Surgical Management of Meniscal Tears

Theodore Shybut, M.D., and Eric J. Strauss, M.D.

Abstract

The menisci have an essential function in force transmission across the knee. Injuries to the menisci are common. The indications for repair should be expanded, as the results of partial meniscectomy may deteriorate over time. Tears in younger, higher demand patients should be prepared to optimize the healing environment and be meticulously repaired, particularly in the setting of concurrent anterior cruciate ligament reconstruction. For complex, recurrent, or avascular zone tears, particularly when surgery is limited to meniscal work, consideration can be given to augmenting the repair with a fibrin clot or platelet rich plasma. Partial meniscectomy is a suitable option for lower demand or older patients. Meniscal allograft transplantation is a salvage procedure.

Meniscal pathology remains a commonly encountered clinical entity for the practicing orthopaedic surgeon. In Clayton and Court-Brown’s recent prospective study of musculoskeletal injuries, meniscal injury to the knee was the most common, occurring at a rate of 23.8/100,000 per year. According to the American Academy of Orthopaedic Surgeons, the incidence in the United States is, 61/100,000. These injuries are especially frequent in athletes who participate in high demand cutting sports, particularly soccer, football, and basketball. There are over 636,000 knee arthroscopies performed annually in the USA, and arthroscopic treatments of meniscal injuries are among the most common orthopaedic procedures performed, constituting 10% to 20% of all surgeries at some centers. Surgery is increasingly the choice management for younger patients, athletes, and acute tears. Operative treatments for meniscal injuries have evolved in tandem with our understanding of the structure, function, and biology of the meniscus. This paper will trace the development of meniscal surgery from total meniscectomy to partial meniscectomy, evolving methods of repair, meniscal scaffold implants, and allograft transplantation. This discussion will focus on the treatment of tears in non-arthritic knees. The purpose of this discussion is to call attention to the shortcomings of partial meniscectomy and, therefore, to direct attention toward promising areas of development in meniscal surgery.

The menisci are two semilunar biconcave disks that reside within the medial and lateral tibio-femoral articulations (Fig. 1). The medial meniscus is longer in the anterior-posterior direction than in the medial-lateral direction. It is attached to the deep medial collateral ligament, which renders it less mobile than the lateral meniscus and more prone to tears. It is a secondary stabilizer of the knee against anterior instability, and thus is commonly torn in anterior cruciate ligament deficient knees. The lateral meniscus has a more circular shape. It is more mobile than its medial counterpart, and it covers a greater portion of the articular cartilage. The lateral meniscus is more commonly torn in association with acute anterior cruciate ligament ruptures.

Under the microscope, the meniscus is composed of dense fibrocartilage and sparsely populated with cells called fibrochondrocytes because they exhibit characteristics of both fibroblasts and chondrocytes. These cells synthesize and maintain the extracellular matrix, which is primarily

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(90% to 95%) type I collagen. The major collagen bundles are oriented circumferentially and are bound together with radial or transverse ties. The other components of the extracellular matrix include proteoglycans, elastin, small amounts of other collagen types, and water.6

**Total Meniscectomy**

Historically, treatment of meniscus tears was complete excision. The meniscus was regarded as “…functionless remnants of intra-articular leg muscles” according to Bland-Suttons’ then authoritative *Ligaments and Their Morphology*,7 published in 1897. Likewise, McMurray8 wrote in his 1940 text *The Semilunar Cartilages*, “The cause of failure of meniscal removal lies in the failure to remove the entire affected cartilage.” In 1948, Fairbanks9 published what is now a landmark article, in which he described characteristic radiographic changes following meniscectomy. Specifically, he noted that radiographs of meniscus deficient knees demonstrated narrowing of the joint space, flattening of the femoral condyle, and ridge (peripheral osteophyte) formation. While it is apparent now that these so-called Fairbanks changes reflect derangement of the tibiofemoral articulation due to meniscal deficiency, Fairbanks noted in his conclusion that, “It seems likely that narrowing of the joint space will predispose to degenerative changes, but a connection between these appearances and later osteoarthritis is not yet established and is too indefinite to justify clinical deductions.”9 Subsequently, throughout a large part of the 20th century, orthopaedic surgeons performed open total meniscectomies for torn menisci. Short-term results reported in the literature at that time were favorable, with high rates of return to heavy labor and athletic competition without ill effects.10

