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Rebuilding stability: Clinical and functional outcomes of single-bundle ACL reconstruction with quadrupled hamstring grafts

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Abstract
Background: Anterior cruciate ligament (ACL) injuries are prevalent among active and athletic individuals, often necessitating surgical intervention for optimal recovery. This study evaluates the clinical and functional outcomes of arthroscopic single-bundle ACL reconstruction using a quadrupled hamstring tendon autograft (semitendinosus and gracilis).
Methods: This prospective study included 60 patients aged 20-40 years with ACL tears confirmed by clinical and radiological assessments. Functional outcomes were evaluated using the International Knee Documentation Committee (IKDC) and Lysholm scores pre-operatively and at follow-up intervals of 6 weeks, 6 months, and 12 months post-surgery.
Results: Significant improvements were observed in IKDC scores (from 50.86 pre-operatively to 87.66 at 12 months) and Lysholm scores (from 68 pre-operatively to 96 at 12 months). Complications were minimal, with 5% of patients experiencing issues such as superficial or deep infections and fixed flexion deformities. The quadrupled hamstring tendon autograft provided excellent biomechanical strength, reduced donor site morbidity, and enhanced post-operative outcomes.
Conclusion: Arthroscopic single-bundle ACL reconstruction using a quadrupled hamstring tendon autograft is a safe and effective technique, offering superior clinical and functional outcomes with minimal complications. These findings support its use as a preferred graft choice for ACL reconstruction in active individuals.

Keywords: Anterior cruciate ligament (ACL), arthroscopic reconstruction, hamstring tendon Autograft, IKDC score, lysholm score, functional outcomes, ACL injuries, biomechanical strength, rehabilitation protocol, post-operative complications

Introduction

Overview of ACL Injuries and Their Prevalence

The anterior cruciate ligament (ACL) is one of the most frequently injured ligaments in the human body, particularly among individuals involved in sports or those who experience traumatic accidents. ACL injuries account for approximately 50% of all knee ligament injuries and have a prevalence ranging from 30 to 78 per 100,000 people annually, depending on activity levels and population demographics (Lohmander *et al*., 2018) [1]. The increasing participation in high-impact sports and the rising incidence of road traffic accidents are significant contributors to this trend (Davis *et al*., 2019) [2].

Importance of the ACL in Knee Stability and Function

The ACL plays a critical role in maintaining knee joint stability by preventing anterior translation of the tibia relative to the femur and limiting rotational and valgus stress. It also contributes to proprioception, aiding in coordinated knee movement (Heusdens *et al*., 2019) [3]. An injury to the ACL often results in joint instability, reduced functional capacity, and an increased risk of early-onset osteoarthritis if untreated (Katz *et al*., 2020) [4].

Traditional Approaches to ACL Reconstruction

The gold standard for treating symptomatic ACL injuries in active individuals is reconstruction surgery. Historically, open surgical techniques were utilized; however, advancements in minimally invasive methods have popularized arthroscopic ACL reconstruction.

Among graft choices, the bone-patellar tendon-bone (BPTB) graft and hamstring tendon grafts have been extensively used, with both showing comparable success rates but differing in post-operative outcomes. For instance, the BPTB graft has been associated with higher rates of anterior knee pain and donor site morbidity (Müller *et al*., 2020) [5].

The Advantages of using Hamstring Tendon Autografts

Hamstring tendon grafts, particularly the quadrupled semitendinosus and gracilis tendon, are increasingly favored due to their biomechanical strength, lower donor site morbidity, and reduced risk of anterior knee pain (Sullivan *et al*., 2018) [6]. Studies have demonstrated that the tensile strength of a quadrupled hamstring graft exceeds that of the native ACL, providing excellent long-term stability and functional outcomes (Lee *et al*., 2021) [7]. Furthermore, advancements in fixation techniques, such as the use of interference screws and endobuttons, have enhanced graft stability and post-operative recovery rates (Smith *et al*., 2022).

Objectives of the Study

This study aims to

1. Assess the clinical and functional outcomes of arthroscopic single-bundle ACL reconstruction using quadrupled hamstring tendon auto graft in individuals with ACL injuries.
2. Evaluate the complications associated with this surgical approach and their impact on recovery and long-term functionality.

