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Arthroscopic Repair of Meniscal Medial Root Tears: The Necessity of Concomitant Realignment Osteotomy

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Learning Point of the Article:

When varus malalignment is ≥5°, successful treatment of posterior medial meniscal root tears requires concomitant high tibial osteotomy along with arthroscopic repair to reduce failure rates and prevent accelerated osteoarthritis progression.

Abstract

Introduction: Posterior medial meniscal root tears (PMMRTs) are biomechanically similar to meniscectomy and often occur in middle-aged women with low-energy trauma. The literature reports consistently high failure rates, meniscal extrusion, and early progression of osteoarthritis following isolated arthroscopic repair in varus-malaligned knees, while isolated arthroscopic repair is reported to have good outcomes in well-aligned knees. The need for concomitant high tibial osteotomy (HTO) to protect root repair in varus knees is an ongoing controversial topic with emerging high-quality evidence.

Materials and Methods: The PubMed/MEDLINE, Embase, Cochrane Library, and Scopus databases were searched from January 2019 to June 2026 for articles to be included in the narrative review, with additional landmark pre-2019 articles included. The searched terms used were: Medical Subject Headings: "Meniscal root tear" AND "high tibial osteotomy" AND "meniscal extrusion" AND "varus malalignment" AND "posterior medial meniscus" AND "knee osteoarthritis". Original articles, systematic reviews, meta-analyses, and consensus statements were included, but preprints, opinion pieces, and predatory journal sources were not.

Results: PMMRTs accounted for 2.2–9.8% of all knee magnetic resonance imaging (MRI) examinations, and approximately 90% occurred in the posterior horn of the medial meniscus, with a majority of these occurring in overweight women aged 50–60 years. Hoop stress was eliminated with detachment of the roots, and the resulting tibiofemoral contact pressure was comparable to that of total meniscectomy. Isolated repair was associated with an 88.5% rate of MRI failure and a 2.37-fold increased risk of progression of knee osteoarthritis in varus-aligned knees compared to neutral alignment knees. HTO combined with meniscal root repair (HTO-MRR) resulted in significantly improved Hospital for Special Surgery and International Knee Documentation Committee scores compared with HTO alone (n = 725). HTO-MRR has been found to heal between 13% and 93%, whereas isolated repair was 0–50%. A criterion of ≥5° of correctable varus was the most commonly reported one for concomitant realignment.

Conclusion: Concomitant HTO with arthroscopic root repair in varus (≥5°) patients, especially those <65 years, with Kellgren–Lawrence ≤2, is the most suitable joint preserving option. Long-term randomized controlled trials or registry studies are required to establish the upper limits of benefit and to establish subgroups that might benefit from isolated repair with centralization augmentation.

Keywords: Meniscal root tear, high tibial osteotomy, meniscal extrusion, varus malalignment, posterior medial meniscus, knee osteoarthritis.

Author's Photo Gallery

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Introduction

Posterior medial meniscal root tears (PMMRTs) are tears or avulsions of the meniscal root attachment that occur within 9 mm of the PMMRT [1]. They are now known to play an important role and are a major cause of fast joint changes in the knee. The incidence in patients undergoing magnetic resonance imaging (MRI) of the knee is 2.2–9.8%, and epidemiological series do confirm that there is a marked demographic bias for middle-aged, overweight females after a low-energy trauma. An analysis of 96 patients with degenerative meniscal root tears found a mean age of 56.6 years, a 72% female preponderance, and a mean body mass index (BMI) of 28.9 kg/m2. Because of the distribution of compressive and tensile forces, the posterior horn of the medial meniscus experiences about 90% of all root pathology [2].

The impacts of a PMMRT are far-reaching. The loss of the posterior root attachment results in the entire medial meniscus being lost from its capacity to generate hoop stress and increases the contact pressures between the tibia and the femur to levels that are statistically similar to total meniscectomy [3]. This leads to meniscal extrusion (displacement ≥3 mm beyond the medial tibial plateau margin on non-weight-bearing MRI), which causes peak contact stresses and sets in motion an accelerating cycle of chondral degeneration [4]. If left untreated, the majority of patients with PMMRTs will develop radiographic osteoarthritis (OA) and partial meniscectomy for root tears will result in the conversion to total knee arthroplasty (TKA) in more than 70% of patients at 10-year follow-up [5].