As longer term follow-up emerged in patients who had undergone total meniscectomy, it became increasingly clear to surgeons that the results were unfavorable. Tapper and Hoover from the Mayo clinic reported 10- to 30-year retrospective follow-up on 213 patients and found only 68% had good or excellent results. Only 38% of operative knees were asymptomatic. The investigators did note that bucket-handle tears in which the peripheral rim was preserved had a higher rate of excellent outcomes.11 Along those lines, Johnson and colleagues12 found that 74% of post-meniscectomy knees had at least one Fairbanks change and 39.4% had degenerative arthritis, as compared to 6% of contralateral normal knees. They reported that unsatisfactory results increased with increasing Fairbanks changes, and this correlation was significant. Additionally, they found that results for lateral meniscectomy were significantly worse than for medial meniscectomy, and resection of both menisci produced results significantly worse than either isolated medial or lateral meniscectomy. Yocum and coworkers13 found only 54% satisfactory results at 7-year follow-up in normal, stable knees. Of note 20 out of 26 of these patients had lost motion.13 Ahmed and Burke’s testing of cadaveric knees showed the medial meniscus transmits 50% of the force across the tibiofemoral articulation, while the lateral meniscus transmits 70%. In flexion, the meniscal load increases to 85%. With total meniscectomy, they found an increase in tibiofemoral contact forces of 100% to 200%.14

**Partial Meniscectomy**

The development of arthroscopic surgical instruments and techniques facilitated a movement toward meniscus preserving surgery. Rather than resection of the entire meniscus, partial meniscectomy became a mainstay of treatment for symptomatic tears (Fig. 2). Short-term results of partial meniscectomy are excellent. Jarequito and associates15 reported 90% good and excellent outcomes at 2-years follow-up, with 85% of patients returning to their desired activity level. At 8

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Figure 1 Medial meniscus.

Figure 2 Partial meniscectomy.
years, though, these results had declined to only 62% good or excellent outcomes, and only 48% of patients maintained their desired activity level. In a longer-term study, Burks and colleagues reported 88% good and excellent results after 15 years follow-up. They also reported that results were not significantly different for medial versus lateral tears. Patients with valgus as opposed to varus alignment had better results after partial medial meniscectomy. Radiographic examinations demonstrated a 0.24% mean decline in osteoarthritis grade. Of note, their study population consisted of low-demand patients. Along those lines, Lee and coworkers found in a biomechanical study that even partial meniscectomy significantly affected force transmission. They tested intact knees at 0°, 30°, and 60° of flexion and then performed serial sectioning of the posterior horn of the medial meniscus, with repeat testing after each incremental removal of meniscal tissue. They found that all meniscectomy conditions produced decreased tibiofemoral contact area and increased mean and peak contact forces compared to the intact knee; they concluded that surgical intervention should aim to preserve as much meniscus as possible. The results of a recent imaging study is further evidence of the inadequacy of partial meniscectomy in avoiding deterioration of the tibiofemoral articulation. In this study, magnetic resonance imaging (MRI) of asymptomatic patients 5 years after isolated partial meniscectomy demonstrated high rates of radiographic degenerative changes in knees with intact cartilage at the time of surgery. Thus, there is biomechanical and clinical evidence suggesting that partial meniscectomy is better than total meniscectomy but still has significant shortcomings in failing to correct the abnormal biomechanics that predispose to radiographic and clinical knee degeneration.

**Meniscal Repair**

As surgeons developed familiarity with arthroscopic surgical techniques, some began investigating the possibility of meniscal repair in an effort toward meniscal preservation. Arnozcky and Warren performed a series of vascular injection studies using Spalteholz technique in human cadaveric menisci. They found that the peripheral 10% to 25% of the meniscus was well vascularized by a pericapsular plexus and that the major arterial supply comes from the lateral, medial, and middle geniculate arteries. In addition, there is a synovial fringe that overhangs the meniscus but does not anastamose with its circulation. We now frequently refer to this vascular peripheral meniscus as the red-red zone, while the central-most avascular region is termed white-white. The border region between the two is termed red-white to reflect that, while it is not directly vascularized, it is in relative proximity to the blood supply.

A year after characterizing the vascular supply of the human meniscus, Arnozcky and Warren published their results of related experiments in canines. They created meniscal injuries in dogs and studied the response to injury.

![Figure 3 Inside-out repair.](image)

Their observations included similar dye injection studies. They found that peripheral zone tears healed in 10 weeks with an associated proliferation of the perimeniscal plexus and fibrovascular scar formation. In addition, they found that avascular zone tears with extension out to the vascular periphery also healed. Zheng and associates utilized a goat model of meniscal tears repaired with suture to examine the effect of trephination. They found that suture alone of avascular zone tears resulted in poor healing. However, suture repair of avascular zone tears in tandem with trephination of the peripheral tissue resulted in partial or complete healing in all cases.

