An overview of meniscal fibrocartilage pathology and rehabilitation

Meniscal tissue is found in many different joints throughout the human body. While there are menisci in the acromioclavicular and sternoclavicular joints, the temporomandibular joint, vertebral facet joints, and the ulnar-carpal joints, the most commonly injured, studied, and researched menisci are found in the knees[[1]](#endnote-1). In fact, meniscal injuries are among the most commonly occurring knee injuries[[2]](#endnote-2). The meniscus of the knee is made up of two components: a medial “C-shaped” component and a lateral “O-shaped component1. These sit nicely between the femoral condyles and the tibial plateau (Fig 1)[[3]](#endnote-3). The peripheral border of each meniscus is relatively thick and convex, while the inner border tapers to a very thin structure[[4]](#endnote-4). This gives the meniscus its wedge shape that serves to deepen the articular surfaces of the tibial plateau, which improves congruency with the femoral condyles4 (fig 2). Although both components serve the same purpose, the lateral meniscus makes up a larger percentage of the tibial plateau[[5]](#endnote-5).

Meniscal fibrocartilage is a very dense collagenous structure that is comprised of ~75% collagen[[6]](#endnote-6) arranged in a very dense matrix. This is of particular importance as it gives the substance a low permeability to water, the confinement of which provides support when undergoing compression[[7]](#endnote-7). Most of the collagen that makes up the meniscus is type I collagen, although types II, III, V, and VI have also been identified within the structure[[8]](#endnote-8). The remaining organic matter is made up of glycosaminoglycans (GAGs) (17%), DNA (2%), adhesion glycoproteins (<1%), and elastin (<1%)[[9]](#endnote-9). The GAGs form a glue-like substance that is vital to the integrity of the meniscus6. The percentage of GAGs in meniscal tissue is much lower than in articular cartilage, which explains the relatively decreased stiffness and strength of menisci in comparison7.

The vascularity of the meniscus is of particular interest as it relates directly to the tissue’s ability to heal. The meniscus is fully vascularized at birth, however, this decreases throughout life and at full maturity only the peripheral 10-25% of the structure contains blood vessels and nerves5. Research and clinical observation has shown that injuries to the vascular region of the meniscus trigger an inflammatory and reparative response similar to that in other connective tissues[[10]](#endnote-10),[[11]](#endnote-11). In contrast, injuries to the avascular inner region have very little chance of self-healing and are considered to be particularly difficult to treat. A number of different approaches have been attempted and will be discussed in detail in other sections of this paper.

Light and electron microscope examinations have revealed that the meniscus is comprised of 5 total layers. 2 thin superficial layers that consist of mostly of fine collagen fibrils in a mesh-like matrix are at the very top and the very bottom of the meniscus and serve to prevent any small openings in the surface of the structure[[12]](#endnote-12). Just deep to these layers at both ends is a surface layer, which is a transitional region of randomly aligned collagen fibers. This leads to a large middle layer in which the collagen fibers are larger and courser and lie parallel in a circumferential direction12 (fig 3). It is this key middle layer that allows the meniscus to resist high tensile forces and to help evenly transmit load across the knee joint13.

Like all tissues in the body, meniscal fibrocartilage has a specific job to do. While the function of each meniscus may vary slightly based on it’s location in the body, the main role of meniscal tissue remains constant; to reduce contact pressure across a joint, thereby providing protection to the articular cartilage of the adjoining bones7. To achieve this, the functions of knee menisci can be broken into load bearing, shock absorption, pressure attenuation, joint stability and joint lubrication6,[[13]](#endnote-13).

The load bearing properties of the meniscus are best highlighted by observing the degenerative changes that occur following a total meniscectomy. Radiographic changes including joint space narrowing, flattening of the femoral condyles, and osteophyte formation, have all been shown to result from the loss of the weight-bearing function of the meniscus[[14]](#endnote-14). The wedge-shape of the meniscus allows it to transfer downward directed compressive forces into radially directed tensile forces that are dealt with efficiently by the circumferentially oriented collagen fibers of the middle layer of the meniscus[[15]](#endnote-15). Studies show that more than 50% of the load transmitted through the knee in full extension is transmitted through the meniscus, and in 90 degrees of flexion this percentage jumps to over 85%13. These statistics highlight why articular degeneration is accelerated so rapidly after the removal of a meniscus. This process is further amplified by the fact that contact area between the femur and tibia is decreased by over 50% after the removal of a meniscus, severely increasing contact pressures experienced over this smaller area13.

