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Meniscus Radial Tears: Current Concepts on Management and Repair Techniques

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Abstract

Purpose of Review This review provides a historical perspective on the approach to radial tears and collates the currently available evidence on repair techniques, rehabilitation, and outcomes following the treatment of meniscus radial tears.

Recent Findings Recent literature shows that the repair of meniscus radial tears reports improved patient-reported outcome scores with high return to function and activity. However, no single technique nor construct was proven better than the other.

Summary Various methods of repairing radial tears can be employed, with biomechanical research supporting all-inside double vertical sutures, the addition of vertical "rip-stop" mattress sutures, and transtibial pullout augmentation. To ensure proper healing before undergoing physical therapy, it is crucial to abstain from weight-bearing and deep knee flexion for the first 6 weeks after surgery. Despite considerable heterogeneity in surgical techniques and rehabilitation protocols found in the current literature, studies reporting on radial repairs report positive results, with high healing rates and improved patient-reported outcomes.

Keywords Meniscus radial tear · Meniscus repair · Postoperative outcomes

Introduction

The menisci are essential to the homeostasis of the knee joint, due to their key role in increasing tibiofemoral congruency, dynamic load distribution, joint stability, and proprioception [1, 2]. Injuries to the menisci remain one of the most common knee injuries in athletes and the elderly but can occur across all ages, sex, and activity levels [3]. At a reported incidence of 0.61 to 0.70 per 1000 person-years in the general population in the United States, the treatment for these injuries is an important current topic in orthopedic surgery. With surgical intervention on the uprise given the emerging emphasis on meniscal preservation meniscal surgeries cost nearly 4 billion dollars per year [4], and account for 10–20% of all orthopedic surgeries each year [3].

Numerous types of meniscal tears exist, among which radial tears comprise a subtype historically associated with relatively poor prognosis, often leading to early accelerated knee osteoarthritis [5]. Radial tears are unique because they are oriented perpendicular to the meniscal axis and disrupt

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the circumferential collagenous fibers in the peripheral end of the menisci. These fibers act by converting axial loads into tensile strains in the form of hoop stresses [2]. Damage to the circumferential fibers results in significant loss of function, leading to increased contact pressure [6], with prior evidence demonstrating a higher grade of cartilage damage, as well as higher rate and severity of meniscal extrusion in knees with a radial tear relative to other types of tear [7, 8]. Given their impactful consequences, high incidence—reports up to 28% of medial meniscus tears—and technically challenging treatment, radial tears are of particular importance.

Management of meniscal radial tears is complex and has changed drastically during the past decades. A deep understanding of meniscus anatomy, biomechanics, and their function during activities played a key role in the change of conception of present-day interventions. Continuous optimization in diagnostic methods, surgical repair techniques, and rehabilitation protocols resulted in improved short- and long-term outcomes of radial tear management. The objective of this review was to provide a historical perspective on the approach to radial tears and to collate the currently available evidence on repair techniques, rehabilitation, and outcomes following the treatment of meniscus radial tears.

Historic Perspective

There has been a dramatic change in the approach to meniscus tears in the past few decades [6, 9]. The exponential growth in the knowledge base pertaining to meniscus biomechanics, healing, and long-term outcomes [10] has fueled a paradigm shift from Smillie's 1967 "If it is torn, take it out" [11] to the present-day "save the meniscus!" maxim [12].

Radial tears that encompass the avascular white-white zone of the meniscus have been historically considered irreparable, and therefore treated with meniscectomies [13–17]. While patients largely experience short-term symptomatic relief following a meniscectomy [18], an overwhelming number of studies ultimately demonstrated the deleterious effects of meniscal deficiency, whether biomechanically following a radial tear [10] or through what is now extensive long-term data on the degenerative consequences of meniscectomies—particularly of the lateral meniscus [12].