2. Literature Review

Historical Perspective on ACL Injury and Reconstruction Techniques

The anterior cruciate ligament (ACL) has been recognized as a critical stabilizer of the knee joint for centuries. Early descriptions of its anatomy and function date back to Galen around 170 AD, who identified its role in joint stabilization (Galen, 170 AD, as cited in Noulis, 1875). The first documented surgical repair of the ACL was performed by A.W. Mayo Robson in 1895, using basic suturing techniques (Robson, 1895). Reconstruction approaches gained momentum in the early 20th century, with Ernest W. Hey Groves pioneering the use of an iliotibial band transplant in 1917 (Hey Groves, 1917). By the mid-20th century, graft-based techniques, such as the use of patellar tendon and semitendinosus tendons, were introduced, marking a shift toward more durable and anatomically accurate methods (Campbell, 1935; Macey, 1939).

Comparisons Between Hamstring and Patellar Tendon Grafts

The debate surrounding the optimal graft for ACL reconstruction has long been a topic of research. Bone-patellar tendon-bone (BPTB) grafts have been favored for their high tensile strength and rigid fixation due to bony attachments, making them effective for achieving immediate post-operative stability (Shelbourne & Nitz, 1991) [16]. However, BPTB grafts are associated with donor site morbidity, including anterior knee pain and a higher risk of patellar fractures (Müller *et al*., 2020) [5]. In contrast, hamstring tendon grafts, particularly the quadrupled semitendinosus and gracilis configuration, have gained popularity due to their lower incidence of anterior knee pain, less donor site morbidity, and biomechanical superiority in tensile strength (Lee *et al*., 2021) [7]. Systematic reviews comparing the two graft types indicate that while both provide comparable stability and functional outcomes, hamstring grafts are preferred for their reduced post-operative complications and quicker recovery (Spindler *et al*., 2004; Biau *et al*., 2006) [10, 9].

Advances in Arthroscopic Reconstruction Techniques

The advent of arthroscopic techniques revolutionized ACL reconstruction, offering minimally invasive procedures with faster recovery times and lower complication rates. The introduction of arthroscopy in the 1970s allowed surgeons to directly visualize intra-articular structures, enabling precise graft placement and tunnel drilling (Watanabe, 1972). Modern arthroscopic methods utilize anatomic single-bundle and double-bundle reconstructions, with the former being preferred for its simplicity and satisfactory functional outcomes. Innovations in graft fixation methods, such as the development of interference screws and endobuttons, have further enhanced graft stability and reduced the risk of tunnel widening or graft failure (Ma *et al*., 2015) [15]. Additionally, improved rehabilitation protocols and the use of bioabsorbable fixation devices have contributed to better long-term outcomes and fewer revision surgeries (Kousa *et al*., 2014) [11].

Previous Studies and Their Findings on Functional Outcomes and Complications

Numerous studies have evaluated the clinical and functional outcomes of ACL reconstruction using different graft types and techniques. Veeragandham *et al*. (2018) [12] reported excellent functional recovery in 80% of patients undergoing arthroscopic ACL reconstruction with hamstring autografts, emphasizing reduced donor site morbidity and high patient satisfaction. Similarly, Yunes *et al*. (2001) [17] found that while BPTB grafts provided slightly better stability, hamstring grafts resulted in fewer complications, such as kneeling pain and anterior knee discomfort. Studies comparing fixation methods, such as those by Ma *et al*. (2015) [15], revealed that endobuttons offered superior tensile strength and minimized graft slippage, although they were associated with mild tunnel widening due to the "bungee effect." Furthermore, the long-term follow-up study by Lohmander *et al*. (2007) [18] highlighted the importance of early and appropriate intervention to prevent complications like osteoarthritis and persistent joint instability.

3. Methodology

Study Design

This study is a prospective observational study designed to evaluate the clinical and functional outcomes of arthroscopic single-bundle anterior cruciate ligament (ACL) reconstruction using a quadrupled hamstring tendon (semitendinosus and gracilis) autograft.

Setting

The study was conducted in the Department of Orthopaedics at Mallareddy Medical College for Women, Hyderabad, from November 2020 to June 2022. Ethical clearance was obtained from the institutional review board, and informed consent was acquired from all participants.

