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Unraveling the challenges: Complications in ACL reconstruction with quadrupled hamstring grafts

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Abstract
Background: Anterior cruciate ligament (ACL) reconstruction using a quadrupled hamstring graft has emerged as a widely accepted technique, offering significant improvements in functional outcomes and reduced donor site morbidity compared to patellar tendon grafts. This review highlights the surgical technique, complications, and outcomes associated with this approach.
Methods: Optimal tunnel placement and graft fixation are critical for preventing issues such as graft failure, tunnel widening, and reduced joint stability. Post-operative rehabilitation protocols play a pivotal role in restoring knee function and minimizing complications such as stiffness and elongation. Functional assessments using IKDC and Lysholm scores consistently show substantial improvements post-surgery, aligning with findings from existing studies.
Results: Despite advancements, limitations such as infections, stiffness, and long-term risks like osteoarthritis persist. Studies demonstrate significant improvements in IKDC and Lysholm scores post-operatively, reflecting enhanced functional outcomes. Innovations in fixation devices, bioengineered grafts, and surgical technologies show promise for further reducing complications.
Conclusion: This study underscores the importance of precise surgical execution and structured rehabilitation to achieve optimal clinical outcomes in ACL reconstruction. Continued research into advanced techniques and materials is essential to address persistent challenges and improve long-term results.

Keywords: ACL reconstruction, quadrupled hamstring graft, tunnel placement, graft fixation, post-operative rehabilitation, IKDC score, lysholm knee score, graft failure, tunnel widening, osteoarthritis risk

Introduction

Background on ACL Injuries Anterior cruciate ligament (ACL) injuries are among the most common knee injuries, particularly in athletes involved in sports requiring sudden stops, pivots, or changes in direction. ACL reconstruction aims to restore knee stability and function, enabling patients to return to their pre-injury activities (Wang *et al*., 2020) [3].

Significance of Hamstring Grafts in ACL Reconstruction The use of hamstring tendons, particularly when quadrupled, has become a prevalent method for ACL reconstruction. This technique is favored due to its favorable biomechanical properties and lower donor site morbidity compared to bone-patellar tendon-bone grafts (Sharma *et al*., 2021) [2]. Quadrupling the hamstring tendons enhances graft strength and stability, making it a popular choice among orthopedic surgeons.

Overview of Potential Complications Despite the advantages of using hamstring grafts, ACL reconstruction is associated with various complications. These complications can be broadly categorized into surgical and postoperative issues, including graft failure, infection, nerve injury, and stiffness (Schatz *et al*., 2019) [1]. Understanding these complications is crucial for optimizing surgical techniques and postoperative care to improve patient outcomes.

Purpose of the study this paper aims to review the complications associated with ACL reconstruction using quadrupled hamstring grafts, emphasizing the incidence, risk factors, and impact on patient recovery. By synthesizing existing literature, the study seeks to provide insights that can guide clinical practice and enhance patient management strategies.

Background and Literature Review

Historical Development of ACL Reconstruction Techniques

The understanding and treatment of ACL injuries have evolved significantly over time.

The first ACL repair was described by Mayo Robson in 1895, emphasizing the importance of ligament integrity in knee stability. Subsequent advancements, such as the use of grafts in the 20th century, laid the groundwork for modern techniques. For example, arthroscopic procedures introduced by Watanabe in the 1970s revolutionized ACL reconstruction by reducing surgical morbidity and improving visualization (Watanabe *et al*., 2018) [4]. The shift from open to arthroscopic techniques has allowed for more precise graft placement and reduced recovery time (Ebert *et al*., 2020) [5].

Overview of Quadrupled Hamstring Graft Usage

Quadrupled hamstring grafts, made from the semitendinosus and gracilis tendons, have become a widely used option in ACL reconstruction. These grafts are valued for their high tensile strength, which can exceed the strength of the native ACL (Pappas *et al*., 2019) [6]. They also offer the advantage of reduced donor site morbidity, as the harvest site heals with minimal long-term effects compared to patellar tendon grafts. Additionally, the flexibility in graft length and size allows surgeons to customize the reconstruction for individual patients, making this technique versatile and reliable (Maletis *et al*., 2018) [7].

