Pediatric Meniscal Tears

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Abstract: As pediatric youth sports involvement has increased, there has been an increase in meniscus tears associated with acute pediatric knee injuries. The meniscus of pediatric patients has a more robust blood supply which may help its healing potential. The discoid meniscus is an anatomical variant that is more prone to meniscal tears in pediatric patients. Meniscectomy and saucerization are usually the treatment of choice for the complex meniscus tear and the discoid meniscus tear. Meniscus repair should be attempted when at all possible due to the good outcomes associated with meniscus repair and poor results associated with meniscectomy in pediatric patients.

Key Words: pediatric meniscus, meniscus repair, discoid meniscus, pediatric knee injury, meniscectomy

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Acute pediatric knee injuries can often result in meniscus tears. Understanding the anatomy and function of the meniscus can lead the physician to the correct treatment. Historically, the meniscus was thought to be an embryological remnant that could be treated with total meniscectomy.[1] Through long-term follow-up, total meniscectomy was determined to result in poor outcomes due to a change in joint reactive forces causing early osteoarthritis.[2] Due to an improved understanding of the meniscus, treatment has shifted to preservation of the meniscus with improved surgical techniques, including limited meniscectomy and meniscal repair.[3]

Anatomically, the difference in the blood supply to the meniscus allows for better healing potential in pediatric patients. The blood supply to the meniscus is more robust in pediatric patients until 10 years of age when its vascularization starts to resemble that of adults.[4] Congenital meniscal abnormalities such as the discoid meniscus may predispose the pediatric patient to acute meniscal injuries. The importance of recognizing a discoid meniscus compared with a normal meniscus leads to important differences in surgical techniques, re-tear rates, and long-term outcomes.

As participation in youth sports has increased, pediatric knee injuries, including both anterior cruciate ligament (ACL) tears and meniscus tears, have also increased.[5,6] In 2020, pediatric meniscus tears were reported to occur at a rate of 0.51 per 10,000 athlete exposures.[2] Pediatric meniscal tears occur during athletic activities 80% to 90% of the time.[7–9] As a result, techniques for preserving the meniscus are critical to limit poor outcomes. Surgical techniques to repair the meniscus are improving with novel instrumentation that allows the surgeon to attempt to repair more complex tear patterns. Postoperative rehabilitation is also important to allow the pediatric athlete to return to activity after their acute meniscal injury.

ANATOMY

The menisci are smooth, crescent-shaped structures located in the tibio-femoral joint of the knee. They function to enhance the articulation between the femoral condyles and tibial plateaus by distributing load and increasing stability of the joint.[10] A cellular component is embedded in a dense extracellular matrix (ECM), making the menisci uniquely suited for these tasks. The extracellular matrix is ~70% water and 20% collagen. The remaining portion of the ECM is made up of proteoglycans, noncollagenous proteins, and glycoproteins.

Although the medial and lateral menisci vary in shape and size, they both serve an important role in stabilization, load transmission, lubrication and nutrition, and shock absorption.[11] The medial meniscus is C-shaped and covers ~50% to 74% of the articular compartment.[10,12–14] The lateral meniscus is more triangular in cross-section and covers a larger area of the tibial surface at 75% to 93% when compared with the medial meniscus.[13,15] In addition, the size and shape of the menisci change during growth and development, likely in response to bone growth and the forces that they encounter. Ligamentous attachments to the bone and joint capsule provide stability to the menisci. These sites of attachment include the medial collateral ligament, the meniscofemoral ligaments, and tibial and femoral bony attachments of the anterior and posterior horns. The lateral meniscus is more mobile than the medial meniscus, and this increased mobility is likely a result of fewer ligamentous attachments at the popliteal hiatus.[16]

VASCULAR SUPPLY

The fetal meniscus is fully vascularized, gradually decreasing in vascularity until approximately the age of 10, when the vascularity resembles an adult meniscus.[4,17] The adult meniscus is largely an avascular structure, with only the peripheral 10% to 30% of both the medial and lateral meniscus receiving direct blood supply. This blood supply is from the medial and lateral geniculate arteries, which branch from the popliteal artery. The directly vascularized periphery is referred to as the "red zone," while the inner "white zone" receives its vascularization through synovial diffusion.[11,17,18]

DISCOID MENISCUS

The discoid meniscus is a congenital anatomical variant of the normal meniscus. The lateral meniscus is more commonly found to be discoid in nature compared with the medial meniscus; however, the discoid medial meniscus is described and is noted to be abnormal in size, shape, and composition. This results in a meniscus that is prone to

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tearing and can lead to instability of the knee joint.[19] Lateral discoid meniscus has a reported incidence in the US ranging from 3% to 5%, with a higher incidence among Asian populations, with reported incidences of up to 15%.[20]

