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Structural factors associated with Baker's cyst volume in degenerative knees: A large MRI-based cohort study

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Abstract

Purpose: To evaluate structural factors associated with Baker's cyst volume and determine whether cyst enlargement is related to medial meniscus posterior root tear (MMPRT), medial meniscus extrusion (MME), posterior tibial slope (PTS), and radiographic osteoarthritis severity. **Methods:** This retrospective study included 876 knee MRI examinations with MRI-confirmed Baker's cysts after predefined exclusions. Baker's cyst volume, MMPRT status, MME, PTS, and Kellgren–Lawrence osteoarthritis grade were assessed using standardized imaging protocols. Factors associated with cyst volume were evaluated using multivariable linear regression. Logistic regression and receiver operating characteristic analysis were performed to assess the relationship between cyst volume and MMPRT. Measurement reliability was evaluated using intraclass correlation coefficients. **Results:** MMPRT was independently associated with larger Baker's cyst volume ($p = 0.004$). Greater PTS was also associated with increased cyst volume, with each 1° increase corresponding to a significant volume increase ($p = 0.012$). Increasing Kellgren–Lawrence grade remained independently associated with larger cyst volume ($p < 0.001$), and MME showed an independent but modest association ($p = 0.044$). The final regression model was significant ($F(8,867) = 23.45$, $p < 0.001$) and explained 17.8% of the variance. ROC analysis identified 10.16 cm^3 as the optimal cyst volume threshold for identifying MMPRT; however, discriminative performance was modest, indicating that cyst volume should not be interpreted as a standalone diagnostic marker. ICC values ranged from 0.79 to 0.91. **Conclusion:** Baker's cyst enlargement is associated with MMPRT, increased PTS, greater MME, and increasing osteoarthritis severity. Larger cysts may prompt careful evaluation of the medial meniscus posterior root and degenerative joint burden on routine knee MRI, but cyst volume should be interpreted together with other structural imaging findings.

Keywords

Baker's cyst, medial meniscus posterior root tear, posterior tibial slope, knee osteoarthritis, MRI volumetry

Level of evidence

IV (retrospective cross-sectional study)

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Introduction

Baker's cyst, or popliteal cyst, represents a distension of the gastrocnemius–semimembranosus bursa that maintains communication with the knee joint and is commonly identified on magnetic resonance imaging (MRI).[1] Although traditionally considered a passive reservoir of synovial fluid, several imaging-based investigations have demonstrated that Baker's cysts reflect dynamic interactions between intra-articular inflammation, capsular distension, and altered joint biomechanics rather than simple effusion accumulation.[1,2]

Baker's cysts are frequently observed in degenerative knee disorders. MRI and clinical studies have demonstrated that joint effusion and synovial inflammation commonly coexist with Baker's cysts, supporting the concept of a shared intra-articular inflammatory environment rather than a simple isolated bursal process. Collectively, these observations indicate that Baker's cysts reflect the overall inflammatory and structural burden within the knee joint rather than functioning solely as passive fluid collections.[3,4]

Baker's cysts are frequently encountered in knees with degenerative joint disease. Previous imaging and clinical studies have demonstrated a higher prevalence of Baker's cysts in osteoarthritic knees and in association with cartilage degeneration and joint effusion. Rather than a direct linear relationship with radiographic Kellgren–Lawrence grade, these findings suggest that cyst formation and enlargement reflect the cumulative degenerative and inflammatory burden within the joint.[5,6]

Meniscal pathology—particularly posterior horn and root tears of the medial meniscus—is one of the most consistently reported intra-articular abnormalities associated with Baker's cysts. MRI-based studies have demonstrated that meniscal tears are present in a substantial proportion of knees with Baker's cysts, most commonly involving the posterior horn of the medial meniscus, supporting a structural link between meniscal insufficiency and posterior bursal distension.[2,7] Medial meniscus posterior root tears (MMPRTs) disrupt the hoop-stress mechanism, resulting in elevated tibiofemoral contact pressure, accelerated cartilage degeneration, and medial meniscus extrusion (MME).[8,9] MME is widely recognized as a structural marker of advanced meniscal insufficiency and degenerative joint disease. Rather than acting as an independent driver of joint effusion or synovitis, extrusion reflects loss of meniscal function and altered load distribution within the medial compartment. These structural alterations contribute to progressive cartilage degeneration and cumulative intra-articular mechanical stress, factors that may indirectly influence Baker's cyst formation and enlargement.[10–12] Importantly, posterior horn medial meniscal tears are frequently observed in knees with Baker's cysts, reinforcing the concept that meniscal insufficiency may facilitate posterior bursal distension.[2,7]

Posterior tibial slope (PTS) influences sagittal-plane knee biomechanics and has been associated with increased anterior tibial translation and altered load distribution across the menisci and cruciate ligaments. A steeper PTS has been identified as a risk factor for medial meniscus posterior root tears and degenerative meniscal pathology, likely due to increased shear forces and altered joint mechanics.[13] These biomechanical alterations may contribute to cumulative intra-articular stress, meniscal insufficiency, and chronic joint degeneration, which are recognized contributors to Baker's cyst development and volumetric progression. However, the relationship between PTS and cyst volume has not been adequately investigated in large-scale imaging-based cohorts. Accordingly, PTS should be interpreted as a potential biomechanical modifier of intra-articular structural degeneration rather than as a direct causal determinant of cyst formation.

Given these gaps, the present study aimed to evaluate the relationship between Baker's cyst volume and four key structural determinants among knees with established Baker's cysts. Importantly, the study was designed to identify factors associated with cyst enlargement rather than to determine predictors of cyst presence. Accordingly, cyst-negative knees were not included, as the primary outcome of interest was volumetric variation within an affected cohort.

We hypothesized that (1) MMPRTs and greater MME would be associated with larger Baker's cyst volumes; (2) increased PTS would independently predict cyst enlargement; and (3) cyst volume would demonstrate a dose-dependent association with OA grade, even after controlling for other structural parameters.

Materials and methods

Study design and patient selection

This retrospective observational study was conducted at a tertiary orthopedic referral center between January 2015 and December 2023. Institutional review board approval was obtained, and the requirement for informed consent was waived due to the retrospective design. Consecutive knee MRI examinations were screened, and patients aged 18–85 years with MRI-confirmed Baker's cysts were eligible for inclusion. Because the primary aim of the study was to evaluate structural determinants of cyst volume, only cyst-positive knees were included in the final analytic cohort.

