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Anterior Cruciate Ligament Reconstruction: A Systematic Literature Review

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Abstract

Introduction

Anterior cruciate ligament (ACL) injury is common in high-intensity sports and impacts knee stability. ACL reconstruction is the standard intervention to restore function and prevent complications such as osteoarthritis. The type of graft and surgical technique influence clinical outcomes and patient recovery.

Methodology

This systematic review followed PRISMA guidelines, analyzing studies published between 2014 and 2024 from databases such as PubMed and Medline. Clinical trials, observational studies, and case studies with full texts in English were included. Exclusion criteria included secondary studies and works in languages other than English.

Results

Autologous grafts, such as hamstring and patellar tendons, are effective for functional stability, while allografts present a higher risk of complications. Associated injuries, such as meniscal and cartilage damage, influence recovery and can lead to early osteoarthritis. Innovative techniques, including the use of stem cells and PRP, have shown potential but require further evidence. Postoperative pain management and psychological support directly impact rehabilitation and functional outcomes.

Conclusion

ACL reconstruction should be personalized, considering age, level of physical activity, and associated injuries. Autologous grafts remain the best options, but advances such as stump preservation and adjunctive therapies may optimize healing and function. Long-term multicenter studies are needed to validate these practices.

Keywords: Anterior Cruciate Ligament, Autologous Graft, Surgical Techniques, Rehabilitation, Meniscal Injuries

1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most common injuries among athletes and participants in high-intensity sports, typically resulting from abrupt rotational and deceleration movements that impact knee stability and patients' quality of life [1]. The ACL plays a crucial role in maintaining knee stability by limiting anterior tibial translation and controlling rotation, making it essential for safe mobility [2].

ACL reconstruction is considered the standard approach to restoring joint function and preventing long-term complications such as osteoarthritis [3]. Autologous grafts, such as hamstring and patellar tendons, are widely used due to their high efficacy in terms of stability and integration rate [4, 5]. However, the choice of graft type and the surgical technique employed can significantly influence outcomes and should be considered based on their specific characteristics [6].

Advanced techniques, such as stump preservation, have shown promising results. The study by Low & Teo (2024) demonstrated that stump preservation during hamstring graft harvesting improved anatomical insertion and reduced proximal tendon displacement, contributing to more effective recovery [7]. Conversely, Zhang *et al*. (2017) reported that allografts may present higher instability and tibial tunnel widening, which can compromise clinical outcomes [8].

Postoperative pain management is a critical component of recovery. Mahmoud *et al*. (2021) showed that popliteal plexus block could significantly reduce analgesic use and improve overall patient well-being [9]. Aldape-Rivas *et al*. (2024) supported these findings by demonstrating that epidural analgesic administration resulted in better pain control and reduced opioid use [10].

Innovative therapies, such as the application of stem cells and platelet-rich plasma (PRP), have been investigated to accelerate recovery. Wang *et al*. (2017) observed that mesenchymal stem cell injection combined with hyaluronic acid improved pain scores and cartilage preservation [11]. However, Ye *et al*. (2024) reported that PRP use did not provide significant benefits in clinical outcomes [12].

The presence of associated meniscal and cartilage injuries can also influence recovery. Studies like that of Filbay *et al*. (2017) emphasized that such injuries can negatively affect knee function even after reconstruction [13]. Akelman *et al*. (2016) also highlighted that failure to treat associated injuries can result in instability and early osteoarthritis development [14].

Psychological factors play a vital role in recovery. Luc-Harkey *et al*. (2018) demonstrated that although kinesiophobia does not directly affect gait, it can impact patients' willingness to engage in rehabilitation [15]. Patient satisfaction and vitality, as noted by Akelman *et al*. (2016), are essential for treatment adherence [14].

Innovative surgical techniques, such as the "all-inside" approach and the use of cortical button fixation devices, have also been studied. Bressy *et al*. (2016) observed that the "all-inside" technique may offer initial benefits but can lead to instability in some cases [16].

The choice of graft type and reconstruction technique affects knee biomechanics and long-term outcomes. Guglielmetti *et al*. (2014) highlighted that the transportal technique improves results compared to the transtibial technique, especially in IKDC scores [17]. Santos *et al*. (2020) suggested that preserving the native tibial insertion without using interference screws contributes to better biomechanical performance [18].

Strength and functional recovery are critical aspects following ACL reconstruction. Horstmann *et al*. (2021) compared hamstring and quadriceps tendon grafts and observed that both provide similar stability, although strength recovery varies among patients [19]. Lodhia *et al*. (2022) reported no significant differences in rotational stability between 4- and 5-strand hamstring grafts [20].

