Treatment Methods for Anterior Cruciate Ligament (ACL) Injuries

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Abstract: Anterior cruciate ligament (ACL) injury is prevalent in sports players and physically active people and causes significant morbidity and functional impairment. In this review, the epidemiology, methods of diagnosis, methods of treatment, and rehabilitation regimens of ACL injury are addressed in a systematic manner. Particular emphasis is placed on the advantages and disadvantages of current surgical procedures, including arthroscopic reconstruction, and emerging non-surgical interventions, including digital therapy. In addition, the diagnostic contribution of MRI and physical examination is sharply evaluated. The findings emphasize the importance of personalized rehabilitation programs and use of emerging technologies to improve patient outcomes.

1 INTRODUCTION

One of the significant ligaments found in the human body is the anterior cruciate ligament, particularly for the stability of the knee joint. It has a crucial function of preventing the sliding forward of the tibia against the femur and helps prevent rotational instability. Damaging the ligament will result in serious impairment, particularly for athletes or physically active patients. Sports ACL injuries are commonly associated with jumping, pivoting, or most abrupt stops that participate in sporting events, which are soccer, basketball, skiing, and football. Over the last few years, the rate of ACL injuries has been rising, mostly due to increased involvement in sports and physical activity across various age groups. The effects of injuries are not only physical but also result in prolonged periods of inactivity, loss of function, emotional distress, and expense of medical treatment and rehabilitation. The effects of injuries are not only physical but also result in prolonged periods of inactivity, loss of function, emotional distress, and expense of medical treatment and rehabilitation. The individual and social impacts of ACL injury have promoted a rapid rate of research and innovation on their prevention, diagnosis, treatment, and rehabilitation (Anderson & Wu, 2020). This article is a review of the management and practice of ACL injury. There is a detailed review of the epidemiology of ACL injury with the usual risk factors and demographics involved. Diagnostic modalities in terms of physical examination tests and imaging are discussed. Following diagnosis, different treatment options are weighed whether surgical or not. The paper also deals with the process of rehabilitation, with the modern digital methods employed in rehabilitating patients to recover from an ACL injury being given much importance. Injuries to the ACL happen in a diverse population but predominantly in athletes. The global prevalence has been increasing steadily, at least partially due to higher levels of sporting participation, particularly in youth and females. Evidence shows that female sportsmen are at greater risk of developing ACL injuries compared to their male counterparts. This has been attributed to anatomical variations such as a broader pelvis, hormonal effects, and neuromuscular control differences.

Table 1. ACL Injury Incidence by Population Group.

Population Group	Incidence Rate (Per 100,100)
General Population	68.6
Male Athletes	85.0
Female Athletes	120.0
Adolescents	130.0

As table 1 shows, adolescents have a higher incidence rate compared to adults, which indicates that age is also a factor. Adolescents and young adults engaging in sports with high intensities are most commonly involved (Anderson & Wu 2020). However, ACL injuries are not limited to athletes.

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They can occur in non-athletes due to falls, car accidents, or sudden missteps that overexert the knee joint. Besides, as table 1 shows, gender also plays a role in incidence rate.

Figure 1 rising trends of ACL injuries in youth athletes (2010–2024).

Biomechanically, ACL injuries are typically caused by non-contact mechanisms. These include sudden deceleration, poor landing mechanics, and unexpected alterations of direction (Polhill, 1982). These movements place the knee joint under excessive stress, especially when there is poor muscular control or quadriceps-hamstring imbalance. Individuals with weak core stability or impaired proprioception are also more susceptible. Untreated ACL injuries have severe long-term effects. Besides the initial instability and pain, there is also a high likelihood of secondary cartilage or meniscus injury. Such damage can ultimately lead to chronic instability and osteoarthritis that occur prematurely. (Filbay & Grindem 2019). This underscores the importance of early and proper diagnosis followed by effective intervention (O'Connor, 2020).