Attempts at operative meniscal repair followed these studies showing meniscal healing potential as well as from biomechanical studies, such as that of Baratz and colleagues, which showed even partial loss of meniscal tissue significantly altered force transmission across the knee. Scott and coworkers and Cannon developed inside-out repair techniques (Fig. 3). Warren first described the outside-in repair, which has subsequently undergone several modifications. Morgan described an all-inside repair technique utilizing arthroscopic knots. Subsequently, orthopaedic device manufacturers have developed several generations of implants that facilitate all-inside repair. Based on the early experience with repair attempts, orthopaedic surgeons developed criteria for assessing which tears are amenable to repair, that is, which tears had the potential to heal. According to Dehaven, considerations include tear location, tear type and configuration, tear size, and tear stability. Peripheral location is key, as these tears are in the vascular zone, and therefore have the best biological potential for healing. Cannon and Vittori reported 90% healing rates for tears less than 2 mm from the periphery, as compared to 50% for tears with 4 to 5 mm rim width and 74% for those within 3 mm. In addition,
they found significantly increased repair success when the tears were relatively acute. Vertical-longitudinal tear types are most amenable to repair, as are tears longer than 8 to 10 mm. Hanks and Kalenak described stability as inability to displace the tear more than 3 mm with an arthroscopic probe.

Outcomes of repairs based on these criteria have been favorable. Horibe and colleagues reported 73% complete healing and 17% partial healing on second look arthroscopy in 132 of 256 consecutive meniscal repairs. The investigators also noted 21 new tears and that tears near the popliteal hiatus had a higher rate of incomplete healing. Cannon and Vittori reported significantly higher healing rates (93%), as assessed by arthroscopy or arthrography at 7 months, when meniscal repair was performed concurrently with anterior cruciate ligament reconstruction. Turman and Diduch’s recent review of the literature found isolated repairs are successful 60% to 80% of the time and repairs with concurrent anterior cruciate ligament reconstruction are 90% successful. Numerous biomechanical studies have shown that vertical mattress suture is the strongest repair construct when compared to other suture configurations or to meniscal repair devices.

Results of repairs with early iterations of all-inside repair devices were inconsistent. For example, Gill and Diduch reported 90.6% success with the meniscal arrow at a mean 2.3-year follow-up for repairs performed in conjunction with anterior cruciate reconstruction. Longer-term follow-up of this cohort showed that these results deteriorated to 71.4% at 6.6 years. In addition, the literature contains reports of chondral and neurovascular injuries, as well as implant breakage, migration, inflammatory reaction, and failure re-

Figure 4 For meniscal allograft implantation, the allograft is prepared on the back table (A), and its bone bridge is sized (B). The allograft is then inserted using a slot technique (C) and fixed using an inside-out meniscal repair technique (D).
sulting from these devices. More recent short-term outcomes with newer generation devices have been better and success rates are comparable to repair with suture.\textsuperscript{36} However, devices remain a costly alternative to suture repair, and multiple investigators have affirmed that inside-out repair remains the gold standard.\textsuperscript{31} In summary, meniscal tears that meet conventional indications for repair have favorable outcomes when meticulously repaired.

The major challenge, therefore, is how to deal with more central tears. We have seen that partial meniscectomy offers a short-term solution, but biomechanical, radiologic, and clinical outcome evidence suggests that resultant abnormal force transmission across the knee results in declining function and knee health over time. Consideration, therefore, ought to be given to a more aggressive approach with regard to meniscal repair. Rubman and coworkers\textsuperscript{37} have reported their results of repairs of meniscal tears extending into the avascular zone, including complex and radial tears. In the largest series, 198 inside-out repairs were assessed at a mean of 42 months. Overall, 80\% of patients had no tibiofemoral symptoms. The other 20\% had received additional surgical intervention. Of patients who had second-look arthroscopy, 25\% had healed completely, and 38\% had partially healed.\textsuperscript{37} The investigators reported that for patients less than 20 years old, 75\% were asymptomatic at a mean 41-month follow-up, and for those who had concurrent anterior cruciate reconstruction, 87\% had normal or very good outcome.\textsuperscript{38} For patients over 40 years of age, 87\% were asymptomatic, and 75\% felt subjectively normal or very good.\textsuperscript{39} Of particular note is that their surgical technique included inducing subchondral bleeding in the femoral notch using a microfracture pick. Boyd and Myers\textsuperscript{40} further support the concept that repair of complex and avascular zone tears may be successful. In their technical report on repairing such tears, including horn avulsions, double longitudinal tears, radial tears, and re-tears, they observed that their own experience in nearly 300 tears was that less than 10\% re-tore following repair. Again, the investigators emphasized the importance of adequate preparation of the rim and meticulous inside-out repair with sutures. They further noted that delaying rehabilitation to allow adequate time for meniscal healing was a key part of their treatment.\textsuperscript{40}