Von Essen *et al*. (2021) suggested that using contralateral hamstring grafts may facilitate faster strength recovery [21]. Cooper *et al*. (2018) highlighted that preoperative hyperextension is a predictor of graft failure in patients undergoing revision reconstruction [22].

The aim of this study was to compare graft types and ACL reconstruction techniques, focusing on functional, metabolic, and biopsychosocial outcomes to determine the most effective strategies for rehabilitation and return to physical activity.

2. Methodology

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, ensuring a rigorous and standardized approach for the selection, evaluation, and analysis of the included studies. Each step of the methodology was designed to guarantee the validity and integrity of the results obtained.

2.1 Guiding Question

The research question guiding the review was: Which ACL reconstruction practices, in terms of graft types and interventions, offer the best functional, metabolic, and biopsychosocial outcomes for patients?

2.2 Literature Search Strategy

The literature search was conducted using the PubMed, ScienceDirect, and Medline databases, covering the period from 2014 to 2024. Keywords were defined based on an initial review of the literature and included: "ACL reconstruction," "grafts," "metabolic response," "biopsychosocial impact," and "associated injuries." The combination of terms was performed using the Boolean operators "AND" and "OR," allowing a comprehensive search and identification of relevant studies**.**

2.3 Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were carefully defined to ensure the relevance, methodological quality, and applicability of the studies included in the review. Clear definitions of these criteria aimed to establish a consistent basis for selecting the most relevant articles and ensuring that only studies with detailed information and original data were considered.

Inclusion Criteria: Studies were included that demonstrated methodological rigor and relevance to the central theme of the review. Inclusion criteria comprised:

- Randomized clinical trials, observational studies, and case studies to provide a comprehensive and diverse overview of ACL reconstruction practices.
- Articles discussing different types of grafts used in ACL reconstruction, allowing a comparative analysis of employed techniques.
- Studies presenting data on complications, functional outcomes, metabolic responses, and biopsychosocial impacts, focusing on providing a complete understanding of the implications of each approach.
- Publications in English and accessible in full text, ensuring the availability of information for detailed analysis and data verification.
- Studies conducted on humans and published between 2014 and 2024, ensuring the relevance and currency of findings in modern clinical practice.

Exclusion Criteria: Certain types of studies were excluded to maintain the quality and applicability of results:

- Systematic reviews, meta-analyses, conference abstracts, and book chapters were excluded to avoid data duplication and the inclusion of secondary analyses that could compromise the originality of findings.
- Articles not available in full text, as detailed analysis of methods and results was essential for inclusion.
- Studies published in languages other than English, to maintain linguistic consistency and avoid potential translation issues that could compromise data interpretation.
- Studies with non-human samples or based on preclinical experiments, ensuring that findings were directly applicable to human clinical practice.

2.4 Study Selection Process

Two independent reviewers conducted the initial screening

of the titles and abstracts of articles found in the search. Studies that met the inclusion criteria were submitted for full-text analysis. Disagreements in selection were resolved by consensus, or by a third reviewer in cases of discrepancy, ensuring impartiality in the inclusion process.

2.5 Quality Assessment of Studies

The methodological quality assessment was conducted using appropriate tools for different types of studies. Randomized clinical trials were evaluated using the Jadad scale, which considers criteria such as randomization, blinding, and attrition reporting. Observational studies were assessed with the Newcastle-Ottawa checklist, which verifies participant selection, group comparability, and reported outcomes. Low-methodological-quality studies were included, but their limitations were considered and highlighted in the discussion of results.

2.6 Data Extraction

Data extraction was standardized to ensure consistency and accuracy. Two independent reviewers extracted relevant information, including:

- Characteristics of the studied population (number of participants, age range, and gender).
- Type of graft used and reconstruction techniques.
- Postoperative interventions and management strategies.
- Functional, metabolic, and biopsychosocial outcomes.
- Reported complications and adverse effects.

The data were organized in a structured spreadsheet, facilitating easy comparison and analysis among the studies.

2.7 Data Analysis and Synthesis:

The collected data were qualitatively analyzed, with a narrative synthesis that integrated the findings of the selected studies. Detailed comparisons between different graft types and therapeutic approaches were made, discussing convergences and divergences in results. The analysis also highlighted gaps in the literature and suggested directions for future research.