A discoid meniscus is grossly characterized by overcoverage of the tibial plateau and increased thickness of the meniscus.[21] The various shapes of a discoid meniscus were classified by Watanabe et al[22] in 1969. Type I entails a complete discoid shape that is mechanically stable to both arthroscopic probing and palpation and covers the entire tibial plateau. Type II is a partial discoid shape that is mechanically stable to both arthroscopic probing and palpation and covers up to 80% of the tibial plateau. Type III is termed a Wrisberg variant, which is a posteriorly unstable meniscus that has a normal or discoid shape. The instability of type III discoid meniscus is due to the sole attachment of the posterior meniscofemoral ligament of Wrisberg and the absence of any other normal posterior meniscotibial attachments.[19,20,22] More recently, a classification system was proposed by a group with the Pediatric Research in Sports Medicine (PRiSM). This classification system provides additional metrics for classification, including width, height, presence or absence of a tear, and anterior versus posterior instability; all of which were not captured by the Watanabe classification system.[23]

When compared with a normal meniscus, the discoid lateral meniscus is a more mobile and unstable phenotype.[21] The composition of a discoid meniscus also differs from a normal meniscus. The matrix of a discoid meniscus has fewer collagen fibers that are poorly organized when compared with a healthy meniscus.[21,24] The vascular perfusion pattern is also abnormal, leaving a larger proportion of the meniscus avascular. The abnormal stability, size, shape, composition, and vascular abnormalities in a discoid meniscus are some of the risk factors that make the discoid meniscus more prone to tears.[21]

A discoid meniscus may be clinically silent until the meniscus becomes unstable or is torn. A high index of suspicion and thorough clinical evaluation are required when evaluating a patient with symptoms of meniscus tear. The evaluation begins with a thorough history and physical examination. The patient may report knee pain, catching, locking, giving way, swelling, and a lack of terminal extension. Classically, discoid lateral meniscus causes

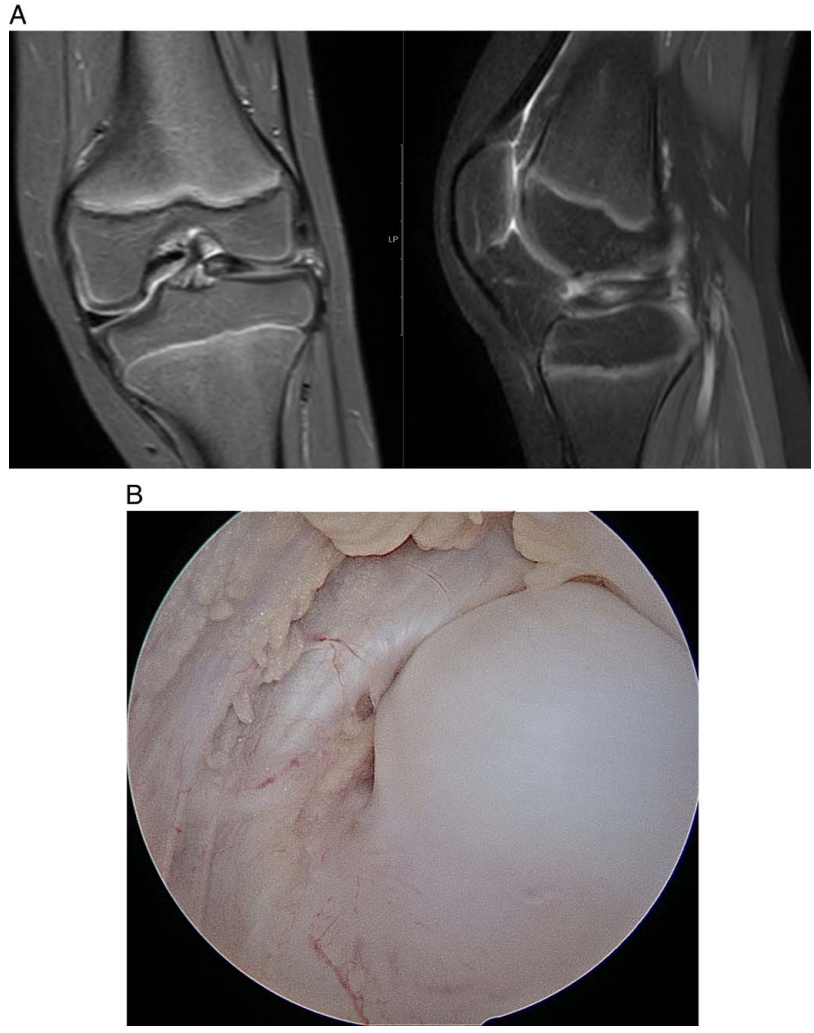

FIGURE 1. A, MRI depicting complete discoid meniscus with intrabody tear. B, Arthroscopic photo showing the discoid meniscus pressed up against the ACL blocking access to the lateral compartment.