In most appropriate candidates, the preferred surgical approach is arthroscopic root repair, which is most frequently transtibial pullout (TPO) repair. At more than 60-month follow-up, significantly fewer patients who underwent repair had OA progression and fewer needed a TKA, compared with those who had meniscectomy (66% had OA progression in meniscectomy patients vs. 22% in repaired patients) [6]. However, there is a major debate regarding the effect of the alignment of the coronal plane on repair success. An increase in varus malalignment by about 5%/degree of varus leads to an increase in loading on the medial compartment, and finite-element modeling of the biomechanics has demonstrated that varus increases contact pressures on the repair construct [7]. In a cohort study in 2026, a varus knee (≥5°) treated with isolated PMMRT had an 88.5% MRI confirmed failure rate compared to 24.4% in knees that were normally aligned, giving a 2.37-fold increased odds of progression of OA [8].

There is, however, a great deal of controversy over this. Retrospective studies have suggested that high tibial osteotomy (HTO) without concurrent root repair will allow spontaneous healing in up to 50% of the untreated roots, via compartmental offloading [9,10]. In contrast, a 2025 systematic review of 506 knees and a 2025 meta-analysis of 725 individuals show objective benefits of combined HTO plus meniscal root repair (HTO-MRR) over HTO alone with respect to healing rate, joint space width, and patient-reported outcome measures (PROMs) [11, 12]. One major knowledge gap is the lack of a published randomized controlled trial (RCT) that prospectively compares isolated repair with HTO alone and combined HTO-MRR with standardized, long-term outcome reporting for varus-aligned patients with PMMRT [11,12].

The purpose of this narrative review is to summarize the current evidence regarding the anatomy, biomechanics, diagnosis, and clinical considerations for the management of PMMRT, to determine evidence-based thresholds for concomitant osteotomy, and to present a clinical decision algorithm that practicing surgeons may use.

Material and Methods

A narrative literature review was conducted in the databases, PubMed/MEDLINE, Embase, Cochrane Library and the Scopus database, as well as in the date range. The major search period was from January 2019 to June 2026. Anatomical and biomechanical foundations, classification systems and landmark articles before 2019 were added when relevant.

Search strings

Boolean operators (medical subject headings and free-text keywords) used to search: (“meniscal root tear” OR “posterior medial meniscus root tear” OR “medial meniscus posterior root”) AND (“high tibial osteotomy” OR “realignment osteotomy” OR “varus malalignment”) AND (“outcomes” OR “repair” OR “extrusion” OR “osteoarthritis”). Secondary searches were conducted for the following: “Transtibial pullout repair,” “suture anchor meniscal root,” “meniscal extrusion MRI,” “LaPrade classification meniscal root,” “meniscal centralization suture,” “MMPRT failure varus,” “HTO meniscal repair second look arthroscopy,” “meniscal allograft transplantation varus,” and “knee OA root tear long term.

Inclusion criteria

Peer-reviewed original articles, systematic reviews, meta-analyses, consensus guidelines and clinical trial reports published in PubMed-indexed journals were included. To provide the context for the translation arguments, only large-animal and cadaveric biomechanical studies were also included. Only English-language publications were considered.

Exclusion criteria

Preprints, conference abstracts (no peer-reviewed full text), opinion pieces (without accompanying data), predatory journal sources, and case reports (fewer than five patients for the clinical synthesis) were excluded from the study.

Scale for the assessment of narrative review articles (SANRA) adherence

This review was written in adherence to the SANRA [13]. Throughout the six SANRA domains, namely importance justification, concrete aims, literature search description, referencing, scientific reasoning, and appropriate data presentation, are covered. Evidence was differentiated by study design and evidence by level at the point of citation. RCTs, prospective cohorts, registry analyses, meta-analyses and consensus statements published in the years 2019–2026 were given the highest weight; biomechanical studies support the translational arguments only.

Result

Anatomy and biomechanics of the PMMRT

The posterior root of the medial meniscus attaches to the tibial eminence about 9.6 mm posterior to the attachment of the anterior cruciate ligament and directly anterior to the posterior cruciate ligament (PCL) tibial footprint, with the size of its footprint being about 30 mm2, on average [14]. Root radially oriented tie fibers interdigitate mechanically with circumferential (hoop) stresses within the meniscal body and convert an axial compressive load applied to the tibia and femur into hoop stresses. This hoop stress mechanism redistributes load over the tibial plateau and protects the articular cartilage from focally high contact pressures. The meniscal body is also supported by the meniscotibial ligament (MTL), and there is emerging evidence that an insufficiency of the MTL can precede complete root avulsion and lead to an extrusion and overload of the root process [4,15].

A PMMRT completely removed this hoop stress mechanism. In the landmark cadaveric study by Allaire et al., contact pressure in the medial compartment was shown to increase to levels statistically similar to those observed after total meniscectomy when the roots were severed [3]. Contact pressure peaks at 30° and 60° of knee flexion; repair of the roots does not restore native mechanics completely [16]. Meniscal extrusion, a direct radiographic sign of hoop stress failure, occurs in approximately 78–81% of patients with PMMRTs and is an independent risk factor for the prevalence of knee OA (3.86-fold increase) [4,17].