Comparative Outcomes of Patellar Tendon vs. Hamstring Grafts

The choice of graft for ACL reconstruction remains a subject of debate. Patellar tendon grafts (BPTB) have been the traditional gold standard due to their high initial fixation strength and bone-to-bone healing properties (Voss *et al*., 2019) [1, 8]. However, studies have shown that these grafts are associated with higher rates of anterior knee pain, patellar tendonitis, and difficulty kneeling (Schmidt *et al*., 2021) [9]. In contrast, hamstring grafts have gained popularity for their reduced anterior knee pain and fewer complications related to kneeling, despite concerns about graft fixation and elongation (Chahla *et al*., 2019) [10]. Functional outcomes between the two grafts are comparable in most studies, with no significant differences in failure rates over the long term (Spindler *et al*., 2020) [20].

Review of Existing Studies on Complications in ACL Reconstructions

Complications in ACL reconstruction can range from surgical technical errors to postoperative and long-term issues. Tunnel misplacement, graft fixation failures, and improper tensioning are common intraoperative challenges (Lai *et al*., 2018) [12]. Postoperatively, complications such as infections, stiffness, and graft failure are documented, with infection rates being relatively low but potentially severe (Giannoudis *et al*., 2020) [13]. Long-term studies highlight issues like tunnel widening and early onset osteoarthritis, which can impact functional outcomes (Petersen *et al*., 2021) [14]. Specific to hamstring grafts, tunnel widening due to the "bungee" effect and reduced proprioception have been noted, though advancements in fixation techniques have mitigated some of these risks (Liu *et al*., 2022) [15].

Surgical Technique Overview

Quadrupled Hamstring Graft Preparation and Fixation

The quadrupled hamstring graft is created using the semitendinosus and gracilis tendons. These tendons are harvested through a small oblique incision near the tibial tuberosity, ensuring minimal disruption to surrounding tissues. The tendons are cleaned of residual muscle fibers, looped to form a four-strand graft, and pre-tensioned to reduce elongation during rehabilitation. A whipstitch is applied to both ends of the graft to ensure stability during passage and fixation (Mellor *et al*., 2019) [16]. The graft is attached to an endobutton on the femoral side for secure fixation and an interference screw on the tibial side to maintain proper tension (Pinczewski *et al*., 2020) [17].

Techniques for Tunnel Drilling and Graft Tensioning

Accurate tunnel placement is critical to replicate the native ACL anatomy and ensure optimal graft function. The femoral tunnel is created using an anteromedial portal, with the entry point marked at the native ACL footprint. Drilling is performed in hyperflexion to achieve a more anatomical placement. The tibial tunnel is drilled at approximately 55°-60° to the longitudinal axis of the tibia, ensuring alignment with the femoral tunnel (Kousa *et al*., 2018) [18].

Once the tunnels are prepared, the graft is passed through the tibial tunnel, across the joint, and into the femoral tunnel. The endobutton is flipped to secure the graft proximally. The graft is tensioned by cycling the knee through flexion and extension several times to eliminate slack before final fixation with a tibial interference screw (Davis *et al*., 2020) [19]. Proper tensioning ensures the graft's stability while minimizing risks of elongation or fixation failure during rehabilitation.

Post-Operative Rehabilitation Protocols

Post-operative rehabilitation is crucial for restoring knee function and preventing complications. The protocol is divided into phases, beginning with immobilization and gradual mobilization. In the first two weeks, patients focus on controlling swelling, regaining full extension, and initiating quadriceps activation through straight leg raises and passive knee flexion (Shelbourne *et al*., 2019) [20]. Weight-bearing is typically allowed as tolerated, with the use of crutches for support.

From 2-6 weeks, the focus shifts to improving range of motion (targeting 0°-120° flexion) and strengthening exercises for the quadriceps and hamstrings. Closed-chain exercises, such as wall squats and leg presses, are introduced to enhance stability. By 12 weeks, patients transition to sport-specific drills and plyometric training, provided quadriceps strength exceeds 65% of the contralateral limb (Aglietti *et al*., 2020) [21]. Return to sport is generally permitted around six months post-operatively, contingent upon achieving functional benchmarks such as full range of motion, symmetrical strength, and stable knee dynamics (Feller *et al*., 2021) [22].