"snapping-knee syndrome," which correlates with pain and tenderness along the lateral joint line and snapping or clunking with a McMurray test. There may or may not be a known history of injury. In addition, the meniscus may be palpable as a "bulge" if there is an unstable or displaced meniscus that protrudes at the joint line.[19–21,25]

In cases of suspected discoid meniscus, radiographical studies and MRI may be helpful for confirmation. Radiographs of a knee with a discoid meniscus typically show squaring of the lateral femoral condyle, increased obliquity and cupping of the lateral tibial plateau, increase in the lateral tibial spine height, and widening of the joint space are often noted.[26] MRI criteria for the diagnosis of discoid lateral meniscus includes 3 or more consecutive 5 mm sagittal slices or 4 or more consecutive 4 mm sagittal slices demonstrating continuity of the anterior and posterior horns. This is termed the "bowtie" appearance.[26] In a retrospective review of discoid lateral meniscus, an associated meniscal tear was present in 70% of all knees studied via arthroscopic examination.[20,27] MRI diagnostic studies for discoid lateral meniscus reported a 75% sensitivity and 50% specificity for the identification of tears in a discoid lateral meniscus and found that the diagnosis of a tear on MRI has a low correlation with arthroscopic findings[28] (Figs. 1A, B). A more systemic evaluation, such as that used with the PRiSM classification system, can aid in the assessment, diagnosis, and treatment plan for a patient with discoid lateral meniscus.[21,23]

MECHANISM OF INJURY

The mechanism of injury is most commonly hyperextension, twisting, or cutting with the foot planted or a direct blow to the knee. Meniscal injuries are also often found after an ACL injury when the meniscus becomes caught between the distal femur and proximal tibia due to the rotation and anterior translation of the tibia relative to the femur. A valgus force to the knee, which can also cause an ACL injury, is often noted with lateral meniscus tears due to the posterior horn and body being squeezed between the tibia and femur. In addition, meniscal tear, displacement, and entrapment are frequently associated with femoral shaft fractures, tibial plateau fractures, and tibial spine avulsion fractures.[15]

HISTORY AND PHYSICAL EXAM

In young patients, sports-related injuries to the meniscus account for more than one third of all cases of meniscal tears.[29] A thorough history after trauma should include the mechanism of injury, location of pain, and any mechanical symptoms of locking, clicking, catching, giving way, or buckling.[30]

A comprehensive physical exam should be done after obtaining a history. The physical exam should include inspection for knee swelling, erythema, bruising, effusions, masses, muscular development, patellar location and mobility, and total leg length, and should always be done in comparison to the uninjured knee. The knee should then be examined for range of motion and palpated for tenderness, warmth, masses, and circulatory status.[31] When meniscal pathology is suspected, exam maneuvers such as the McMurray test, Joint Line Tenderness test, Thessaly test, Apley test, and Ege test may be considered for screening. A comprehensive hip exam should also be conducted to rule out referred knee pain from hip pathology.

TREATMENT: NONOPERATIVE MANAGEMENT

Once the meniscal tear has been identified, multiple factors determine the next step in management. The surgeon considers the duration of symptoms, associated injuries, meniscal tear size, and meniscal tear location. Occasionally, an MRI will be obtained that shows an incomplete discoid meniscus without a tear. Nonoperative management is generally recommended for incidental findings of a discoid meniscus. In pediatric patients with small, isolated, peripheral, nondisplaced tears in the lateral meniscus, nonoperative management may be appropriate based on adult literature that shows good results in partial tears, tears with less than 3 mm of displacement, and longitudinal tears <10 mm in length.[1,32] Risk factors for failure of nonoperative treatment of meniscus tears left alone during an ACL Reconstruction included medial meniscus tears and younger patient age.[33]

Nonoperative treatment should include limited weight-bearing, immobilization, pain control, and rehabilitation.[34] At the time of injury, limiting weight-bearing and immobilizing the knee will help pain control and allow the patient to be ambulatory. A hinged knee brace or knee immobilizer will help with activity restrictions. Ice and anti-inflammatories will help decrease swelling and allow the patient to be comfortable. As pain and swelling subsides, the patient may start rehabilitation focusing on gait training, range of motion, and neuromuscular control. As the patient progresses back to activities, rehabilitation can focus on strengthening and return to sports training. Once the patient returns to full activities, there is no evidence of functional knee bracing to limit the risk of meniscal reinjury. Nonoperative treatment generally takes 12 weeks to return to cutting and pivoting sports.

TREATMENT: SURGICAL MANAGEMENT

Meniscectomy

If the decision is made for surgical management, meniscal preservation should be prioritized. While meniscal repair is generally encouraged, occasionally, meniscal tears may not be amenable to repair, and resection of the tear must be pursued. Chronic bucket-handle meniscus tears and oblique flap tears often will not reduce back to an anatomic location due to degeneration and remodeling. Because of poor tissue quality and nonanatomic reduction, a repair will likely fail, necessitating a partial meniscectomy. Radial tears with the complete location of the meniscal flaps in the white-white zone have poor healing potential after a repair attempt. Complex tears, often associated with a complete discoid meniscus, will require saucerization before encountering the meniscal tear, which may be multidirectional. Occasionally meniscal repair is still required in conjunction with saucerization of the discoid meniscus.