These reports emphasize that providing a biological environment that promotes healing of meniscal tears is critical to the success of repair. Henning and associates\textsuperscript{41} supported this concept with their fibrin clot work. For isolated tears they reported a 41\% repair failure, as compared to 8\% failure rate when a fibrin clot was incorporated into the repair.\textsuperscript{41} Bhar- gava and colleagues\textsuperscript{42} showed in a canine model that platelet derived growth factor (PDGF) stimulates DNA synthesis and cellular migration in all zones of the meniscus. In addition to PDGF, platelets have been shown to release a number of growth factors when activated, including platelet derived epidermal growth factor, transforming growth factor beta, insulin-like growth factor, and vascular endothelial growth factor.\textsuperscript{43} Recently, techniques for concentrating platelets as platelet-rich plasma have become commercially available. Ishida and coworkers\textsuperscript{44} showed that placement of a platelet-rich gel into avascular zone tears in rabbits significantly improved healing on histologic examination. They also found significant increased mRNA expression of extracellular matrix proteins biglycan and decorin and concluded that PRP appears to enhance the healing of meniscal defects.\textsuperscript{44} Investigators have begun a number of preclinical and clinical trials examining whether platelet-rich plasma can improve bony and soft tissue healing.

**Allograft Transplantation**

There remains the worst-case scenario of total meniscal deficiency, for example, in cases of failed repair, extensive complex tears, re-tears, or tears of remaining tissue after prior meniscectomy. Techniques for transplantation of allograft meniscal tissue have been developed in an attempt to address patients with symptomatic total meniscal deficiency (Fig. 4). Initial hopes were that allograft transplantation into patients with osteoarthritis might halt progression of knee degeneration. However, results in these patients were particularly poor.\textsuperscript{45} As with meniscal repair, the early experience with transplantation produced generally accepted indications for allograft transplantation, and they are quite narrow. Patients with significant chondromalacia are considered poor candidates, and condylar flattening or osteophyte formation are contraindications. The knee must be stable, so any ligamentous deficiencies (for example, anterior cruciate ligament or posterior cruciate ligament) must be addressed concurrently. Along those lines, any malalignment must also be addressed. The patient should be relatively young, typically under 50 years of age.\textsuperscript{46} Finally, and most critically, the patient must have pain in the compartment. This compartment specific pain in meniscal deficiency has been called the “post-meniscectomy syndrome.” The ideal patient, therefore, is young, without any ligamentous instability, normally aligned, has intact cartilage surfaces, and has focal pain in the meniscus deficient compartment.\textsuperscript{47}

The results of meniscus transplant have ranged from promising to disappointing. Garrett reported successful outcomes in 81\% of 43 patients at 2- to 7-year follow-up. Of 28 patients who had second look arthroscopy, 20 allografts were intact. Patients with Outerbridge grade III and IV chondral changes fared worse.\textsuperscript{45} Noyes and associates\textsuperscript{46} found 89\% of patients felt subjectively improved at follow-up; 76\% were able to return to some “light, low impact sports” (e.g., swimming or biking). However, 28\% of grafts had failed or torn by clinical exam or MRI.\textsuperscript{46} Cole and colleagues\textsuperscript{48} reported significant short-term improvements in Lysholm, IKDC, Cincinnati knee, Tegner, and SF-12 scores. These results appear to deteriorate markedly over time; however, as Hommen and coworkers\textsuperscript{49} reported, 25\% of medial allografts and 50\% of lateral allografts had failed at a mean of 141 months of follow-up by IKDC and pain scores. The inves-
tigators reported that when they added second-look surgery, MRI, and improvement survey results to their analysis, the overall failure rate was 55%. Moreover, 85% of the patients in this series had undergone subsequent procedures on the transplant knee.

Conclusion and Summary
In summary, meniscal injury is common. The menisci have an essential function in force transmission across the knee. The indications for repair should be expanded, as the results of partial meniscectomy may deteriorate over time. We agree with recommendations that tears in younger and higher demand patients should be meticulously repaired, particularly in the setting of concurrent anterior cruciate ligament reconstruction. When performing repair, the biological environment should be optimized for healing by preparing the rim appropriately. Raspiging, shaving, trephination, and synovial fold abrasion should be used liberally and aggressively to enhance the healing potential of the repair. For complex, recurrent, or avascular zone tears, particularly when surgery is limited to meniscal work, consideration should be given to augmenting the repair with a fibrin clot or platelet-rich plasma. Platelet-rich plasma may have the potential to enhance healing in these repairs. Partial meniscectomy is a suitable option for lower demand or older patients. Meniscal allograft transplantation remains, at present, a salvage operation with narrow indications. There are additional considerations in treating meniscal injuries that are beyond the scope of this review, such as the management of degenerative tears in arthritic knees, the contribution of malalignment, the anterior cruciate ligament deficient knee, discoid menisci, and rehabilitation protocols. It is important to keep in mind that none of the treatments we discussed have been definitively shown to halt the progression of knee degeneration and osteoarthrosis. However, we should continue to follow the current promising avenues of investigation toward that goal.

Disclosure Statement
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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