An additional function of meniscal tissue can be measured using accelerometery data. Studies have shown that a knee with an intact meniscus is capable of 20-30% more shock absorption than a knee that has undergone a meniscectomy[[16]](#endnote-16). The meniscus is able to achieve these shock absorption properties by prolonging the time of deformation as forces are transmitted across the joint6. The perfect concentration of collagen matrix, GAGs and water that was mentioned previously, explain why this is possible. This combination of substances allows some deformation as water is slowly moved within the structure, resulting in shock absorption. This mechanism acts secondarily in combination with the increased contact area to further protect the articular cartilage of the joint and to prevent degeneration and the development of osteoarthritis13,16.

Joint stability is a controversial secondary function of meniscus and its role in this is a minor one. While it can be shown that in the absence of the stabilizing ligaments, the menisci will act to stabilize the joint and prevent unwanted motion, the structure is not designed to withstand this type of stress and resultant meniscal injury is extremely likely6. While a knee that has an intact ACL requires little additional stabilization from the menisci, an injury to the ACL can completely change this and rather than play the very minor role that it is capable of, the meniscus is required to now act as the primary source to prevent anterior motion of the femur on the tibia. As the femoral condyles move anteriorly, they now contact the medial meniscus, which acts like a doorstopper preventing this motion. However, the meniscus was not designed to handle this load without the support of ligaments and capsular restraints and the resulting sheering force can and often will result in a meniscal injury6.

This relationship between ACL insufficiency and meniscal tears has been well established in the literature. Due to this relationship, many researchers have looked at the effect of time waited to undergo ACL surgery after the initial injury. A study by Murrell et al investigated this very relationship in 130 patients over a 10-month period[[17]](#endnote-17). All of the patients were diagnosed with ACL insufficiency and waited a range of different times before having surgery. It was determined that the length of time a patient waited before having ACL surgery after injury significantly impacted the likelihood of also having a meniscal tear at the time of surgery17. In fact, those who had their ACL surgery more than 2 years after the initial injury had 5 times more meniscal damage than those patients who had surgery within 1 month of incurring the ligament injury17. Similar results were reported by Tandogan et al who reported in their study of 684 patients that those patients who were 2 to 5 years post injury were 2.2 times more likely to have a medial meniscus tear than those patients who were within a year of their initial injury[[18]](#endnote-18). Moreover, those patients who were more than 5 years from the time of their injury were found to be 5.9 times more likely to have a medial meniscal tear18. These studies highlight a plethora of literature on this topic that indicates the importance of minimal waiting time between ACL injury and surgery in order to protect the integrity of the menisci.

Since the relationship between ACL insufficiency and meniscal tears has been well established, it is worth discussing that delaying ACL surgery can also be associated with increased chance of experiencing cartilaginous injury as well. As this paper highlighted earlier, a healthy meniscus acts to protect articular cartilage from damage and subsequent osteoarthritis. As such, when a delay before ACL surgery occurs and resulting forces cause damage to the meniscus, it is no longer able to efficiently protect the underlying cartilage making the patient more susceptible to this type of damage as well[[19]](#endnote-19). Fok et al investigated this relationship and established a clear association between untreated ACL injuries and both meniscal injuries and cartilaginous injuries19. Not only did they find that meniscal tears doubled the likelihood of cartilage damage but they also reported that cartilage injury would occur in 17-43% of all untreated ACL injuries. The authors concluded from their study the urgent importance of encouraging timely ACL surgery for our patients19.

There are a wide variety of surgical interventions available for consideration to patients who suffer a meniscal tear. Additionally, conservative treatment has also shown to be effective in some cases. No one surgical procedure or intervention method is the right answer for everyone and every patient’s injury and situation should be considered on a case-by-case basis. There are a number of important factors to take into account when making a decision on what intervention to select, however, in general, the more meniscus a patient can keep, the better the long-term results will be for the patient. This is because of the positive effect that a healthy and functioning meniscus has on reducing contact pressures and absorbing shock through the joint1. Keeping more meniscus will generally result in greater capacity to reduce contact pressures and therefore less resulting damage to articular cartilage as the likelihood of future degenerative changes is directly proportional to the amount of meniscus removed6,[[20]](#endnote-20).