Historically, meniscectomy was done through an open approach, and a complete meniscectomy was performed, which led to poor results.[35] With improved arthroscopic techniques, partial meniscectomy is performed to preserve as much meniscus as possible to improve outcomes. Arthroscopy in the pediatric patient can safely be done with a standard 4.0 mm arthroscope. Traditional medial and lateral portals next to the patella tendon are used for standard knee arthroscopy. If the meniscus tear is deemed to be irreparable, partial meniscectomy is performed using an appropriately sized arthroscopic shaver and meniscal biters.

Care is taken to avoid iatrogenic cartilage damage and over-resection of the healthy meniscus.

Special consideration is needed for the saucerization of a complete discoid meniscus. For visualization, the traditional 30-degree arthroscope may have difficulty visualizing the anterior horn of the lateral meniscus. Occasionally, switching to a 70-degree arthroscope or moving the 30-degree arthroscope to the medial portal is needed to truly evaluate the anterior horn of the lateral discoid meniscus. A complete discoid meniscus is typically hard to initially evaluate due to it being twice the normal size, pressed up against the ACL, and blocking access to the lateral joint. Since the discoid meniscus is thicker than a normal meniscus, a biter may not open wide enough, and the shaver usually will not grab the meniscus unless there is a tear. Arthroscopic scissors are an excellent instrument to start the saucerization process. The saucerization is easiest to start anterior next to the ACL. Multiple angled biters are usually necessary to saucerize the body and anterior horn of the discoid meniscus. The anterior horn is the hardest part of the discoid meniscus to saucerize, so a 90-degree biter through the medial portal or a back biter and 11 blade through the lateral portal is sometimes necessary to perform the anterior horn saucerization. After saucerization has been performed, resection of the central component of the discoid meniscus will allow evaluation of inner body tears that require either further meniscectomy or possible meniscal repair. Incomplete discoid meniscus tears typically present as oblique flap tears that are amenable to resection through partial meniscectomy.

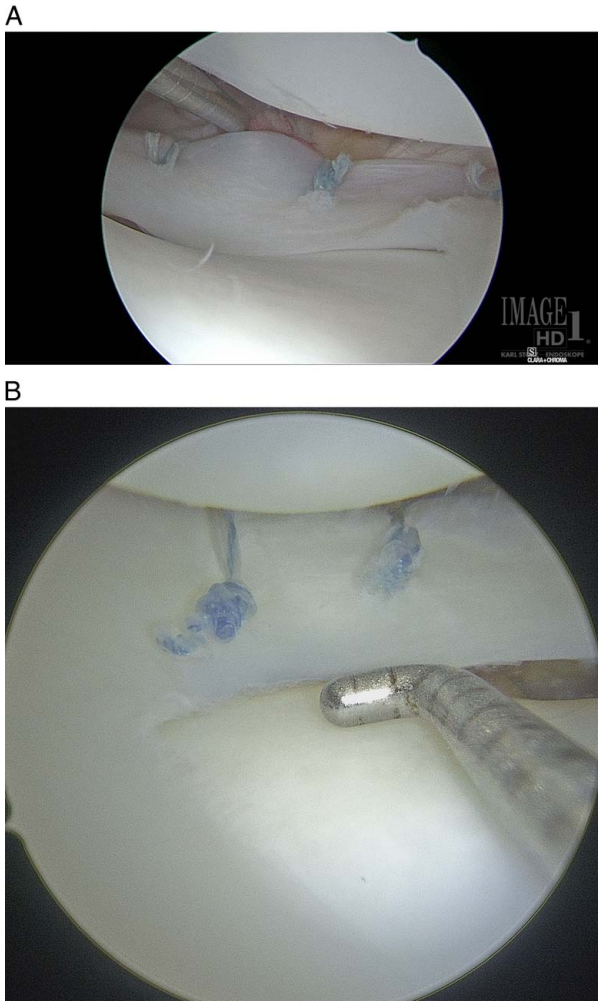

FIGURE 2. A, All-inside repair with capsular fixation technique. B, All-inside repair with knot-tying technique.

Inside-out Meniscus Repair

The gold standard of meniscus repair historically was the arthroscopic inside-out meniscus repair. The repair involves passing a suture through the meniscus and out the capsule of the knee joint. Inside-out meniscal repair is primarily used for bucket-handle meniscal tears and radial body meniscal tears. A secondary incision is needed to allow for the protection of peroneal nerve laterally and the saphenous nerve medially. A protective instrument is usually placed through the incision to aid in needle passage and protect the relevant neurovascular structures. Zone-specific cannulas placed through the arthroscopic portal are necessary to access the entire meniscus. The suture is usually attached to a long, flexible needle that facilitates passage through the cannula in the knee joint. Sutures are typically placed in a vertical mattress fashion for a bucket-handle meniscus tear repair and in a horizontal mattress fashion for a radial meniscus tear repair. Vertical mattress sutures are placed on the superior and inferior surface of the meniscus to allow for circumferential compression. The suture is then tied outside the knee joint over the capsule to secure the meniscal tear. Suture tensioning is done while visualizing the repair through the knee joint to avoid over-tensioning or under-tensioning the repair. A well-qualified assistant is necessary to help with the procedure when it comes to suture retrieval and protection of the neurovascular structures.

