Current Reviews in Musculoskeletal Medicine (2024) 17:313–320
https://doi.org/10.1007/s12178-024-09907-w

REVIEW

Meniscus Tears in Elite Athletes: Treatment Considerations, Clinical Outcomes, and Return to Play

Erick M. Marigi[1,2] · Michael R. Davies[2] · Robert G. Marx[2] · Scott A. Rodeo[2] · Riley J. Williams 3rd[2]

Accepted: 28 May 2024 / Published online: 4 June 2024

Abstract

Purpose of Review Management of meniscal injuries in the elite athlete is a difficult problem secondary to the high demands of athletic competition, the need for a timely return to sport, and the desire to maximize performance over time. The purpose of this review is to provide an up-to-date summary on the current literature and trends regarding the management of meniscus injuries with a special consideration for elite athletes.

Recent Findings Historically, partial meniscectomy has been the primary treatment option for meniscus injuries. However, in recent years there has been an increased emphasis on meniscus preservation due to the increased risk of cartilage degeneration over time. Moreover, while partial meniscectomy still provides a quicker return to sport (RTS), recent literature has demonstrated similar rates of RTS and return to pre-injury levels between partial meniscectomy and meniscus repair. In the setting of symptomatic meniscal deficiency, meniscus allograft transplantation has become an increasingly utilized salvage procedure with promising yet variable outcomes on the ability to withstand elite competition.

Summary Currently, there is no uniform approach to treating meniscal injuries in elite athletes. Therefore, an individualized approach is required with consideration of the meniscus tear type, location, concomitant injuries, athlete expectations, rehabilitation timeline, and desire to prevent or delay knee osteoarthritis. In athletes with anatomically repairable tears, meniscus repair should be performed given the ability to restore native anatomy, provide high rates of RTS, and mitigate long-term chondral damage. However, partial meniscectomy can be indicated for unrepairable tears.

Keywords Meniscus · Meniscus tears · Partial meniscectomy · Meniscus repair · Meniscus allograft transplantation · Elite athlete

Introduction

The medial and lateral menisci are fibrocartilaginous semilunar discs within the knee which transmit load, contribute to the congruity and stability of the tibiofemoral joint, and aid in joint proprioception and lubrication [1]. Comparatively, the medial meniscus maintains more capsular and ligamentous attachments and is thus less mobile, making it more susceptible to injury. However, injury to medial or lateral meniscus can be function-altering, particularly for individuals participating in high level athletic activities [1].

In young athletes, meniscus injuries have been estimated to account for 10–20% of knee injuries in this population [2, 3]. This results in missed game time, prolonged rehabilitation, and the potential for a shortened or altered athletic career. Furthermore, management of meniscus tears in this patient population remains challenging as treatment must account for the increased demands of the athlete as well as

✉ Erick M. Marigi
marigi.erick@mayo.edu

Michael R. Davies
daviesm@HSS.edu

Robert G. Marx
MarxR@HSS.edu

Scott A. Rodeo
RodeoS@HSS.edu

Riley J. Williams 3rd
WilliamsR@HSS.edu

[1] Department of Orthopedic Surgery, Mayo Clinic Florida, 4500 San Pablo Rd S, Jacksonville, FL 32224, USA

[2] Department of Orthopedic Surgery, Hospital for Special Surgery, New York City, New York, USA

prevention of further degeneration of the knee joint. Treatment for meniscus tears ranges from non-operative management to surgical intervention. Non-operative management may include activity modification, physical therapy, non-steroidal anti-inflammatory analgesics, and joint injections. For surgical management, several criteria should be considered prior to operating. This includes assessment of the meniscus tear pattern, size, location, concomitant injuries, and knee stability as major factors for treatment success.

In elite sports, the surgeon's responsibility to ensure long-term knee health must be balanced against the considerable pressure from athletes, coaches, and organizations to return to play as soon as possible. This can complicate the shared decision-making process and place physicians in a challenging position when recommending certain treatment options. In this review, we summarize the epidemiology and management of meniscus tears in athletes, with a focus on indications, treatment options ranging from non-operative management, partial meniscectomy, meniscus repair, and meniscus allograft transplantation, and clinical outcomes including return-to-play.

Epidemiology of Meniscus Tears in Athletes

Large epidemiological studies of high school athletes and military service members have provided valuable insight into the prevalence of meniscus tears in these active populations. Mitchell et al. reviewed athletic exposure and injury data in 1082 meniscus injuries occurring in high school athletes over a 6-year period, demonstrating an overall injury rate of 5.1 per 100,000 athletic exposures [4]. Sports with the highest risk of meniscus injury were boys' football, girls' soccer, girls' basketball, and boys' wrestling, with a higher rate of injuries seen following player-player contact compared to non-contact injury mechanisms [4]. Notably, while boys' football comprised 42.4% of all injuries, leading an overall higher injury rate in male athletes compared to female athletes, there was a higher injury rate for females compared to males in all gender-comparable sports [4].