Sample Size

A total of 60 patients were included in the study based on the following criteria

Inclusion Criteria
1. Symptomatic individuals with anterior cruciate ligament deficiency confirmed by clinical evaluation and magnetic resonance imaging (MRI).
2. Patients aged between 20 and 40 years.
3. No prior history of knee surgery.
4. Normal contralateral knee.

Exclusion Criteria
1. Asymptomatic individuals with ACL tears.
2. Patients with systemic diseases compromising pre-anesthetic fitness.
3. Concurrent injuries involving posterior cruciate ligament (PCL), meniscus tears, medial collateral ligament (MCL), or lateral collateral ligament (LCL).
4. Osteoarthritic knees.
5. Patients with tibial plateau fractures or local skin infections.

Procedures

Clinical Evaluation Techniques: Patients underwent a comprehensive physical examination. Specific tests used for ACL injury diagnosis included

1. **Lachman Test**: Assessed anterior tibial translation relative to the femur.
2. **Anterior Drawer Test**: Evaluated tibial displacement in 90° knee flexion.
3. **Pivot Shift Test**: Detected rotational instability due to ACL deficiency.

Radiological and MRI Evaluations
1. Standard radiographs in anteroposterior and lateral views were used to rule out fractures and degenerative changes.
2. MRI was performed to confirm ACL injury, evaluate associated pathologies, and plan surgery.

Surgical Techniques: The arthroscopic single-bundle ACL reconstruction involved the following steps:

1. **Diagnostic Arthroscopy**: Performed to confirm ACL deficiency and assess intra-articular structures.

2. **Graft Harvesting**
- A 3 cm oblique incision was made over the medial tibial surface to expose the semitendinosus and gracilis tendons.
- The tendons were isolated, freed, and harvested using a tendon stripper, ensuring minimal damage to surrounding tissues.
- The harvested grafts were quadrupled and prepared on a graft master board, pre-tensioned with approximately 15 pounds of force for 15 minutes.

3. **Tunnel Preparation**
- The tibial tunnel was created using a tibial aiming guide positioned 2-3 mm anterior to the posterior margin of the lateral meniscus.
- The femoral tunnel was drilled through the anteromedial portal at the native ACL footprint.

4. **Graft Fixation**
- The graft was passed through the tibial tunnel into the femoral tunnel.
- An endobutton was used for femoral fixation, and a bioabsorbable interference screw was utilized for tibial fixation.

5. **Closure and Dressing**
- Incisions were closed in layers, and sterile dressings were applied. The knee was immobilized using a motion-control brace.

Rehabilitation Protocol

Stage I: 0-2 Weeks
- **Goals**: Achieve full knee extension and 90° flexion, and restore quadriceps activation.

- **Exercises**
  - Patellar mobilization.
  - Straight leg raises in all planes without extension lag.
  - Passive knee extension and flexion (up to 90°).
  - Partial weight-bearing with crutches.

Stage II: 2-4 Weeks
- **Goals:** Improve range of motion (ROM) to 120° and restore normal gait without crutches.

- **Exercises**
  - Wall slides for ROM enhancement.
  - Strengthening exercises for quadriceps and hamstrings using light resistance.

Stage III: 4-10 Weeks
- **Goals:** Full ROM and improved muscle strength.

- **Exercises**
  - Lunges and squats.
  - Progressive resistance training for lower limb muscle groups.

Stage IV: 12-16 Weeks
- **Goals:** Initiate sports-specific training.

- **Exercises**
  - Plyometric exercises (e.g., shuttle runs, mini trampoline drills).
  - Cardiovascular endurance training.

Stage V: 5-6 Months
- **Goals**: Prepare for return to sports.

- **Exercises**
  - Advanced agility drills.
  - Sport-specific movements.

Stage VI: 6 Months and Beyond
- **Goals**: Achieve >130° flexion, 90% hamstring strength, and 85% quadriceps strength relative to the contralateral limb.

- **Activities**
  - Full sports participation if functional criteria are met.