Improved understanding of several aspects pertinent to the menisci has since renewed the interest in extending the indications of meniscal repair to include radial tears, as opposed to only repairing the more amenable peripheric vertical tears. Biomechanically, numerous ex vivo studies demonstrated that large radial tears and root tears significantly decrease contact area and increased contact pressures in the affected compartment, functionally approximating a total meniscectomy [19, 20]. In consonance with the impaired biomechanics observed in cadaveric studies, multiple in vivo motion analysis studies reported that, despite symptomatic relief, partial meniscectomy led to significantly increased knee adduction and flexion moments post-operatively—parameters often associated with varying stages of knee osteoarthritis [21–23]. In terms of biological healing, a recent investigation by Chahla et al. demonstrated multipotent mesenchymal stromal progenitor cells and vascularization in the white-white zone of the meniscus, indicating its better healing potential than previously believed [24]. Additionally, in terms of clinical outcomes, a recent review by Everhart et al. revealed that meniscus repair failure rates in patients older than 40 years are comparable to those of younger patients [25]. This is important, given that radial tears are often of degenerative nature in older patients—particularly of the medial meniscus [5]. Finally, the past couple of decades have observed vastly modernized techniques and devices for meniscal repair, allowing for maximization of the biomechanical and biological aspects of surgical treatment [10, 26].

With all those factors in mind, radial tears extending into the circumferential fibers of the meniscus, especially into the periphery and meniscus-synovial junction, should always be repaired whenever possible, with an aim to restore native biomechanics and potentially prevent rapid degenerative progression.

Types of Common Radial Tears

Radial tears are cleavage tears arising from the central region (white-white) to the periphery (red-red) and can occur in all anteroposterior zones of the medial and lateral meniscus. They can be characterized according to their location within the meniscus, as affecting the anterior horn, body or posterior horn [2]. Whenever a radial tear is located within 1 cm of the meniscal root, it is considered a meniscal root tear [27].

Radial tears can be further divided in partial-thickness or full-thickness tears, which result in different biomechanical consequences. Cadaveric investigations suggest that tears up to 60% of meniscal width have little impact on load distribution function – albeit aforementioned in vivo evidence demonstrated pathological kinetic profile even during simple overground gait [2]. In light of that, partial meniscectomy is still often indicated for smaller partial "white-white" radial lesions. On the other hand, tears of 100% of the meniscal width (full-thickness tears) result in complete loss of meniscal function [28, 29] and can lead to the rapid development of knee osteoarthritis [30].

Regarding etiology, radial tears can be classified as either of traumatic or degenerative nature. Lateral meniscus radial tears are more frequently traumatic and associated with

ACL injuries (33% vs 8% of medial meniscus radial tears) in younger patients [31]. Medial radial and root tears are typically degenerative, and as such, are unfortunately underdiagnosed [27].

Nakata et al. proposed a classification based on the morphology of radial tears. Type A tears were characterized as a radial split that extended to less than 50% of the width of the peripheral rim. Type B tears extended to more than 50%, further divided into the following two subtypes: type B1, a simple radial split tear; and type B2, a flap tear including a radial tear. A complete radial split tear, which extended to the peripheral rim was classified as Type C. Bucket-handle tears including a radial tear component were defined as Type D, most often traumatic and associated with ACL tears [27].

Repair Techniques and Biomechanics

Several repair techniques and suture configurations pertinent to radial tears have been developed and tested (Fig. 1). Repair constructs can differ based on surgical approach (inside-out, all-inside, and outside-in), use of a transtibial pullout augmentation, as well as the number, orientation, and pattern of suture placement. Technique choice must weigh factors such as potential iatrogenic damage to the meniscal tissue, neurovascular risk, technical ease of use, operative time, and cost.

Traditionally, the repair of radial tears was performed using an inside-out approach with horizontal stitches across the tear edges (Fig. 1A) [32]. Advantages including considerably lower cost and the ability to deploy multiple sutures with minimal damage to the meniscus must be reconciled with the need for a posterior incision increasing the risk of neurovascular injury, postoperative pain, increased surgical time, need for an experienced assistant and needlestick injury to the surgical team [33]. More recently, all-inside repairs have gained exponential popularity due to significant improvements in device technology and technique [34]. Albeit more costly, modern all-inside repair is less time-consuming, less technically challenging, and reduces iatrogenic risk to neurovascular structures compared to alternative techniques, without sacrificing biomechanical strength or healing [26, 33, 35].