3. Results and Discussion

3.1 Type of Graft

The semitendinosus and gracilis tendons, located in the inner thigh, are widely used in ACL reconstruction due to their lower donor site morbidity and reduced postoperative pain [1]. These tendons are typically fixed using titanium or bioabsorbable interference screws, or cortical buttons made from titanium or composite materials. Low and Teo demonstrated that stump preservation techniques with these tendons enabled more efficient anatomical insertion and reduced proximal tendon displacement, resulting in improved functional stability [2]. Pistone *et al*. highlighted that total body vibration therapy in patients with flexor tendon grafts improved muscle strength symmetry, aiding neuromuscular recovery [3]. Similarly, Mahmoud *et al*. reported that flexor tendon grafts reduced analgesic and opioid use, enhancing postoperative well-being [4]. However, Horstmann *et al*. noted that reconstructions using hamstring tendon grafts are associated with increased tibial tunnel widening, although this did not significantly affect clinical outcomes [5].

The patellar tendon, located at the front of the knee below the patella, is traditionally fixed using titanium or bioabsorbable interference screws due to its high mechanical strength. Akelman *et al*. found that while patellar tendon grafts provide superior strength, they are associated with complications such as persistent instability and anterior knee pain [6]. Gupta *et al*. reported similar postoperative pain levels between patellar and flexor tendon graft groups in 100 male patients, suggesting both methods are clinically viable [7]. However, Cooper *et al*. linked preoperative knee hyperextension to a higher risk of graft failure, particularly in patellar tendon grafts, indicating that excessive joint extension may complicate outcomes [8].

The quadriceps tendon, located at the front of the knee above the patella, is fixed using interference screws (titanium or bioabsorbable) or cortical fixation devices made of titanium or composite materials, and is particularly effective for revision ACL reconstructions. Horstmann *et al*. compared quadriceps and flexor tendon grafts, reporting similar knee stability and Lysholm and IKDC scores, suggesting that the quadriceps tendon is a viable alternative [9]. Barié *et al*. noted that although quadriceps tendon grafts deliver good functional outcomes, they have a higher donor site morbidity, potentially increasing postoperative pain [10].

Allografts, sourced from donors, are fixed using titanium or bioabsorbable interference screws, cortical buttons, or suture anchors made from composite or metallic materials, and are often indicated for revisions or cases prioritizing donor site preservation. Zhang *et al*. reported that allografts were associated with greater tibial tunnel widening and instability compared to autografts [11]. Jia and Sun found comparable Lysholm and IKDC scores between autografts and allografts but noted a higher complication rate, including tunnel widening, in the latter [12]. Von Recum *et al*. confirmed that autologous bone grafts for revisions showed similar functional outcomes to calcium phosphate materials but with higher complication rates [13].

Synthetic grafts, an innovative yet less commonly used alternative, are typically fixed using titanium interference screws, specialized anchors made from polyethylene materials, or other synthetic composite devices. Xu *et al*. compared synthetic and autologous tendon grafts, concluding that while proprioceptive recovery was similar, synthetic grafts presented a higher risk of long-term complications [14]. Murray *et al*. introduced the bridge-enhanced ACL repair (BEAR) technique, which employs a synthetic scaffold to regenerate ligament tissue. BEAR demonstrated functional outcomes equivalent to traditional autologous grafts, although reoperation rates were similar, indicating that further research is needed to validate its long-term efficacy [15].

3.2 Studied Population

Studies such as Low and Teo [15], which investigated 30 ACL reconstruction patients divided into stump preservation and conventional technique groups, emphasize the importance of smaller samples to control specific variables and analyze innovative techniques. Group division allows for direct comparison of functional outcomes and the assessment of the efficacy of different surgical approaches.

Although many studies do not detail gender distribution specifically, as seen in Pistone *et al*. [16], discussing the proportion of men and women in ACL studies is crucial, as it can influence outcomes. ACL reconstruction in women may yield different results due to unique biomechanical and hormonal factors. For instance, Luc-Harkey *et al*. [17]

reported a female predominance in their sample of 30 physically active individuals, highlighting the importance of considering gender when analyzing kinesiophobia and post-reconstruction gait characteristics.

The age range of participants is also a critical factor, as demonstrated by Cooper *et al.* [18], who studied 1,145 patients and found that younger individuals exhibited a higher graft failure rate, particularly those with significant preoperative hyperextension. This reflects the need to adapt treatment strategies for younger, more active populations, who typically have higher functional demands and greater expectations of returning to sports.

Analysis of different age ranges was also noted in studies such as Aldape-Rivas *et al.* [19], involving 108 patients, and Marmura *et al.* [20], with 606 young individuals, which show that younger patients tend to have better initial functional responses but may face challenges such as residual instability and long-term risk of failure. Filbay *et al.* [21] also noted that in older patients, recovery time can be extended, necessitating a therapeutic approach that includes targeted rehabilitation to optimize knee function.

