Christopher Hope

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Review of Meniscal Fibrocartilage in the Knee

Properties and characteristics

The meniscus is a fibrocartilaginous tissue composed of cells scattered throughout an intertwined network of collagen fibers. It's debatable whether the two types of cells found in the meniscus are more similar to fibroblasts or chondrocytes, or whether they represent a mixture of both. Regardless, one type is located in the superficial zone and resembles those cells found in the superficial zone of articular cartilage, while the second type is located throughout the rest of the tissue.[1]

The extracellular matrix is composed mostly of collagen (75%), of which about 90% is Type I fibers, which is important in distinguishing fibrocartilage from hyaline cartilage. Moreover, the meniscus contains only about 10% of the glycosaminoglycan (GAG) content found in hyaline articular cartilage. Non-collagenous proteins make up an additional 8-13% of meniscal tissue composition, with hexosamine comprising and additional one percent.[1]

The function of the meniscus is directly related to the orientation of its collagen fibers in the extracellular matrix. Three different layers have been observed: a superficial layer, surface layer, and middle layer. The outermost superficial layer is composed of a mesh-like matrix of fine collage fibrils. Just beneath the superficial layer, the surface layer contains irregularly aligned collagen bundles. The larger middle layer is composed of large, coarse fibers aligned circumferentially and in parallel.[1]

In humans, the meniscus begins as a condensed layer of mesenchymal tissue and can be clearly identified in as young as an eight-week old fetus. At this point, though, the meniscus is comprised mostly of fibroblasts and vascular channels, without much extracellular matrix. As the fetus develops and with increased joint motion, the matrix becomes more collagenous and the collagen fibers take on a circumferential arrangement. Additionally, the menisci decrease in vascularity to the point in mid to late adolescence that the internal and intermediate regions become altogether avascular.[1]

With the introduction of weight-bearing, vascularity by joint capsule and synovial membrane vessels decreases until only the outer portions of the menisci are vascularized (10-30% of medial meniscus and 10-25% of lateral meniscus[1]).[2] Considering this, the peripheral menisci receive nutrients through these capillaries. However, the central portion relies on the diffusion of nutrients through synovial fluid by weight-bearing or muscle contractions.[2] This has implications for immobilization, non-weightbearing, inflammation, repair, and remodeling following an injury.[2] The meniscal horns and vascularized periphery are innervated with nociceptors and mechanoreceptors.[2] These nerve endings may provide information regarding proprioception and pain.[1,2]

The menisci are located on top of the tibial condyles and can be considered extensions of the tibia.[1] Covering one-half to two-thirds of the articular surface of the tibial plateau, the menisci act to create a deepened concave articulation for the femoral condyles.[2] These structures are thick peripherally where they attach to the inside of the joint capsule, and thin and flat centrally where they rest on the tibial surface.[1,2] The menisci are attached to each other anteriorly by the transverse ligament, they are attached to the patella by the patellomeniscal ligaments, and they are attached to the peripheral tibial condyle by coronary ligaments.[2]

The medial meniscus forms a semicircular C-shape and is considerably wider posteriorly than anteriorly.[1,2] Its anterior horn is attached to the tibial plateau in front of the anterior cruciate ligament (ACL), while its posterior horn attaches firmly to the tibial intercondylar fossa between the posterior cruciate ligament (PCL) and the lateral meniscus.[1] The lateral meniscus is similarly semicircular, but more completely forms about four fifths of a circle and covers more tibial surface than the medial meniscus.[2] The anterior horn is attached to the tibial plateau behind the ACL (with which it partially blends).[1] The posterior horn attaches just in front of the posterior horn attachment of the medial meniscus.[1] The greater ligamentous and capsular restraints imposed on the medial meniscus make it less mobile than the lateral meniscus, which may contribute to its increased incidence of injury.[1]