Specific to radial tears, all-inside repair has gained traction as the preferred technique as consistent evidence of biomechanical superiority has emerged [26]. Beamer et al.

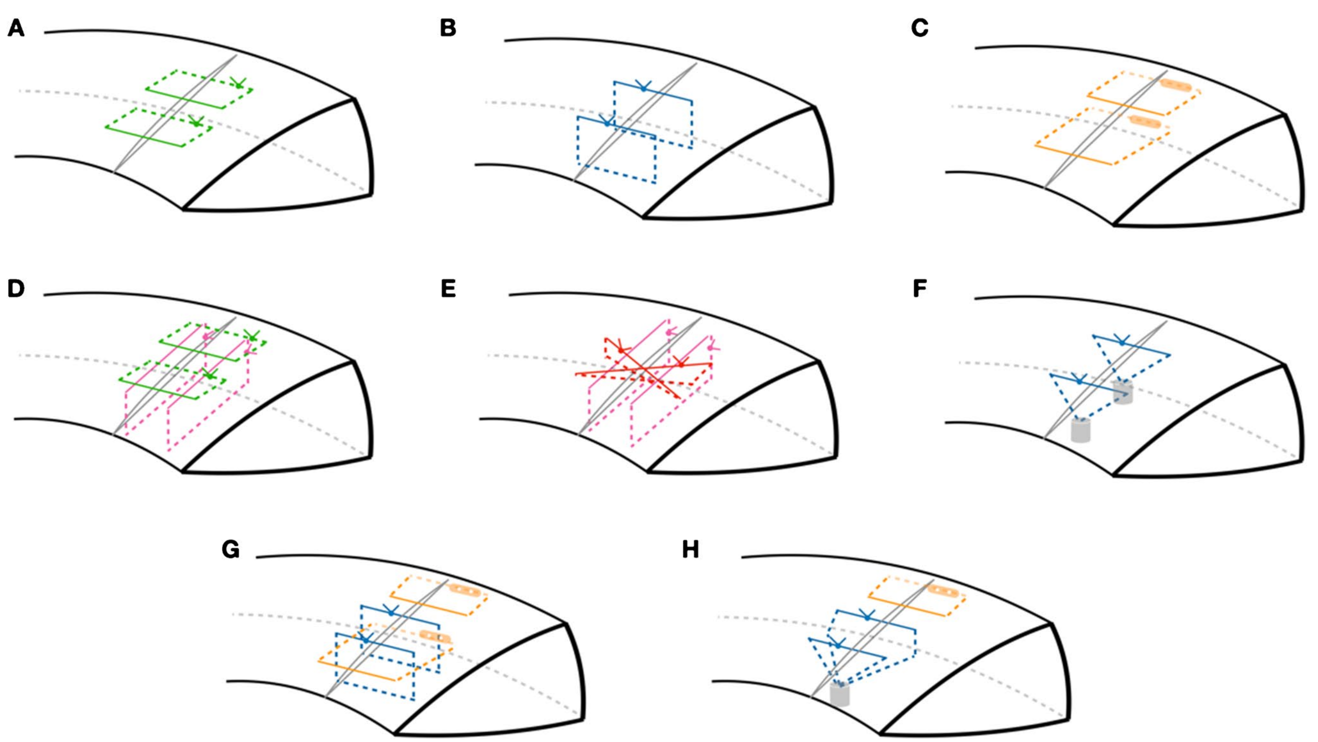

Fig. 1 Schematic representation of key radial repair techniques. **A** Conventional horizontal inside-out repair (green); **B** suture-based all-inside double vertical repair (blue); **C** anchor-based all-inside horizontal repair (orange); **D** "hash-tag" construct, with inside-out horizontal repair reinforced with vertical mattress "rip-stop" sutures (pink); **E** "cross-tag" construct, with suture-based all-inside figure-of-eight configuration (red) reinforced with vertical mattress "rip-stop" sutures; **F** two-tunnel transtibial pullout repair; **G** hybrid suture-based double vertical and anchor-based all-inside horizontal repair (see Fig. 3); **H** hybrid double-vertical transtibial pullout with all-inside horizontal repair (see Fig. 2)