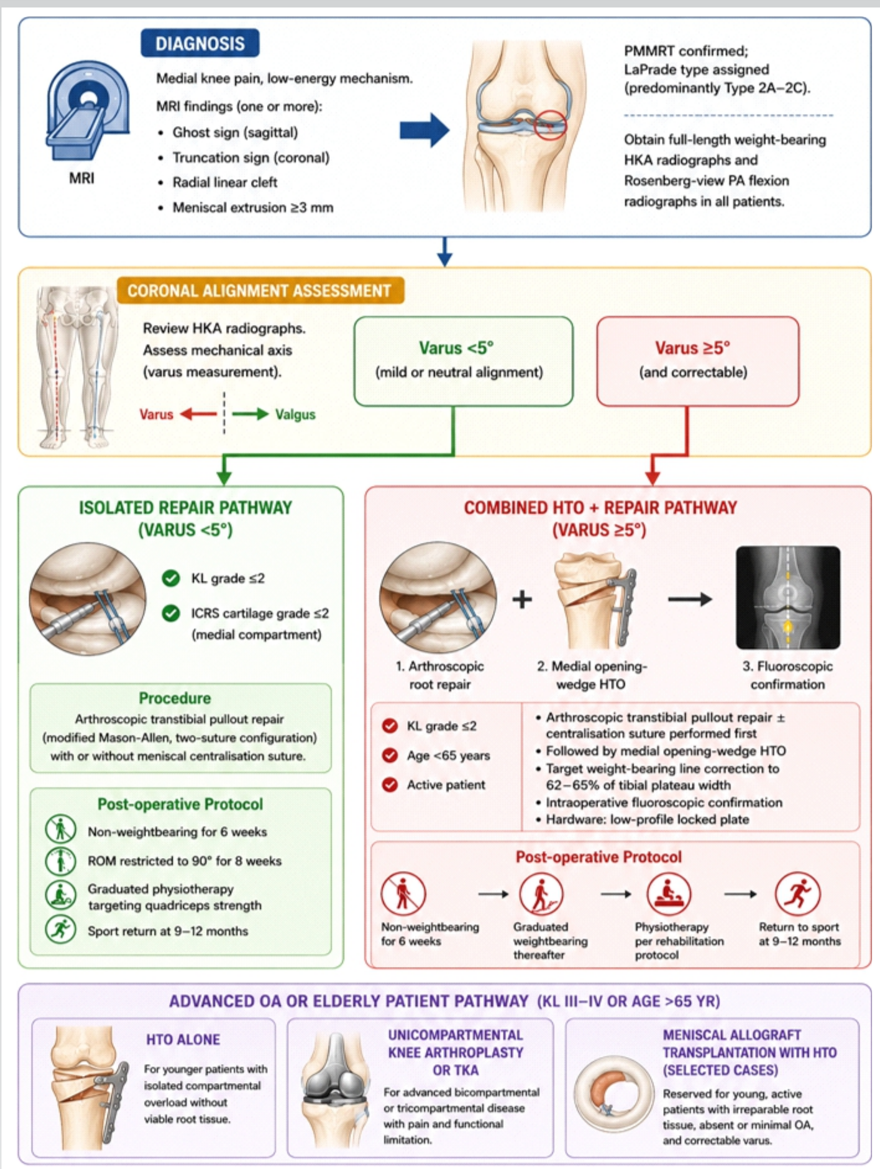

Figure 1: Clinical decision algorithm for arthroscopic repair of posterior medial meniscal root tear with or without concomitant high tibial osteotomy.

Epidemiology and demographical data, LaPrade classification

The PMMRTs are 2.2–9.8% of the total number of MRIs performed on the knee. In a study of 96 patients that occurred in 2025, 72% were female, the mean age was 56.6 years, the mean BMI was 28.9 kg/m2, and 92% of the localization was at the posterior horn of the medial meniscus. The most common mechanism is low-energy trauma, such as deep knee flexion or squatting, on a degeneratively compromised root attachment. Up to 20% of cases have a subchondral insufficiency fracture of the medial tibial plateau that is significantly associated with tear gap width and grade. In 15–60% of surgical series, associated varus malalignment is the most common and controllable risk factor for repair failure [2].