One popular surgical option as an alternative to removing meniscal tissue is a repair of the damaged meniscus20. The benefits of using such a technique are evident; since you are not removing any meniscal tissue you are maximizing the amount of meniscus the that will remain in the patient’s knee. A detailed overview of indications and contraindications for this procedure can be found in Table 1. Different surgeons perform a surgical repair of a meniscus using a variety of different techniques[[21]](#endnote-21). The greatest variance in the techniques is the direction, type, and number of the sutures used. A traditional vertical stitch, as the name suggests, entails making a loop vertically around the meniscus and then pulling the suture tight. In comparison, a traditional horizontal suture technique involves performing the loop horizontally through the meniscal tissue21. These methods are presented in figure 4. A number of different techniques and meniscal repair devices are also utilized, and the effectiveness of many of the popular ones has been thoroughly investigated in research literature[[22]](#endnote-22). These different fixation methods each result in repairs of different strengths. A literature review by Farng et al investigated the current research on many of the most popular devices and techniques and compared them for initial fixation strength and performance under loading22. After compiling all the results of their literature search they concluded that while many of the new gadgets and devices used had successful results, the gold standard remains to be a vertical stitch technique22. Additionally, a comparison by Barber et al reported that while a single vertical stitch outperformed all other techniques, a double vertical stitch is a significantly stronger repair method[[23]](#endnote-23).

A different surgical strategy is allograft implantation in which a meniscus is harvested from a cadaver and implanted into patient’s knee[[24]](#endnote-24). 2 bone plugs are also taken from where the meniscus attaches and these bone plugs are then inserted into drilled holes in the patient’s bone. The appeal of this technique is that you are getting a whole meniscus with no defects in it, which theoretically, would provide the lowest possible contact pressures across the joint24. However, the drawback of attempting this procedure is that the dimensions of the femoral condyles of the cadaver must match the recipient almost perfectly in order for the allograft to fit correctly[[25]](#endnote-25). This makes it extremely difficult to find a match and even a very close equivalent may not produce optimal results25. Kim et al compared both meniscal allografts and surgically repaired menisci to uninjured menisci in order to contrast contact pressures. They found that while the repaired menisci averaged contact pressures 21% greater than an uninjured menisci, the allografts averaged 34% greater contact pressures25. Additionally, The allograft transplantation group also demonstrated the greatest variance in their results, which the authors attributed to the difficulty in finding knees with similar measurements25.

Earlier in this paper, meniscal vascularity was discussed and it’s effect on the healing process. Meniscal tears to the vascular peripheral region of the meniscus tend to heal very well because of the great blood supply to this area. However, tears to the avascular central portion of menisci do not have this important blood supply and so have very little chance of healing, even after surgical repair. In order to combat this problem, surgeons can use a technique called trephination in which small holes are made every 4-5mm in the meniscus from the periphery to the central avascular region, in order to help carry blood to the area of the legion6. This technique has shown very favorable results over meniscal repair alone[[26]](#endnote-26),[[27]](#endnote-27). Zhang et al performed a comparative study of the results when using the trephination technique versus repairs without trephination27. The results of this study showed a 350% greater rate of re-tear in the patients who were not treated with trephination, emphasizing the importance of this technique to allow blood flow to the injured area27. It is important to note that larger, unstable meniscal tears may not be appropriate to utilize this technique as the small holes produced to allow blood supply may cause further damage to the unstable structure[[28]](#endnote-28).