Patients were excluded if they had a history of prior knee surgery or meniscal repair, acute multiligamentous knee injury (defined as tears involving two or more of the ACL, PCL, MCL, or LCL), inflammatory arthropathy (including rheumatoid

arthritis, seronegative spondyloarthropathy, or gout), neoplastic, infectious, or traumatic lesions involving the posterior knee, or motion-degraded/incomplete MRI examinations.

A total of 21,703 consecutive knee MRI examinations were screened. After removal of duplicate studies and application of the exclusion criteria, 876 knees met the study criteria and were included in the final analysis. The screening and exclusion process is summarized in Figure 1.

MRI acquisition protocol

All MRI examinations were performed using a 1.5-T system with a dedicated knee coil. The standardized protocol included: Sagittal proton-density (PD) fat-suppressed sequence, Coronal PD fat-suppressed sequence, Axial T2-weighted fat-suppressed sequence.

Slice thickness was 3–4 mm with a 0.5-mm interslice gap. All measurements were obtained digitally using the institutional PACS workstation at full magnification.

Because this was a retrospective cross-sectional study including predominantly chronic degenerative knee conditions, the interval between symptom onset and MRI acquisition was not standardized and was not included as a variable in the analysis.

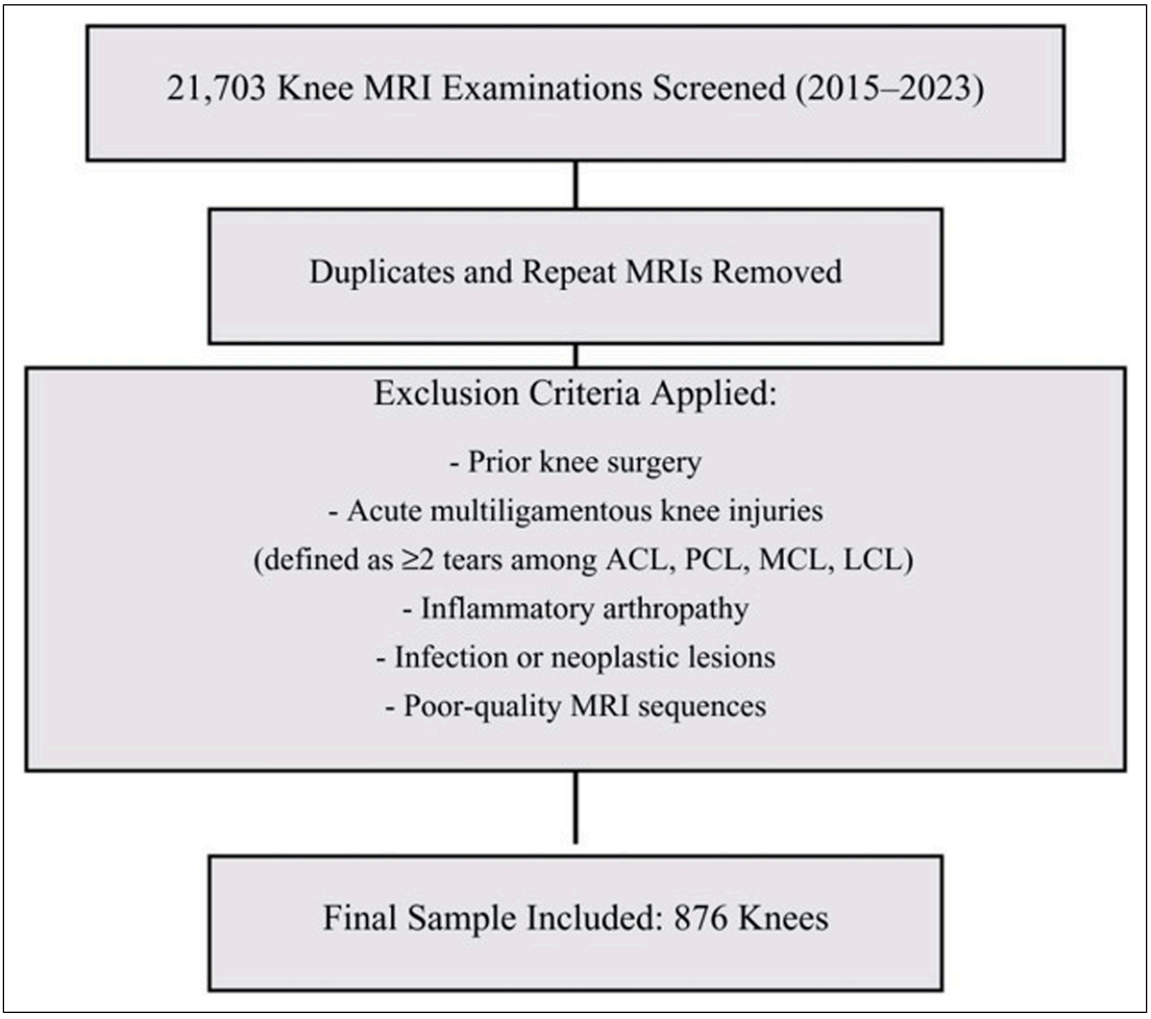


Figure 1. Study flow diagram. From a total of 21,703 knee MRI examinations screened, only those meeting strict inclusion criteria and demonstrating MRI-confirmed Baker's cysts with complete imaging data were retained for analysis.

Baker's cyst identification and volume measurement

A Baker's cyst was defined as a fluid-filled lesion located between the medial head of the gastrocnemius and the semimembranosus tendon with a demonstrable neck connecting to the knee joint. Other cystic lesions or soft-tissue masses without clear joint communication were excluded to avoid diagnostic ambiguity.

Cyst volume (cm^3) was calculated using the ellipsoid formula: Volume $= \frac{4}{3}\pi \times \frac{a}{2} \times \frac{b}{2} \times \frac{c}{2}$

where a = maximal longitudinal length, b = maximal transverse diameter, and c = maximal anteroposterior diameter measured on sagittal and axial fat-suppressed sequences (Figure 2).

