Advances in the Diagnosis and Treatment of Meniscal Tears

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Abstract. Meniscus tears are a common knee joint injury which significantly impact joint function and the risk of osteoarthritis. According to morphological classification, they are classified as vertical tears, bucket handle tears, radial tears, and horizontal tears. Classified by the site of injury, they can be categorized into anterior horn, body, and posterior horn tears. Current diagnostic methods, including magnetic resonance imaging (MRI) and arthroscopy, which have high accuracy. However, limitations in accessibility and invasiveness are their drawbacks. Treatment selection hinges on tear stability, pattern, site, age, activity demand, and cartilage status. For stable and degenerative tears, conservative treatments such as non-steroidal anti-inflammatory drugs, physical therapy, and intra-articular injections are preferred, while surgical options such as meniscus repair, partial meniscectomy, or transplantation are reserved for unstable, traumatic, or complex tears. Emerging therapies such as platelet-rich plasma (PRP) injections, mesenchymal stem cell (MSC) injections, and tissue engineering are promising in promoting meniscus regeneration and delaying osteoarthritis, while their long-term efficacy and safety still require further verification. This review summarizes the classification, diagnosis, and promising treatment patterns for meniscus tears, emphasizing the importance of individualized management and the potential of regenerative medicine approaches.

1 Introduction

The meniscus is composed of fibrocartilage with important functions such as load transmission, shock absorption, maintaining joint stability, and lubrication. Meniscal tears are one of the most common conditions in knee joint injuries. This injury typically occurs during sports trauma or degenerative processes and prevalent in the athletic population and older age groups. With the increasing aging of the population and the popularity of sports activities, the incidence of meniscus injuries is on the rise. Patients commonly exhibit symptoms of knee pain, swelling, locking, and limited mobility, severely affecting daily life and athletic ability. If not intervened in a timely manner, meniscal tears may also accelerate the development of knee osteoarthritis, leading to irreversible joint damage [1, 2].

Currently, the treatment methods for meniscus tears are conservative treatment and surgical treatment. Conservative treatments such as medication and physical therapy are suitable for mild tears or certain types of tears. However, their effectiveness is limited, especially for complete tears or complex injuries. Surgical techniques have evolved from simple excision to complex repair methods (such as all-inside suturing, inside-out suturing) and alternative surgeries like meniscus allograft transplantation (MAT). Treatment options vary according to multiple factors such as tear type, location, stability, patient age, activity demands, and associated injuries. Although surgical methods can better restore anatomical structure, they have issues such as significant surgical trauma, long recovery periods, and high risks of postoperative complications.

In recent years, with the development of biomedical engineering and regenerative medicine, new treatment methods such as platelet-rich plasma (PRP), stem cell injections, and tissue-engineered meniscus transplants have gradually been applied clinically. These methods show good clinical application prospects by promoting the self-repair and regeneration of meniscal tissue. However, their long-term efficacy, safety, and applicability still require more high-quality clinical research for verification. Therefore, this review aims to systematically summarize the epidemiological characteristics, pathological mechanisms, and existing diagnostic and therapeutic strategies for meniscal tears, as well as focusing on the latest advances and evidence in rehabilitation treatment, and assessing the potential and limitations of new treatment methods.

2 Classification and Diagnosis of Meniscus Tears

2.1 Classification of Meniscus Tears

Meniscal tears are common injuries in the knee joint, and their classification and diagnosis are the basis of treatment and rehabilitation plans. Different clinical and imaging characteristics can be depicted with different classification systems, and morphological classification is the most common classification method in clinical practice. Based on it, there are several kinds of tears.

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Firstly, the longitudinal tear, refers to tears where the direction is parallel to the annular fibers of the meniscus, which are common among younger patients and those with more active lifestyles. Secondly, the traumatic tear, which is caused by acute injury mechanisms such as twisting. If the tear is extensive and the central fragment is displaced, it is termed a bucket handle tear, which typically leads to knee locking [1]. After that, the radial tear which disrupts the circumferential collagen fiber network at the meniscus's outer edge, severely compromising load distribution. Commonly, the horizontal tear can be seen in degenerative cases, referring to injuries that split the meniscus into upper and lower layers in a horizontal direction. Finally, the complex tear often exhibits multiple morphological features, reflecting long-term tissue damage accumulation and indicating increased treatment difficulty.

