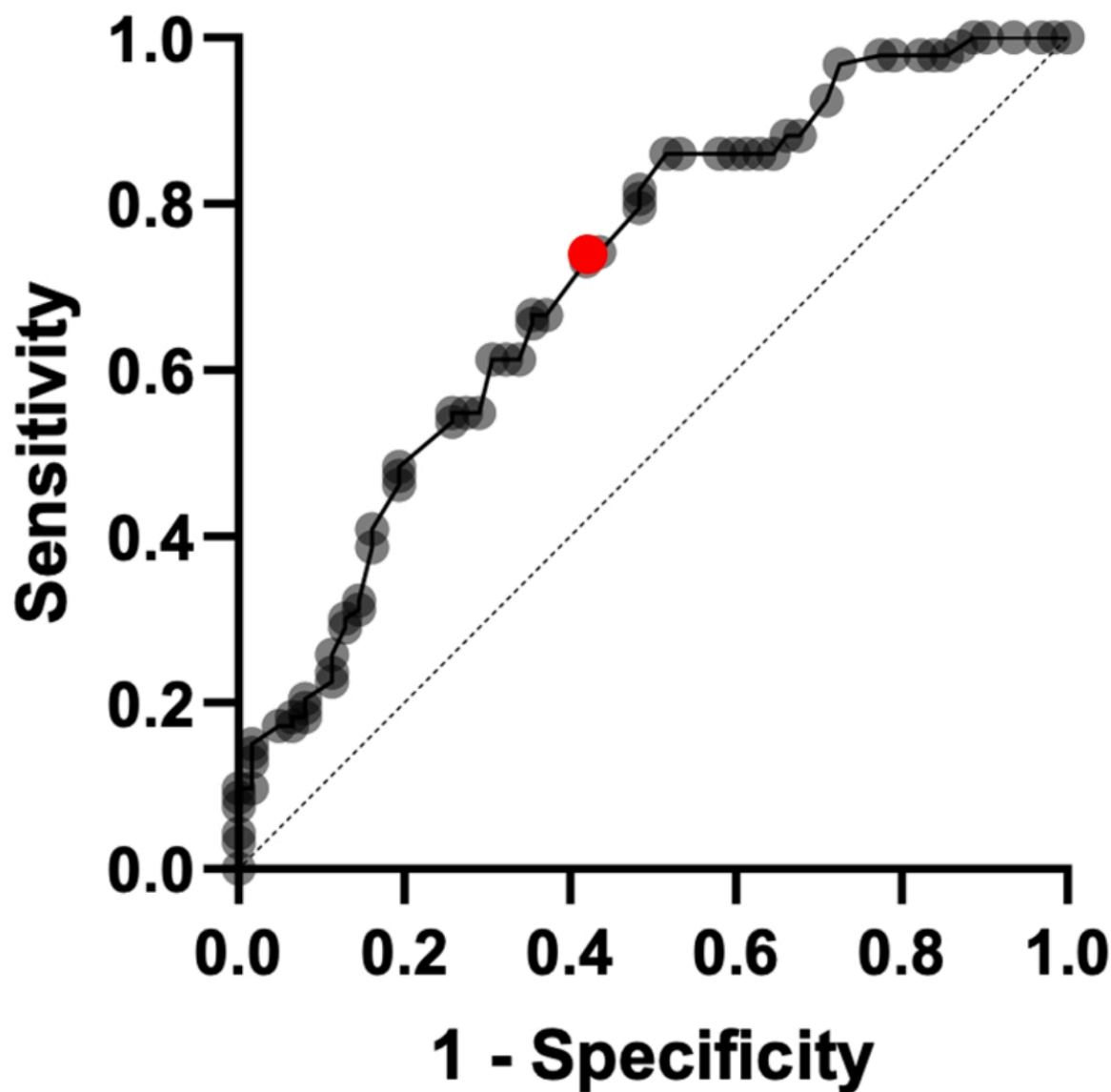


Figure 2

Receiver Operating Characteristic analysis of medial tibial plateau depth (MTPD)

The sensitivity and specificity were 74.19 % and 58.06%, respectively, when the MTPD cutoff value was set at 1.92 mm (red point)