Function and role

During gait and stair climbing, compressive forces in the knee may reach 1-2 times body weight, while running increases compressive force to 3-4 times body weight.[2] Impressively, the menisci absorb 50-70% of this compressive load.[2] This highlights one of the primary roles of the menisci: load bearing. Compared to articular cartilage, meniscal fibrocartilage has less than one half the average intrinsic elastic modulus and six times less average permeability.[1] This means that when compressed, the meniscus is softer and much less permeable than articular cartilage.[1] Research has shown that the meniscus absorbs at least 50% of compressive loading with the knee in extension, and 85% with the knee in 90 degrees of flexion.[3] As mentioned previously, the meniscus is thicker peripherally and thinner and flatter centrally, forming a wedge shape. This is important because when compressed, the meniscus is also pushed outward, creating a radial stress component [Appendix A]. Fortunately, the circumferentially oriented collagen fibers in the middle layer of the meniscus are in prime position to resist this tensile force (hoop stress).[1,4] Additionally, the strong attachments of the anterior and posterior horns to the tibial surface provide further resistance.[1,4] In this way, the compressive force acting on the femoral surface is partially redirected when acting on the tibial surface.[1,4] Without the meniscus, stress on the articular cartilage of the femur nearly doubles and increases 6-7 times on the tibial plateau.[2,5]

The other primary function of menisci is to increase the contact area between the convex femoral condyles and the relatively flat tibial plateau [Appendix B].[2] The increased contact area decreases contact pressure through the knee and reduces stress on articular cartilage.[6] In a knee that has undergone meniscectomy, contact areas in the femoro-tibial joint are largely reduced and therefore peak stress on articular cartilage of the tibial surface are considerably increased.[6]

The knee meniscus also plays an important role in shock absorption by attenuating shock waves generated from impulse loading during normal gait.[1] Research has shown a normal knee has the capacity to absorb 20% more shock than a knee that has undergone meniscectomy[7] (although other evidence questions the ability of the meniscus to absorb energy at all[12]). Once again, the structure and composition of meniscal tissue is closely related to this function. As discussed previously, meniscal fibrocartilage is softer and less permeable than articular cartilage. During loading and deformation, energy is absorbed and dissipated by the meniscus when fluid is forced to move through the less permeable extracellular matrix.[1] This, along with deformation, helps to increase loading time and thereby decrease the amount of force transmitted to articular cartilage.

A secondary role played by menisci is that of assisting in knee joint stability. This role is facilitated by the increased congruency provided to the femoral condyles on the flat tibial plateau.[1] Studies indicate that the extent of knee stability offered by the meniscus depends on several factors, including articular surface geometry, knee flexion angle, compressive joint load, and ligamentous and capsular integrity.[1] One study found that anterior-posterior laxity increased 20% with the removal of both the medial and lateral menisci.[8] In the presence of ligamentous injury, the meniscus is required to increase its role in joint stability, often to the point of injury also. A study of subjects with anterior cruciate ligament (ACL) injury found that when waiting an average of 23 months to receive reconstructive surgery, the subjects had a 67% incidence of meniscal tear.[9] A similar study agreed, finding that the longer a subject waited before surgery to repair an ACL rupture correlated strongly with increased incidence of meniscal damage.[10] It is also suggested that the meniscus serves a secondary role in joint lubrication by providing joint conformity that allows for hydrodynamic fluid-film lubrication.[1,11,12]

Injury and healing

The menisci assist in facilitating arthrokinematic motion of the knee. During knee flexion, the femoral condyles roll posteriorly and glide anteriorly on the tibia. The contact force of the menisci promotes the anterior glide of the femoral condyles, while at the same time the force from the femur pushes the menisci posteriorly. The posterior translation of the meniscus is aided by attached musculature as well: the semimembranosus on the medial meniscus and the popliteus on the lateral meniscus. Some deformation occurs since the menisci are tethered to the tibial surface by the anterior and posterior horns. This allows the menisci to stay directly under the femoral condyles, providing continued load bearing and friction reduction. When returning to extension from flexion, the menisci continue this movement in reverse and return back to their neutral position.[2]