found that vertical all-inside repair (Fig. 1B) of a medial meniscus radial tear resulted in lower displacement, higher load to failure, and greater stiffness relative to conventional horizontal inside-out repair [36]. A later study by Branch et al. also demonstrated higher load to failure and superior construct stiffness of all-inside repair using varying all-inside suture configurations compared to a double horizontal inside-out construct [37]. Similarly, for lateral meniscus radial tears, a systematic review by Alentorn-Geli et al. found significantly higher construct stiffness following all-inside compared to inside-out techniques [38].

When comparing all-inside techniques, a study by Doig et al. reported that radial repairs with a meniscus-based all-inside all-suture construct (Fig. 1B) led to significantly less displacement after cyclic loading, as well as superior stiffness and load to failure when compared to capsule-based all-inside repair with anchors (Fig. 1C) [39]. These findings were reflected in a recent systematic review by Oosten et al., with suture-based configurations largely presenting favorable displacement and strength profiles [26].

In terms of suture configuration, the use of a double vertical repair has consistently shown favorable biomechanical properties [26]. This technique consists of passing two sutures vertically orientated in the borders of the lesion, parallel to the radial tear. The rationale behind a vertically oriented repair consists in positioning sutures transversally to the circumferential fibers of the meniscus. All-inside vertical repair generates higher load to failure and stiffness compared to inside-out horizontal repair [26, 36, 40]. The aforementioned review by Oosten et al. [26] found mixed results from studies examining horizontal and oblique sutures (Fig. 1D), suggesting that it may not be particularly beneficial to implement a crossing pattern during repair, while the authors recommend to otherwise focus on adding “rip-stop” suture reinforcements. Of note, the collated literature points to two main advancements in the modern arsenal of radial repairs are the addition of “rip-stop” sutures and the use of transtibial tunnel pullout [26].

Reinforcing repair constructs with a pair of vertical “rip-stop” mattress sutures (Fig. 1E) can minimize the risk of suture cut-out compared to non-reinforced repairs, and thus enhance the healing potential [26]. These combined repair configurations with vertical mattress include the “hash-tag”, “cross-tag” [41], “rebar” [42], and “tie-grip” [43] repairs. Multiple studies have found consistent superiority of suture configurations including rip-stop reinforcement sutures relative to non-reinforced constructs [37, 41, 44].

A novel transtibial tunnel repair technique (Fig. 1F) has shown favorable biomechanical outcomes regarding resistance to failure load and displacement, as reported by Bhatia et al. [45] and James et al. [46] There is, consonantly, ample evidence to support excellent biomechanical and clinical outcomes observed when using a similar two-tunnel pullout when repairing posterior root tears [47]. As tension is applied to the sutures, their crisscross orientation allows the re-apposition of the torn margins of the meniscus [46]. Transtibial pullout can be employed to augment multiple suture configurations, and performed with either a single tunnel or two tunnels. Recent investigations report reduced median gapping distance at the tear site, higher average load to failure, and less biomechanical variability between repairs when compared to a standard inside-out horizontal mattress [26, 45].

The all-inside double vertical repair and the transtibial two-tunnel technique combined with four horizontal inside-out sutures have shown to be the strongest regarding the load-to-failure, when compared to other 21 techniques within 20 studies in Oosten et al.’s review, including all-inside and inside-out repair with different configurations [26].

