Treatment Methods for Anterior Cruciate Ligament (ACL) Injury

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Abstract: Anterior cruciate ligament (ACL) injury is a common sports-related injury in clinical practice that severely affects the patient's mobility and quality of life. Treatment methods for ACL injury include conservative treatment and surgical treatment, among which arthroscopic ACL reconstruction is the most widely used surgical approach. Rehabilitation plays a crucial role in the treatment process, and a scientifically designed rehabilitation plan can not only promote postoperative recovery but also reduce the risk of secondary injury. This article reviews the epidemiological background, diagnostic methods, treatment plans, and rehabilitation strategies for ACL injuries, analyzes the advantages and shortcomings of existing treatment methods, and discusses possible future optimization directions.

1 INTRODUCTION

ACL injuries can generally be categorized into partial tears and complete ruptures. In partial tears, the ligament fibers are not completely torn, and some stability is retained, though it may lead to limited knee movement or pain. In complete ruptures, the ACL is fully torn, causing a significant decrease in knee stability. Patients may experience joint laxity, functional impairment, and an increased risk of secondary injury. After an ACL injury, the stability, coordination, and balance of the knee joint are all affected, and it may also be accompanied by damage to the meniscus, collateral ligaments, and cartilage, further exacerbating knee dysfunction (Sun, 2024).

The incidence of ACL injuries is influenced by factors such as age, gender, and type of sport. Statistics show that approximately 30 to 80 cases of ACL injuries occur annually per 100,000 people, with a particularly high incidence in competitive sports. Female athletes are at a 2 to 8 times higher risk of ACL injury compared to males, which may be related to anatomical structure, biomechanics, and hormonal factors. Globally, the incidence of ACL injuries is rising. For example, in the United States, approximately 250,000 people sustain an ACL rupture due to sports each year, and the majority of these patients require ACL reconstruction (ACLR). ACL injuries not only affect professional athletes but are also common among adolescents and recreational sports enthusiasts, potentially leading to long-term impacts on their athletic abilities, daily life, and mental health (Pan, 2024 & Xu, 2024).

The causes of ACL injuries can be divided into non-contact and contact injuries. Non-contact injuries, which account for over 70% of cases, typically occur during activities such as landing from a jump, sudden stops, or quick changes in direction. These injuries result from knee valgus, excessive anterior tibial translation, or rotational forces, which overload the ligament. Non-contact ACL injuries are common in sports such as basketball, soccer, and volleyball. Contact injuries are more prevalent in sports like football and rugby, where direct external force is applied to the knee joint, potentially leading to ACL tears or ruptures.

2 DIAGNOSIS

Accurate diagnosis of anterior cruciate ligament (ACL) injury is crucial for developing an appropriate treatment plan. Clinically, ACL injury is primarily assessed through MRI, X-ray, and physical examination.

MRI (Magnetic Resonance Imaging) is a high-resolution imaging technique that can clearly display the morphology, position, and integrity of the ACL and is widely used in the clinical diagnosis of ACL injuries. Currently, the MRI diagnosis of ACL injuries relies on both direct and indirect signs. Direct signs refer to abnormal changes in the ACL's signal or morphology, including discontinuity (signal interruption, typically seen in fresh injuries),

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abnormal direction (the ACL appears abnormally angled or drooping), signal loss (no ACL signal in the intercondylar notch, often seen in chronic injuries), and pseudo-tumor formation (proliferation of tissue at the torn ends, encapsulated by synovium). Indirect signs include meniscal damage (with 22.50% of cases involving lateral meniscus damage and 20.00% involving medial meniscus damage), collateral ligament injuries (20.00% medial and 2.50% lateral), bone contusions (62.50%), and Segond fractures (12.50%), which occur on the lateral tibial plateau and suggest a higher likelihood of ACL injury. MRI offers a high diagnostic accuracy rate (95.34%), is non-invasive, and provides multi-planar imaging, making it the gold standard for diagnosing ACL injuries. However, it is relatively costly, time-consuming, and may have some limitations in early assessment of acute injuries (Pan, 2024).

X-ray examination is primarily used to exclude fractures and can also be used to observe bone contusions or skeletal abnormalities. For example, a Segond fracture (avulsion fracture on the lateral tibial plateau) may indicate the presence of ACL injury. Although X-ray cannot directly show the ACL itself, it still holds value in the auxiliary diagnosis of ACL injuries.

Physical examination, combined with the patient's medical history, can serve as an initial screening method for ACL injury. Common examination techniques include the Lachman Test, the Anterior Drawer Test, and the Pivot-Shift Test. In the Lachman Test, when the ACL is injured, the tibia moves anteriorly to a greater extent, indicating a positive result. The Anterior Drawer Test evaluates the degree of anterior tibial translation to assess the integrity of the ACL. The Pivot-Shift Test is the most specific physical examination for ACL injury but requires the patient to relax their muscles, making it difficult to perform during the acute injury phase.

3 TREATMENT

Recent advancements in the treatment of ACL injuries focus on improving the healing process through biological augmentation (BA) techniques, which aim to enhance graft healing and improve long-term outcomes post-surgery. One of the most studied BA methods is platelet-rich plasma (PRP), which is believed to promote graft healing by providing growth factors that aid tissue regeneration and remodeling. Studies have shown mixed results, with some indicating that PRP can accelerate the graft maturation process and improve knee function, while others report minimal or no clinical benefits (Shen, Shi & Li, 2024).

Biological augmentation can be applied during ACL reconstruction (ACLR) through techniques such as the use of PRP, mesenchymal stem cells (MSCs), or various growth factors like bone morphogenetic proteins (BMPs). These techniques aim to optimize graft healing, enhance osseointegration at the graft-tunnel interface, and promote better ligamentization of the graft. However, the clinical evidence supporting the routine use of BA in ACLR remains inconclusive. A survey indicated that a minority of surgeons currently use BA in primary ACLR, and those who do report inconsistent clinical outcomes (L, 2025).