Another important component of knee flexion is tibial internal rotation. During rotation, the menisci move with the femur. If, for example, external tibial rotation is forced during knee flexion (instead of internal rotation), the menisci are at an increased risk for injury or tear. The same is true for forced external tibial rotation during extension. Furthermore, flexion and/or extension without the rotational component may also result in meniscal injury. Because the medial meniscus is less mobile, it is more likely to tear. Often, these injuries occur when an individual experiences compression and rotation, such as when an athlete's cleats secure the foot, then tries to twist with the knee in a semi-flexed position.[11]

Additionally, meniscal injury may occur in hyperflexion. As previously indicated, when the knee is fully flexed, the femoral condyles roll posteriorly on the tibia, pushing the meniscus posteriorly as well. But the meniscus can only be pulled as far posteriorly as the horns and capsule and ligaments will allow. Once the meniscus has reached this point, further flexion is likely to result in a meniscal tear. Adding rotation to this scenario is especially troublesome since rotation means that one of the femoral condyles must move even farther posteriorly. This type of injury may occur when someone tries to twist while in a full squat position.[11]

Traumatic meniscal tears are more common in individuals aged 13-40 years, whereas degenerative tears are more common in persons older than 40 years. Vertical longitudinal tears are the most common traumatic tears.[1] Because these tears occur between the circumferential collagen fibers, knee biomechanics may not be disrupted and the individual may be asymptomatic.[13] This type of injury is more associated with the medial meniscus, appearing there 2.5 times more often than the lateral meniscus.[1] Vertical transverse (radial) tears are also traumatic tears, but are more commonly found in the lateral meniscus and tend to disrupt the circumferential fibers and affect the load-bearing capabilities of the meniscus.[13] Unfortunately, these tears are not usually conducive to repair, and partial meniscectomies don't restore full function and leave the meniscus susceptible to degenerative changes.[13] Considering the larger middle layer of the meniscus is comprised of large collagen bundles arranged mostly in a circumferential orientation, the overall most common type of meniscal tear is horizontal, a degenerative type tear that separates the meniscus into top and bottom portions.[14] Oblique and complex tears are also degenerative tears, which are associated with advanced age and degenerative articular cartilage.[1,13] Longitudinal and oblique tears are generally reparable, whereas horizontal, radial, and complex tears typically require at least a partial meniscectomy.[14]

Healing in the meniscus is largely dependent upon the location of the injury in regards to blood supply. As discussed previously, the menisci of a young adult are vascularized only in the outer 25-33%; in older adults (over 50 years), only the periphery is vascularized.[2] Therefore, the avascular central region has a reduced ability to heal following an injury since only the outer vascularized region can undergo inflammation, repair, and remodeling following a tear.[2] Research indicates that injuries in the vascular area undergo healing in a similar fashion to the rest of the body: formation of wound hematoma and fibrin scaffold, migration of blood vessels, proliferation of cells, and remodeling.[1] Ten weeks following a complete radial lesion, repair tissue resembles that of a fibrovascular scar tissue that will take months to convert to meniscal fibrocartilage.[1]

Diagnostic tests

Diagnosing a meniscal tear can be difficult since a large portion of the menisci are avascular and have no nerve supply, meaning injuries in these regions may not produce pain or swelling. Additionally, only about 50% of meniscal injuries have joint line tenderness, further complicating the diagnosis. In general though, signs and symptoms of meniscus injury include joint line pain, loss of flexion and/or extension, swelling, crepitus, and a positive special test. Therefore, a combination of tests and clinical signs should be considered when suspicious of meniscal injury. A number of special tests have been developed to evaluate meniscal injury, but those with moderate to strong statistical and clinical support include Apley's, Ege's, McMurray, and Thessaly tests.[15]

A recent study found that musculoskeletal clinicians were better able to accurately apply and interpret Thessaly's test, McMurray's test, Apley's test, joint line tenderness exam, and a standardized clinical history than primary care clinicians.[16] Furthermore, all physical tests and the clinical history were significant predictors of MRI. The study reported that joint line tenderness was actually the most sensitive test used by musculoskeletal clinicians. Additionally, "no diagnostic physical test was better at diagnosing a meniscal tear than a well-trained musculoskeletal clinician taking a clinical history."[16ch.4] When used by primary care clinicians, the study found diagnostic accuracies of 55% for clinical history, 54% for Thessaly's, McMurray's, and joint line tenderness, and 53% for Apley's test.[16] As mentioned, patient history can be a strong predictor of meniscal injury – up to 70-80% predictive value according to one study that included the variables of joint line tenderness, knee "locking", and missed work time.[18,19]