Authors’ Preference

Our typical indication for radial repair consists of a complete tear or a high-grade partial tear of over 2/3 of the width of the meniscus, as partial tearing under that threshold has been shown to result in minimal biomechanical changes [28]. Acute traumatic tears should always preferably be repaired, while repair indication in chronic degenerative tears will depend on meniscal tissue quality and accompanying degenerative changes in the joint with joint space under 3 mm, Kellgren-Lawrence grade ≥ III knee osteoarthritis and modified Outerbridge grade ≥ 3 chondral lesions comprising relative contraindications [27]. As mechanical malalignment may present a complicating factor and the postoperative rehabilitation of a radial repair entails a coinciding non-weightbearing period with an osteotomy, we advise considering realignment in knees with over 3° of mechanical varus or when the mechanical load-bearing axis of the limb (Mikulicz line) is beyond the edge of the correspondent tibial spine [48].

All-inside repairs are currently preferred by the senior author, given its favorable biomechanical profile, as well as the obviated need for accessory posterior incisions, and less cumbersome and time-consuming technique.

When repairing medial meniscus radial tears, our technique of choice is a hybrid construct with transtibial pullout of a double vertical all-suture repair with the addition of anchor-based all-inside stitches. The technique is schematically illustrated in Fig. 1H and detailed in Fig. 2. It is our belief that the addition of a more stable fixation on medial meniscus radial repairs better reproduces the native anatomy of the meniscotibial ligaments [2]. On the other hand, in radial tears of the lateral meniscus, given its higher mobility, our preferred technique is a similar combination of suture-based and anchor-based all-inside techniques without transtibial tunnel augmentation (schematically represented in Fig. 1G and