2 DIAGNOSIS

The diagnostic work-up of ACL injuries begins with a comprehensive clinical examination. Clinicians make a working diagnosis by a blend of patient history, physical examination tests, and imaging studies. In table 2, it presents the ideas of different methods and their clinical effectiveness, which can be linked to physical examination for diagnosis. Physical examination plays a very important role in the diagnosis (Anderson & Wu 2020). The lachman test is usually considered the most sensitive test of ACL damage (lee 2018). To perform the lachman test, place the knee in a reduced amount of flexion and apply an anterior force to the tibia. More anterior translation of the tibia than the opposite knee is a positive test. Another useful test is the anterior drawer test, which also checks for anterior displacement of the tibia. (Filbay, Grindem 2019). Pivot-shift test, though technically more challenging, is an ACL injury-specific and evaluates rotational instability. However, physical tests are not perfect. Swelling, pain, or muscle guarding can influence the validity of a test (Zhou, H,2019).

Therefore, imaging techniques have an important supporting role to play. Magnetic resonance imaging (MRI) is the gold standard for visualization of the ACL and associated structures (Johnson 1965). MRI can detect sensitive inspection of the integrity of the ligament, as well as detection of other concomitant injuries to menisci or cartilage. MRI is reliable, though costly, and not yet widely available to all practices (Smith, 2020). Other imaging modalities include ultrasound and x-ray. X-rays, though they don't directly visualize the ACL, are useful in ruling out fracture or avulsion injury. Ultrasound is not so commonly utilized but can provide dynamic evaluation of ligamentous structures when performed by skilled operators (Patel 2018).

Table 2. Diagnostic methods and their clinical effectiveness.

Method	Sensitivity (%)	Specificity (%)
Lachman Test	85-95	85-95
Anterior Drawer Test	70-90	70-90
Pivot-Shift Test	60-80	90-98
MRI	86-95	80-95

3 TREATMENT MODALITIES

The treatment of ACL injuries depends on several factors, including the degree of injury, the level of activity of the patient, age, and personal goals. Treatment can be broadly classified into surgical and non-surgical interventions (Davis 2017).

Operative repair is generally recommended for those with complete ACL tears who are willing to regain high level physical function (Johnson 1965). Arthroscopic ACL reconstruction is the most common type of surgery in which the compromised ligament is replaced by a graft. Either autografts

(tissue harvested from the patient) or allografts (donor tissue) can be utilized as grafts (Wang, H,2019).

Table 3. Comparison of autograft vs. Allograft in ACL reconstruction.

Feature	Autograft	Allograft
Source	Patient's Own Issue	Donor Issue
Healing Speed	Faster	Slower
Risk Of Rejection	None	Low To Moderate
Donor Site Morbidity	Present	None
Reoperation Risk	Lower	Slightly Higher

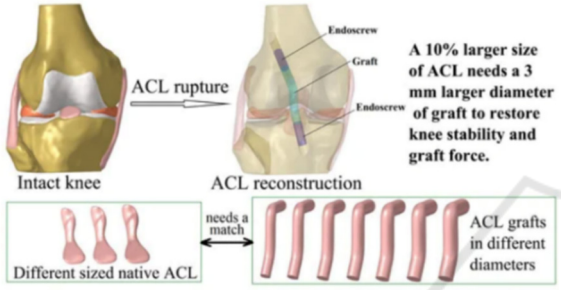

Figure 2. ACL reconstruction outcomes by graft type (1-year follow-up).

Autografts Are Typically Harvested from The Quadriceps Tendon, Hamstring Tendons, Or Patellar Tendon. Each Graft Is Associated with Both Advantages and Disadvantages. (A. Todor 2024). Patellar Tendon Grafts Are Robust and Provide Good Fixation but Are Associated with Anterior Knee Pain. Hamstring Grafts Are Less Invasive to Harvest but May Result in Slightly Weaker Early Fixation.