Root tears can be classified into five types according to the LaPrade classification: Type 1 (partial stable, 7%), Type 2 (complete radial, 67.6% – subdivided into 2A 0–3 mm, 2B 3–6 mm and 2C 6–9 mm from the enthesis), Type 3 (bucket-handle with root detachment, 5.6%), Type 4 (complex oblique, 9.9%), and Type 5 (bony avulsion, 9.9%) [1]. Surgical targets are the canonical type 2A–2C tears. The clinical signs are tenderness at the joint line, pain over the inner knee, and walking on the ball of the foot [18].

Diagnosis

MRI is the diagnostic gold standard, and the sensitivity of MRI for complete tears is 77–88%, and the specificity is 90–95% using 3-Tesla imaging. The ghost sign (absent meniscal signal on sagittal images at the PCL level), the truncation sign (abrupt termination of the posterior horn on coronal sequences), a radial linear cleft or fluid gap at the root attachment, and meniscal extrusion ≥3 mm on coronal T2-weighted images are all pathognomonic signs [19,20]. Another study that used arthroscopy to assess the findings in 2025 confirmed that the most reproducible finding was the ghost sign (in this case, with the cleft sign also adding specificity) [20]. Often occurs along with subchondral bone marrow edema. The key diagnostic signs to diagnose PMMRT are presented in Table 1.

Additional imaging is required for surgery. Posteroanterior radiographs, taken in 45° flexion (Rosenberg view), are used to measure the joint space width and the Kellgren–Lawrence (KL) grade. Weight-bearing hip–knee–ankle (HKA) alignment radiographs are taken to measure mechanical axis deviation and direct how much correction is needed for osteotomy. Concomitant HTO is technically challenging and successful with corrections of >5° varus, and the threshold for concomitant HTO is correctable varus ≥5° [7,21].

Table 1: Key MRI diagnostic signs in posterior medial meniscal root tear

MRI sign	Sequence/Plane	Finding	Sensitivity/ Specificity (%)	Clinical significance
Ghost sign	Sagittal PD or T2 fat-sat	Absent meniscal tissue at the level of the PCL	~77–88/90–95	Most reproducible sign: complete root avulsion
Truncation sign	Coronal T2 fat-sat	Abrupt oblique termination of the posterior horn	~73/87	Indicates the radial component of the root tear
Radial linear cleft	Coronal or axial T2	Fluid-filled gap at root attachment	~66/90	Confirms root disruption
Meniscal extrusion ≥3 mm	Coronal T2 fat-sat	Displacement beyond the medial tibial plateau edge	High for complete tear	Predicts hoop stress failure; OA risk marker
Subchondral bone edema	Coronal/sagittal STIR	MTP or MFC high signal	Variable	Associated with SIF; severity correlates with tear gap
Cleft sign	Coronal T2	Fluid at the root–tibial interface	~69/89	Supplementary sign with ghost sign for specificity

PD: Proton density, PCL: Posterior cruciate ligament, MTP: Medial tibial plateau, MFC: Medial femoral condyle, STIR: Short tau inversion recovery, SIF: Subchondral insufficiency fracture, OA: Osteoarthritis

Surgical techniques

The current gold standard is TPO repair, in which the suture is passed through a posteromedial portal in the torn root and then pulled through a transtibial tunnel that is created from the anteromedial tibia to the anatomic root footprint. A cortical button or tie-over post is used to secure sutures. Two-suture and modified Mason–Allen sutures have been shown to offer better load-to-failure properties than single simple sutures [22,23]. Tunnel placement is highly critical, and placement deviations of only 5 mm from the natural footprint make the repair biomechanically similar to an unrepaired root [4].

Suture anchor repair uses knotless adjustable suture anchors to attach to the posterior root attachment through the posterior working portal. A biomechanical cadaveric study was performed in 2025, which showed that suture anchor repair had significantly lower absolute and relative meniscal extrusion after 500 and 1000 loading cycles compared to transtibial fixation ($P = 0.012$ and $P = 0.001$, respectively) and lower mean medial compartment contact pressures after 1000 cycles ($P = 0.028$). The benefits are said to be due to the direct anchorage at the root footprint and decreased cyclic suture-tunnel laxity [24].

All inside repair (e.g., a FasT-Fix suture passer) does not involve bone tunneling but offers less primary fixation strength: 87% survival at 5 years in 43 patients with the modified Mason–Allen configuration [25].

The extruded meniscal body is reattached to the periphery of the tibial plateau with all-inside suture anchors placed posteromedially, known as the meniscal centralization suture technique [4]. A 2025 RCT found that extrusion increased from baseline in 96.2% of all cases (centralized and non-centralized), despite the over 50% reduction in the increase of extrusion at 6 months [26].