This technique has been validated in prior radiological studies examining cystic knee lesions and synovial distension.[1,2,6]

Assessment of medial meniscus posterior root tears

An MMPRT was defined according to established MRI criteria: Ghost sign on sagittal imaging, Truncation of the posterior horn, Radial tear within 9 mm of the posterior insertion, Absent or displaced posterior root fibers (Figure 3).[8,9]

Assessment of anterior cruciate ligament rupture

ACL rupture was defined on MRI by the presence of complete fiber discontinuity, abnormal ligament orientation, increased intraligamentous signal intensity on proton-density sequences, and/or secondary signs such as anterior tibial translation or empty notch sign. Only complete ruptures were considered positive findings.

Measurement of medial meniscus extrusion (MME)

MME was measured on the mid-coronal proton-density fat-suppressed image at the level of the medial tibial spine (Figure 4). Extrusion was defined as the perpendicular distance between the peripheral meniscal margin and the edge of the tibial plateau, excluding osteophytes.[10–12] MME $\geq$ 3 mm was considered pathologic.

Radiographic measurement of posterior tibial slope (PTS)

PTS was measured on true lateral knee radiographs using the method described by Jiang et al. (Figure 5).[13] The tibial anatomical axis was defined by connecting the midpoints of two circles placed 5 cm apart within the proximal tibial diaphysis.

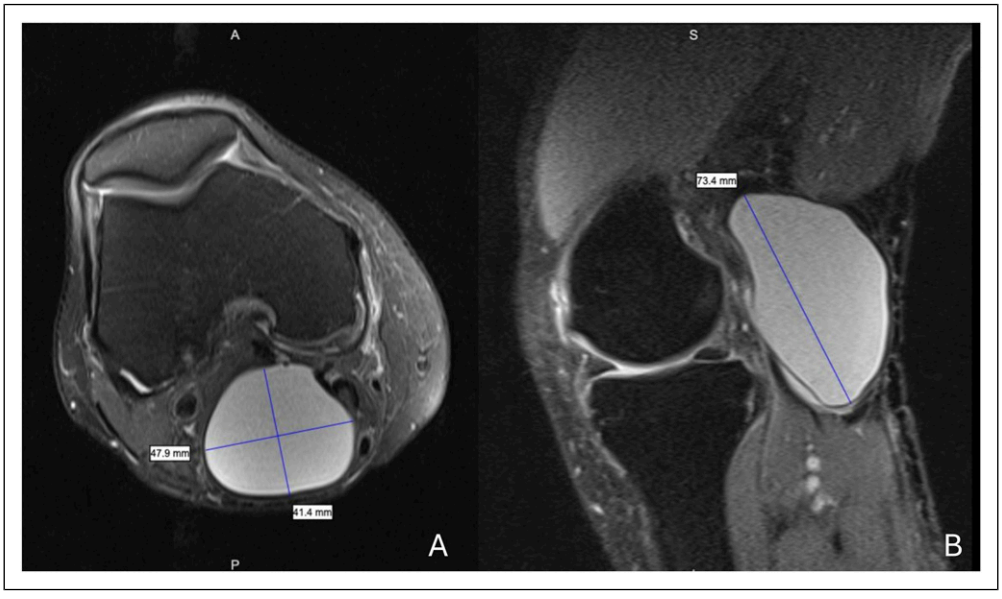


Figure 2. Cyst volume (cm^3) calculated using the ellipsoid formula Volume = (4/3\)π × a/2 × b/2 × c/2, where *a* is the maximal longitudinal length, *b* the maximal transverse diameter, and *c* the maximal anteroposterior diameter measured on sagittal and axial fat-suppressed sequences. (a) Axial view. (b) Sagittal view.

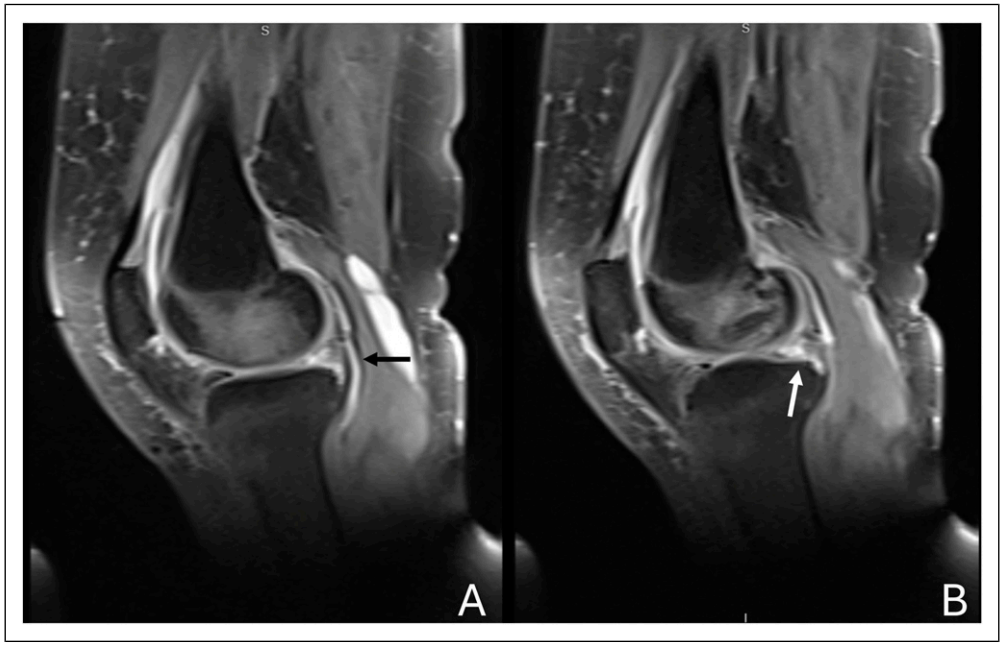


Figure 3. MRI findings indicative of a medial meniscus posterior root tear. (a) Posterior horn truncation, radial tear near the root insertion, and displaced/absent root fibers are demonstrated (indicated by arrow). (b) Ghost sign and absent root fibers at the posterior root attachment are shown (indicated by arrow).

A tangent line was drawn along the medial tibial plateau, and the PTS was defined as the angle between this tangent and a line perpendicular to the tibial anatomical axis.

All measurements were performed on true lateral radiographs with superimposed femoral condyles. To reduce variability, measurements were obtained from the medial tibial plateau in all cases.