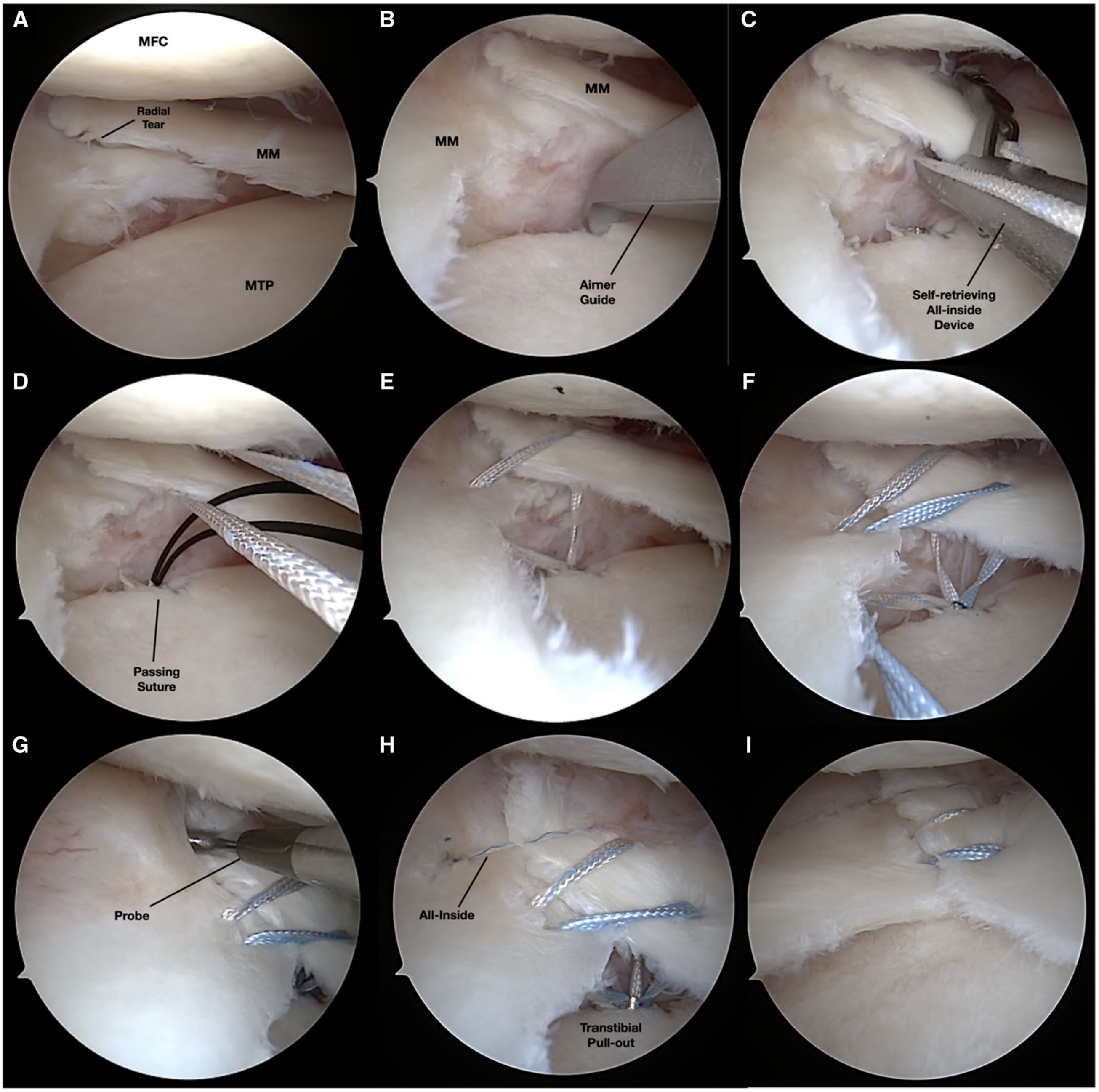

Fig. 2 Authors' preference for medial meniscus radial tears, as represented in Fig. 1H and seen in a left knee arthroscopy following pie-crusting of the superficial medial collateral ligament (**A**). A single transtibial tunnel is created with the aid of a curved aimer guide and metallic cannula (FirstPass Mini, Smith & Nephew) (**B**). An all-inside self-retrieving device (**C**) is used to pass a suture tape in a vertical mattress configuration across the borders of the radial tear (**D**–**E**); and pulled out of the tibial tunnel using a monofilament nitinol passing suture (**D**). These steps are then repeated with a second suture tape, producing a double vertical all-suture repair (**F**). The remaining gap identified with the use of a probe (**G**) is then closed using one anchor-based all-inside horizontal stitch (**H**). The all-inside suture in then tensioned and the knot cut, followed by manual tensioning of the transtibial pullout under arthroscopic visualization (**I**) and final fixation with an anchor (Footprint, Smith & Nephew) is carried out. MFC, medial femoral condyle; MM, medial meniscus; MTP, medial tibial plateau

detailed in Fig. 3). Whenever faced with a lateral meniscus tear far into the posterior horn, it is wise to avoid anchor-based repair, if possible, due to proximity to the popliteal artery.

Rehabilitation

Adequate postoperative rehabilitation in a stepwise fashion is instrumental in the management of meniscal tears. Radial