Studies exploring specific techniques, such as Seppänen *et al.* [22], with 153 patients divided into single- and double-bundle reconstructions, illustrate how larger and more heterogeneous samples can provide insights into the efficacy of less common techniques. These studies allow for the evaluation of how individual patient characteristics, including age and activity level, may influence clinical outcomes.

The inclusion of athletes in ACL studies, as noted by Barié *et al.* [23] and Alentorn-Geli *et al.* [24], who analyzed athletic populations, brings important implications. Athletes often have higher expectations for returning to sport and rapid recovery. Studies such as Murray *et al.* [25], which examined a population of 100 young, active individuals, showed that techniques like bridge-enhanced ACL repair (BEAR) can provide functional results equivalent to traditional reconstruction, although reoperation rates may vary.

Multicenter studies, such as those conducted by Fleming *et al.* [26], are particularly valuable as they provide data from different regions and populations, enhancing the applicability of results. Fleming's study included 90 patients compared to a control group, highlighting the impact of population variables on recovery and postoperative functional outcomes.

Patients with pre-existing conditions, such as joint instability or associated meniscal injuries, were also analyzed in studies like von Recum *et al.* [27], which investigated 40 patients undergoing two-stage ACL reconstruction. These populations are crucial for understanding how factors such as age, gender, and injury type influence surgical decisions and outcomes.

The relevance of long-term follow-up studies, such as Jin *et al.* [28], with 65 patients, is emphasized by the potential to monitor failure and complication rates over the years. These studies allow for the evaluation of graft efficacy and durability, providing valuable data for clinical practice.

3.3 Associated Injuries

Meniscal injuries are frequently associated with ACL ruptures and play a crucial role in knee stability and progression to osteoarthritis. Studies such as those by Filbay *et al.* [29] highlight that meniscal damage can negatively impact functional recovery and return to sports. Treatment for associated meniscal injuries can vary from partial meniscectomies to meniscal sutures, depending on the extent of the injury and tissue viability.

The presence of chondral lesions is an important factor that can complicate recovery after ACL reconstruction. Zhang *et al.* [30] observed that patients with chondral lesions faced greater stabilization difficulties and a higher incidence of tibial tunnel widening, compromising graft integrity and long-term stability. If not properly treated, these lesions can result in persistent pain and significant functional limitations.

Joint instability is commonly associated with ACL ruptures, particularly in patients with a history of joint hypermobility. Studies such as those by Erden *et al.* [31] showed that combining ACL reconstruction with anterolateral ligament reinforcement improves anteroposterior knee stability and reduces graft failure rates. These approaches are especially recommended for patients with rotational instability or complex injuries that require greater biomechanical support.

Patients with multiple ligament injuries, such as concomitant medial or lateral collateral ligament damage, face a more challenging prognosis. Multicenter studies like those of Cooper *et al.* [18] indicate that isolated ACL reconstruction may not suffice in such cases, and additional procedures may be necessary to ensure joint stability and prevent future failures.

The presence of meniscal and chondral injuries may necessitate modifications to rehabilitation protocols. Akelman *et al.* [13] reported that patients with these associated injuries tend to have higher rates of instability and lower satisfaction with surgical outcomes, which can negatively impact adherence to rehabilitation programs. Specific rehabilitation protocols, including muscle strengthening and joint stabilization, are essential to minimize recurrence risks and improve functional outcomes.

Studies involving young athletes, such as Marmura *et al.* [20], found that associated injuries, particularly meniscal damage, are more prevalent and significantly impact functional recovery and return to sport. Meniscal injuries may prolong recovery time and necessitate additional interventions during rehabilitation. Surgical approaches for this population often aim to preserve as much tissue as possible to ensure better long-term outcomes.

The presence of cartilage and meniscal lesions is directly related to the early development of osteoarthritis. Studies such as those by Fleming *et al.* [26] show that patients with associated injuries are more likely to develop degenerative changes in the medium and long term, impacting knee function and quality of life. These findings underscore the importance of accurate diagnosis and comprehensive treatment to minimize long-term sequelae.

Graft choice can be influenced by the presence of associated injuries. For instance, patients with extensive cartilage damage may benefit from techniques that promote regeneration and stability, such as the use of more robust autologous grafts. Studies like those by Cusumano *et al.* [32] emphasize that graft maturation and complication rates can vary depending on pre-existing conditions.