Arthroscopic examination has been used to confirm the statistical properties of McMurray's and Apley's tests compared to MRI. Both tests were more sensitive than the MRI, while the MRI was more specific. All three had a diagnostic accuracy of about 80%.[17] Interestingly, despite being a costly traditional diagnostic tool, MRI has been shown to have lower diagnostic utility than physical examination, demonstrating a false positive rate of 65% and 43% for medial and lateral meniscal tears, respectively.[18,20]

A meta-analysis found that joint line tenderness demonstrated superior diagnostic utility, including statistically larger sensitivity values, compared to Apley's and McMurray's tests.[18] The authors suggest that diagnostic accuracy may be improved when compressive forces are applied, such as in Ege's test and Thessaly's test, which both demonstrated higher diagnostic odds ratios compared to McMurray's and Apley's (but with smaller sample sizes).[18]

Overall, evidence is mixed regarding the effectiveness of tools used to diagnose meniscal tears. Therefore, it's important for clinicians to consider a combination of tests and clinical signs, including obtaining and interpreting a patient's clinical history in conjunction with physical presentation and special tests.

Treatment and intervention

Treatment for meniscal injuries can be grouped as either surgical or conservative (non-surgical), with degenerative tears being more likely to result in non-surgical treatment.[13] If surgery is not considered, then the goal of treatment is restoration of normal biomechanics through mobilization, strengthening, and activity modification.[11] Initially following an injury, the patient should be instructed to decrease weight-bearing, avoid extreme ranges of motion, and consider alternative activities or activity modifications.[21] Dynamic strengthening and protection during activity (i.e. bracing) should also be considered, in addition to weight loss (if applicable) and attenuation of ground reaction forces transmitted through the knee.[21] Exercise can reduce joint pain and improve knee function.[13] A randomized controlled trial found that subjects with medial meniscal tears who performed an eight-week exercise regimen aimed at improving muscle strength, flexibility and proprioception produced significant improvements that were not different from a group that received partial meniscectomy and exercise, and the results were still similar five years later.[22] A similar study found that after twelve months, no significant difference was observed between partial meniscectomy and physical therapy alone in measurements of functional status and pain.[23] Despite these benefits, about one third of patients go on to have a meniscectomy.[13]

Meniscectomies produce significant changes in the biomechanics of the knee. Following a total medial meniscectomy, and depending on the amount of tissue removed, intra-articular contact area can decrease by 75% and peak contact pressure can increase by as much as 235%.[24] In these cases, pressure on the contralateral meniscus might increase by 85% in flexion and contact pressure might increase by up to 100-200%.[25] A systematic review with 8-16 year follow-up found that all studies (n=5) demonstrated statistically significant incidence of radiographic signs of osteoarthritis in operative knees compared to control knees.[26] Considering this, partial meniscectomies are performed when possible.

Evidence suggests better results when arthroscopic partial meniscectomy is performed rather than open partial or total meniscectomy. Studies report 88-90% of patients report good or excellent satisfaction following arthroscopic surgery, compared to 68% for open surgery.[27,28] Around 85% of patients resume pre-injury activities two years following partial meniscectomy, and 90% of patients show satisfactory short-term clinical results.[29] Longitudinal studies show that 53% of knees with partial meniscectomy had radiographic evidence of osteoarthritis 8.5 years after surgery, compared to 22% for non-surgical control knees.[30] For athletes 14 years after meniscectomy, 89% displayed radiographic changes and 46% had given up or reduced sporting activity.[31] However, evidence exists that indicates strength-training exercise may have beneficial effects on factors associated with osteoarthritis, including improved knee joint cartilage composition and, when supplemented with glucosamine, a positive effect on the mechanical properties of muscle and prevention of build-up of factors associated with OA.[32,33]