In a study of 2969 meniscus tears among military service members aged 18–51 that occurred over a 2-year surveillance period, Tropf et al. reported that 52.1% involved an isolated medial meniscus tear, 17.9% involved an isolated lateral meniscus tear, 15.3% involved both menisci, and 30.3% of all tears occurred in the setting of a concomitant ligamentous injury [5]. Additional studies have reported a higher prevalence of medial meniscus tears relative to lateral meniscus tears in athletes with a stable knee [6, 7]. However, there are certain notable exceptions. Yeh. et al. performed an epidemiologic study following basketball players in the national basketball association (NBA) for 21 seasons. They identified 129 isolated meniscus tears, of which 59.7% involved the lateral meniscus, and 40.3% involved the medial meniscus, with an inverse relationship between player age and rate of lateral versus medial meniscus tear [8]. Specifically, lateral meniscal tears were more likely to occur up to 30 years of age; medial meniscal tears were more common in athletes above 30 years of age.

In the setting of acute anterior cruciate ligament (ACL) injuries, lateral meniscus tears have also been found to be more common than medial meniscus tears, which occur more often in the chronically ACL-deficient knee [9, 10]. Among the most common variants of lateral meniscus tear associated with acute ACL injuries is the posterior horn lateral meniscal oblique radial tear (LMORT), which was found to occur in 18% of patients who presented with acute ACL tears in combination with meniscus injuries [11].

Partial Meniscectomy

The treatment of meniscus tears in athletes is dictated by tear characteristics including location, tear pattern and size, and athlete-specific factors. Non-operative treatment of meniscus tears in athletes may be indicated for certain tear patterns associated with a high rate of spontaneous healing or a low rate of tear progression in conjunction with tolerable symptoms. For the medial meniscus, this may include degenerative tears of the posterior horn which are not associated with pain on or mechanical symptoms of catching or locking [12–14]. For the lateral meniscus, this includes horizontal cleavage tears which are asymptomatic as well as degenerative tears of the anterior horn [12, 15]. For symptomatic meniscus tears associated with an unstable, irreparable flap, partial meniscectomy may be indicated.

The lateral meniscus is essential for increasing congruity of the lateral tibiofemoral joint given the convex nature of the lateral tibial plateau [1]. Small reductions in lateral meniscal volume have been shown to result in significant increases in lateral tibiofemoral contact forces in biomechanical studies [16–18]. In a study of eleven cadaveric knees with horizontal cleavage tears of the lateral meniscus, resection of the inferior leaflet of the torn meniscus resulted in a 139% increase in contact pressures at 60 degrees of flexion, which further increased to 155.5% with superior leaflet resection [19]. In athletic populations, partial lateral meniscectomy, compared to partial medial meniscectomy, has been associated with a slower return to sport as well as a higher rate of post-surgical complications, including rapid chondrolysis of the lateral compartment of the knee [20–22]. Therefore, many authors recommend avoidance of partial lateral meniscectomy whenever possible in athletes, and reserving its use for highly symptomatic tears that are not amenable to repair. Furthermore, meniscus resection should

be limited to the minimum amount of tissue necessary to achieve a stable surface.

With respect to return to play, a study of 90 professional soccer players found an average return to play of 7 weeks after lateral meniscectomy, with an overall rate of return to preinjury level of competition that was 6 times lower than that exhibited by players who underwent partial medial meniscectomy [20]. Within the National Football League (NFL), 61% of players who underwent a partial lateral meniscectomy were able to return to play at the previous level of competition. However, the average time to return was a little longer at 8.5 months, but this was defined as the first time a player played in a regular-season NFL game and not time to being medically cleared [23]. In professional baseball players, the overall rate of return-to-sport following meniscectomy (medial or lateral) was 80%, with no difference in RTS between players who underwent lateral vs. medial meniscectomy [24].

Compared to partial lateral meniscectomy, partial medial meniscectomy has generally been well-tolerated in athletic populations and may be considered for symptomatic longitudinal tears which occur in regions of the meniscus with poor vascularity, horizontal cleavage tears, or complex tears associated with an unstable, irreparable fragment [12, 25••]. These displaced flaps can occasionally abut the deep MCL in the medial gutter, inciting a painful inflammatory response [26]. Anatomically, the medial compartment of the knee exhibits greater bony congruity than the lateral compartment, supplementing the role of the medial meniscus in maintaining joint contact pressures [27]. Similarly, it has been demonstrated that partial medial meniscectomy results in less severe changes in joint contact pressures compared to lateral meniscectomy [16]. Nawabi et al. found that professional soccer players returned to sport at an average of 5 weeks following partial medial meniscectomy with a significantly lower rate of adverse events (8% vs. 69%) compared to players who underwent partial lateral meniscectomy [20].