All-inside Meniscus Repair

As instrumentation and single-use meniscus repair devices have improved, the all-inside meniscus repair technique has grown in popularity. All-inside meniscal repair allows the surgeon to perform the procedure without the need for a qualified assistant and avoids the secondary incision. Results from a systematic review of all-inside versus inside-out meniscus repairs show no difference in healing or functional outcomes.[36] Decreased operative time has been reported with all-inside meniscus repairs.[36]

The first type of all-inside meniscus repair is done with a single-use meniscus repair device that is dependent on capsular fixation to secure the suture (Fig. 2A). Vertical posterior horn meniscal tears are the ideal tear pattern for all-inside capsular meniscus repair fixation. A spinal needle through the arthroscopic portal allows for trephination of the capsule of the knee, which may aid in meniscal healing. A meniscal rasp instrument may also be used to stimulate healing before repair. A sled device is used to ease the passage of the pointed tip of the device through the soft tissues of the knee joint and to protect against iatrogenic cartilage damage from the tip of the implant. When inserting the tip of the implant device into the meniscus, the tip should be angled away from important neurovascular structures.[37] When deploying the capsule fixation device, knee flexion will move the neurovascular structures away from the joint capsule. Patient size and meniscal pathology should determine the depth of the penetration of the device to avoid complications in the pediatric patient.[38] Once the device has been completely deployed, the suture is tensioned

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to secure the meniscus tear. Proprietary devices are now made with different angulation of the implant tip to allow placement of sutures on the superior and inferior surfaces of the meniscus. Horizontal tears in the discoid meniscus often require circumferential suture placement in a hay bale technique pattern to compress the superior and inferior leaflets of the discoid meniscus tear.

The second type of all-inside meniscus repair involves suture passage through the meniscus and tying standard arthroscopic knots (Fig. 2B). Horizontal meniscus tears that require circumferential compression and vertical meniscus tears anterior to the popliteus are ideal patterns for this type of all-inside meniscus repair. A suture-passing device is used to shuttle a free suture through the inferior surface of the meniscus and out the superior surface of the meniscus. The suture is then tied with arthroscopic knots to secure the meniscus inside the knee joint.

Outside-In Meniscus Repair

The outside-in meniscus repair technique is ideal for anterior discoid meniscus tears or bucket-handle tears that are too anterior for all inside-out repair. The arthroscope is moved to the contralateral portal of the meniscus tear to allow for improved anterior visualization. An initial spinal needle is used to allow passage of suture through the meniscus into the joint. A second spinal needle is used to retrieve the suture through the meniscus to bring it out of the joint. Since the repair is anterior and away from the neurovascular structures, capsular knot-tying can be done through a small secondary incision.

Meniscal Root Repair

Meniscus root tears of the lateral meniscus typically occur with an ACL injury while posterior medial root avulsions are more likely to occur with contact and multiligament knee injuries.[39] If the repair is performed with an ACL or PCL surgery, tunnel placement should be performed to avoid any convergence of tibial tunnels. Visualization with a 70-degree camera, notch-plasty, or tibial spine-plasty is necessary to improve visualization of the posterior root (Fig. 3A). A suture passing device is used to pass luggage tag sutures into the meniscus root for repair (Fig. 3B). A meniscus root tibial guide is used to place a small tibial tunnel into the meniscus root footprint. The tunnel allows for the passage of the luggage tag sutures down to the anterior tibial cortex. The sutures may be tensioned while looking with the arthroscope and secured to the tibial cortex to repair the meniscus root (Fig. 3C).

Postoperative Rehabilitation

Rehabilitation protocols are usually determined by meniscectomy versus surgical repairs. Patients undergoing partial meniscectomy are usually allowed to perform weight-bearing and knee range of motion as tolerated without a brace.[40] Meniscus repair rehab protocols vary widely and are often based on surgeon preference due to the type of repair performed.[34] Typically, a brace will be used for 4 to 6 weeks to limit deep flexion since that puts the most compression on the posterior horns of the medial and lateral meniscus.[41] Early protected weight-bearing is usually allowed since the physiologic loading may cause compression at the repair site in longitudinal tear patterns.[42] We recommend leaving the rehabilitation up to the individual surgeon based on the tenuousness of the repair and the comfort of the physical therapist.

Complications

Complications after pediatric meniscal surgery may include infection, deep venous thrombosis (DVT), implant complications, and neurovascular damage. Infection and DVT are rare in the pediatric population but do occur. The rate of DVT after knee arthroscopy is 0.25% the first 90 days after knee arthroscopy in the adult population.[43] All-inside meniscus repair can result in hardware irritation and chondral damage due to implant breakage, migration, and malposition.[36]

Neurovascular damage is at the highest risk with posterior horn lateral meniscus repairs.[36] Both inside-out and all-inside posterior horn lateral meniscus repairs put the peroneal nerve and popliteal bundle at risk in the pediatric patient.[38] During an all-inside lateral meniscus repair, the meniscal repair device may be as close to the peroneal nerve as 3.2 mm and as close to the popliteal artery as 1.9 mm.[37] As pediatric patients age and approach skeletal maturity, the distance to these important structures does increase.[38,44] The saphenous nerve is also at risk with inside-out repairs of the medial meniscus.