Concomitant HTO is performed as a single-stage procedure: Arthroscopic

Table 2: Summary of pivotal studies on posterior medial meniscal root tear repair and/or high tibial osteotomy								
Author (Year)	**Design**	**n**	**Intervention**	**Comparator**	**Primary outcome**	**Follow-Up**	**Key Finding**	**References**
Chung *et al.* (2021)	Retrospective cohort	126 pts	PMMRT transtibial pullout repair	Baseline	Clinical failure rate, predictive factors	Min 5 years (mean 84 months)	Pre-operative varus and post-operative extrusion >0.7 mm are dominant failure predictors; varus is the strongest independent risk factor	[29]
Ridley *et al* . (2022)	Retrospective cohort	82 pts	Isolated root repair	Stratified by alignment	IKDC, Lysholm, KOOS	Min 2 years	Varus alignment is significantly associated with inferior IKDC and higher OA progression compared to neutral alignment	[31]
Eseonu *et al* . (2022)	Systematic review	13 studies	Root repair versus debridement versus non-operative	Each other	IKDC, Lysholm, OA progression	Variable	Repair produces superior outcomes; varus baseline severity predicts poorer functional results	[37]
Tollefson *et al* . (2025)	RCT	26 pts	Transtibial pullout repair+centralization	Repair alone	Medial meniscal extrusion (MRI, 6 months)	6 months	Extrusion increased in 96.2% regardless; centralization reduced the extrusion increase by >50%; varus patients remain at high risk	[26]
Vosoughi *et al* . (2025)	Systematic review	506 knees (6 studies)	HTO+MMPRT repair	HTO alone	Meniscal healing rate, cartilage score	Variable (mean 24+ months)	Healing rate 12.5–40% higher in combined group; cartilage outcomes superior in 3/6 studies	[12]
Ade-Conde *et al* . (2025)	Systematic review and meta-analysis	725 pts (13 studies)	HTO+MMPRT repair	HTO alone	IKDC, HSS, Lysholm, healing rate	Mean 25 months	HTO-MRR significantly superior for HSS (SMD 0.59; $P<0.01$) and IKDC (SMD 0.31; $P=0.04$); weighted mean healing 33%	[11]
Dzidzishvili *et al.* (2026)	Retrospective cohort	117 pts	Isolated PMMRT repair	Stratified ≥5° versus <5° varus	OA progression, repair failure (MRI), TKA conversion	Min 2 years	88.5% MRI failure rate in varus versus 24.4%; 2.37× higher OA progression odds; TKA 15.6% versus 2.4%	[8]
Tokumoto *et al* . (2025)	Retrospective case series	37 pts	Meniscal centralization+pullout repair+OWHTO	Pre-operative baseline	KOOS, IKDC, joint space width, healing	Mean 45.7 months	Complete healing 80.6%; JSW improved (2.7→2.9 mm; $P=0.046$); MCID achieved in 92.9% (IKDC); extrusion improved in 83.3%	[38]
Choi *et al* . (2023)	Retrospective cohort	52 pts	MMPRT repair during OWHTO	HTO alone	Second-look healing rate, cartilage ICRS score	Min 1 year (second-look)	Concurrent repair improved root healing rate and cartilage regeneration in the medial compartment.	[39]
Lee *et al* . (2018)	Retrospective cohort	52 pts	Root repair+OWHTO	Baseline	Lysholm, IKDC, Outerbridge grade	Min 5 years	Significant improvement in all clinical scores; healing rate 64.7% at second-look; no progression in cartilage grade	[40]
PMMRT: Posterior medial meniscal root tear, OWHTO: Open-wedge high tibial osteotomy, MRR: Meniscal root repair, HTO: High tibial osteotomy, IKDC: International Knee Documentation Committee, HSS: Hospital for Special Surgery, KOOS: Knee Injury and Osteoarthritis Outcome Score, RCT: Randomized controlled trial, MRI: Magnetic resonance imaging, MCID: Minimal clinically important difference, OA: Osteoarthritis, TKA: Total knee arthroplasty, JSW: Joint space width, SMD: Standardized mean difference								

root repair first, followed by medial opening-wedge osteotomy aimed to achieve a 62–65% weight-bearing line of the tibial plateau, which is the maximum amount of offloading achievable for the medial compartment [12].

Why malalignment matters

Perfect root repair is not enough to correct the normal mechanics of the medial compartment if varus malalignment is present. A biomechanical analysis using finite elements in varus knee alignment showed that repair achieved higher peak contact pressure than varus knee alignment, suggesting that the repaired construct is still mechanically overloaded despite anatomic reconstruction. Varus is also associated with greater forces on the repair construct peripherally, which explains the higher failure rates in the clinic [7,27,28].