Meniscus Repair

The meniscus plays a key role in the prevention or delay of degenerative changes through chondroprotection, joint lubrication, and joint stability [28, 29]. As a result, there has been a shift towards meniscal preservation in both the general and athletic population [11, 12, 25, 30••, 31]. With respect to meniscal repair, it is important to note that the tear morphology, tear location, associated injuries, and type of sport can influence the type of repair performed and outcomes of surgery. For example, isolated meniscus injuries have traditionally had lower healing rates than meniscus tears associated with anterior cruciate ligament reconstruction [32, 33]. Similarly, horizontal cleavage tears have frequently been deemed irreparable with minimal healing capacity and therefore have been managed with partial or complete meniscectomy. However, Morris et al. demonstrated an 80% satisfaction rate, 93.1% return to sport rate, and 11.4% reoperation rate which is comparable to other tear patterns [34].

Fundamentally, meniscus repair should include (1) anatomic reduction, (2) biological stimulation, and (3) stable suture repair with circumferential tear compression. Several standard methods for meniscus repair can be used, including inside-out (IO), outside-in, and all-inside (AI) arthroscopic meniscus repairs. The IO technique consists of utilization of an accessory posteromedial or posterolateral incision with smaller diameter needles that allow for multiple sutures to be passed through the meniscus and then externally tied to the capsule [35]. This approach is suited for tears in the posterior horn and mid-body of the meniscus. For reparable tear patterns which predominantly involve the anterior horn or middle of the meniscus, an outside-in (OI) approach may also be considered. This technique was originally described in 1985 as a way of avoiding injury to the peroneal nerve in the setting of lateral meniscus repairs [36, 37]. It involves the use of a small accessory incision positioned to minimize the risk of neurovascular injury, through which 18-guage spinal needles may be used to pass sutures from outside into the joint, where they may then be retrieved and tied using a variety of different techniques [38, 39]. When appropriately indicated based on tear pattern and location, OI repairs have demonstrated improvement in patient-reported outcomes and a low failure rate [40].

The AI technique is a growing and evolving approach that utilizes suture devices to arthroscopically repair the meniscus to the capsule [41–43]. In the general population, multiple meta-analyses have demonstrated no significant differences in clinical outcomes and overall failure rates [35, 43, 44]. With respect to elite athletes, Borque et al. recently reviewed a total of 192 meniscal repairs performed between 2013 and 2019 treated with either IO or AI techniques [30]. Over the study period they observed a 21% failure rate in this athletic cohort, defined as needing subsequent surgery. Furthermore, medial meniscus repairs (MMR) with the AI technique failed at a significantly higher rate than IO MMR (58% vs. 23%; $P < .001$) or lateral meniscus repairs (LMR) with the IO (14%) or AI (12%). Notably, there was no statistical difference between IO or AI lateral meniscus repairs (14% vs. 12%; $P = .103$).

While meniscus repair provides preservation of meniscal volume and restoration of normal cartilage contact kinematics, it does require more extensive rehabilitation and typically requires much longer time away from competition. Eberbach et al. performed a systematic review of 28 studies with isolated meniscal repair, where they demonstrated a 90% return to sport rate in mixed-level athletes

and 86% in professionals at an average delay of 4.3 to 6.5 months [45]. Fried et al. performed a more recent systematic review of 88 investigations focusing on return to play and rehabilitation. These authors demonstrated a high rate of return-to-play (range: 71.2–100%) following meniscal repair with a majority of athletes returning within 4–6 months [46].

Understandably, athletes with concomitant anterior cruciate ligament tears should expect a longer rehab with most studies suggesting RTS at 9 to 12 months. While this delay is limited by the ACL reconstruction, multiple investigations have noted improved rates of meniscal healing in the setting of concomitant ACL surgery [33, 47–50]. This may be due to a variety of factors such as a more formal, closed-chain rehabilitation program or increased time away from ballistic activity. Additionally, ACL reconstruction is known to restore stability to the knee, thus decreasing the risk of future translational injuries. This may subsequently result in less stress to previously repaired meniscus tears and / or a decreased risk of new meniscus trauma [33, 47–50].

Compared to meniscal repair, partial meniscectomy has been performed in cases of nonviable meniscal tissue or unfavorable healing potential and should be considered in certain cases. In 2018 Ekhtiari et al. performed an analysis of 725 athletes undergoing meniscectomy or meniscus repair as both isolated or concomitant injuries [51]. They observed similar rates of RTS (80.4% vs. 86.5%; $P = .24$) between partial meniscectomy and meniscus repair but a shorter pooled mean time to RTS in the partial meniscectomy group (4.3 months vs. 7.6 months; $P < .001$). D'Ambrosi et al. performed an updated systematic review involving 421 elite athletes with isolated meniscus injuries participating in wrestling, baseball, soccer, rugby or handball [25]. Similarly, they demonstrated comparable rates of return to competitive sports (84.7% vs. 85.1%) and pre-injury activity level (78.3% vs. 75.5%) for both partial meniscectomy and meniscal repair, respectively. However, there was a shorter mean time to RTS (35–50 days vs. 141 days and a lower rate of revision surgery (3.7% vs. 17%) in partial meniscectomy compared to meniscal repair. Notably, the authors also observed an 83.3% rate of revision surgery for the lateral meniscus after partial meniscectomy.