Treatment Outcomes

Long-term outcome studies have shown largely poor results with meniscectomy in pediatric patients. A long-term follow-up study of 16.8 years' post-op showed 36% of pediatric patients had decreased range out motion, 45% suffered grade 1 instability, and 89% of knees showed joint space narrowing after meniscectomy.[45] It has also been noted that 80% of meniscectomy patients will have radiographic signs of early arthritis at 5.5 years after surgery.[34]

Meniscus repair is generally associated with better results. Repairs of simple meniscus tears result in no pain, no mechanical symptoms, and no further surgery 80% of the time.[46] Patients with open physes seemed to have better clinical results with meniscus repair compared with skeletally mature patients.[47] Repair of medial meniscus tears seems to heal at a lower rate than lateral meniscus tears.[46] Complex meniscus tears were reported to heal only 13% of the time, but that improved to 57% when repair was performed at the same time as ACL Reconstruction.[46,48] One study showed that repair of the meniscus in the white-white zone of pediatric patients has similar healing rates as repair in the red-red zone.[47]

CONCLUSIONS

Meniscus tears are pediatric knee injuries most commonly associated with sporting injuries. The increased blood supply to the meniscus in pediatric patients makes them good repair candidates due to the increased healing potential. Meniscectomy is necessary for irreparable meniscus tears and saucerization of the discoid meniscus, but the long-term results are poor compared with meniscus repair. There are multiple techniques for meniscus repair that should be tailored by the surgeon to the type and location of the meniscus tear. Good results with meniscus repair have been found when using the correct repair technique. Rehabilitation after meniscus surgery varies widely and is usually dependent on the type and location of the meniscal repair. Successful outcomes after meniscus repair are improved with younger age, lateral meniscus tears, simple tear pattern, peripheral tears, and concurrent ACL reconstruction.