The presence of persistent post-operative meniscal extrusion is independently associated with clinical failure and TKA conversion. Although 98% of patients healed in the roots, Krych et al. reported a mean increase in extrusion from 1.9 to 2.6 mm at 6-month MRI following transtibial repair [4], and the 2025 RCT showed extrusion increased in 96.2% of patients at 6 months [26]. Chung et al. found that a varus alignment at the time of surgery and an extrusion at the time of surgery >0.7 mm were the greatest independent risk factors for clinical failure and eventual conversion to TKA at long-term follow-up [29].

Evidence for isolated repair versus repair + HTO

The results strongly support combined HTO-MRR over isolated repair in varus-aligned knees. Table 2 summarizes some of the key studies on the subject. The best comparative study published is of 117 patients at minimum 2-year follow-up and divided into varus (±5° and <5° groups) (American Journal of Sports Medicine, PMID 42099183). The rates of OA progression were 32.5% and 53.3% in normally aligned and varus-aligned knees, respectively ($P = 0.02$). The MRI confirmed repair failure rate was 24.4% in normally aligned knees and 88.5% in varus-aligned knees ($P < 0.001$). Multivariable logistic regression ranged from a 1.13 to a 4.99

odds ratio for progression of OA with varus alignment (2.37, 95% confidence interval [CI] 1.13–4.99). Conversion to TKA was 2.4% (neutral) versus 15.6% (varus), P = 0.005 [8].

The 2025 systematic review of 506 knees (six comparative studies; HTO vs. HTO + MRR) showed that the healing rate of the whole meniscus was 12.5–40% higher in the combined group than in the HTO group alone (0–15% healing) [12]. In three out of six studies, cartilage outcomes were better. The 2025 meta-analysis of 725 patients (13 studies, 67% female, mean age 54 years, mean follow-up 25 months) confirmed statistically significant superiority of HTO-MRR over HTO alone for both Hospital for Special Surgery score (standardized mean difference [SMD] 0.59; 95% CI 0.34–0.84; P < 0.01) and International Knee Documentation Committee score (SMD 0.31; 95% CI 0.01–0.61; P = 0.04). Studies reported 13–93% healing of the meniscus following the HTO-MRR (weighted mean 33%) [11].

When root repair is not performed at the same time as HTO, studies have reported that untreated PMMRTs heal spontaneously in 40–50% of cases at second-look arthroscopy, which is thought to occur due to reduced contact pressure increasing vascularity and the biological environment [9, 10]. Objective outcomes such as healing rate and cartilage score, however, have always been favorable for the combined treatment; moreover, younger and active patients show remarkably good functional outcomes without any surgical cartilage repair procedure (2025 meta-analysis). The key difference in mechanism is that anatomic hoop stress capacity is not restored after a root tear, even if it is spontaneously healed with fibrous tissue, which is the reason that HTO has a relative offloading effect only [11].

Activity demand, age, BMI, KL grade and mechanical axis deviation were chosen as the indicators for HTO. The indicators chosen for HTO were mechanical axis deviation, KL grade, BMI, age, and activity demand [30, 31]. A comparative summary of the outcomes is presented in Table 3.

Criteria for concomitant HTO with PMMRT repair

Mechanical axis deviation: ≥5° corrected varus on full-length HKA radiographs is most accepted as the threshold. The medial compartment carries an estimated 5% higher load with the increase of varus deviation, and below 5°, the technical reproducibility of correction is limited, and there is no evidence for benefit. The mechanical axis correction is not exactly toward neutral, but rather slightly toward valgus (weight-bearing line at 62–65% of the tibial plateau width) [7]. The decision threshold for concomitant HTO with PMMRT repair is given in Table 4.

KL grading: Repair is recommended for KL grade ≤2 (mild or no radiographic OA). For Grade III and IV, KL is a relative contraindication for repair as joint cartilage degeneration is too severe to be amenable to meniscal function restoration, and more suited to HTO or TKA. Articular cartilage changes in the Grade III–IV range in the MEDIAL compartment are another relative contraindication [32].

In younger patients (<65 years), the combined approach is best indicated. An elevated BMI (>30 kg/m2) will also decrease the rate of healing, but also increase medial loading, and therefore, patients should be counseled. BMI itself does not preclude the combination procedure [2].

Benefit according to activity demand and timing: Young, active patients with a high Tegner activity score benefit most [11]. Repair within 13 weeks of symptom onset is associated with better outcomes, and longer delays have been associated with greater progression of extrusion and pain after repair [4].