According to the different locations of the damage, meniscal tears can be categorized into the anterior horn, body, and posterior horn tear. Among them, the posterior horn is a key area for load bearing and stress concentration. However, the probability of tearing in this place is higher than that in others because of poor blood supply, and its healing capability is relatively weaker. The body tear is often related to sports-related injuries, while the anterior horn tear is relatively rare and usually coexists with the discoid meniscal deformity. Meniscal tears can also be categorized as stable and unstable tears based on stability, and the main distinction between them is the displacement distance of the torn fragments. By observing this, it can be decided whether to opt for conservative treatment or surgical intervention. This indicates that classification is not only an academic descriptive tool but also a direct basis for treatment choices.

2.2 Clinical and Imaging Diagnosis

Clinical diagnosis relies on a combination of symptoms, physical examinations, and imaging studies to improve the accuracy of diagnostic results. If tests are conducted based solely on the characteristics of symptoms or signs, it may result in low to moderate accuracy. Imaging examinations can be performed using techniques such as MRI and arthroscopy. MRI is a key non-invasive tool that has high accuracy in distinguishing between meniscus tears and other knee joint disorders. However, its systematic use depends on availability and legal issues in different countries. Arthroscopy is the gold standard for diagnosis because it allows direct visualization of the tear's morphology and stability. However, it is not suitable for routine screening because of its invasiveness and postoperative risks [2-4]. Additionally, it can also be used as a diagnostic method through kinematic analysis or biomechanical assessment such as gait analysis and three-dimensional motion capture technology. They help to analyze the changes in knee joint biomechanics after tears and provide reference for the subsequent design of rehabilitation programs.

3 Conservative Treatment

Generally, conservative treatments are suitable for patients with stable tears, no significant symptoms, or degenerative tears without mechanical symptoms. These treatments include the use of non-steroidal anti-inflammatory drugs and analgesics, or recommendations from physicians to engage in physical exercises to strengthen muscles. One of principles is to alleviate symptoms through anti-inflammation and analgesia. Then using ultrasound and electrotherapy to promote tissue repair, thereby creating a natural healing environment for the body. And dynamically stabilizing the knee joint by strengthening the quadriceps, especially the vastus medialis and hamstring muscles, to restore the range of motion of the joint and improve neuromuscular control.

In terms of medication treatment, ibuprofen and acetaminophen can be taken orally to relieve pain and combat inflammation. In some cases, intra-articular injections of corticosteroids may be used short-term to reduce acute synovitis, but attention should be paid to the potential risk of chondrotoxicity. Although acetaminophen is weaker in symptom control, it has better tolerance and is suitable for elderly patients with underlying gastrointestinal diseases. Cold compresses can alleviate swelling and pain during the acute phase, while heat packs can promote blood circulation and relieve muscle stiffness during the chronic phase.

The advantages of conservative treatment are non-invasive and low-cost effectiveness. However, it is ineffective for unstable tears or displaced fragments and carries the risk of persistent or worsening symptoms. Studies have shown that 70% of patients with horizontal meniscal tears opt for conservative treatment. That's because when they choose an experienced physician for arthroscopic surgery with limited resection, most still rely on medication or physical therapy post-surgery, with symptoms worsening instead of improving. However, if the tear width is confirmed to be large by MRI or if there are mild cartilage lesions, arthroscopic surgery may provide a more ideal treatment effect compared to conservative treatment. Therefore, when deciding on the treatment methods for meniscal tear patients, all factors should be thoroughly evaluated on a case-by-case basis instead of focusing solely on mechanical symptoms [5].