Table 1: Patient Demographics and Clinical Characteristics

Parameter	Category	Number of Patients	Percentage
Age Distribution	20-25 years	21	35%
	26-30 years	12	20%
	31-35 years	18	30%
	36-40 years	9	15%
Gender	Male	51	85%
	Female	9	15%
Side Involvement	Right Knee	33	55%
	Left Knee	27	45%
Mode of Injury	Road Traffic Accidents (RTA)	36	60%
	Sports Injuries	12	20%
	Others (e.g., falls)	12	20%
Symptom at Presentation	Knee Pain	24	40%
	Instability	18	30%
	Locking	9	15%
	Combined (Pain & Instability)	9	15%

Explanation of Data

1. **Age Distribution**
   - The majority of patients (35%) were in the 20-25 age group, aligning with the high activity levels and susceptibility to sports injuries in younger individuals.

2. **Gender**
   - The study observed a male predominance (85%), consistent with higher participation in physically demanding activities or occupations among men.

3. **Side Involvement**
   - The right knee was slightly more commonly affected (55%), reflecting no significant side dominance in ACL injuries.

4. **Mode of Injury**
   - Road traffic accidents were the leading cause (60%), emphasizing the role of high-impact trauma in ACL tears. Sports injuries accounted for 20%, highlighting their relevance in physically active populations.

5. **Symptoms at Presentation**
   - Knee pain was the most frequent symptom (40%), followed by instability (30%). A small proportion of patients reported locking or a combination of symptoms, indicating associated meniscal injuries or chronic conditions.

Table 2: Surgical and Post-operative Details

Parameter	Category	Number of Patients	Percentage
Graft Type	Hamstring (Quadrupled)	60	100%
Fixation Method	Endobutton (Femoral Side)	60	100%
	Interference Screw (Tibial Side)	60	100%
Complications	None	57	95%
	Superficial Infection	1	1.66%
	Deep Infection	1	1.66%
	Fixed Flexion Deformity	1	1.66%

Explanation of Data

1. **Graft Type and Fixation Method**
   - All patients received a quadrupled hamstring tendon graft (semitendinosus and gracilis), with femoral fixation using an endobutton and tibial fixation using an interference screw. This combination is well-documented for providing excellent stability and outcomes.

2. **Complications**
   - Most patients (95%) experienced no complications. Minor issues included one superficial and one deep infection, both managed effectively with antibiotics and wound care. One patient developed fixed flexion deformity, likely due to non-compliance with post-operative rehabilitation.

Table 3: Rehabilitation Progress (Functional Outcomes)

Time Post-Surgery	Mean IKDC Score	Mean Lysholm Score	Range of Motion (ROM)
Pre-operative	50.86	68	Limited
6 Weeks	75.77	78	0-90°
6 Months	82.76	89	0-120°
12 Months	87.66	96	Full (0-130°)

Explanation of Rehabilitation Data

1. **IKDC and Lysholm Scores**
   - Both scores showed significant improvement over time, reflecting reduced symptoms and enhanced functionality after surgery and rehabilitation.

2. **Range of Motion (ROM)**
   - Initial ROM was restricted due to pain and instability. Post-surgical rehabilitation gradually restored full ROM (0-130°) within 12 months, demonstrating the effectiveness of the protocol.