Complications of Quadrupled Hamstring Graft

Intraoperative Complications

Tunnel Misplacement and Size Mismatch

Proper tunnel placement is crucial for replicating the native ACL anatomy. Misplaced tunnels, whether too anterior on the tibial side or non-anatomical on the femoral side, can result in graft impingement, restricted range of motion, and early graft failure (Ebert *et al*., 2019) [29]. Additionally, incorrect tunnel size can lead to improper graft fixation or slackening of the graft, reducing knee stability (Kousa *et al*., 2018) [18].

Graft Tensioning Issues

Insufficient or excessive tensioning of the graft during

surgery can impact postoperative outcomes. Over-tensioning may cause limited knee flexion, while under-tensioning can lead to instability and early graft elongation (Pinczewski *et al*., 2020) [17]. Cycling the knee through full range of motion during surgery is critical to achieving optimal tension.

Damage to Surrounding Structures

During graft harvest or tunnel drilling, there is a risk of damaging neurovascular structures, particularly the saphenous nerve near the hamstring harvest site, which can lead to postoperative sensory deficits (Aglietti *et al*., 2020) [21].

Postoperative Complications

Infections

Although relatively rare, infections can occur postoperatively, ranging from superficial to deep infections. Superficial infections, involving the skin and subcutaneous tissue, are typically managed with antibiotics and local wound care. Deep infections, involving the joint or graft, may require surgical debridement and can compromise graft integrity (Giannoudis *et al*., 2020) [13].

Graft Failure

Graft failure may result from technical errors, such as improper tunnel placement, inadequate fixation, or insufficient tensioning, as well as biological factors like inadequate graft integration. Re-rupture rates for hamstring grafts are reported to be 3-8% over long-term follow-up (Spindler *et al*., 2021) [5].

Knee Stiffness

Postoperative stiffness, often presenting as a fixed flexion deformity, can occur due to poor adherence to rehabilitation protocols or excessive scar tissue formation. Limited range of motion significantly impacts functional outcomes and may necessitate additional interventions, such as manipulation under anesthesia (Shelbourne *et al*., 2019) [20].

Donor Site Morbidity

Pain and scarring at the graft harvest site are common issues associated with hamstring grafts. Some patients experience persistent weakness in hamstring function, which can affect activities requiring knee flexion strength (Feller *et al*., 2021) [22].

Tunnel Widening

Mechanical effects such as the "windshield wiper" (lateral graft movement) and "bungee" (longitudinal graft movement) effects can cause tunnel widening, potentially leading to graft instability and failure. These issues are particularly prevalent with soft-tissue grafts like hamstring tendons when fixation techniques are inadequate (Kousa *et al*., 2018) [18].

Long-term Complications

Risk of Osteoarthritis Development

Long-term studies indicate a higher risk of osteoarthritis in patients who undergo ACL reconstruction, particularly if concomitant meniscal injuries are not addressed. This risk is attributed to altered knee biomechanics and persistent instability (Petersen *et al*., 2021) [14].

Reduced Proprioception and Joint Stability

Hamstring grafts, while effective, may not fully replicate the proprioceptive function of the native ACL. This deficit can lead to subtle instability and an increased risk of reinjury during high-demand activities (Yasuda *et al*., 2019) [23].

Reduced Proprioception and Joint Stability

Hamstring grafts may offer less proprioceptive feedback than native ACLs, potentially affecting joint stability during high-stress activities (Yasuda *et al*., 2019) [23].

Clinical and Functional Outcomes

Functional Scoring Methods

The International Knee Documentation Committee (IKDC) and Lysholm Knee Scores are widely used tools for evaluating clinical outcomes after ACL reconstruction. The IKDC subjective score assesses symptoms, functional limitations, and overall knee performance, providing a score from 0 to 100, with higher scores indicating better function (Hefti *et al*., 1993) [25]. The Lysholm score evaluates parameters such as limping, instability, and pain, categorizing outcomes as excellent (95-100), good (84-94), fair (65-83), or poor (<64).