More understanding of the functional importance of the meniscus, and consideration of the complications from meniscectomy, has produced an increasing interest in meniscal repair. Studies have demonstrated the healing capability of peripheral meniscal tissue, as well as the inability of healing to spontaneously occur in the avascular central portion.[34,35] Attempts have been made to stimulate healing by introducing bleeding to the avascular region, including exogenous fibrin clots[36], synovial abrasion[1], synovial pedicle flaps[1], bioabsorbable conduits[44], and trephination of vascular channels[37]. Meniscal repairs have shown good long-term results, with 76-79% successful clinical outcomes observed ten years after surgery.[38,39]

Alternative treatments include stem cells, scaffolding, and transplantation. Mesenchymal stem cells promote meniscus regeneration and may be a viable treatment for damaged meniscal tissue.[45,46] Another study found that biodegradable scaffolding promoted tissue ingrowth in 81% of patients studied.[47] Meniscal allograft transplantations have been found effective more than 11 years following surgery, with survival rates of 74% for medial allografts and 69% for lateral allografts.[48]

Directly comparing repairs to meniscectomies is difficult considering the numerous variables. However, one study did just that and found that after more than 8 years follow-up 80% of repairs showed no signs of osteoarthritic progression, compared to only 40% for partial meniscectomies, and 96% of repairs returned to pre-injury level of activity, compared with 50% of meniscectomies.[40] A number of repair techniques have evolved. Suture-based devices have demonstrated superior load-to-failure strength compared to rigid devices – of the suture-based devices, the double vertical suture proved strongest.[41] Systematic reviews, though, have found no differences between inside-out and all-inside techniques when considering clinical failure rate or subjective outcome, and found a failure rate of 20-24% for all repair techniques after five years.[42,43]

Considering the number and variety of surgical intervention techniques, many factors play into postoperative rehabilitation. Acute meniscal tears are more favorable to repair, in which case immobilization is necessary while healing occurs and complete recovery is expected in about 6 months. It’s important to limit compressive loading of the knee until sufficient protection can be offered by supporting musculature and joint structure, as well as the establishment of proper movement mechanics. During rehabilitation, closed kinetic chain exercises are emphasized since open chain exercises create significant shear and compression forces through the knee. PNF techniques can be used with manual resistance to accentuate dynamic and/or static muscle contractions in positions that simulate weightbearing, but to a lesser degree. Progression to higher levels of weight-bearing closed chain exercises occurs once full weight-bearing restrictions have been lifted, such as assisted squats and lunges with resistance from therapeutic tubing. Balance, neuromuscular and proprioceptive training should all be introduced with progression to higher-level closed chain free-weight strengthening exercises.[11] (A sample rehabilitation protocol for meniscus repairs and transplants has been provided [Appendix C[49]].)