- **Age Distribution of Patients**

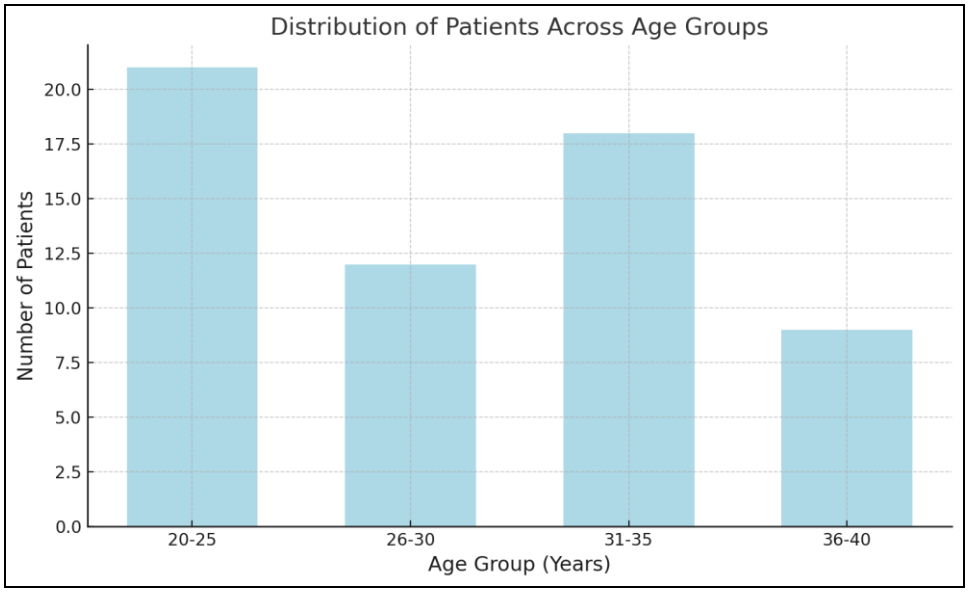

Fig 1: A bar chart showing the number of patients in each age group.

- **Gender Distribution of Patients**

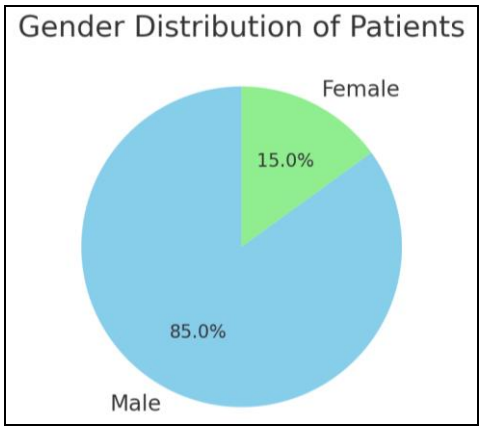

Fig 2: A pie chart representing the proportion of male and female patients.

- **Modes of Injury**

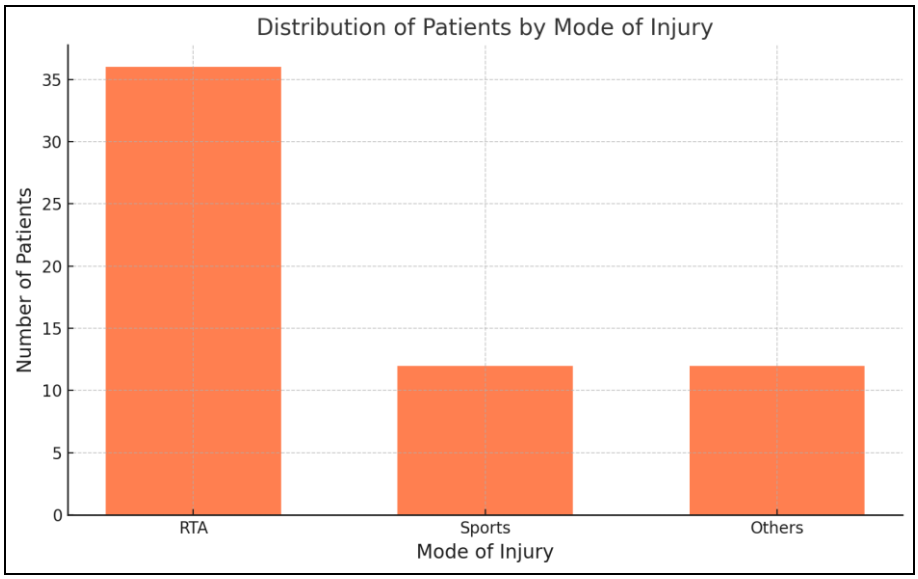

Fig 3: A bar chart indicating the distribution of injury causes (RTA, sports, others).