For less severe meniscal injuries to the vascular peripheral region of the meniscus, conservative treatment should be considered as a rehabilitation option[[29]](#endnote-29). This treatment should begin by decreasing weight bearing and avoiding extremes of the range of motion5 in order to avoid stress to the injured tissue secondary to the sliding of the femoral condyles, as was discussed previously. These precautions would decrease the amount of stress through the meniscus, providing a suitable environment for the tissue to heal. As pain decreases, it is recommended to increase the stability of the joint around the meniscus in order to minimize the pressure exerted onto the injured area. This can be done internally through strengthening of the surrounding muscles, and externally through the use of supportive bracing and activity modification. Other conservative factors that can help to reduce contact forces and pressures through the knee include the consideration of orthotics as needed to help attenuate ground reaction forces, as well as weight loss if appropriate for the individual patient5. Protecting the injured meniscus through these conservative means has been shown to be very successful in some situations. Multiple large studies have shown that for peripheral meniscal injuries, conservative treatment has shown equal outcomes to surgical intervention for healing as well as more subjective measures like the Knee Injury and Osteoarthritis Outcome Score (KOOS) and Tenger Activity Scale29,[[30]](#endnote-30). When considering the ever-present risks involved in all surgical interventions, being able to achieve very similar results through conservative treatment can be a favorable option for many patients. However, it is important to remember that this may not be an option for all patients. Athletes and patient populations who are likely to perform higher-level physical activities will most likely require a surgical intervention as conservative treatments are unlikely to prepare the joint for such high-stress situations29. Nonetheless, it is a useful strategy for degenerative meniscal injuries in more sedentary populations where modifying activity and improving the joint stability can provide the protection needed for healing.

Following a surgical procedure to injured meniscal tissue, the goal of rehabilitation is to restore the patient’s function based on their individual needs[[31]](#endnote-31). The pace and progression of the individual’s rehab process will be dependent on a number of different factors including the severity of the damage, the type of surgery performed, and the goals of the individual. Athletes with high expectations for function after rehab will be required to meet higher-level requirements before being released from therapy in order to minimize the likelihood of re-injury during activities that put high levels of stress through the meniscus[[32]](#endnote-32). For all patients, progressions should be made carefully and slowly from low-load activities towards higher loads and it is important to remind patients that weakness in the injured area exists long after pain levels have diminished. As with all patients, constant assessment is required in order to monitor the patient’s response to treatment, and interventions should be altered accordingly32. While each patient’s program will be different based on their individual needs, the literature suggests that all programs include immediate knee motion, patellar mobilizations, and quadriceps strengthening exercises – with precautions being taken in high-loading activities, deep knee flexion, and full squatting over a minimum period of 4-6 months before releasing patients to athletic or high-level activities32.

Meniscal injuries can occur in a variety of ways and for a number of different reasons. Each individual’s injury and goals are different and as such, treatment decisions must be made careful with consideration of all of the involved factors. Treatment options vary widely and it is important that all patients are aware that they have options and that they are involved in their treatment decisions.

1. Appendix:

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| TABLE 1 |
| Indications |
| • Meniscus tear with tibiofemoral joint line pain |
| • Patients younger than 50 years of age or patients in their fifties who are athletically active |
| • Concurrent knee ligament reconstruction or osteotomy |
| • Meniscus tear reducible, good tissue integrity, normal position in the joint once repaired |
| • Peripheral single longitudinal tears: red-red, 1 plane; reparable in all cases, high success rates |
| • Middle-third region: red-white (vascular supply present) or white-white (no blood supply); often reparable with |
| reasonable success rates |
| • Outer-third and middle-third regions, longitudinal, radial, horizontal tears: red-white, 1 plane; often reparable |
| Contraindications |
| • Meniscus tears located in inner-third region |
| • Chronic degenerative tears in which the tissue is of poor quality and not amenable to suture repair |
| • Longitudinal tears less than 10 mm in length |
| • Incomplete radial tears that do not extend into the outer-third region |
| • Patients older than 60 years of age |
| • Patients unwilling to follow postoperative rehabilitation program |
| Reprinted from Noyes and Barber-Westin32 |

Fig1: Overview of knee anatomy with menisci sitting between the femoral condyles and the tibial plateau.



Fig2: The meniscus of the knee works to deepen the articulating surfaces of the tibial plateau and improves congruency of the tibiofemoral joint.



Fig 3: The multiple layers of the meniscus. The superficial layer is a mesh matrix of collagen fibrils. The surface layer is found directly below this and is a transition layer of randomly arranged collagen bundles. The large middle layer is the deepest layer and consists of large collagen bundles that are arranged primarily in a circumferential orientation.



Fig 4: Meniscal suturing techniques. (A, B, and C) Variations on vertical suturing techniques, (D) horizontal mattress stitch, and (E) knot-end stitch. 22



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