Comparative Analysis of Pre- and Post-Operative Functional Scores

Significant improvements in functional outcomes have been consistently observed following ACL reconstruction. For instance, reported an average increase in IKDC scores from 50 preoperatively to 88 postoperatively, demonstrating substantial recovery of knee function. Similarly, Lysholm scores often improve from a pre-operative mean of 68 to above 90 in patients without complications.

Patients undergoing reconstruction with quadrupled hamstring grafts often achieve comparable or superior outcomes relative to other graft types, thanks to advancements in fixation techniques and tailored rehabilitation protocols. For example, Spindler *et al*. (2021) [5] found no significant difference in long-term functional outcomes between hamstring and patellar tendon grafts, although hamstring grafts demonstrated lower rates of anterior knee pain.

Correlation between Complications and Functional Outcomes

Post-operative complications significantly impact functional outcomes. For instance, patients with graft failures typically exhibit lower IKDC and Lysholm scores due to persistent instability and reduced joint performance (Shelbourne *et al*., 2019) [20]. Similarly, complications such as knee stiffness or donor site morbidity can hinder rehabilitation progress, delaying functional recovery and leading to suboptimal outcomes. Tunnel widening, a potential issue with hamstring grafts, may reduce graft stability and contribute to subpar Lysholm scores in certain cases (Kousa *et al*., 2018) [18].

Additionally, infections, though rare, can severely affect outcomes by necessitating prolonged treatment and revisions, resulting in lower functional scores (Barker *et al*., 2021) [31]. On the contrary, adherence to structured rehabilitation protocols and proper management of complications are correlated with higher IKDC and Lysholm scores, emphasizing the importance of a comprehensive post-operative care plan (Feller *et al*., 2021) [22].

Preventive Strategies

Optimal Surgical Techniques for Tunnel Placement and Graft Fixation

Accurate tunnel placement is crucial to prevent complications such as graft impingement, instability, or failure. The femoral tunnel should be drilled at the anatomical footprint of the ACL, ensuring proper alignment with the tibial tunnel to replicate native knee kinematics. The anteromedial portal

technique allows for better visualization and placement compared to the transtibial technique, reducing the risk of non-anatomical graft positioning (Musahl *et al*., 2019) [30]. Additionally, maintaining the appropriate tunnel size is essential to avoid fixation issues; oversized tunnels can compromise graft stability, while undersized tunnels can damage the graft during passage.

Use of Appropriate Fixation Devices

The choice of fixation devices significantly impacts graft stability and long-term outcomes. Interference screws, either metallic or bioabsorbable, are commonly used for graft fixation at the tibial side. They provide direct graft compression against the bone tunnel, ensuring secure fixation and allowing for early mobilization. However, interference screws carry risks such as graft laceration during insertion or difficulty during revision surgery if deeply embedded (Kousa *et al*., 2018) [18].

Endobuttons are widely preferred for femoral fixation, particularly with soft tissue grafts. These devices allow for looped graft fixation, ensuring maximal graft length within the tunnel and reducing the risk of slippage. The use of endobuttons is associated with strong cyclic loading resistance, though excessive tunnel widening due to the "windshield wiper" or "bungee" effects remains a concern (Yasuda *et al*., 2019) [23]. A combination of interference screws on the tibial side and endobuttons on the femoral side has been shown to provide excellent mechanical stability in quadrupled hamstring grafts.

Emphasis on Structured Rehabilitation Protocols

A well-designed and structured rehabilitation program is critical for minimizing complications and optimizing functional recovery. Early mobilization is encouraged to prevent stiffness, with emphasis on achieving full knee extension within the first two weeks post-surgery (Shelbourne *et al*., 2021) [27]. Quadriceps and hamstring strengthening exercises should progress gradually, starting with isometric exercises and transitioning to dynamic and closed-chain exercises.

By 8-12 weeks, activities like partial squats and lunges are introduced, with a focus on enhancing joint stability and proprioception. Sport-specific training and plyometrics can be initiated around the 4-6-month mark, provided functional benchmarks such as symmetrical muscle strength and stable knee dynamics are achieved (Feller *et al*., 2021) [22]. Adherence to these protocols not only accelerates recovery but also reduces the risk of complications such as graft elongation or secondary injuries.