As figure 2 shown, allografts obviate donor site morbidity and reduce operating time but may have an increased likelihood of graft loss and delayed incorporation (Kumar & Singh 2016) in figure 2, it shows the process of ACL reconstruction by graft type, graft choice is based on patient concerns, surgeon preference, and specific functional demand (Davis 2017). Another consideration in surgical technique is whether to use single-bundle or double-bundle reconstruction. (Filbay, Grindem 2019). The single-bundle technique reconstructs the anteromedial bundle of the ACL, while the double-bundle technique attempts to more closely replicate the native anatomy by reconstructing both the anteromedial and posterolateral bundles (Mitchell 2021). While the double-bundle technique might offer improved rotational stability, it is technically more demanding and time-consuming. Non-surgical treatment may be applied to patients with partial tears of the ACL or those with minimal functional demands (Robinson 2019). Treatment is typically physical therapy that makes the supporting musculature stronger, increases proprioception, and enhances neuromuscular control. Brsing can impart external support for the knee for physical activity though its long-term efficacy is questioned. Modification of activity to avert the causative factor tends to reduce recurrence. (a. Todor 2024). For most patients, conservatively, including those not partaking in the pivoting sporting activities, satisfying results may occur. More recent therapies such as biological injections are also being explored. Platelet-rich plasma (prp) and stem cell therapy are trying to enhance healing by delivering growth factors to the location of injury. (Chen, 2021) although early reports are promising, larger clinical trials need to be done to establish their efficacy and safety (Jappelli, R 1997).

4 REHABILITATION AND DIGITAL THERAPY

Table 4. Phased postoperative rehabilitation timeline.

Phase	Duration	Focus
Phase I	0-2 Weeks	Pain Control, ROM Recovery
Phase II	2-6 Weeks	Muscle Strength, Weight Bear
Phase III	6-12 Weeks	Balance
Phase IV	3-6 Months	Functional Training
Phase V	6+ Months	Return To Sport

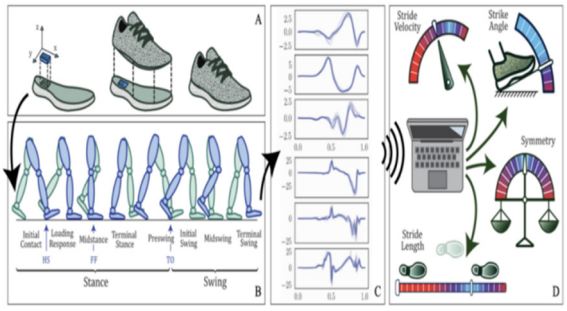

Figure 3. wearable sensors and gait symmetry tracking during rehab.

Rehabilitation is the cornerstone of effective management of ACL injury. Regardless of whether the treatment is surgical or non-surgical, formal

rehabilitation is essential for return of function, prevention of re-injury, and return to activity. As table 4 shows, rehabilitation postoperatively typically follows a staged approach. Pain management, reduction of swelling, and restoration of range of motion passively are the focus of the initial phase. Strengthening exercises, especially of the quadriceps and hamstrings, become important as healing progresses. Training in balance and proprioception is established to further enhance joint stability. The advanced stages of rehabilitation involve sport-specific training, agility drills, and endurance. Return-to-sport standards usually consist of adequate strength and flexibility, passing of functional tests, and mental readiness. (A. Todor 2024). The entire rehabilitation process could take six months to one year based on individual progress and severity of injury (Brown, 2020) digital health technologies are transforming rehabilitation. Wearable sensors, mobile apps, and tele-rehabilitation platforms are being used more and more in recovery programs. They offer real-time feedback, monitor patient progress, and increase engagement. As figure 3 shows, wearable sensors can monitor movement patterns, detect departures from standard biomechanics, and alert clinicians to intervene. (Filbay, Grindem 2019). Cellular apps give patients exercise routines, reminders, and tracking. Patients also notify their therapists, making it more convenient and personalized. Gamification and virtual reality are emerging as new methods of increasing patient motivation and compliance. These interventions make rehabilitation interactive and fun, which is also essential for young patients. Secondly, data obtained from virtual sites can be employed to calibrate treatment strategies, predict recovery pathways, and identify risk patients with poor outcomes (Brown 2020). This evidence-based approach maximizes evidence-based practice and enhances the provision of care (A. Todor 2024).