Resources

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Appendix A

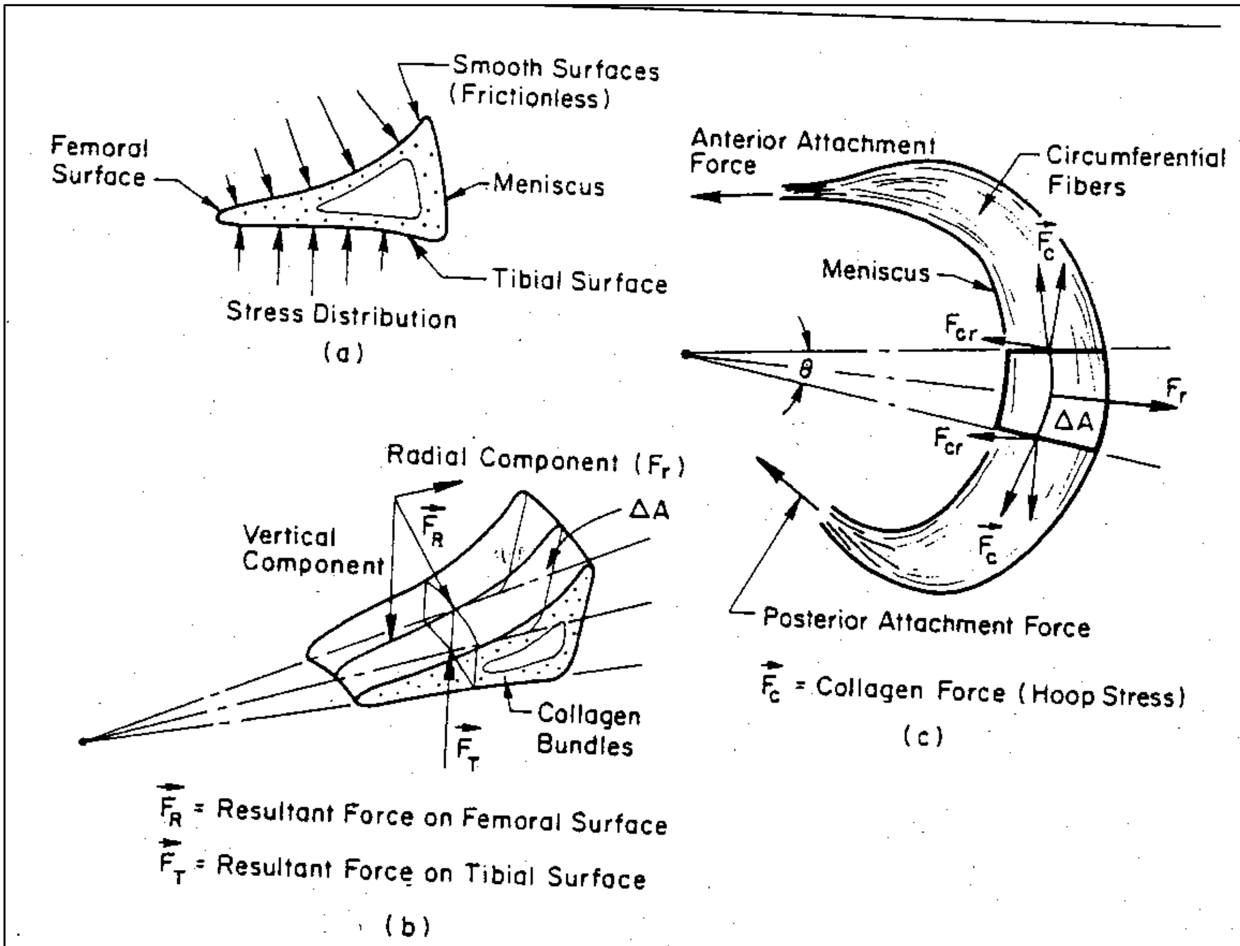
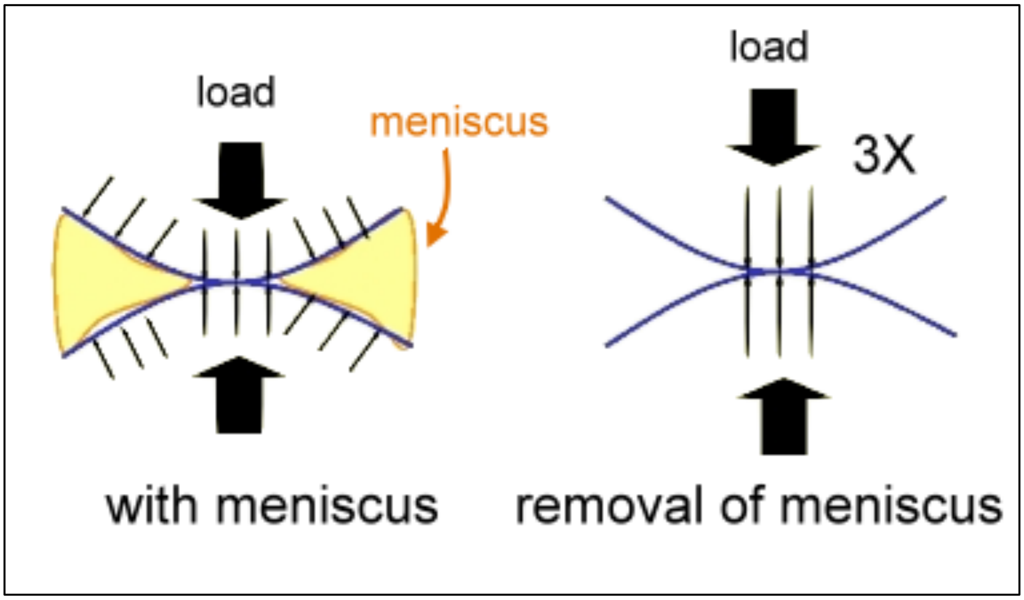