As such, meniscus repair should be considered whenever technically possible, especially in the setting of a favorable healing environment or concomitant injury. This is further preferred if the athlete can tolerate the longer, but necessary, postoperative recovery timeline or has concerns of future cartilage degeneration. These benefits must be balanced with the increased risk of revision surgery with meniscal repair compared to partial meniscectomy, especially on the medial side. During meniscus repair, the inside-out technique may be advantageous compared to all-inside for certain medial meniscus tear patterns given the lower failure rates observed in certain series, but both IO and AI techniques have comparable ability to manage most tear patterns [30].

Meniscus Allograft Transplantation

In the meniscal-deficient knee, meniscus allograft transplantation (MAT) has been demonstrated to help decrease the elevated tibiofemoral contact pressures and reduce symptoms [52]. MAT is typically not a first-line modality for management of the meniscal deficient knee. Extensive non-operative measures such as activity modification, non-opioid pharmacologic medications, judicious use of intermittent injections, and bracing should be pursued first. General indications for MAT includes persistent knee pain secondary to meniscal deficiency, and ideally minimal degenerative changes in the involved compartment with Outerbridge grade 2 or less. Full thickness-articular cartilage loss is typically a contraindication unless there is an isolated defect that can be managed with a cartilage repair or restoration procedure. Architectural remodeling (flattening of the subchondral contour) and axial malalignment are also contraindications to MAT. Chronologic age of less than 50 years has been considered a cut-off age, but physiologic age and level of activity are factors that should be considered rather than solely chronologic age [53].

In athletes, the role of MAT is very limited. The authors believe that MAT should be considered only when an athlete can no longer perform or decides to retire from their sport. Advanced chondral damage is frequently present in chronic meniscal deficient patients and should be addressed concomitantly for patients undergoing MAT. Prior to MAT, selection of an allograft from an American Association of Tissue Banks (AATB)-certified tissue bank is key to assure quality and disease screening. Size-matching of the meniscus allograft is critically important. The meniscus allograft should match the native meniscus as closely as possible to positively affect knee joint load distribution. Multiple methods can be used to ensure appropriate sizing, ranging from the radiographic Pollard Method, magnetic resonance imaging (MRI), or 3 dimensional MRI [54]. Multiple surgical techniques exist for implantation and fixation of a meniscus transplant, including all suture fixation or bone fixation which can be accomplished using bone bridges or bone plugs. Both soft tissue and bone fixation have demonstrated similar clinical outcomes over time; however, graft fixation with bone plugs or a bone bridge has been found to result in less graft extrusion compared to soft tissue fixation alone [55].

Clinical outcomes after MAT remain variable and are influenced by the degree of associated chondral degeneration, type of sport, and level of activity [56•]. In professional athletes Marcaccieta et al. reported a 92% RTS rate at a mean

on 10.3 months with 75% returning to the same preinjury level among 12 professional soccer players [57]. Similarly, Bonanzinga et al. reported a 100% RTS rate at 11.8 months in 13 professional athletes (10 soccer, 1 basketball, 1 fencer, and 1 wrestler) [58]. Grassi et al. performed a meta-analysis of MAT where 77% of patients were able to return to any form of sport or physical activity and 67% returned to the same sport or physical activity with soccer, swimming, and running as the most common activities [59]. These patients also experienced a 23% reoperation rate at a mean follow-up of 3.4 years but only 13% were graft-related complications. Subsequently, Cvetanovich et al. demonstrated a 76% RTS rate at a mean of 12.6 months after surgery. However, only 48% of patients were able to reach their preoperative level of intensity. Most recently, Ahmed et al. assessed 14 studies published through 2020 where they found a wide range of RTS between 20% and 91.7% and a mean time to return ranging from 7.6 months to 16.9 months, postoperatively. Notably, most studies (8 of 11) reported a substantial return to the same level of sports (66.7% to 96.2%).

Despite some of the favorable findings in the literature, the lack of higher-quality studies evaluating sports performance and RTS following a MAT complicates the ability to make global recommendations. Certain patients can undergo meniscal transplantation and successfully return to daily activities or "low impact" sports. However, there remains considerable uncertainty regarding the ability of athletic patients to fully return to their preinjury ability with ballistic activities such as jumping, cutting, and pivoting. As such, surgeons should remain cautious and treat each case on an individual level. Clinicians should also counsel that a MAT is an interim approach to joint preservation, that is currently viewed as a "salvage" procedure aimed to make symptoms tolerable. It should be discussed that progressive degenerative change can accumulate in the tissue with time, possibly necessitating further surgery in the future. Furthermore, the time to RTS is likely longer when compared to a partial meniscectomy or meniscus repair.