Figure 4. Measurement of medial meniscus extrusion (MME) on the mid-coronal proton-density fat-suppressed MRI image at the level of the medial tibial spine. Extrusion is defined as the perpendicular distance from the peripheral meniscal margin to the edge of the tibial plateau, excluding osteophytes.

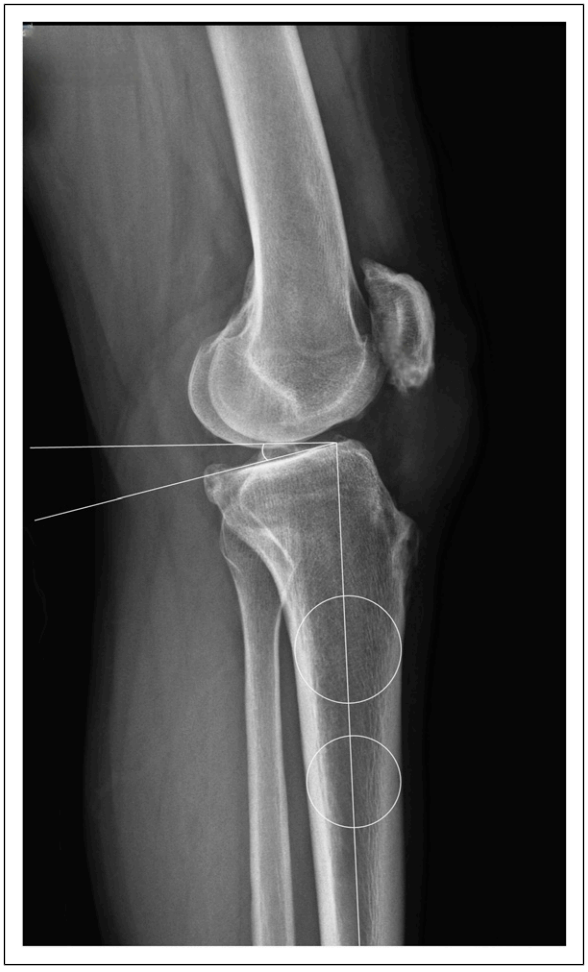


Figure 5. Measurement of medial posterior tibial slope on a true lateral knee radiograph. The tibial anatomical axis was defined by connecting the midpoints of two circles placed 5 cm apart within the proximal tibial diaphysis. A tangent line was drawn along the medial tibial plateau to determine the medial posterior tibial slope.

Radiographic osteoarthritis severity

Radiographic OA was graded on weight-bearing anteroposterior and lateral radiographs according to the Kellgren–Lawrence (KL) classification: Grade 0: no OA, Grade 1: doubtful narrowing, Grade 2: definite osteophytes, Grade 3: moderate narrowing, Grade 4: severe OA with sclerosis and deformity.

KL grading was performed independently from MRI reviewers.

Observer reliability

A subset of 120 randomly selected knees underwent repeated assessment after 3 weeks to evaluate intraobserver reliability. All radiological measurements were independently performed by two fellowship-trained orthopaedic surgeons. Inter-observer and intraobserver reliability were assessed using intraclass correlation coefficients (ICC), calculated with a two-way random-effects model and absolute-agreement definition.

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp). Statistical significance was set at $p < 0.05$. Normality of continuous variables was assessed using the Shapiro–Wilk test and Q–Q plots. Continuous variables were compared using the independent samples t-test or Mann–Whitney U test as appropriate, while categorical variables were analyzed using the chi-square test. Pearson correlation analysis was performed to evaluate pairwise associations among

continuous variables, including age, BMI, PTS, MME, and Baker's cyst volume. For subgroup comparisons, the cohort was stratified according to the presence or absence of MMPRT, and demographic, radiological, and structural variables were compared between groups.

Multivariable linear regression analysis was performed to identify independent predictors of Baker's cyst volume. Predictor variables included age, sex, body mass index (BMI), MMPRT status, MME, PTS, anterior cruciate ligament (ACL) rupture, and osteoarthritis severity. Osteoarthritis severity was modeled primarily as an ordinal Kellgren–Lawrence variable (per 1-grade increase). A secondary sensitivity analysis was conducted using dichotomized advanced osteoarthritis (grade III–IV vs grade 0–II) to confirm model robustness. Multicollinearity was assessed using variance inflation factor (VIF), with values below 2.5 considered acceptable.

Multivariable logistic regression analysis was additionally performed to evaluate independent predictors of MMPRT presence. Receiver operating characteristic (ROC) curve analysis was primarily performed to evaluate the discriminative ability of Baker's cyst volume for identifying MMPRTs. Additional exploratory ROC analyses were conducted for selected structural and demographic variables (age, BMI, PTS, and MME) to contextualize the relative diagnostic contribution of cyst volume. Linear regression results were reported as unstandardized B coefficients with 95% confidence intervals. ROC analyses were summarized using area under the curve (AUC) values. The final sample size (n = 876) exceeded the minimum recommended threshold for multivariable modeling (>10 events per predictor), ensuring adequate statistical power.

Results

Demographic and radiological characteristics

A total of 876 knees from 876 patients were analyzed. The mean age was 52.93 ± 13.62 years, and the mean body mass index (BMI) was 31.60 ± 4.11 kg/m^2. Women constituted 63.0% (n = 552) of the cohort, whereas men accounted for 37.0% (n = 324). The evaluated knees were 41.1% right (n = 360) and 58.9% left (n = 516).

Regarding radiographic osteoarthritis (OA), 9.6% (n = 84) of knees had no OA (grade 0), 14.7% (n = 129) had grade I, 45.9% (n = 402) grade II, 22.9% (n = 201) grade III, and 6.8% (n = 60) grade IV disease. The mean PTS was 9.84 ± 2.56°. Medial meniscus posterior root tears (MMPRTs) were present in 56.8% of knees (n = 498), and 43.2% (n = 378) showed no root tear. Anterior cruciate ligament (ACL) rupture was identified in 28.1% of knees (n = 246), and 71.9% (n = 630) had an intact ACL. The mean MME was 2.47 ± 1.53 mm, and the mean Baker's cyst volume was 16.30 ± 17.54 cm^3 (Table 1).

Table 1. Demographic, clinical, and radiological characteristics of the study cohort.