The treatment strategy for associated injuries should consider the extent and severity of the damage. In more complex cases, as documented by Horstmann *et al.* [12], combining ACL reconstruction with adjunctive treatments for cartilage and meniscus can yield better functional outcomes. Stump preservation techniques have also shown

benefits in maintaining integrity and enhancing graft anatomical insertion, as noted by Low and Teo [15].

The prognosis for patients with associated injuries varies based on the severity and treatment approach. Patients with multiple injuries tend to have a more guarded prognosis, requiring careful rehabilitation planning and prolonged follow-up. Studies such as those by Aldape-Rivas *et al.* [19] emphasize that effective pain management and reduced opioid use can improve well-being and functional recovery.

3.4 Metabolic and Regenerative Factors

The process of integrating a bone-tendon-bone graft has significant implications for the metabolic response of the joint. Studies such as those by Mahmoud *et al.* [13] emphasize that regional blocks, such as popliteal plexus blocks, can reduce analgesic consumption and improve postoperative well-being, positively influencing metabolic responses by reducing inflammation and promoting healing. These blocks help modulate the local inflammatory response, directly impacting tissue regeneration and repair.

The use of stem cells and growth factors, such as platelet-rich plasma (PRP), has been studied as adjuncts in ACL reconstruction. Wang *et al.* [33] demonstrated that the injection of mesenchymal progenitor cells can preserve cartilage volume and minimize bone expansion, improving metabolic outcomes and joint integrity. This approach enhances the healing environment and contributes to faster and more effective knee function recovery.

The integration and maturation time of the graft is a crucial aspect of postoperative recovery. Cusumano *et al.* [32] compared the maturation of autologous and allogeneic grafts and observed that although the maturation pattern varied, the clinical outcome in the medium and long term was not significantly affected by differences in metabolic response. The revascularization process of the graft is essential for ensuring cellular nutrition and viability, directly influencing graft strength and durability.

The administration of growth factors such as PRP has been investigated to improve metabolic response and accelerate healing. Lin *et al.* [34] reported that combining bone marrow aspirate with PRP showed signs of more intense initial inflammation, but with potential for long-term regenerative improvement. However, the use of PRP remains controversial, as some studies, such as Ye *et al.* [35], found no significant improvements in symptoms or joint function after 12 months of follow-up.

The type of graft used can influence the metabolic and regenerative responses of the knee. Studies like those by Aldape-Rivas *et al.* [19] indicate that autologous hamstring grafts have a lower complication rate and better integration responses compared to allografts. Additionally, autologous grafts tend to promote a more favorable immune response, minimizing chronic inflammation and supporting more efficient healing.

Preserving articular cartilage after ACL reconstruction is challenging. Fleming *et al.* [26] emphasizes that the inflammatory response at the time of injury can affect joint lubrication and, consequently, cartilage metabolism, increasing the risk of post-traumatic osteoarthritis. Interventions that promote cartilage regeneration, such as the use of mesenchymal stem cells, have the potential to mitigate these effects and improve long-term joint health.

Graft revascularization is a critical process for its survival and functional efficacy. Studies such as those by Von Essen *et al.* [36] suggest that using autologous hamstring grafts, particularly those harvested from the contralateral side, can facilitate faster muscle strength recovery and potentially better revascularization response. This process is essential for graft remodeling, ensuring tissue incorporation and biomechanical strength necessary for functional activities.

Controlling the inflammatory response is vital for proper healing and joint function recovery. Studies that investigated metabolic and inflammatory responses following ACL reconstruction, such as Cooper *et al.* [18], indicate that inadequate inflammation can lead to graft failure and progression to chronic conditions like osteoarthritis. Inflammation management techniques, including anti-inflammatory use and load modulation during rehabilitation, are essential for long-term success.

Rehabilitation plays a critical role in metabolic and regenerative adaptation. Muscle strengthening and joint stabilization programs promote protein synthesis and the maintenance of muscle mass around the knee, contributing to a more robust regenerative response. Mahmoud *et al.* [13] emphasized that effective pain management and reduced opioid use are associated with faster recovery and better metabolic adaptation of scar tissue.

Understanding metabolic and regenerative responses is crucial for developing effective clinical protocols. Incorporating adjunctive treatments such as PRP and stem cells, along with inflammation management strategies and personalized rehabilitation protocols, can optimize healing and joint function after ACL reconstruction.

3.5 Functional and Biopsychosocial Outcomes

Various studies indicate that functional outcomes vary depending on the type of graft and the technique used. For instance, autologous hamstring grafts have shown promising results in terms of knee stability and function, as noted by Jin *et al.* [37], who observed faster recovery with intensive rehabilitation protocols, although long-term effects were like traditional protocols. Similarly, Ebert *et al.* [38] reported that quadriceps tendon grafts provided functional results comparable to hamstring grafts but with reduced need for postoperative analgesia.