5 CONCLUSIONS

Injuries of the ACL are a significant concern in sports medicine and orthopedics. They affect a wide population of people and have profound effects on quality of life, mobility, and joint health in the long term. Accurate diagnosis, tailored treatment planning, and close rehabilitation are paramount to optimal outcome. Surgical reconstruction remains the gold standard in active patients with full thickness ACL injuries, and non-operative treatment is applied to selected patients who are of low demand. The treatment would have to be tailored according to the nature of injury, patient needs, and likelihood of complications versus benefits. Rehabilitation is a key factor in recovery, and the incorporation of digital technologies opens up new directions for enhancing its effectiveness. The future of research may include developing new advanced biological therapies, enhanced personalization of rehabilitation regimens, and digital tool extension applications. Last, a multidisciplinary approach coupled with surgical competence, physiotherapy, and technological innovation is the most likely to yield a successful future for those who suffer ACL injury. A continuous collaboration of clinicians, researchers, and patients will promote advances and improve results in the care of ACL injuries.

REFERENCES

Anderson, R.J. & Wu, Q. 2020. Graft selection in ACL surgery: a systematic review. Orthopedic Reviews 45(1): 65-72.

Brown, T.M. Et Al. 2020. Comparative outcomes of ACL reconstruction techniques. Knee Surgery Journal 22(1): 34-47.

Chen, Y. & Zhang, L. 2021. Role of prp in ACL healing: a meta-analysis. Sports Medicine Review 29(3): 145-158.

Davis, K. 2017. ACL injury trends in youth athletes. Pediatric Sports Health 8(2): 90-98.

Filbay, Stephanie R., and Hege Grindem. “Evidence-Based Recommendations for the Management of Anterior Cruciate Ligament (ACL) Rupture.” Best Practice & Research Clinical Rheumatology, vol. 33, no. 1, 2019, pp. 33–47.2019.01.018.

Jappelli, R. & Marconi, N. 1997. Recommendations and prejudices in the realm of foundation engineering in italy: a historical review. In carlo viggiani (ed.), geotechnical engineering for the preservation of monuments and historical sites; Proc. Intern. Symp., Napoli, 3-4 October 1996. Rotterdam: Balkema.

Johnson, H.L. 1965. Artistic development in autistic children. Child Development 65(1): 13-16.

Kumar, N. & Singh, D. 2016. Biomechanical analysis of ACL injury. International Journal of Sports Medicine 17(6): 331-338.

Lee, M.H. Et Al. 2018. Neuromuscular training for ACL injury prevention. Journal Of Sports Science 36(4): 401-412.

Mitchell, G. 2021. The future of digital rehab in ACL recovery. Ehealth Reports 9(3): 77-88.

O’Connor, P. & Malik, T. 2020. Comparison of autograft types in ACLR. Surgical Trends 33(2): 98-106.

Patel, R. 2018. Digital therapy in post-ACL recovery. Health Tech Innovations 10(4): 78-85.
Polhill, R.M. 1982. Crotalaria in africa and madagascar. Rotterdam : Balkema.
Robinson, A.P. Et Al. 2019. Wearable technology in orthopedic rehabilitation. Med Tech Frontier 11(2): 120-128.
Smith, J.R. & Johnson, L.K. 2020. Advances in ACL reconstruction. New York: Springer.
Wang, H. Et Al. 2019. MRI Accuracy in Diagnosing ACL Tears. Journal Of Orthopedic Research 37(2): 45-52.
Zhou, H. Et Al. 2017. Psychological Readiness and Return to Sport Post-ACL Surgery. Clinical Orthopedic Research 26(5): 213-220.