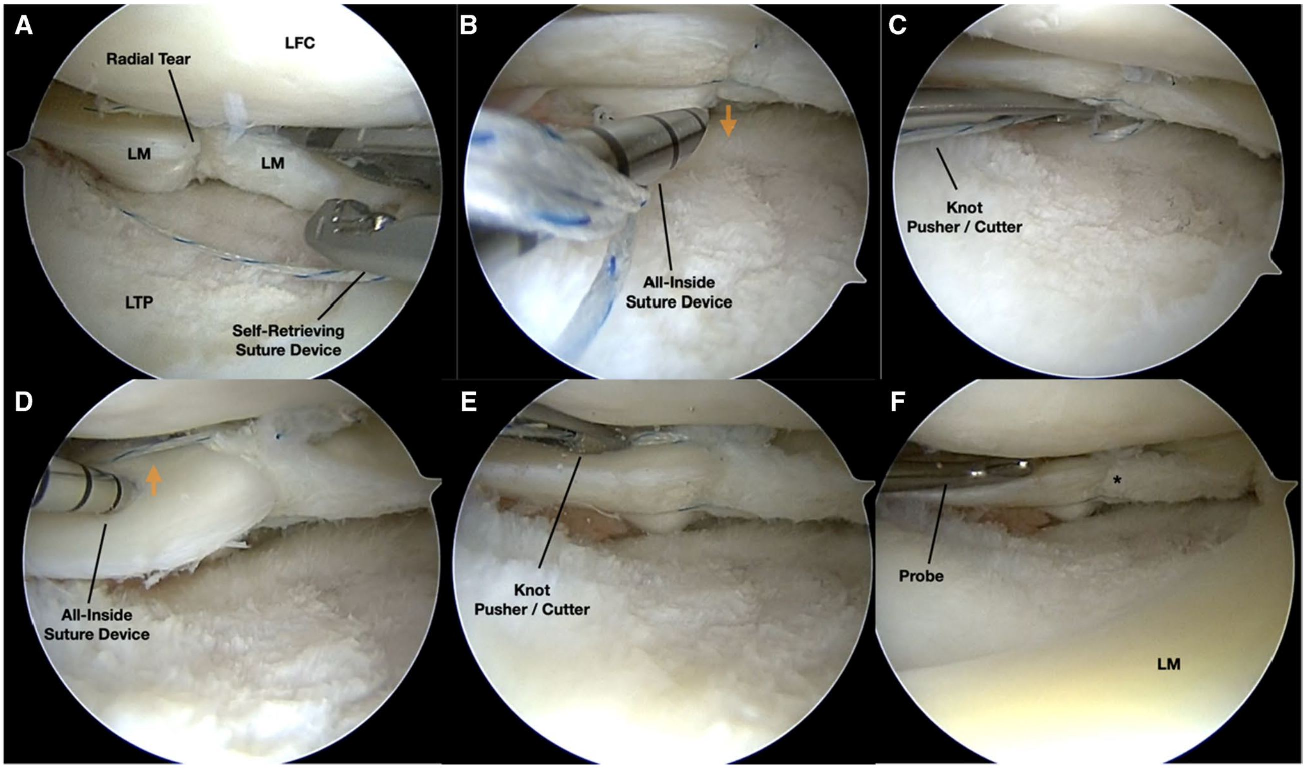

Fig. 3 Authors' preference for lateral meniscus radial tears, as represented in Fig. 1G and seen in a right knee arthroscopy (**A**). A self-retrieving all-inside device (Novostitch, Smith & Nephew) is used to deploy suture-based double vertical side-to-side sutures (**A**). The construct is then completed with the addition of two anchor-based all-inside horizontal sutures, the first attaching the inferior surface of the meniscus to the capsule (**B**, **C**) and the second through the superior aspect of the meniscus into the capsule (**D**, **E**). The final hybrid construct is then visualized with satisfactory apposition of the borders (*) and probed for adequate stability. LFC, lateral femoral condyle; LM, lateral meniscus; LTP, lateral tibial plateau

tears experience distraction forces and increased strain with axial loading [29]. Therefore, the effect of loading and deep flexion inherently increases the chances of repair failure. Simulated early postoperative weight-bearing induced significant and unrecoverable loosening of sutures following a root repair in a study by Steineman et al. [49]. Thereafter, emphasis on non-weightbearing (NWB) status is imperative during the first 6 weeks, during which range of motion (ROM) is also restricted to 90º. Our complete post-operative protocol is detailed in Table 1. Full clearance to return to sports participation typically takes place between 6 and 9 months.

Although there is no consensus for a standardized post-operative protocol, a systematic review by Spang et al. compared 6 protocols of publicly available academic residency programs and orthopedic sports medicine fellowships, the average time with a brace, time to return to sport, time to full range of motion, and time to full weight bearing [49, 50]. Protocols for radial tears were more likely to delay return to full range of motion than general protocols, with 7.3 weeks on average versus 6.7 weeks on average, respectively. Most studies waited until 8 weeks to return to full range of motion, compared to 6 weeks on non-radial meniscus repair. The recommended time in a brace was 1 week longer compared to non-radial meniscus repair. Most radial repair protocols reported 7–8 weeks in a brace. All radial repair protocols reported 7–8 weeks until full weight bearing was allowed, while non-radial repairs ranged from 2 to 12 weeks, with most studies reporting 6 weeks until full weight bearing was allowed. Considering the lack of data supporting safe early weight bearing and full range of motion, most protocols tend to be more conservative with radial tear repairs [50].