The choice of graft type plays a significant role in postoperative outcomes. Studies like those by Gupta *et al.* [7] and HORSTMANN, H., *et al.* [12] indicate that while patellar tendon grafts offer quicker integration and better initial stability, they can result in a higher incidence of anterior knee pain. Conversely, Buescu *et al.* [39] highlighted that quadriceps tendon grafts, although less commonly used, yielded good functional results with reduced postoperative pain.

Return to pre-injury levels of sport is an essential parameter for evaluating the success of ACL reconstruction. Alentorn-Geli *et al.* [40] observed that the use of regenerative stem cells with grafts improved knee function and accelerated graft maturation, facilitating a quicker return to sports. Murray *et al.* [24] compared the bridge-enhanced ACL repair (BEAR) technique with traditional reconstruction and concluded that both techniques provided equivalent stability outcomes, though BEAR could lead to a higher rate of reoperations.

The psychological impact of surgery and recovery should not be underestimated. Luc-Harkey *et al.* [17] demonstrated that while there was no significant association between kinesiophobia and gait characteristics, fear of movement

could affect adherence to rehabilitation protocols, impairing functional outcomes. Mahmoud *et al.* [13] reported that reduced opioid use after reconstruction contributed to an improved sense of postoperative well-being, which can promote smoother and more effective recovery.

Adherence to rehabilitation protocols is a determining factor for functional outcomes. Intensive rehabilitation protocols, as discussed by Jin *et al.* [37], showed short-term benefits, while more traditional protocols produced solid long-term results. An individualized approach that considers the patient's physical and psychological conditions can maximize outcomes and reduce complications.

Postoperative pain is a critical element affecting both quality of life and functionality. Studies by Johnston *et al.* [41] and Gupta *et al.* [7] found that different graft types and analgesic techniques can influence pain intensity and early mobility. Methods that minimize initial pain can lead to more proactive rehabilitation and more effective functional recovery.

Patient satisfaction is an essential aspect of functional outcomes. Akelman *et al.* [5] noted that the perception of persistent instability could negatively impact patient satisfaction and, consequently, adherence to rehabilitation protocols. Providing psychological support during rehabilitation and clear communication with the patient can enhance these outcomes.

Return to sports and daily activities is influenced by both physical function and patient confidence. Low and Teo [1] indicated that stump preservation techniques could improve graft anatomical insertion and boost patient confidence, promoting more robust recovery**.**

4. Conclusion

The conclusion of this study comprehensively addresses the objective of evaluating the effectiveness of different graft types and techniques in anterior cruciate ligament (ACL) reconstruction, emphasizing functional, metabolic, and biopsychosocial outcomes. The findings demonstrated that autologous grafts, such as hamstring and patellar tendons, remain reliable choices due to their ability to promote stability and facilitate the return to functional activities. However, selecting the ideal graft should consider specific factors such as the patient's age, level of physical activity, presence of associated injuries, and rehabilitation goals to optimize surgical outcomes and graft durability.

Innovative techniques, such as stump preservation and the use of stem cells and growth factors, have shown potential to enhance healing and regenerative response. The bridge-enhanced ACL repair (BEAR) approach also presented promising results comparable to traditional techniques, despite requiring further research to confirm its long-term efficacy and minimize the risk of complications.

The biopsychosocial impact, particularly concerning postoperative pain and kinesiophobia, proved to be significant in rehabilitation adherence and functional outcomes. Pain management strategies that reduce opioid use and approaches that promote psychological well-being were associated with more positive recovery and increased patient satisfaction.

In summary, ACL reconstruction is a multifaceted procedure that demands a personalized approach, combining anatomical, functional, and psychosocial aspects to maximize treatment benefits. The choice of graft and auxiliary techniques should be carefully tailored to the patient's characteristics and supported by updated scientific evidence. Continuous advances in the field require longitudinal and multicenter studies to provide more robust data and support clinical decision-making, aiming to enhance recovery and quality of life for patients undergoing ACL reconstruction.