Discussion

Analysis of Findings in Relation to Existing Studies

The findings from ACL reconstruction using a quadrupled hamstring graft align closely with outcomes reported in the literature. Functional improvements, evidenced by significant increases in post-operative IKDC and Lysholm scores, confirm the effectiveness of the technique. Studies such as demonstrated similar gains in IKDC scores, averaging from 50 pre-operatively to 88 post-operatively, indicating restored knee stability and function. Moreover, the reduced incidence of anterior knee pain compared to patellar tendon grafts is consistent with findings by Feller *et al*. (2021) [22], who emphasized the lower morbidity associated with hamstring grafts.

However, complications such as graft failure, knee stiffness, and tunnel widening remain concerns. For instance, Kousa *et al*. (2018) [18] noted the "windshield wiper" and "bungee" effects contributing to tunnel widening, potentially compromising long-term graft stability. Infection rates, though low at 0.14% to 1.7% (Barker *et al*., 2021) [31], underline the need for meticulous surgical techniques and infection control measures. The variability in functional outcomes across studies highlights the influence of surgeon experience, graft preparation methods, and adherence to rehabilitation protocols.

Limitations of Current Surgical and Post-Operative Approaches

Current surgical techniques, while advanced, have inherent limitations. Anatomical tunnel placement, though improved with techniques like the anteromedial portal, can still be challenging, particularly in cases with distorted anatomy due to prior injuries or surgeries (Musahl *et al*., 2019) [30]. Tunnel widening, as reported by Yasuda *et al*. (2019) [23], persists as a biomechanical drawback of soft tissue grafts, necessitating further refinement of fixation methods.

Post-operative rehabilitation protocols, though effective in most cases, may not be uniformly followed by patients. Non-compliance with rehabilitation programs can lead to complications such as stiffness or graft elongation, adversely affecting outcomes (Shelbourne *et al*., 2021) [27]. Additionally, the variability in patient-specific factors like age, activity level, and pre-existing conditions adds complexity to achieving universally optimal outcomes.

Future Directions for Improving Outcomes and Reducing Complications

Advancements in surgical techniques and materials are critical to reducing complications. Improved fixation devices, such as hybrid systems combining interference screws and cortical buttons, may offer enhanced stability and mitigate tunnel widening. Robotic-assisted surgeries and augmented reality tools could further enhance precision in tunnel placement and graft tensioning (Musahl & Karlsson, 2019) [30].

Infection control strategies, such as pre-operative skin decolonization and intra-operative antibiotic irrigation, can further reduce the already low infection rates (Barker *et al*., 2021) [31]. Future research should also explore bioengineered grafts and regenerative therapies, such as the use of growth factors or scaffolds to enhance graft integration and healing.

Enhanced rehabilitation programs, leveraging digital health technologies for remote monitoring and patient engagement, could address non-compliance and ensure consistent post-operative care. Additionally, long-term studies focusing on the durability of quadrupled hamstring grafts and their impact on the development of osteoarthritis will provide valuable insights for tailoring treatment protocols (Lohmander *et al*., 2007).

Conclusion

The use of a quadrupled hamstring graft for ACL reconstruction shows significant improvements in functional outcomes, as evidenced by increased IKDC and Lysholm scores. The advantages of reduced anterior knee pain and lower donor site morbidity compared to patellar tendon grafts make hamstring grafts a preferred choice, especially for active patients. Nonetheless, complications such as tunnel widening, graft failure, and stiffness highlight the necessity for precise surgical techniques and patient adherence to rehabilitation

protocols (Feller *et al*., 2021; Kousa *et al*., 2020) [22, 18].
Orthopedic surgeons should prioritize anatomical tunnel placement utilizing techniques such as the anteromedial portal and employ robust fixation devices, such as a combination of interference screws and endobuttons, to enhance graft stability and minimize biomechanical complications. A structured rehabilitation program that emphasizes early mobilization and progressive strengthening is essential for optimizing patient outcomes and reducing the risk of complications such as stiffness and graft elongation (Shelbourne *et al*., 2022) [28].
Future advancements, including bioengineered grafts and precision tools like robotic assistance, offer promising potential for further reducing complications and enhancing outcomes. Orthopedic surgeons should stay informed about these innovations while adhering to evidence-based practices to achieve optimal functional recovery for their patients.

Conflict of Interest
Not available

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