Results

In evaluating the healing rates of radial repairs through a second-look arthroscopy, numerous studies have found healing rates ranging from 60 to 86% [51••]. Magnetic resonance imaging assessment studies present a wider range of healing rates, and a mismatch between clinical outcomes and imaging findings, due to the difficulty in distinguishing signal changes with healing, scar tissue, and an unhealed

Table 1 Rehabilitation protocol following radial repair

0–4 weeks
• Non-weightbearing (NWB) in brace in extension with crutches until 6 weeks post-op
• Brace in extension for sleeping 0–2 weeks
• Active/passive ROM 0–90°
• Quadriceps sets, SLR, Heel Slides
• Patellar mobilization
4–6 weeks
• Progress flexion until full ROM is achieved
• Maintain NWB status
6–8 weeks
• Advance to weight-bearing as tolerated (WBAT) at 6 weeks post-op after transitioning to the unloader brace
• Discontinue immobilizer brace when quad strength adequate (typically around 6 weeks)
• Discontinue crutches when gait normalized
• Wall-sits to 90°
8–12 weeks
• WBAT with use of unloader brace until 6 months post-op
• Full ROM
• Progress with closed-chain exercises
• Lunges from 0 to 90°
• Leg-press 0–90°
• Proprioception exercises
• Begin stationary bike
12–16 weeks*:*
• Progress strengthening exercises
• Single leg strengthening
• Begin jogging and progress to running
• Sports-specific exercise

Legend: ROM, range of motion; *SLR*, straight leg raise

tear. Approximately 90% of patients show imaging signs of at least partial healing following radial repairs [52, 53].

Patient-reported outcomes were analyzed in a recent systematic review by Milliron et al., with qualitative improvement in Lysholm, International Knee Documentation Committee (IKDC), Western Ontario and McMaster University Osteoarthritis index (WOMAC), and pain scores across the included studies. No single technique nor construct was proven better than the other [51••]. Although there is a scarcity of data specific to return to sports following radial repair, the improved patient-reported outcomes in conjunction with six studies reporting Tegner Activity Scale scores improving from 1–4 to 4.7–6.7 post-operatively, demonstrate that radial repair is effective in terms of return to function and activity [52, 54–57, 58•]. Although limited by largely low level of evidence studies—with absent clinical trials, and predominantly retrospective designs—the results were consistent across the studies. Publication bias in retrospective studies could also lead to misinterpretation of data since studies with negative results are often not accepted in journals. Another limitation of the current literature is the short period of follow-up (mean 35 months) [51••] Whether the observed healing rates are reflected in the long-term delayed progression of cartilage damage and joint degeneration is yet to be assessed.

Literature is still not clear as to which repair technique is superior to another. More randomized controlled studies with long-term follow-up are needed, comparing clinical outcomes of different techniques of radial meniscus repair. Furthermore, the impact of orthobiologics when added specifically to radial repair constructs is yet to be analyzed with methodologically robust investigations. Several techniques of biologic augmentation have been described, including trephination, fibrin-clot, and marrow-venting procedures, among others [59–61].

Conclusion

There has been an important paradigm shift in the management of radial tears of the menisci in the past decades. A deeper understanding of anatomy and biomechanics was the foundation for the development of novel treatments that focused on meniscus preservation and restoration of native anatomy. Different radial repair techniques can be used, with biomechanical evidence supporting all-inside double vertical sutures, the addition of vertical “rip-stop” mattress sutures, and transtibial pullout augmentation. Avoiding weight-bearing and deep flexion in the first 6 weeks following surgery is key to ensuring adequate healing before physical therapy progression.

Despite considerable heterogeneity in surgical techniques and protocols of rehabilitation across the current literature, the results of meniscal repair in radial tears trend positively, showing high healing rates and improved patient-reported outcomes. Whether the observed healing rates are reflected in the long-term delayed progression of cartilage damage and joint degeneration is yet to be assessed.

Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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• Of importance
•• Of major importance

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