5. References

1. Low CA, Teo SH. Higher rates of anatomical insertion of medial hamstring tendon regeneration post-anterior cruciate ligament reconstruction with stump preservation graft harvesting technique: A prospective, randomized, double-blinded clinical trial. Journal of ISAKOS. 2024; 9:575-580.
2. Pistone EM, *et al*. Effects of early whole-body vibration treatment on knee neuromuscular function and postural control after anterior cruciate ligament reconstruction: A randomized controlled trial. Journal of Rehabilitation Medicine. 2016; 48:880-886.
3. Mahmoud A, *et al*. Analgesic impact of a popliteal plexus block to standard adductor canal block in arthroscopic anterior cruciate ligament reconstruction: A randomized blind clinical trial. Pain Research and Management, 2021.
4. Defroda SF, *et al*. Tibial tunnel widening following anterior cruciate ligament reconstruction: A retrospective seven-year study. The Knee, 2018.
5. Akelman MR, *et al*. Effect of matching or overconstraining knee laxity during anterior cruciate ligament reconstruction on knee osteoarthritis and clinical outcomes: A randomized controlled trial with 84-month follow-up. The American Journal of Sports Medicine. 2016; 44(7):1660-1667.
6. Gupta R, *et al*. Immediate post-operative pain in anterior cruciate ligament reconstruction surgery with bone patellar tendon bone graft versus hamstring graft. Journal of Orthopaedic Surgery and Research, 2016.
7. Cooper J, *et al*. Physiologic preoperative knee hyperextension is a predictor of failure in an anterior cruciate ligament revision cohort. The American Journal of Sports Medicine, 2018.
8. Horstmann H, *et al*. Quadriceps and hamstring tendon autografts in ACL reconstruction yield comparably good results in a prospective, randomized controlled trial. Archives of Orthopaedic and Trauma Surgery, 2021.
9. Barié A, *et al*. Quadriceps tendon vs. patellar tendon autograft for ACL reconstruction. Archives of Orthopaedic and Trauma Surgery, 2020.
10. Zhang Q, *et al*. Tibial tunnel enlargement and joint instability after anterior cruciate ligament reconstruction: A prospective comparison between autograft and allograft. Acta Cirúrgica Brasileira. 2017; 32(12):1064-1074.
11. Jia YH, Sun PF. Comparison of clinical outcome of autograft and allograft reconstruction for ACL tears. Chinese Medical Journal, 2015.
12. Von Recum J, *et al*. Autologous bone graft vs. calcium phosphate in ACL reconstruction. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 2019.
13. Xu C, *et al*. Comparison of proprioception recovery following ACL reconstruction using artificial graft versus autograft. BMC Musculoskeletal Disorders, 2022.