Fig. 12–12 *Free-body diagrams of forces acting on various segments of the meniscus.*

Arnoczky et al: Chapter 12 Meniscus. In Woo SL, Buckwalter JA (eds): Injury and Repair of the Musculoskeletal Soft Tissues. Park Ridge, Illinois, American Academy of Orthopaedic Surgeons, 1988, p509

Appendix B



http://www.pt.ntu.edu.tw/hmchai/Kines04/KINlower/Knee.htm. Updated December 5, 2004. Accessed December 2, 2015

[CLINICAL COMMENTARY]

TABLE 3 REHABILITATION PROTOCOL SUMMARY FOR MENISCUS REPAIRS AND TRANSPLANTS*

	Postoperative Weeks					Postoperative Months			
	1-2	3-4	5-6	7-8	9-12	4	5	6	7-12
Brace									
Long-leg postoperative	C, A, T	C, A, T	C, T						
Range-of-motion minimum goals									
0° to 90°	X								
0° to 120°		X							
0° to 135°			X						
Weight bearing									
Toe touch: half body weight	P								
Three-quarters to full		P							
Toe touch: one-quarter body weight	C, T, A								
Half to three-quarters body weight		C, T, A	C, A						
Full			T	C, A					
Patellar mobilization	X	X	X						
Stretching									
Hamstring, gastroc-soleus, iliotibial band, quadriceps	X	X	X	X	X	X	X	X	X
Strengthening									
Quadriceps isometrics, straight leg raises, active knee extension	X	X	X	X	X	X	X	X	X
Closed-chain: gait retraining, toe raises, wall sits, minisquats		P	C	X	X	X	X	X	
Knee flexion hamstring curls (90°)			P	C	X	X	X	X	X
Knee extension quadriceps (90°-30°)			X	X	X	X	X	X	X
Hip abduction-adduction, multihip			X	X	X	X	X	X	X
Leg press (70°-10°)			P	P	X	X	X	X	X
Balance/proprioceptive training									
Weight shifting, minitrampoline, BAPS, BBS, plyometrics	P	X	X	X	X	X	X	X	X
Conditioning									
Upper-body ergometer		X	X	X					
Bike (stationary)				X	X	X	X	X	X
Aquatic program					X	X	X	X	X
Swimming (kicking)					P, C	X	X	X	X
Walking					X	X	X	X	X
Stair-climbing machine					P, C	P, C	P, C	P, C	X
Ski machine					P	P	P	C	X
Running									
Straight†						P	P	C	X
Cutting									
Lateral carioca, figure-of-eight†							P	P	X
Full sports†							P	P	X

Abbreviations: A, all-inside meniscus repairs; BAPS, Biomechanical Ankle Platform System; BBS, Biodex Balance System; C, complex inside-out meniscus repairs extending into middle third region; P, peripheral meniscus repairs; T, transplants; X, all meniscus repairs and transplants.
**Modified from Heckmann et al,[22] with permission.*
†Return to running, cutting, and full sports based on multiple criteria. Patients with noteworthy articular cartilage damage are advised to return to light recreational activities only.

Noyes FR1, Heckmann TP, Barber-Westin SD. Meniscus repair and transplantation: a comprehensive update. .J Orthop Sports Phys Ther. 2012 Mar;42(3):274-90. doi: 10.2519/jospt.2012.3588. Epub 2011 Sep 4.