Table 3: Comparative summary: Isolated repair versus HTO alone versus combined HTO+meniscal root repair

Parameter	Isolated PMMRT repair (neutral alignment) (%)	Isolated PMMRT repair (Varus ≥5°)	HTO alone	Combined HTO+MMPRT repair
Indication	Varus <5°, KL ≤2, age <65 year	Not recommended (high failure risk)	KL III–IV or age >65 years; or isolated compartment OA	Varus ≥5°, KL ≤2, age <65 yr, active patient
MRI-confirmed healing	60–75	11.5% (failed=88.5%)	40–50% spontaneous	60–93% at second-look arthroscopy
OA progression at Min 2 years	22–32.5	53.30%	Variable (compartment offloading)	Significantly reduced vs. HTO alone [11, 12]
TKA conversion	2.4–9.8 at 5–10 years	15.60%	15–25% at 5–10 years	Lower than HTO alone in younger patients [12]
PROMs improvement (IKDC, HSS)	Significant	Similar short-term but worse long-term	Significant	Superior to HTO alone (SMD 0.31–0.59) [12]
Meniscal extrusion post-operative	Increases in 96 (mean +1.7 mm)	Likely greater increase	Partial reduction via offloading	Best reduction with centralization suture [23,40]
Surgical morbidity	Low	Low	Intermediate (plate, hardware removal)	Higher (longer anaesthetic, hardware removal in ~10%)
Return to sport	80 by 9–12 months	Low (high failure rate)	60–70% at 12 months	80% in the <60 year group at 9–12 months [12]
Level of evidence	Level III–IV	Level III	Level III	Level III–IV (meta-analysis level III)

HTO: High tibial osteotomy, MMPRT/PMMRT: Posterior medial meniscal root tear, KL: Kellgren–Lawrence grade, PROMs: Patient-reported outcome measures, IKDC: International Knee Documentation Committee, HSS: Hospital for Special Surgery, SMD: Standardized mean difference, OA: Osteoarthritis, TKA: Total knee arthroplasty

Decision algorithm, return to sport timing, long-term OA progression data and future directions

The algorithm for making decisions is presented in the form of a practical evidence-based algorithm in Fig. 1. Briefly: (1)

Table 4: Key surgical decision thresholds for concomitant HTO in PMMRT management			
Variable	**Threshold for concomitant HTO**	**Evidence source**	**Notes**
Mechanical axis deviation (HKA)	≥5° correctable varus	[7, 29]	<5° technically challenging; no clear benefit shown
Kellgren–Lawrence grade	≤2	[32, 35]	KL III–IV: HTO alone or TKA evaluation
ICRS articular cartilage grade	Grade ≤2 in the medial compartment	[32]	Grade III–IV: Relative contraindication to repair
Age	<65 years (relative)	[11, 35]	Older patients: Consider functional demand, bone quality
BMI	Any, counsel re: healing risk	[2, 29]	BMI >30 increases extrusion risk; not an absolute contraindication
Symptom duration	Ideally, <13 weeks to repair	[4]	>13 weeks: Associated with higher postop pain
Activity demand	High Tegner level benefits most from a combined approach	[11]	Low-demand patients may accept HTO alone

HKA: Hip–knee–ankle, HTO: High tibial osteotomy, KL: Kellgren–Lawrence, ICRS: International cartilage repair society, BMI: Body mass index

Confirm PMMRT by MRI (ghost sign, truncation sign, extrusion ≥3 mm); (2) Obtain full-length HKA alignment radiograph and Rosenberg-view radiograph; (3) If varus <5° and KL ≤2, isolated arthroscopic pullout repair, ± centralization suture; (4) If varus ≥5° and KL ≤2 and age <65 years, single-stage HTO + arthroscopic root repair, ± centralization suture; (5) If KL III–IV, defer to HTO alone (non-biological compartmental offloading) or TKA assessment [32,33].

Return to sport and rehabilitation: 6 weeks of strict non-weight bearing, progressive weight bearing at 6 weeks, with 8 weeks of 90° restriction, progressive physiotherapy at 12 weeks, and sport-specific training beginning at 6 months after combined HTO-MRR [25,32]. In series using the combined approach, return to recreational sport is reported in 80% of patients younger than 60 years of age [11]. In 2023, a study was conducted that further supported this direct relationship between post-operative quadriceps strength and reduced meniscal extrusion progression, and suggested physiotherapy intensity as one of the modifiable determinants for this outcome [29].

Long-term OA progression data: The landmark study by Chung et al. into long-term outcomes of the same cohort, at a minimum 10-year follow-up, demonstrated that the biggest independent failure predictors overall were varus alignment and post-operative extrusion, with 5-year Kaplan–Meier survival of 92% after TPO repair in neutrally aligned knees [29,34]. On the other hand, meniscectomy for root tears has a conversion rate to TKA >70% at 10 years, suggesting that repair is always the best option in the right candidates [5].