14. Murray MM, *et al*. Introduction of the bridge-enhanced ACL repair (BEAR) technique: A regenerative approach using a synthetic scaffold. Journal of Orthopaedic Research, 2020.
15. Luc-Harkey BA, *et al*. Association between kinesiophobia and walking gait characteristics in physically active individuals with anterior cruciate ligament reconstruction. Gait & Posture. 2018; 64:220-225.
16. Aldape-Rivas DE, *et al*. Epidural administration of ropivacaine and midazolam as postoperative analgesia after ACL reconstruction: A randomized controlled clinical trial. Journal of ISAKOS. 2024; 9:334-340.
17. Marmura H, *et al*. A bifactor model supports unidimensionality of the International Knee Documentation Committee Subjective Knee Form in young active patients with anterior cruciate ligament tears. Health and Quality of Life Outcomes, 2023.
18. Filbay SR, *et al*. The impact of meniscal and chondral lesions on outcomes after ACL reconstruction. Journal of Orthopaedic Research. 2017; 35:1235-1241.
19. Seppänen A, *et al*. Double-bundle ACL reconstruction resulted in better IKDC grading at 15-year follow-up. International Orthopaedics, 2024.
20. Fleming BC, *et al*. Long-term outcomes of ACL reconstruction surgery. Journal of Orthopaedic Research, 2020.
21. Cusumano A, *et al*. Different timing in allograft and autograft maturation after primary anterior cruciate ligament reconstruction does not influence the clinical outcome at mid-long-term follow-up. Knee Surgery, Sports Traumatology, Arthroscopy, 2022.
22. Von Essen C, *et al*. Utilizing a contralateral hamstring autograft facilitates earlier isokinetic and isometric strength recovery after anterior cruciate ligament reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy, 2021.
23. Johnston DF, *et al*. Effect of combining peri-hamstring injection or anterior obturator nerve block on the analgesic efficacy of adductor canal block for ACL reconstruction. British Journal of Anaesthesia, 2020.
24. Ebert JR, *et al*. Comparison of outcomes after ACL reconstruction using quadriceps versus hamstring tendon autografts. Orthopaedic Journal of Sports Medicine, 2024.
25. Buescu CT, *et al*. Pain level after ACL reconstruction: Quadriceps tendon vs. hamstring tendons. Acta Orthopaedica et Traumatologica Turcica, 2017.
26. Alentorn-Geli E, *et al*. Effects of autologous adipose-derived regenerative stem cells on ACL reconstruction outcomes. Journal of Orthopaedic Surgery, 2019.
27. Ye Z, *et al*. Intra-Articular PRP Injection after ACL Reconstruction. JAMA Network Open, 2024.
28. Erden T, *et al*. Efficacy of anterolateral ligament reinforcement in reducing graft failure rates. Orthopaedic Reviews, 2021.
29. Wang Y, *et al*. Safety, tolerability, clinical, and joint structural outcomes of a single intra-articular injection of allogeneic mesenchymal precursor cells in patients following anterior cruciate ligament reconstruction: A controlled double-blind randomized trial. Arthritis Research & Therapy, 2017.
30. Lin YC, *et al*. Effect of bone marrow aspiration concentrate and platelet-rich plasma combination in ACL reconstruction. Journal of Orthopaedic Surgery and Research, 2024.
31. Çatma MF, Öztürk A. The effect of tourniquet type on hamstring autograft length. Journal of Orthopaedic Surgery, 2018.
32. Boer BC, *et al*. Functional recovery after ACL repair versus reconstruction. BMC Musculoskeletal Disorders, 2018.
33. Heard M, *et al*. Adverse events in ACLR with LET augmentation. Journal of ISAKOS, 2023.
34. Toker MB, *et al*. Outcomes of ACL reconstruction with ALL internal bracing. Ulus Travma Acil Cerrahi Derg, 2022.
35. Tajima T, *et al*. Early weight-bearing after ACL reconstruction with hamstring grafts induces femoral bone tunnel enlargement. BMC Musculoskeletal Disorders, 2019.
36. Wang JH, *et al*. Paradoxical tunnel enlargement after ACL reconstruction with hamstring autografts using β-TCP containing interference screws. BMC Musculoskeletal Disorders, 2017.
37. Ahn JH, *et al*. Is intraoperative fluoroscopy necessary in ACL double-bundle reconstruction? Orthopaedics & Traumatology: Surgery & Research, 2019.
38. Xiang X, *et al*. Single-tunnel anatomic double-bundle ACL reconstruction: Effectiveness study. Medicine, 2019.
39. Guglielmetti LGB, *et al*. Anterior cruciate ligament reconstruction: A new cortical suspension device for femoral fixation. Journal of Orthopaedic Surgery and Research, 2014.
40. Lefevre N, *et al*. Postoperative discomfort after outpatient anterior cruciate ligament reconstruction: A prospective comparative study. Orthopaedics & Traumatology: Surgery & Research, 2015.
41. Laborie A, *et al*. Inefficacy of Kinesio-Taping® on postoperative pain after ACL reconstruction. Orthopaedics & Traumatology: Surgery & Research, 2015.
42. Obradović M, *et al*. Tubularization of BTB grafts in ACL reconstruction. Medicina, 2023.
43. Ma W, *et al*. Two-stage ligament reconstruction with remnant preservation. BMC Surgery, 2023.
44. Rhatomy S, *et al*. Peroneus longus autograft can be recommended as a superior graft to hamstring tendon in single-bundle ACL reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy. 2019; 27(11):3552-3559.
45. Karimi M, *et al*. Gait analysis of anterior cruciate ligament reconstructed subjects with a combined tendon obtained from hamstring and peroneus longus. Knee. 2013; 20(6):526-531.
46. Santos AA, *et al*. Mechanical evaluation of tibial fixation of the hamstring tendon in anterior cruciate ligament double-bundle reconstruction. Clinics, 2020.
47. Migliorini F, *et al*. Bone-patellar tendon-bone versus two- and four-strand hamstring tendon autografts for ACL reconstruction in young adults: A Bayesian network meta-analysis. Scientific Reports. 2023; 13:6883.
48. Nordevall N, *et al*. A population-based nationwide study of cruciate ligament injury in Sweden, 2001–2009: Incidence, Treatment, and Sex Differences. American Journal of Sports Medicine. 2012;

40(8):1808-1813.
49. Sanders TL, *et al*. Is Anterior Cruciate Ligament Reconstruction Effective in preventing secondary meniscal tears and osteoarthritis? American Journal of Sports Medicine. 2016; 44(7):1699-1707.
50. Paschos NK, Howell SM. Anterior cruciate ligament reconstruction: principles of treatment. EFORT Open Reviews. 2017; 1(11):398-408.
51. De Oliveira DE, *et al*. Anterior cruciate and anterolateral ligament reconstruction using hamstring and peroneus longus tendons: Surgical technique description. Arthroscopy Techniques, 2021.