Conclusion

Management of meniscus injuries in the elite athlete remains a complex process that needs to balance the increased demands of athletic competition and the expectation to return to play as soon as possible. Currently, there is no standardized way to deal with meniscal tears, and each case should consider the meniscus tear type, concomitant injuries, athlete expectations, timing during the season, ability to rehabilitate, and desire to mitigate further chondral degeneration. In general, repairable meniscus tears should be repaired given the potential to restore native anatomy and provide similar rates of RTS. Repair rather than removal is especially emphasized for the lateral meniscus given the relatively higher healing potential, and increased risk of chondrolysis or revision surgery following partial lateral meniscectomy. When a rapid return to competition is needed, partial meniscectomy can be considered, especially on the medial side, if the benefits of an earlier return outweigh the potential risk of developing knee osteoarthritis over the years. Finally, MAT remains a "salvage" option for symptomatic meniscal deficient athletes with unpredictability in the ability to RTS.

Author Contributions E.M. and M.D wrote the main manuscript text. All authors made substantial contributions to the conception and design of the work, interpretation of literature, and provided critical revisions to the intellectual content of the manuscript. All authors approved the final version to be published and agree to be accountable for all aspects of the work.

Funding No sources of funding.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Markes AR, Hodax JD, Ma CB. Meniscus form and function. Clin Sports Med. 2020;39(1):1–12. https://doi.org/10.1016/j.csm.2019.08.007.
2. Gee SM, Tennent DJ, Cameron KL, Posner MA. The burden of Meniscus injury in young and physically active populations. Clin Sports Med. 2020;39(1):13–27. https://doi.org/10.1016/j.csm.2019.08.008.
3. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: a 10-year study. Knee. 2006;13(3):184–8. https://doi.org/10.1016/j.knee.2006.01.005.
4. Mitchell J, Graham W, Best TM, Collins C, Currie DW, Comstock RD, et al. Epidemiology of meniscal injuries in US high school athletes between 2007 and 2013. Knee Surg Sports Traumatol Arthrosc. 2016;24(3):715–22. https://doi.org/10.1007/s00167-015-3814-2.
5. Tropf JG, Colantonio DF, Tucker CJ, Rhon DI. Epidemiology of Meniscus injuries in the military health system and predictive factors for arthroscopic surgery. J Knee Surg. 2022;35(10):1048–55. https://doi.org/10.1055/s-0042-1744189.
6. Terzidis IP, Christodoulou A, Ploumis A, Givissis P, Natsis K, Koimtzis M. Meniscal tear characteristics in young athletes