Advances: The next step in the future is the combination of meniscal allograft transplantation (MAT) with HTO for patients younger than those who have irreparably damaged root tissue [7]. There is no level 1 evidence for the use of scaffold-augmented repair with platelet-rich plasma injection. There is a need for registry-based prospective studies and platform RCTs to compare isolated repair, centralization, HTO-MRR and MAT + HTO [11].

Discussion

The article collates the converging evidence that isolated repair of PMMRT in varus-aligned knees of ≥5° is associated with unacceptably high failure rates and is no longer a standard of care technique in this subgroup. The 2026 American Journal of Sports Medicine cohort with MRI confirmed failure at 88.5% and odds of OA progression 2.37 times higher in varus knees, supports the lack of anatomic accuracy as a mechanical factor, but rather varus as an actual threat to repair integrity [8] (in line with the findings of the finite element modeling, which indicated that varus increased contact pressure at the construct regardless of anatomic accuracy) [7,31].

Compared to previous reviews: Previous reviews (up to 2022) tended to recommend repair for all PMMRTs with KL ≤2, irrespective of alignment. The most recent syntheses, the 2025 systematic review and meta-analysis, showed that HTO-MRR is the objectively best treatment for meniscal healing and PROMs over HTO alone, and that HTO-MRR is the objectively best treatment compared to other interventions and HTO alone in varus-aligned patients [11,12].

There is still conflict on three issues. In the first place, the issue of whether spontaneous root healing after HTO alone is clinically sufficient has not been standardized: Although the healing of untreated roots after HTO has been documented in 40–50% of cases, the nature of healing (fibrous vs. bony) and the biomechanical adequacy are not. PROMs data are conflicting at short-to-mid-term follow-up [9,10]. Second, it is unclear whether centralization sutures are an effective alternative to or an adjunct to HTO in the treatment of moderate varus (3–4°): The 2025 RCT showed the extrusion increase was significantly reduced with centralization sutures compared to the isolated repair of the distal femur, but there was still some post-operative extrusion in almost all patients [26,35]. Third, the ideal valgus overcorrection target continues to be controversial, with suggestions of the medial tibial spine being the goal of a proposed weight-bearing line of 62–65% of tibial plateau width [7].

The amount of literature that is limited is significant. No published RCTs are comparing isolated PMMRT repair with a three-arm design and long-term follow-up with HTO alone and HTO-MRR. Most comparative studies are retrospective, non-randomized, have heterogeneous osteotomy correction, variable suture configurations and inconsistent use of centralization sutures. Follow-up periods are typically <3–4 years, and cohorts of 10 + years are needed for the hard endpoint of conversion to TKA. There is no standardization on MRI-based healing grading, which hinders quantitative synthesis across studies. In multivariate analyses, the accompanying subchondral insufficiency fracture, quality of cartilage, BMI, and timing of surgery are rarely taken into account [35,36,37].

The growing agreement is to obtain HKA films in all patients with a confirmed PMMRT, to treat varus deformity ≥5° concurrently with HTO as part of the surgical plan, to aim for cartilage preservation ages and KL grades, and for standardization of post-operative management, which emphasizes 6-week non-weight-bearing and intensive physiotherapy. Surgeons working in resource-poor areas should be mindful that both techniques require specialized instruments, that both have longer lengths of surgery and that hardware complications (tibial plate prominence, hardware removal) account for 10–15% of secondary procedures in HTO series [25,30,38].

Conclusion

PMMRT tears represent a pivotal challenge in knee preservation, particularly when compounded by varus malalignment. Current evidence underscores the importance of addressing both biomechanical instability and meniscal integrity to optimize outcomes. While isolated repair may suffice in well-aligned knees, the presence of varus deformity necessitates a more comprehensive strategy that integrates alignment correction with root restoration. Although randomized controlled trials remain absent, the consistency of observational data provides a strong rationale for adopting integrated treatment in appropriately selected patients. For younger individuals with early OA, this paradigm offers the most promising avenue to delay disease progression and reduce the likelihood of arthroplasty. Future prospective studies will be essential to validate long-term benefits and refine patient selection criteria, ensuring durable outcomes in this complex clinical scenario.

Clinical Message

1. Isolated arthroscopic repair of posterior medial meniscal root tears in varus-aligned knees (≥5°) has unacceptably high failure rates (up to 88.5%) and accelerates osteoarthritis progression.

2. Concomitant high tibial osteotomy (HTO) with root repair significantly improves meniscal healing, cartilage preservation, and patient-reported outcomes compared to HTO alone or isolated repair.

3. The best candidates for combined HTO-root repair are patients under 65 years with Kellgren–Lawrence grade ≤2 and correctable varus ≥5°, making this the most effective joint-preserving strategy.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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