Parameter	
Age (x̄±sd)	52.93±13.62
BMI (x̄±sd)	31.60±4.11
Sex (n,%)	
Man	324 (37.0)
Woman	552 (63.0)
Side (n,%)	
Right	360 (41.1)
Left	516 (58.9)
Osteoarthritis (K-L) (n,%)	
None	84 (9.6)
Stage I	129 (14.7)
Stage II	402 (45.9)
Stage III	201 (22.9)
Stage IV	60 (6.8)
Tibial Slope (x̄±sd)	9.84±2.56
Medial Meniscus Posterior Root Tear (MMPRT) (n,%)	
No	378 (43.2)
Yes	498 (56.8)
ACL Rupture (n,%)	
No	630 (71.9)
Yes	246 (28.1)
Medial Meniscus Extrusion (MME) mm (x̄±sd)	2.47±1.53
Baker Cyst Volume cm^3 (x̄±sd)	16.30±17.54

Observer reliability

The reliability analysis demonstrated high consistency across parameters: Baker's cyst volume measurements showed excellent interobserver (ICC = 0.86) and intraobserver (ICC = 0.91) agreement; MME demonstrated similarly high interobserver (ICC = 0.82) and intraobserver (ICC = 0.88) reliability; tibial slope measurements showed moderate-to-high reliability, with interobserver and intraobserver ICC values of 0.79 and 0.85, respectively.

Comparison according to presence of medial meniscus posterior root tear

When patients were stratified according to the presence of MMPRT, several significant differences emerged. Knees with root tears were significantly older (57.93 ± 10.44 vs 46.34 ± 14.51 years; p = 0.001) and had higher BMI values (32.14 ± 4.06 vs 30.89 ± 4.08 kg/m^2; p = 0.001) compared with those without MMPRT.

Sex distribution was similar between groups (p = 0.798). Left knees were more frequently affected in MMPRT group (63.3% vs 53.2%), whereas right knees were relatively more common in the without MMPRT group (36.7% vs 46.8%; p = 0.003).

OA severity differed significantly between groups (p < 0.001). In knees with MMPRT, grade II (49.4%) and grade III (29.5%) predominated, whereas in knees without MMPRT the proportions of grade II (41.3%) and grade III (14.3%) were lower and grade 0–I OA was more frequent.

Mean PTS did not differ significantly between knees with and without MMPRT (9.90 ± 2.67° vs 9.75 ± 2.40°; p = 0.191). ACL rupture was more frequent in knees with MMPRT than in those without MMPRT (33.1% vs 21.4%; p < 0.001).

MME was greater in knees with MMPRT (3.01 ± 1.38 mm) compared with knees without MMPRT (1.75 ± 1.02 mm; p < 0.001). Baker's cyst volume was also significantly higher in knees with MMPRT (20.07 ± 20.41 cm^3 vs 11.33 ± 11.04 cm^3; p < 0.001).

Detailed comparative results are presented in Table 2.

Table 2. Comparative analysis of demographic, clinical, and radiological parameters based on the presence versus absence of a medial meniscus root tear.

Parameter	Root Tear		P value
	No	Yes	
Age (x̄±sd)	46.34±14.51	57.93±10.44	[a]0.001*
BMI (x̄±sd)	30.89±4.08	32.14±4.06	[a]**0.001***
Sex (n,%)			
Man	138 (36.5)	186 (37.3)	[b]0.798
Woman	240 (63.5)	312 (62.7)	
Side (n,%)			
Right	177 (46.8)	183 (36.7)	[b]**0.003***
Left	201 (53.2)	315 (63.3)	
Osteoarthritis (n,%)			
None	75 (19.8)	9 (1.8)	[b]**0.001***
Stage I	87 (23.0)	42 (8.4)	
Stage II	156 (41.3)	246 (49.4)	
Stage III	54 (14.3)	147 (29.5)	
Stage IV	6 (1.6)	54 (10.8)	
Tibial Slope (x̄±sd)	9.75±2.40	9.90±2.67	[a]0.191
ACL Rupture (n,%)			
No	297 (78.6)	333 (66.9)	[b]**0.001***
Yes	81 (21.4)	165 (33.1)	
Medial Meniscus Extrusion mm (x̄±sd)	1.75±1.024	3.01±1.38	[a]**0.001***
Volume cm^3 (x̄±sd)	11.33±11.04	20.07±20.41	[a]**0.001***

[a]Independent Sample T Test.
[b]Chi-Square Analysis; P<0.05*.

Correlation analysis

Pearson correlation analysis demonstrated a moderate positive correlation between age and MME ($r = 0.620$, $p < 0.001$) and a weak positive correlation between age and Baker's cyst volume ($r = 0.285$, $p < 0.001$). A weak positive correlation was observed between MME and cyst volume ($r = 0.344$, $p < 0.001$). No clinically meaningful correlations were identified between PTS and cyst volume. These relationships were visually summarized at Table 3.

Multivariable analysis of factors associated with Baker's cyst volume

Male sex was independently associated with larger cyst volumes ($B = 6.36\ cm^3$; 95% CI 3.99–8.72; $p < 0.001$). PTS showed a positive independent association, with each 1° increase corresponding to a $0.56\ cm^3$ increase in cyst volume (95% CI 0.12–1.00; $p = 0.012$). Presence of a MMPRT was also independently associated with increased cyst volume ($B = 3.56\ cm^3$; 95% CI 1.12–6.00; $p = 0.004$). MME demonstrated an independent but modest association with cyst volume ($B = 1.41\ cm^3$ per mm; 95% CI 0.04–2.77; $p = 0.044$). Osteoarthritis severity, modeled as an ordinal Kellgren–Lawrence variable, remained one of the strongest determinants of cyst volume, with each 1-grade increase associated with a $4.93\ cm^3$ increase (95% CI 2.48–7.38; $p < 0.001$). Age, body mass index, and anterior cruciate ligament rupture did not retain independent significance after adjustment. The overall model was statistically significant ($F(8,867)=23.45$, $p < 0.001$) and explained 17.8% of the variance in cyst volume ($R^2=0.178$) (Table 4).