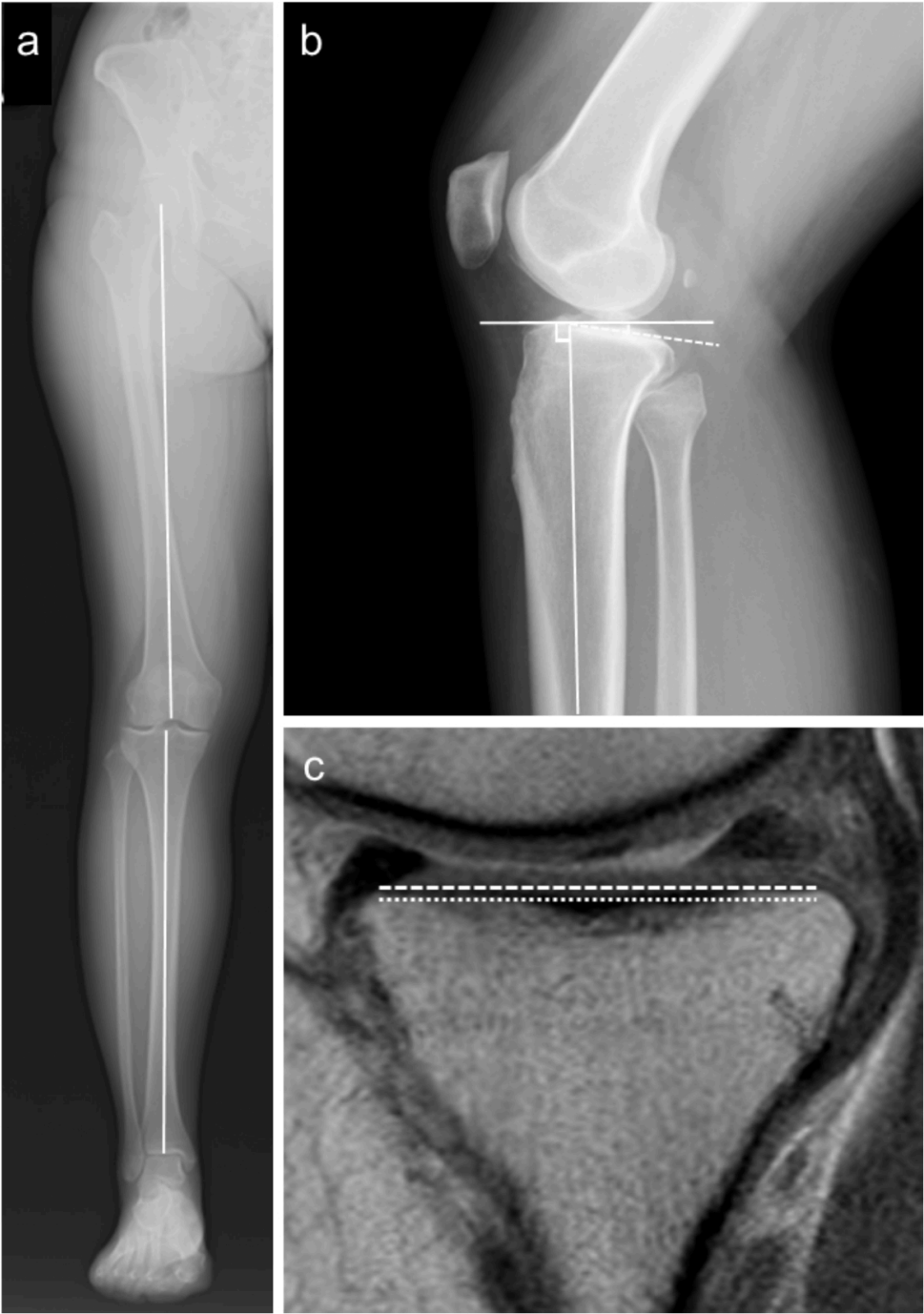


Figure 3

Radiological findings of an atypical case of medial meniscus posterior root tear in a 51-year-old woman (body mass index, 24.8)

Lower-limb alignment was relatively neutral (hip-knee-ankle angle, 2.0° valgus) (a), with a mild medial posterior tibial slope of 6.0° (b), and a shallow medial tibial plateau depth of 0.8 mm (c)