with a stable knee: arthroscopic evaluation. Am J Sports Med. 2006;34(7):1170–5. https://doi.org/10.1177/0363546506287939.
7. Adams BG, Houston MN, Cameron KL. The epidemiology of Meniscus injury. Sports Med Arthrosc Rev. 2021;29(3):e24–33. https://doi.org/10.1097/jsa.0000000000000329.
8. Yeh PC, Starkey C, Lombardo S, Vitti G, Kharrazi FD. Epidemiology of isolated meniscal injury and its effect on performance in athletes from the National Basketball Association. Am J Sports Med. 2012;40(3):589–94. https://doi.org/10.1177/0363546511428601.
9. Cipolla M, Scala A, Gianni E, Puddu G. Different patterns of meniscal tears in acute anterior cruciate ligament (ACL) ruptures and in chronic ACL-deficient knees. Classification, staging and timing of treatment. Knee Surg Sports Traumatol Arthrosc. 1995;3(3):130–4. https://doi.org/10.1007/bf01565470.
10. Feucht MJ, Bigdon S, Bode G, Salzmann GM, Dovi-Akue D, Südkamp NP, et al. Associated tears of the lateral meniscus in anterior cruciate ligament injuries: risk factors for different tear patterns. J Orthop Surg Res. 2015;10:34. https://doi.org/10.1186/s13018-015-0184-x.
11. Krych AJ, LaPrade MD, Cook CS, Leland D, Keyt LK, Stuart MJ, et al. Lateral meniscal oblique radial tears are common with ACL injury: a classification system based on arthroscopic tear patterns in 600 consecutive patients. Orthop J Sports Med. 2020;8(5):2325967120921737. https://doi.org/10.1177/2325967120921737.
12. Borque KA, Jones M, Cohen M, Johnson D, Williams A. Evidence-based rationale for treatment of meniscal lesions in athletes. Knee Surg Sports Traumatol Arthrosc. 2022;30(5):1511–9. https://doi.org/10.1007/s00167-021-06694-6.
13. Giuliani JR, Burns TC, Svoboda SJ, Cameron KL, Owens BD. Treatment of meniscal injuries in young athletes. J Knee Surg. 2011;24(2):93–100. https://doi.org/10.1055/s-0031-1280877.
14. Donohue MA, Zhou L, Haley CA. Meniscus injuries in the military athlete. J Knee Surg. 2019;32(2):123–6. https://doi.org/10.1055/s-0038-1676959.
15. Shelbourne KD, Heinrich J. The long-term evaluation of lateral meniscus tears left in situ at the time of anterior cruciate ligament reconstruction. Arthroscopy. 2004;20(4):346–51. https://doi.org/10.1016/j.arthro.2004.01.029.
16. Peña E, Calvo B, Martinez MA, Palanca D, Doblaré M. Why lateral meniscectomy is more dangerous than medial meniscectomy. A finite element study. J Orthop Res. 2006;24(5):1001–10. https://doi.org/10.1002/jor.20037.
17. Novaretti JV, Herbst E, Chan CK, Debski RE, Musahl V. Small lateral meniscus tears propagate over time in ACL intact and deficient knees. Knee Surg Sports Traumatol Arthrosc. 2021;29(9):3068–76. https://doi.org/10.1007/s00167-020-06356-z.
18. Perez-Blanca A, Espejo-Baena A, Amat Trujillo D, Prado Nóvoa M, Espejo-Reina A, Quintero López C, et al. Comparative biomechanical study on contact alterations after lateral Meniscus posterior root avulsion, Transosseous reinsertion, and Total Meniscectomy. Arthroscopy. 2016;32(4):624–33. https://doi.org/10.1016/j.arthro.2015.08.040.
19. Koh JL, Zimmerman TA, Patel S, Ren Y, Xu D, Zhang LQ. Tibiofemoral contact mechanics with horizontal cleavage tears and treatment of the lateral Meniscus in the human knee: an in vitro cadaver study. Clin Orthop Relat Res. 2018;476(11):2262–70. https://doi.org/10.1097/corr.0000000000000464.
20. Nawabi DH, Cro S, Hamid IP, Williams A. Return to play after lateral meniscectomy compared with medial meniscectomy in elite professional soccer players. Am J Sports Med. 2014;42(9):2193–8. https://doi.org/10.1177/0363546514540271.
21. Sonnery-Cottet B, Archbold P, Thaunat M, Carnesecchi O, Tostes M, Chambat P. Rapid chondrolysis of the knee after partial lateral meniscectomy in professional athletes. Knee. 2014;21(2):504–8. https://doi.org/10.1016/j.knee.2014.01.001.
22. Ishida K, Kuroda R, Sakai H, Doita M, Kurosaka M, Yoshiya S. Rapid chondrolysis after arthroscopic partial lateral meniscectomy in athletes: a case report. Knee Surg Sports Traumatol Arthrosc. 2006;14(12):1266–9. https://doi.org/10.1007/s00167-006-0091-0.
23. Aune KT, Andrews JR, Dugas JR, Cain EL Jr. Return to play after partial lateral Meniscectomy in National Football League Athletes. Am J Sports Med. 2014;42(8):1865–72. https://doi.org/10.1177/0363546514535069.
24. Erickson BJ, Chalmers PN, D'Angelo J, Ma K, Rowe D, Ciccotti MG, et al. Performance and return to sports after Meniscectomy in professional baseball players. Am J Sports Med. 2022;50(4):1006–12. https://doi.org/10.1177/0363546521074021.
25.•• D'Ambrosi R, Meena A, Raj A, Ursino N, Mangiavini L, Herbort M, et al. In elite athletes with meniscal injuries, always repair the lateral, think about the medial! A systematic review. Knee Surg Sports Traumatol Arthrosc. 2023;31(6):2500–10. https://doi.org/10.1007/s00167-022-07208-8. **A systematic review of 421 elite athletes participating in wrestling, baseball, soccer, rugby, and handball. Authors demonstrated that in elite athletes with isolated meniscal injury, partial meniscectomy and meniscal repair had similar rates of return to sport and return to pre-injury levels. Additionally, partial meniscectomy of the lateral meniscus, was associated with an 83.3% rate of revision surgery.**
26. Herschmiller TA, Anderson JA, Garrett WE, Taylor DC. The trapped medial Meniscus tear: an examination maneuver helps predict arthroscopic findings. Orthop J Sports Med. 2015;3(5):2325967115583954. https://doi.org/10.1177/2325967115583954.
27. Mameri ES, Dasari SP, Fortier LM, Verdejo FG, Gursoy S, Yanke AB, et al. Review of Meniscus anatomy and biomechanics. Curr Rev Musculoskelet Med. 2022;15(5):323–35. https://doi.org/10.1007/s12178-022-09768-1.
28. Becker R, Kopf S, Seil R, Hirschmann MT, Beaufils P, Karlsson J. From meniscal resection to meniscal repair: a journey of the last decade. Knee Surg Sports Traumatol Arthrosc. 2020;28(11):3401–4. https://doi.org/10.1007/s00167-020-06316-7.
29. Woodmass JM, LaPrade RF, Sgaglione NA, Nakamura N, Krych AJ. Meniscal repair: reconsidering indications, techniques, and biologic augmentation. J Bone Joint Surg Am. 2017;99(14):1222–31. https://doi.org/10.2106/jbjs.17.00297.
30.•• Borque KA, Laughlin MS, Webster E, Jones M, Pinheiro VH, Williams A. A Comparison of All-inside and Inside-out Meniscal Repair in Elite Athletes. Am J Sports Med. 2023;51(3):579–84. https://doi.org/10.1177/0363546521147058. **This was a retrospective review of 192 elite athletes treated with meniscal repair where a 21% of the cohort sustained treatment failure and needed to undergo subsequent surgery. When comparing techniques medial meniscus repairs treated with the all-inside technique failed at a significantly higher rate than inside-out medial meniscal repairs (58% vs. 23%; P < .001) or lateral**