To further evaluate structural factors associated with MMPRTs, a multivariable logistic regression model was constructed including age, body mass index, posterior tibial slope, medial meniscal extrusion, anterior cruciate ligament rupture, and Baker's cyst volume (Table 5). In this adjusted model, Baker's cyst volume remained an independent predictor of MMPRT presence (OR 1.02 per cm^3 increase; 95% CI 1.01–1.03; $p < 0.001$), indicating that larger cyst volumes were significantly associated with higher odds of root tear. Age (OR 1.06 per year; 95% CI 1.04–1.07; $p < 0.001$) and body mass index (OR 1.07 per kg/m^2; 95% CI 1.03–1.12; $p < 0.001$) also demonstrated independent positive associations with MMPRT. Medial meniscal extrusion showed a strong independent relationship (OR 1.32 per mm; 95% CI 1.16–1.52; $p < 0.001$), consistent with its role as a structural marker of meniscal insufficiency. Anterior cruciate ligament rupture was independently associated with MMPRT (OR 1.66; 95% CI 1.16–2.38; $p = 0.006$). PTS did not retain independent significance after adjustment ($p = 0.81$). The overall logistic regression model was statistically significant ($p < 0.001$) and demonstrated acceptable explanatory capacity (Nagelkerke $R^2 = 0.20$).

Overall, the multivariable model demonstrated good calibration and confirmed that cyst volume remains independently associated with MMPRT even after accounting for demographic, biomechanical, and structural confounders.

ROC analysis for identification of MMPRTs

ROC analysis demonstrated moderate discriminative ability for age and medial meniscus extrusion (AUC = 0.73 for both). Baker's cyst volume showed modest but statistically significant discriminative performance (AUC = 0.64; $p < 0.001$), with an optimal cutoff value of $10.16\ cm^3$ (Table 6). Overall ROC curves indicated that age, medial meniscus extrusion, and cyst

Table 3. Results of Pearson correlation analysis evaluating associations among continuous variables.

Parameter		Age	BMI	Tibial slope	M.M.E. (mm)	Volume cm^3
Age	r	1	.044	.013	**.620****	**.285****
	p		.196	.709	**<.001**	**<.001**
BMI	r	.044	1	**.086***	**.158****	**.051**
	p	.196		**.011**	**<.001**	**.134**
Tibial Slope	r	.013	**.086***	1	-.003	**.028**
	p	.709	**.011**		.936	**.405**
M.M.E. (mm)	r	**.620****	**.158****	-.003	1	.344**
	p	**<.001**	**<.001**	.936		<.001
Volume cm^3	r	**.285****	**.051**	**.028**	.344**	1
	p	**<.001**	**.134**	**.405**	<.001	

Pearson correlation analysis. r: correlation coefficient; $p < 0.05$ was considered statistically significant. Variables with statistical significance are marked as **p < 0.01**** and **p < 0.05***.

Table 4. Multivariable linear regression model demonstrating factors independently associated with Baker's cyst volume.

Outcome	Predictor	B coefficient (95% CI)	P Value
Volume (cm^3)	Age (per year)	-0.07 (-0.19 - 0.06)	0.286
	Sex (Male)	**6.36 (3.99 - 8.72)**	**<0.001***
	BMI (per kg/m^2)	-0.05 (-0.31 - 0.22)	0.731
	PTS (degree)	**0.56 (0.12 - 1.00)**	**0.012***
	MMPRT (yes)	**3.56 (1.12 - 6.00)**	**0.004***
	ACL Rupture (yes)	-0.39 (-2.78 - 2.00)	0.748
	M.M.E. (per mm)	**1.41 (0.04 - 2.77)**	**0.044***
	K–L grade (per 1-grade increase)	**4.93 (2.48 - 7.38)**	**<0.001***

Model: $F(8,867)=\mathbf{23.45}$, $p<0.001$; $\mathbf{R^2=0.178}$.

volume demonstrated statistically significant but clinically modest discriminative ability for predicting MMPRTs, whereas BMI and posterior tibial slope showed limited diagnostic utility (Figure 6).

Discussion

In this large MRI-based cohort of 876 knees with Baker's cysts, we identified male sex, greater posterior tibial slope, presence of MMPRTs, greater medial meniscal extrusion, and increasing radiographic osteoarthritis severity as independent factors associated with larger cyst volume, whereas age, body mass index, and anterior cruciate ligament rupture did not retain independent significance after adjustment. Consistent with prior MRI and review studies, these findings reinforce that Baker's cysts are secondary manifestations of intra-articular pathology—most commonly osteoarthritis and posterior horn meniscal lesions—rather than isolated bursal abnormalities.[1,5,14] Previous imaging series have reported coexistence of intra-articular pathology in more than 90% of cases, underscoring their close relationship with degenerative joint disease.[5] Moreover, population-based MRI studies linking effusion–synovitis with osteoarthritis progression further support the concept that Baker's cysts reflect the global inflammatory and mechanical burden within the knee.[3,4] Our data extend this framework by identifying specific structural factors that quantitatively influence cyst volume in a large clinical cohort. Although Baker's cysts were more frequently observed in women within the cohort, male sex remained independently associated with larger cyst volumes after adjustment. This suggests that cyst occurrence and cyst enlargement may represent distinct phenomena, potentially reflecting sex-related differences in joint loading patterns, muscle mass, or degenerative progression.

Previous investigations have primarily focused on cyst presence rather than quantitative volumetric assessment. In one of the few volumetric analyses, Balik et al. reported associations between larger cyst size and cartilage degeneration or effusion, but not meniscal tear grade.[15] Similarly, Saylik et al. demonstrated moderate correlation with chondral severity and weak correlation with effusion, while meniscal pathology showed limited discriminatory value.[6] However, both studies were limited by small sample sizes and did not incorporate key biomechanical parameters such as MMPRTs, medial meniscal extrusion, or posterior tibial slope. By analyzing a substantially larger cyst-positive cohort, the present study confirms the association with degenerative change while identifying MMPRT and PTS as independent structural factors associated with cyst volume.[16]

Table 5. Multivariable Logistic Regression Analysis for MMPRT Presence. Dependent variable: Presence of medial meniscus posterior root tear (MMPRT).

Variable	OR	95% CI	p
Age (per year)	**1.06**	1.04 – 1.07	<0.001
BMI (kg/m^2)	**1.07**	1.03 – 1.12	<0.001
Posterior tibial slope (°)	1.01	0.95 – 1.07	0.81
Medial meniscus extrusion (mm)	**1.32**	1.16 – 1.52	<0.001
ACL rupture (yes/no)	**1.66**	1.16 – 2.38	0.006
Cyst volume (cm^3)	**1.02**	1.01 – 1.03	<0.001

Table 6. ROC analysis results for the predictive performance of Baker's cyst volume in identifying medial meniscus posterior root tears.