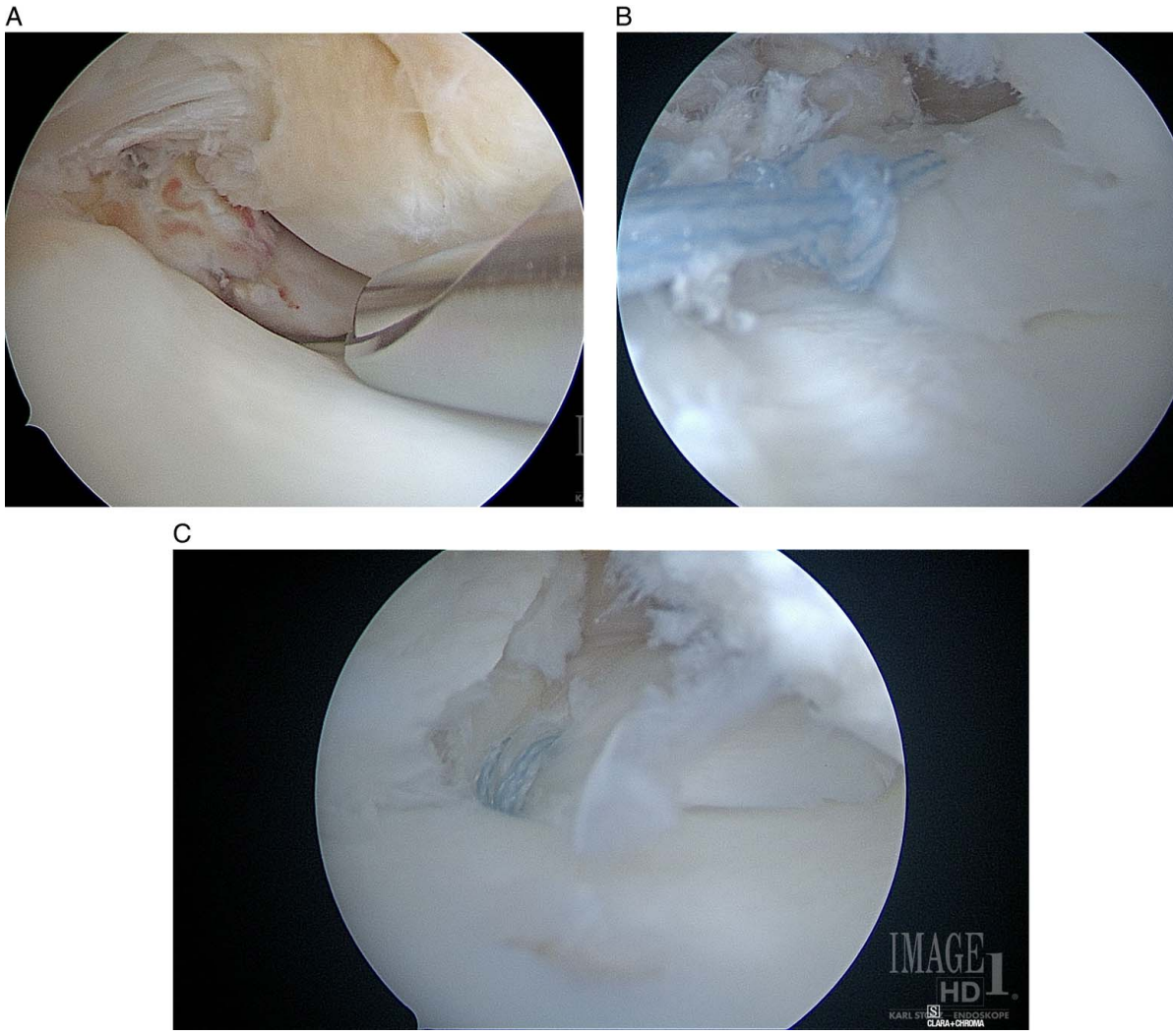

FIGURE 3. A, Medial meniscus root tear. B, Luggage tag sutures placed through the posterior root. C, Repaired posterior medial meniscus root.

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REFERENCES

1. Chambers HG, Chambers RC. The natural history of meniscus tears. *J Pediatr Orthop*. 2019;39(Suppl 1):S53–S55.
2. Gee SM, Tennent DJ, Cameron KL, et al. The burden of meniscus injury in young and physically active populations. *Clin Sports Med*. 2020;39:13–27.
3. Lee WQ, Gan JZ, Lie DTT. Save the meniscus - Clinical outcomes of meniscectomy versus meniscal repair. *J Orthop Surg (Hong Kong)*. 2019;27:1–14. doi:10.1177/2309499019849813
4. Tsujii A, Nakamura N, Horibe S. Age-related changes in the knee meniscus. *Knee*. 2017;24:1262–1270.
5. Mosich GM, Lieu V, Ebramzadeh E, et al. Operative treatment of isolated meniscus injuries in adolescent patients: a meta-analysis and review. *Sports Health*. 2018;10:311–316.
6. Yang BW, Liotta ES, Paschos N. Outcomes of meniscus repair in children and adolescents. *Curr Rev Musculoskelet Med*. 2019; 12:233–238.
7. Shieh A, Bastrom T, Roocroft J, et al. Meniscus tear patterns in relation to skeletal immaturity: children versus adolescents. *Am J Sports Med*. 2013;41:2779–2783.
8. Bellisari G, Samora W, Klingele K. Meniscus tears in children. *Sports Med Arthrosc Rev Mar*. 2011;19:50–55.
9. Andrish JT. Meniscal injuries in children and adolescents: diagnosis and management. *J Am Acad Orthop Surg*. 1996;4:231–237.
10. Gee SM, Posner M. Meniscus anatomy and basic science. *Sports Med Arthrosc Rev*. 2021;29:e18–e23.
11. Markes AR, Hodax JD, Ma CB. Meniscus form and function. *Clin Sports Med*. 2020;39:1–12.
12. Rath E, Richmond JC. The menisci: basic science and advances in treatment. *Br J Sports Med*. 2000;34:252–257.
13. Clark CR, Ogden JA. Development of the menisci of the human knee joint. Morphological changes and their potential role in childhood meniscal injury. *J Bone Joint Surg Am*. 1983; 65:538–547.
14. Fox AJ, Wanivenhaus F, Burge AJ, et al. The human meniscus: a review of anatomy, function, injury, and advances in treatment. *Clin Anat*. 2015;28:269–287.
15. Trunz LM, Morrison WB. MRI of the knee meniscus. *Magn Reson Imaging Clin N Am*. 2022;30:307–324.
16. Aman ZS, DePhillipo NN, Storaci HW, et al. Quantitative and qualitative assessment of posterolateral meniscal anatomy:

defining the popliteal hiatus, popliteomeniscal fascicles, and the lateral meniscotibial ligament. *Am J Sports Med*. 2019;47: 1797–1803.
17. Arnoczky SP, Warren RF. Microvasculature of the human meniscus. *Am J Sports Med*. 1982;10:90–95.
18. Fox AJ, Bedi A, Rodeo SA. The basic science of human knee menisci: structure, composition, and function. *Sports Health*. 2012;4:340–351.
19. Kocher MS, Logan CA, Kramer DE. Discoid lateral meniscus in children: diagnosis, management, and outcomes. *J Am Acad Orthop Surg*. 2017;25:736–743.
20. Saavedra M, Sepúlveda M, Jesús Tuca M, et al. Discoid meniscus: current concepts. *EFORT Open Rev*. 2020;5:371–379.
21. Niu EL, Lee RJ, Joughin E, et al. Discoid Meniscus. *Clin Sports Med*. 2022;41:729–747.
22. Watanabe M, Takeda S, Ikeuchi H. *Atlas of Arthroscopy*. 2nd ed. Igaku Shoin, Tokyo; 1969.
23. Niu EL, Milewski MD, Finlayson CJ, et al. Reliability of MRI interpretation of discoid lateral meniscus: a multicenter study. *Orthop J Sports Med*. 2023;11:1–15. doi:10.1177/23259671231174475
24. Atay OA, Pekmezci M, Doral MN, et al. Discoid meniscus: an ultrastructural study with transmission electron microscopy. *Am J Sports Med*. 2007;35:475–478.
25. Dickhaut SC, DeLee JC. The discoid lateral-meniscus syndrome. *J Bone Joint Surg Am*. 1982;64:1068–1073.
26. Tyler PA, Jain V, Ashraf T, et al. Update on imaging of the discoid meniscus. *Skeletal Radiol*. 2022;51:935–956.
27. Klingele KE, Kocher MS, Hresko MT, et al. Discoid lateral meniscus: prevalence of peripheral rim instability. *J Pediatr Orthop*. 2004;24:79–82.
28. Hampton M, Hancock G, Christou A, et al. Clinical presentation, MRI and clinical outcome scores do not accurately predict an important meniscal tear in a symptomatic discoid meniscus. *Knee Surg Sports Traumatol Arthrosc*. 2021; 29:3133–3138.
29. Makris EA, Hadidi P, Athanasiou KA. The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. *Biomaterials*. 2011;32:7411–7431.
30. Rothenberg MH, Graf BK. Evaluation of acute knee injuries. *Postgrad Med*. 1993;93:75–82.
31. Roberts DM, Stallard TC. Emergency department evaluation and treatment of knee and leg injuries. *Emerg Med Clin North Am*. 2000;18:67–84.
32. Weiss CB, Lundberg M, Hamberg P, et al. Non-operative treatment of meniscal tears. *J Bone Joint Surg Am*. 1989;71: 811–822.
33. Duchman KR, Westermann RW, Spindler KP, et al. The fate of meniscus tears left in situ at the time of anterior cruciate ligament reconstruction: a 6-year follow-up study from the MOON cohort. *Am J Sports Med*. 2015;43:2688–2695.
34. Shi B, Stinson Z, Nault ML, et al. Meniscus repair in pediatric athletes. *Clin Sports Med*. 2022;41:749–767.
35. Abdon P, Turner MS, Pettersson H, et al. A long-term follow-up study of total meniscectomy in children. *Clin Orthop Relat Res*. 1990:166–170.
36. Grant JA, Wilde J, Miller BS, et al. Comparison of inside-out and all-inside techniques for the repair of isolated meniscal tears: a systematic review. *Am J Sports Med*. 2012;40: 459–468.
37. Yen YM, Fabricant PD, Richmond CG, et al. Proximity of the neurovascular structures during all-inside lateral meniscal repair in children: a cadaveric study. *J Exp Orthop*. 2018;5:50.
38. Shea KG, Dingel AB, Styhl A, et al. The position of the popliteal artery and peroneal nerve relative to the menisci in children: a cadaveric study. *Orthop J Sports Med*. 2019;7:1–12.
39. Wilson PL, Wyatt CW, Romero J, et al. Incidence, pesentation, and treatment of pediatric and adolescent meniscal root injuries. *Orthop J Sports Med*. 2018;6:1–13.
40. Koch M, Memmel C, Zeman F, et al. Early functional rehabilitation after meniscus surgery: are currently used orthopedic rehabilitation standards up to date. *Rehabil Res Pract*. 2020;2020:3989535.
41. Vedi V, Williams A, Tennant SJ, et al. Meniscal movement. *An in-vivo study using dynamic MRI J Bone Joint Surg Br*. 1999;81:37–41.
42. McCulloch PC, Jones HL, Hamilton K, et al. Does simulated walking cause gapping of meniscal repairs? *J Exp Orthop*. 2016;3:11.
43. Maletis GB, Inacio MC, Reynolds S, et al. Incidence of symptomatic venous thromboembolism after elective knee arthroscopy. *J Bone Joint Surg Am*. 2012;94:714–720.
44. Schachne JM, Heath MR, Yen YM, et al. The safe distance to the popliteal neurovascular bundle in pediatric knee arthroscopic surgery: an age-based Magnetic Resonance Imaging Anatomic Study. *Orthop J Sports Med*. 2019;7:1–13.
45. Manzione M, Pizzutillo PD, Peoples AB, et al. Meniscectomy in children: a long-term follow-up study. *Am J Sports Med*. 1983;11:111–115.
46. Krych AJ, McIntosh AL, Voll AE, et al. Arthroscopic repair of isolated meniscal tears in patients 18 years and younger. *Am J Sports Med*. 2008;36:1283–1289.
47. Vanderhave KL, Moravek JE, Sekiya JK, et al. Meniscus tears in the young athlete: results of arthroscopic repair. *J Pediatr Orthop*. 2011;31:496–500.
48. Krych AJ, Pitts RT, Dajani KA, et al. Surgical repair of meniscal tears with concomitant anterior cruciate ligament reconstruction in patients 18 years and younger. *Am J Sports Med*. 2010;38:976–982.