Studies on animal models have shown that BA techniques, including PRP and stem cell applications, can significantly improve graft healing by enhancing vascularization and graft-to-bone integration. Despite promising animal study results, the application of these techniques in clinical practice is still debated due to variability in outcomes and a lack of robust evidence from randomized controlled trials. The use of PRP has been particularly controversial, with some studies suggesting it accelerates healing, while others fail to demonstrate substantial clinical improvements.

The timing of ACL surgery remains a critical factor in treatment outcomes. Research suggests that early reconstruction, typically within 1 to 2 weeks after injury, leads to quicker recovery and lower complication rates. Delayed surgery, however, might impair long-term knee function, prolonging rehabilitation. Preoperative rehabilitation focusing on strength training, neuromuscular coordination, and joint mobility is also shown to positively impact postoperative recovery, leading to improved muscle function and reduced postoperative pain (Failla, Arundale, Logerstedt & Snyder-Mackler, 2015).

Post-ACLR rehabilitation remains a key component of treatment success. It is crucial for restoring knee function, improving quadriceps strength, and ensuring the return of full range of motion. Emphasizing neuromuscular training during rehabilitation can also reduce the risk of reinjury and improve knee stability. Furthermore, psychological factors such as fear of reinjury or returning to sports play a significant role in recovery. Incorporating psychological support into rehabilitation programs can help address these concerns, facilitating a smoother return to physical activity (Xu, Yang, Zhang, et al. 2025 & Rodríguez-Merchán, 2021).

4 ACL REHABILITATION

Rehabilitation after ACL surgery is crucial for restoring knee function. A well-designed rehabilitation plan not only helps maximize the surgical outcomes but also reduces the risk of secondary injuries and improves the patient's athletic performance. In recent years, research on post-ACL reconstruction rehabilitation has advanced significantly, showing that optimizing rehabilitation plans is key to successful recovery (Jin, & Li, 2024).

Post-ACL surgery, rehabilitation now focuses not just on restoring knee joint function but also on optimizing movement patterns and improving neuromuscular control. Studies have shown that fast-track rehabilitation programs can speed up knee function recovery compared to traditional methods, particularly for athletes. A properly structured plan can help them return to sports more quickly. Additionally, neuromuscular training plays a central role in rehabilitation. By using strength training, balance exercises, and plyometric training, this approach can effectively correct lower limb biomechanical imbalances, enhance dynamic knee stability, and reduce the risk of reinjury. This type of training not only improves muscle control but also optimizes an athlete's movement patterns, helping them maintain high levels of athletic performance during recovery (Xu, Jiang, Zong, et al. 2024).

For muscle strength recovery after surgery, isokinetic strength training is widely used in ACL rehabilitation. Research shows that isokinetic training allows for precise measurement of muscle strength around the knee, aiding in the development and adjustment of rehabilitation plans. By using both concentric and eccentric training modes, isokinetic training improves the coordination between the quadriceps and hamstrings, stabilizing the knee joint and promoting post-surgery athletic recovery. In the early stages of rehabilitation, combining neuromuscular electrical stimulation and proprioceptive training helps to strengthen the knee's neuromuscular control and improve dynamic balance, reducing the risk of asymmetrical movement patterns during recovery (Xu, Jiang, Zong, et al. 2024 & Jin, Li, 2024).

The rehabilitation plan after ACL surgery should be tailored to the individual. In the early stages, the focus should be on inflammation control, restoring joint range of motion, and proprioceptive training. As recovery progresses, strength training, neuromuscular exercises, and isokinetic training should be gradually introduced to improve knee stability and function. For athletes, fast-track rehabilitation helps them return to their competitive level more quickly, while non-athletic patients can follow a more gradual plan to ensure long-term knee health and stability. With a well-structured rehabilitation strategy, recovery time can be shortened, the risk of secondary ACL injuries reduced, and overall athletic performance significantly improved (Qin, Qian, 2017 & Kong, Li, 2019).

5 CONCLUSION

The treatment methods for ACL injuries are constantly evolving and improving. Significant progress has been made in both precision and recovery efficiency. Surgical treatments, especially arthroscopic ACL reconstruction, have become the preferred option for most patients due to its minimally invasive nature, high postoperative stability, and controlled rehabilitation process. However, conservative treatment still holds value for individuals with low activity levels, particularly when surgery might pose potential risks. Despite these advantages, both approaches have their drawbacks. While surgery can restore knee stability, there is still a risk of recurrence and a lengthy recovery period. Conservative treatment, although less invasive, struggles to fully restore knee function, particularly for individuals with high physical activity demands, and its long-term effectiveness may be limited.

To overcome these limitations, personalized treatment plans and optimized rehabilitation strategies are crucial. The focus of postoperative rehabilitation should not only be on restoring joint range of motion and muscle strength but also on enhancing neuromuscular control to reduce the risk of secondary injuries due to abnormal movement patterns. Isokinetic and neuromuscular training have proven to be highly effective in ACL recovery, and future advancements could include integrating new technologies like virtual reality training and robot-assisted rehabilitation to further improve precision and efficiency. Additionally, prevention should not be overlooked. Improving athletes' body control, optimizing movement patterns, and promoting preventive training programs for high-risk sports could play a more significant role in reducing the incidence of ACL injuries.

While current treatments can help most patients return to daily activities and even sports, there is still room for improvement. Future research should not only focus on postoperative recovery but also delve

deeper into strategies for preventing ACL injuries, ultimately reducing the risk of sports-related injuries for patients.

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