Parameter	Cut-off	Sensitivity (%)	Specificity (%)	AUC (%95 CI)	p value
Age	52.5	66	65	0.73 (0.702-0.765)	<0.001*
Medial Meniscus Extrusion (mm)	2.81	51	83	0.73 (0.704–0.771)	<0.001*
Baker Cyst Volume (cm^3)	10.16	61	61	0.64 (0.605-0.678)	<0.001*

ROC Analysis *p<0.05.

The strong association between MMPRTs and larger cyst volumes aligns with the established biomechanical consequences of root insufficiency. Disruption of the hoop-stress mechanism produces a functional state comparable to subtotal meniscectomy, with increased tibiofemoral contact pressures and accelerated medial degeneration.[9] Imaging studies have consistently shown that MMPRTs lead to progressive medial meniscal extrusion (MME), which correlates with structural deterioration and inflammatory activity within the medial compartment.[10,11] These changes plausibly increase intra-articular mechanical and inflammatory burden, thereby facilitating posterior bursal distension. Unlike prior volumetric studies that did not incorporate root pathology in their analytical framework,[6,15] our findings provide quantitative evidence that MMPRT is one of several structural factors independently associated with cyst enlargement. Complementary logistic regression analysis also demonstrated an independent association between increasing cyst volume and MMPRT status after adjustment for age, BMI, meniscal extrusion, and ACL status. However, the cross-sectional design does not establish the direction or causality of this relationship.

In the multivariable logistic regression model, Baker's cyst volume remained independently associated with MMPRT presence. Although the per-unit odds ratio was modest (OR 1.02 per cm^3), a 10 cm^3 increase in cyst volume corresponded to approximately a 22% increase in the odds of MMPRT. This finding supports an association between cyst enlargement and

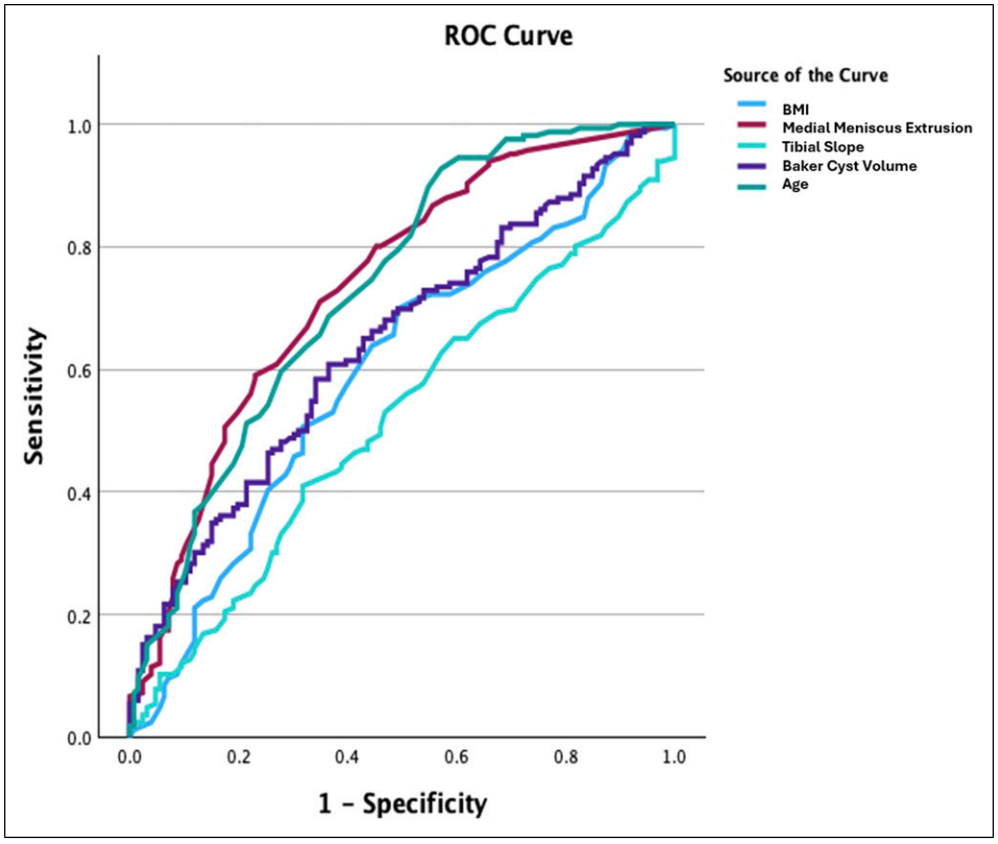


Figure 6. Receiver operating characteristic curves for age, medial meniscus extrusion, Baker's cyst volume, BMI, and posterior tibial slope in identifying MMPRT.

underlying structural degeneration; however, it does not establish cyst volume as a clinically sufficient diagnostic indicator of meniscal root insufficiency.

From a diagnostic perspective, Baker's cyst volume demonstrated only modest discriminative performance for MMPRT, with an AUC of 0.64. Although the identified threshold of approximately 10 cm^3 may prompt closer evaluation of the posterior medial meniscal root, this level of discrimination is insufficient to support the use of cyst volume as a standalone diagnostic marker. Baker's cyst volume should therefore be interpreted as an adjunctive imaging feature together with direct meniscal findings, medial meniscus extrusion, patient age, osteoarthritis severity, and other structural MRI findings.

MME demonstrated an independent but relatively modest association with cyst volume in the adjusted model. This finding likely reflects its strong interrelationship with MMPRT and osteoarthritic severity, as extrusion functions primarily as a structural marker of meniscal insufficiency rather than an isolated primary pathology. When upstream structural variables are included in the model, the independent contribution of extrusion persists but remains smaller than that of MMPRT and osteoarthritis severity.

The association between PTS and Baker's cyst volume should be interpreted cautiously. PTS was not significantly correlated with cyst volume in the univariate analysis and became significant only after multivariable adjustment. Although increased PTS has been associated with altered sagittal-plane loading and meniscal injury,[13,17] no previous study has directly demonstrated a relationship between PTS and Baker's cyst volume. The present finding may reflect the combined influence of meniscal and degenerative variables included in the model rather than a direct effect of PTS on cyst enlargement. Therefore, this association should be considered preliminary and hypothesis-generating until confirmed in independent cohorts. To our knowledge, this is the first large MRI-based cohort to demonstrate an independent association between PTS and Baker's cyst volume.