meniscus repairs with either the inside-out (14%) or all-inside technique (12%).

31. Willinger L, Balendra G, Pai V, Lee J, Mitchell A, Jones M, et al. Medial meniscal ramp lesions in ACL-injured elite athletes are strongly associated with medial collateral ligament injuries and medial tibial bone bruising on MRI. Knee Surg Sports Traumatol Arthrosc. 2022;30(5):1502–10. https://doi.org/10.1007/s00167-021-06671-z.
32. Cannon WD Jr, Vittori JM. The incidence of healing in arthroscopic meniscal repairs in anterior cruciate ligament-reconstructed knees versus stable knees. Am J Sports Med. 1992;20(2):176–81. https://doi.org/10.1177/036354659202000214.
33. Totlis T, Haunschild ED, Otountzidis N, Stamou K, Condron NB, Tsikopoulos K, et al. Return-to-sport rate and activity level are high following arthroscopic all-inside meniscal repair with and without concomitant anterior cruciate ligament reconstruction: a systematic review. Arthroscopy. 2021;37(7):2351–60. https://doi.org/10.1016/j.arthro.2021.02.046.
34. Morris JH, Magnussen RA, DiBartola AC, Aldabbeh S, Duerr RA, Kaeding CC, et al. Patient outcomes after horizontal cleavage tear repair: a systematic review. Arthroscopy. 2020;36(8):2316–31. https://doi.org/10.1016/j.arthro.2020.04.027.
35. Marigi EM, Till SE, Wasserburger JN, Reinholz AK, Krych AJ, Stuart MJ. Inside-out approach to Meniscus repair: still the gold standard? Curr Rev Musculoskelet Med. 2022;15(4):244–51. https://doi.org/10.1007/s12178-022-09764-5.
36. Rodeo SA, Warren RF. Meniscal repair using the outside-to-inside technique. Clin Sports Med. 1996;15(3):469–81.
37. Warren RF. Arthroscopic meniscus repair. Arthroscopy. 1985;1(3):170–2. https://doi.org/10.1016/s0749-8063(85)80005-0.
38. Joshi A, Basukala B, Singh N, Hama B, Bista R, Pradhan I. Outside-in repair of longitudinal tear of medial Meniscus: suture shuttle technique. Arthrosc Tech. 2020;9(4):e407–e17. https://doi.org/10.1016/j.eats.2019.11.016.
39. Dave LY, Caborn DN. Outside-in meniscus repair: the last 25 years. Sports Med Arthrosc Rev. 2012;20(2):77–85. https://doi.org/10.1097/JSA.0b013e318254966a.
40. Migliorini F, Pilone M, Bell A, Celik M, Konrads C, Maffulli N. Outside-in repair technique is effective in traumatic tears of the meniscus in active adults: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2023;31(10):4257–64. https://doi.org/10.1007/s00167-023-07475-z.
41. Rocha de Faria JL, Santos APG, Pavão DM, Radulski M, Leal AC, More ADO, et al. Continuous Vertical Inside-Out Versus Traditional Vertical Inside-Out Meniscal Repair: A Biomechanical Comparison. Orthop J Sports Med. 2023;11(11):23259671231209951. https://doi.org/10.1177/23259671231209951.
42. Bachmaier S, Krych AJ, Smith PA, Herbort M, Ritter D, LaPrade RF, et al. Primary fixation and cyclic performance of single-stitch all-inside and inside-out meniscal devices for repairing vertical longitudinal meniscal tears. Am J Sports Med. 2022;50(10):2705–13. https://doi.org/10.1177/03635465221107086.
43. Fillingham YA, Riboh JC, Erickson BJ, Bach BR Jr, Yanke AB. Inside-out versus all-inside repair of isolated meniscal tears: an updated systematic review. Am J Sports Med. 2017;45(1):234–42. https://doi.org/10.1177/0363546516632504.
44. Smoak JB, Matthews JR, Vinod AV, Kluczynski MA, Bisson LJ. An up-to-date review of the Meniscus literature: a systematic summary of systematic reviews and Meta-analyses. Orthop J Sports Med. 2020;8(9):2325967120950306. https://doi.org/10.1177/2325967120950306.
45. Eberbach H, Zwingmann J, Hohloch L, Bode G, Maier D, Niemeyer P, et al. Sport-specific outcomes after isolated meniscal repair: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2018;26(3):762–71. https://doi.org/10.1007/s00167-017-4463-4.
46. Fried JW, Manjunath AK, Hurley ET, Jazrawi LM, Strauss EJ, Campbell KA. Return-to-play and rehabilitation protocols following isolated meniscal repair-a systematic review. Arthrosc Sports Med Rehabil. 2021;3(1):e241–e7. https://doi.org/10.1016/j.asmr.2020.07.023.