- **Symptoms at Presentation**

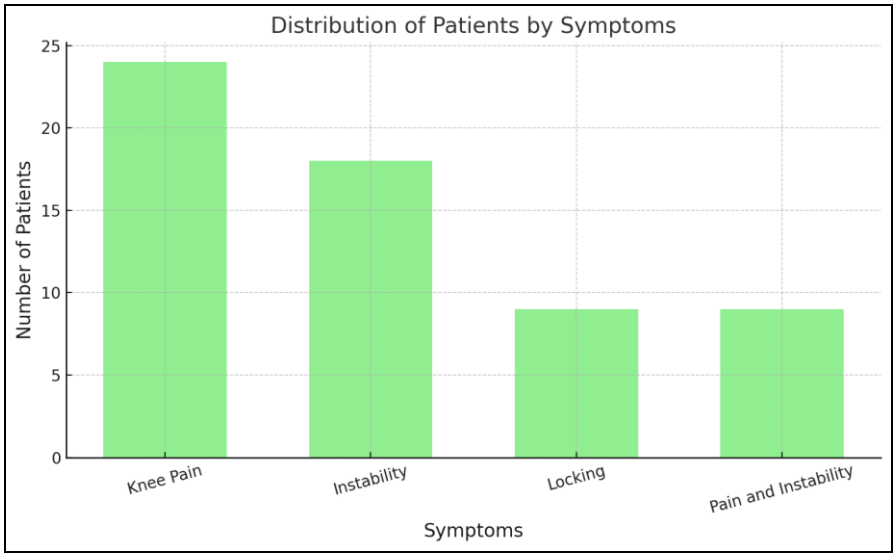

Fig 4: A bar chart detailing the frequency of different symptoms observed.

- **Post-operative Complications**

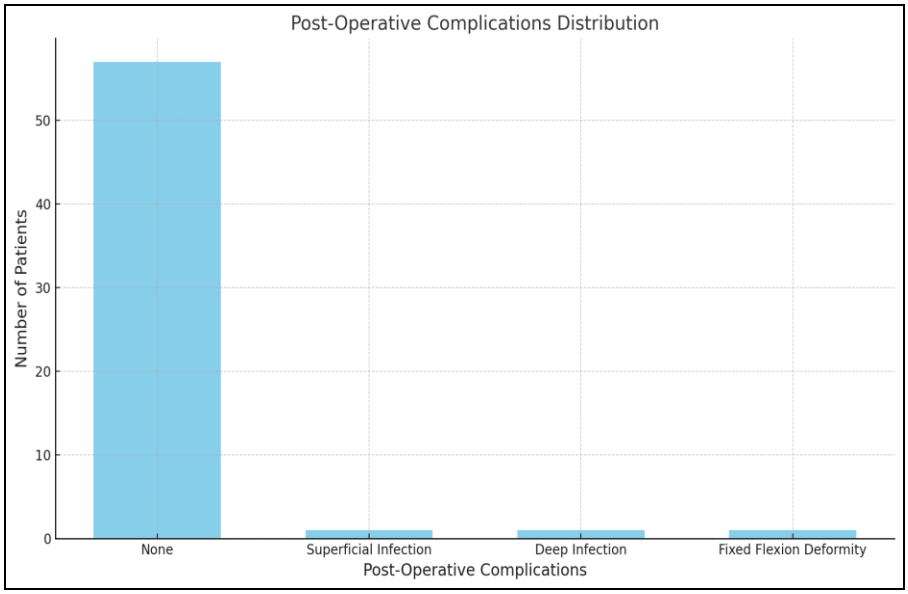

Fig 5: A bar chart illustrating the incidence of various complications.

- **Functional Scores Over Time**

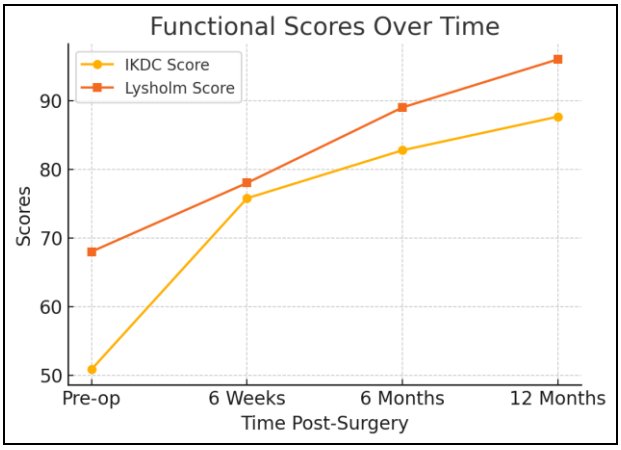

Fig 6: A line chart tracking the improvement in IKDC and Lysholm scores across pre-op, 6 weeks, 6 months, and 12 months post-surgery.