Although ACL rupture was relatively common in this cohort, it did not independently influence cyst volume after adjustment and was not retained as an independent predictor in the multivariable model. Prior imaging studies indicate that ACL injuries often produce acute effusion but do not typically generate the chronic synovial dynamics characteristic of degenerative cyst formation.[18,19] The relatively high ACL prevalence likely reflects the tertiary referral setting and the coexistence of chronic instability with degenerative meniscal pathology.

The coexistence of ACL rupture and MMPRT observed in our cohort (33.1%) is consistent with previous reports describing combined cruciate and posterior meniscal pathology in knees with chronic instability and degenerative overload. Recent studies have demonstrated that complex meniscal pathology frequently coexists with ACL insufficiency, reflecting shared biomechanical stress rather than a direct causal relationship.[20,21]

Radiographic osteoarthritis severity was one of the strongest independent predictors of cyst volume, with grade III–IV knees demonstrating significantly larger cysts. This aligns with prior imaging studies linking advanced OA with increased synovitis, effusion, and periarticular bursal changes.[4,22] Our findings extend this association by demonstrating that OA severity modulates not only cyst presence but also cyst magnitude, supporting the concept that Baker's cysts reflect global joint burden rather than isolated posterior fluid accumulation.

The model explained 17.8% of the variance in Baker's cyst volume, indicating that a substantial proportion of volumetric variability remained unexplained. This finding is consistent with the multifactorial nature of Baker's cyst enlargement and suggests that structural variables alone do not provide a comprehensive explanation.[23–25] Potential unmeasured contributors include synovitis severity, joint effusion volume, cartilage lesion morphology and distribution, coronal limb alignment, capsular compliance, communication-channel anatomy, inflammatory activity, and dynamic loading conditions. Therefore, the identified associations should be interpreted as part of a broader mechanical and inflammatory framework rather than as a complete explanatory model of cyst enlargement.

Collectively, these findings indicate that Baker's cyst enlargement reflects the combined effects of meniscal integrity, tibial morphology, and degenerative severity rather than effusion alone. Cyst volume may therefore serve as a structural indicator of cumulative biomechanical overload and inflammatory activity within the medial compartment.

This study benefits from a large sample size, standardized MRI-based measurements, and high inter- and intra-observer reliability. Integration of MMPRT, MME, PTS, and radiographic OA within a unified multivariable framework provides a comprehensive evaluation not previously reported.

This study has several limitations. First, its retrospective cross-sectional design precludes assessment of temporal relationships and causal inferences between structural abnormalities and Baker's cyst enlargement. Second, standardized MRI-based grading of synovitis and joint effusion was not available. Because both inflammatory activity and intra-articular fluid burden are closely related to Baker's cyst formation and enlargement, their omission may account for part of the unexplained variability in cyst volume. Consistent with this, the multivariable model explained only 17.8% of the variance, indicating that other relevant determinants—including cartilage morphology, coronal limb alignment, capsular and communication-channel anatomy, inflammatory factors, and dynamic loading conditions—were not captured. Third, the study was conducted at a single tertiary orthopaedic referral center, where patients with more advanced degenerative, meniscal, and ligamentous pathology may be overrepresented. Therefore, the observed associations, effect estimates, and

identified ROC threshold may not be fully generalizable to community-based populations, less symptomatic patients, or other clinical settings. Finally, only knees with MRI-confirmed Baker's cysts were included. Accordingly, the present findings apply to volumetric variation among cyst-positive knees and should not be extrapolated to predictors of cyst occurrence.

Conclusion

In this large MRI-based cohort, Baker's cyst volume was independently associated with medial meniscus posterior root tears, posterior tibial slope, medial meniscus extrusion, and radiographic osteoarthritis severity. These findings suggest that cyst enlargement reflects the combined mechanical and degenerative burden within the knee rather than an isolated fluid collection. However, because cyst volume showed only modest discriminative performance for MMPRT, it should not be used as a standalone diagnostic marker. Instead, a large Baker's cyst should prompt careful assessment of the posterior medial meniscal root and other accompanying degenerative structural findings on routine MRI. The observed association with PTS should be regarded as preliminary and requires confirmation in independent cohorts.

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Ethical considerations

This retrospective observational study was conducted at the Department of Orthopaedics and Traumatology, Aksaray University Training and Research Hospital. The study protocol was approved by the Institutional Ethics Committee of Aksaray University (Protocol: SAGETİK148, Approval Number: 2025/004, Date: January 16, 2025). The requirement for informed consent was waived due to the retrospective nature of the study.

Consent to participate

The requirement for informed consent was waived by the Institutional Ethics Committee due to the retrospective design.

Authors contributions

- Çağlar Tuna ISSI: conception, data curation, writing original draft.
- Muhammed Furkan DARILMAZ: methodology, statistical analysis, writing-review&editing.
- Mustafa BULUT: Data curation, data interpretation, statistical analysis.
- Hakan YOLAÇAN: writing-review&editing, validation.
- Serkan GÜLER: supervision, project administration.

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Declaration of conflicting interests

The authors declare that they have no conflict of interests.

Data Availability Statement

The datasets analyzed during the current study are available from the corresponding author upon reasonable request. All data are anonymized and stored securely in accordance with institutional and ethical regulations.

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Appendix

List of abbreviations

ACL	Anterior cruciate ligament
AP	Anteroposterior
AUC	Area under the curve
BML	Bone marrow lesion
BMI	Body mass index
ICC	Intraclass correlation coefficient
KL	Kellgren–Lawrence
LCL	Lateral collateral ligament
MCL	Medial collateral ligament
MME	Medial meniscus extrusion
MMPRT	Medial meniscus posterior root tear
MRI	Magnetic resonance imaging
OA	Osteoarthritis
OAI	Osteoarthritis Initiative
PACS	Picture archiving and communication system
PD	Proton density
PCL	Posterior cruciate ligament
PTS	Posterior tibial slope
ROC	Receiver operating characteristic
TKA	Total knee arthroplasty.