47. Marigi EM, Keyt LK, LaPrade MD, Camp CL, Levy BA, Dahm DL, et al. Surgical treatment of isolated meniscal tears in competitive male wrestlers: reoperations, outcomes, and return to sport. Orthop J Sports Med. 2021;9(1):2325967120969220. https://doi.org/10.1177/2325967120969220.
48. Gerritsen LM, van der Lelij TJN, van Schie P, Fiocco M, van Arkel ERA, Zuurmond RG, et al. Higher healing rate after meniscal repair with concomitant ACL reconstruction for tears located in vascular zone 1 compared to zone 2: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2022;30(6):1976–89. https://doi.org/10.1007/s00167-022-06862-2.
49. Korpershoek JV, de Windt TS, Vonk LA, Krych AJ, Saris DBF. Does anterior cruciate ligament reconstruction protect the Meniscus and its repair? A systematic review. Orthop J Sports Med. 2020;8(7):2325967120933895. https://doi.org/10.1177/2325967120933895.
50. Dancy ME, Marigi EM, Krych AJ, Werner BC, Camp CL. Impact of biologic augmentation on revision surgery rates after Meniscus repair: a matched-cohort analysis of 3420 patients. Orthop J Sports Med. 2023;11(8):23259671231186990. https://doi.org/10.1177/23259671231186990.
51. Ekhtiari S, Khan M, Kirsch JM, Thornley P, Larson CM, Bedi A. Most elite athletes return to competition following operative management of meniscal tears: a systematic review. J ISAKOS. 2018;3(2):110–5. https://doi.org/10.1136/jisakos-2017-000181.
52. Southworth TM, Naveen NB, Tauro TM, Chahla J, Cole BJ. Meniscal allograft transplants. Clin Sports Med. 2020;39(1):93–123. https://doi.org/10.1016/j.csm.2019.08.013.
53. Zaffagnini S, Grassi A, Macchiarola L, Stefanelli F, Coco V, Marcacci M, et al. Meniscal allograft transplantation is an effective treatment in patients older than 50 years but yields inferior results compared with younger patients: a case-control study. Arthroscopy. 2019;35(8):2448–58.
54. Beeler S, Jud L, von Atzigen M, Sutter R, Fürnstahl P, Fucentese SF, et al. Three-dimensional meniscus allograft sizing-a study of 280 healthy menisci. J Orthop Surg Res. 2020;15(1):74. https://doi.org/10.1186/s13018-020-01591-z.
55. Worhacz KM, Carter TR. Meniscal allograft transplantation: does surgical technique influence clinical outcomes? Curr Rev Musculoskelet Med. 2023;16(5):163–72. https://doi.org/10.1007/s12178-023-09825-3.
56.• Ahmed AF, Rinaldi J, Noorzad AS, Zikria BA. Return to Sports Following Meniscal Allograft Transplantation Is Possible but Remains Questionable: A Systematic Review. Arthroscopy. 2022;38(4):1351–61. https://doi.org/10.1016/j.arthro.2021.11.003. **This systematic review provides a thorough summary of**

current analyses pertaining meniscus allograft transplantation. Authors observed significant variability in outcomes with a wide range of return to sport between 20% and 91.7% and a mean time to return ranging from 7.6 months to 16.9 months, postoperatively.

57. Marcacci M, Marcheggiani Muccioli GM, Grassi A, Ricci M, Tsapralis K, Nanni G, et al. Arthroscopic Meniscus allograft transplantation in male professional soccer players:a 36-month follow-up study. Am J Sports Med. 2014;42(2):382–8. https://doi.org/10.1177/0363546513508763.
58. Bonanzinga T, Grassi A, Altomare D, Vitale ND, Zaffagnini S, Marcacci M. Long sports career and satisfactory clinical outcomes after meniscal allograft transplantation (MAT) in young professional athletes involved in strenuous sports. Knee Surg Sports Traumatol Arthrosc. 2022;30(7):2314–9. https://doi.org/10.1007/s00167-021-06779-2.
59. Grassi A, Bailey JR, Filardo G, Samuelsson K, Zaffagnini S, Amendola A. Return to sport activity after meniscal allograft transplantation: at what level and at what cost? A systematic review and Meta-analysis. Sports Health. 2019;11(2):123–33. https://doi.org/10.1177/1941738118819723.