4 Surgical Treatment

4.1 Arthroscopic Meniscal Repair

The core goal of meniscus repair surgery is to preserve its native meniscus function when suturing the tear. Such surgeries are typically performed arthroscopically, and the indications mainly include traumatic tears in young patients as well as tears in the red-red and red-white zones with better blood supply. However, traumatic and degenerative meniscus tears require distinct treatments with different etiologies [6]. For example, the traumatic meniscus tear is often associated with anterior cruciate ligament injuries, which increases

the risk of knee osteoarthritis. Therefore, in the treatment of the traumatic meniscus tear, old tears or tears in obese patients are generally preferred to retain the meniscus initially because early repair yields better results. What is more, in the long run, it can more effectively protect joint cartilage, reduce the risk of knee osteoarthritis, and improve patient satisfaction during the treatment process. However, in clinical practice, the repair rate for meniscus tears is low, and the healing capability of tears in the white-white zone is poor. Postoperatively, there is a need for a period of weight-bearing and activity restriction to protect the repair site. Thus, the final treatment outcome is also influenced by factors such as the patient's recovery time and the completeness of the surgery.

4.2 Partial Meniscectomy and Transplantation

When the tear area is large, the displacement is severe, and it is located in an area with no blood supply, partial meniscectomy is often adopted. The principle is to remove the irreparable torn fragments of the meniscus and stabilize it by reshaping its contour which can achieve the goal of alleviating mechanical symptoms. Before the surgery, it is necessary to determine the type of meniscus injury and assess its size and location. The degree of loss is first classified in formulating the surgical plan. For instance, a tear at the root of the meniscus can severely affect its circumferential function and accelerate cartilage degeneration. Therefore, repairing the root of the meniscus is very important for preventing the accelerated development of osteoarthritis.

However, meniscus resection can lead to tissue defects and changes in joint mechanics. To address this shortcoming, in recent years, it has seen the development of regenerative techniques such as allograft meniscus transplantation and collagen meniscus implantation [7]. Meniscus transplantation is most suitable for young highly active patients in whom persistent pain does not improve after a significant meniscectomy while the articular cartilage remains relatively intact. By accurately matching the dimensions preoperatively and securing the graft to the tibial plateau, pain can be effectively alleviated and functionality can be improved, potentially slowing the progression of arthritis. However, the long-term survival rate, the remodeling mechanisms of the graft, and risks of disease transmission remain focal points of current research.

For patients with non-traumatic or degenerative meniscus tears, the most common method is to perform meniscus resection through arthroscopy. However, there is currently no conclusive evidence that this treatment remains the best option for middle-aged and elderly populations [8, 9]. In this population, resection may further compromise the already weakened biomechanical integrity of the meniscus and thereby accelerate joint degeneration. A randomized controlled trial found that five years after follow-up of patients with degenerative tears, those who underwent physical therapy had overall treatment effects that were not inferior to those who underwent surgical treatment [10]. Additionally, one of the disadvantages of surgical treatment is that the risk of undergoing total knee replacement surgery for advanced osteoarthritis was five times higher compared to traditional physical therapy. In summary, surgical treatment should be individualized based on the type of tears, location, patient age, and functional needs. For young patients with good blood supply who have traumatic tears, repair surgery should be the first choice. For extensive, displaced, and root tears, partial resection and transplantation can be considered as alternatives. For middle-aged and elderly patients with degenerative tears, surgical intervention should be chosen cautiously to avoid excessive intervention.

5 Novel Therapeutic Approaches

5.1 PRP and Stem Cell Based Therapies

Although surgical treatment can restore anatomical structure, it is accompanied by postoperative pain, joint instability, and complications, which is why injection therapies are gradually gaining attention. Research shows that when surgical treatment leads to knee pain, joint instability, or functional impairment, the degradation of cartilage can be repaired and the progression of knee osteoarthritis can be delayed by combining hyaluronic acid with PRP [11]. PRP is a high-concentration platelet concentrate obtained through centrifugation of autologous blood. It is rich in various growth factors, such as PDGF, TGF-β, and VEGF, which can exert anti-inflammatory effects, promote matrix synthesis, and stimulate angiogenesis within the joint. Therefore, injecting it into the joint cavity can suppress inflammation and promote tissue repair and regeneration.

Stem cell therapy provides new possibilities for meniscus regeneration [12]. Mesenchymal stem cells (MSCs) can be sourced from bone marrow, adipose tissue, and synovium. It has the potential for multidirectional differentiation and strong paracrine effects. Animal experiments have confirmed that MSC transplantation can form tissue similar to fibrocartilage at the site of meniscus defects and improve load-bearing capacity. Early clinical trials have also reported the feasibility of autologous bone marrow MSC injection into the joint cavity in patients with degenerative meniscus. However, most studies to date are animal-based, and clinical studies are still in the early stages. Hence, further research is needed to investigate their safety, efficacy, and mechanisms of action.

5.2 Tissue Engineering and Autologous Transplantation

Tissue engineering that combines cells, scaffolds, and biological factors is seen as a potential solution for repairing complex meniscus defects [12]. Composite transplantation of bone marrow mesenchymal stem cells with collagen or polylactic acid scaffolds has shown good results in animal models. Some clinical studies have attempted to repair meniscus defects using collagen scaffolds, achieving initial success. However, engineered menisci still face a series of challenges.

Firstly, there is a high rate of implant failure, with potential issues such as rapid scaffold degradation or displacement of the implant post-surgery. Secondly, material science problems remain unresolved. Although collagen scaffolds have good biocompatibility, they lack sufficient strength. By contrast, synthetic polymer materials like PLA and PGA possess strong mechanical properties, while are often accompanied by inflammatory responses due to degradation products. Moreover, high costs and the complexity of surgical procedures limit their clinical adoption. Therefore, despite the initial success shown by engineered menisci, their shortcomings in long-term durability, mechanical performance, and standardized processes indicate a significant gap before widespread application. Future research needs to focus on the development of biomimetic scaffolds with multi-layered structures, controllable release systems for cell factors, and large-scale randomized controlled trials to truly validate their feasibility and safety in clinical settings.

For young patients after extensive resection, autologous tendon transplantation has been proposed as an alternative option, aimed at addressing the biomechanical changes of the knee joint after meniscectomy and the early issues of osteoarthritis [13]. Clinically, tendons are usually harvested from the semitendinosus, gracilis, patellar tendon, peroneus longus, and quadriceps for transplantation. Bone tunnels are used to secure them near the meniscus to mimic the normal attachment points of the meniscus. Sometimes, bone marrow aspirate is used to promote healing and protect the cartilage. Compared to other grafts, this substitute is derived from autologous tissue, thus there is no risk of immune rejection or disease transmission. The selective nature of tendons meets the needs of different patients and avoids sizing mismatches, while being less expensive than allografts. However, considering that tendons may not fully convert to fibrocartilage, their durability is a long-term issue that needs to be addressed. Some patients have progressed to severe arthritis post-surgery, leading to total knee replacement. Moreover, if the fixation is not secure or if a poor alignment occurs post-operatively, there is a risk of graft displacement. Therefore, while autologous tendon transplantation has advantages of low cost and high safety, its long-term effectiveness and technical standards still require substantial research and trials for validation.

6 Conclusion

Meniscus tears are a common but complex knee joint pathology which requires personal diagnosis and perfect treatment strategies. This review introduces the morphological and functional classifications of tears, emphasizes the role of magnetic resonance imaging (MRI) and arthroscopy in diagnosis, and compares conservative treatment with surgical intervention. Conservative methods are good in stable and degenerative tears, while surgical techniques such as repair or transplantation are crucial for traumatic and unstable tears. Promising approaches such as PRP, MSC therapy, and tissue engineering are regenerative potential. However, their clinical efficacy and safety are still under investigation. Current limitations include the difference in healing abilities of avascular zone tears, the risk of osteoarthritis after meniscectomy, and the high costs and technical challenges of advanced therapies. Future work should focus on refining biological treatments, developing biomimetic scaffolds, conducting large-scale randomized trials, and integrating personalized medicine principles in order to improve the therapy quality of patients with meniscal injuries.

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