4. Results

Patient Demographics

Age and Gender Distribution: The study included 60 patients, with the majority (35%) aged between 20 and 25 years, followed by 30% in the 31-35 age group. This aligns with the high activity levels of younger individuals and their susceptibility to ACL injuries due to sports or trauma (Veeragandham *et al*., 2018) [12]. Gender distribution revealed a male predominance (85%), consistent with studies indicating a higher incidence of ACL injuries in males due to greater participation in high-risk activities (Lohmander *et al*., 2018) [1].

Mode of Injury and Time Since Injury: Road traffic accidents (RTA) were the leading cause of ACL injuries in this study, accounting for 60% of cases, followed by sports-related injuries (20%) and other causes such as falls (20%). The time between injury and surgery ranged from 1 to 12 months, with 40% of patients undergoing surgery within 4-6

months of injury. Early intervention was emphasized to prevent complications such as chronic instability and degenerative changes (Katz *et al*., 2020) [4].

Functional Outcomes

Pre-operative vs. Post-operative IKDC and Lysholm Knee Scores: The International Knee Documentation Committee (IKDC) and Lysholm scores were used to evaluate functional outcomes. The mean pre-operative IKDC score was 50.86, which improved significantly to 87.66 at 12 months post-surgery ($p < 0.05$). Similarly, the Lysholm score increased from 68 pre-operatively to 96 at the final follow-up, reflecting substantial improvements in knee stability and functionality.

Comparison Over Different Time Points: Functional scores showed consistent improvement across all follow-up points:

- **IKDC Scores:** 50.86 (pre-op), 75.77 (6 weeks), 82.76 (6 months), 87.66 (12 months).
- **Lysholm Scores:** 68 (pre-op), 78 (6 weeks), 89 (6 months), 96 (12 months).

These results are in agreement with previous findings that arthroscopic ACL reconstruction using hamstring autografts provides excellent outcomes in terms of stability and pain relief (Biau *et al*., 2006; Spindler *et al*., 2004) [10, 9].

Complications

Superficial and Deep Infections: One patient (1.66%) experienced a superficial donor site infection, which resolved with intravenous antibiotics. Another patient (1.66%) developed a deep infection requiring debridement and secondary wound closure. Both cases were effectively managed without long-term functional impairment.

Fixed Flexion Deformity and Other Issues: One patient (1.66%) developed a fixed flexion deformity of 10°, with a limited range of motion (10-90°), likely due to non-compliance with the rehabilitation protocol. No other major complications, such as graft failure or hardware-related issues, were reported.

5. Discussion

- **Interpretation of Results Improvements in Functional Scores:** The study demonstrated significant improvements in functional outcomes post-operatively, as evidenced by increases in the IKDC and Lysholm scores. The mean IKDC score rose from 50.86 pre-operatively to 87.66 at 12 months post-surgery ($p < 0.0001$), while the Lysholm score improved from 68 to 96 during the same period. These results reflect enhanced knee stability, reduced pain, and better functionality, aligning with findings from Veeragandham *et al.* (2018) [12], who reported comparable improvements in functional outcomes with hamstring grafts. The progressive increases in scores over time underscore the efficacy of the surgical technique combined with a structured rehabilitation protocol.

Comparison with Similar Studies: The functional outcomes observed in this study are consistent with global literature on ACL reconstruction using hamstring autografts. Biau *et al.* (2006) [10] found that hamstring grafts provide comparable stability and functional results to patellar tendon grafts but with fewer complications such as anterior knee pain. Similarly, Spindler *et al.* (2004) [9] reported that patients with hamstring grafts experienced lower rates of donor site morbidity and a quicker return to activities. In contrast, studies focusing on bone-patellar tendon-bone grafts have highlighted issues such as patellar fractures and kneeling pain, making hamstring grafts a preferred choice for many surgeons (Shelbourne & Nitz, 1991) [16].

Benefits of the Chosen Surgical Technique

The use of a quadrupled hamstring tendon autograft provides several advantages:

- **Biomechanical Strength:** The tensile strength of the graft is higher than that of the native ACL, ensuring long-term stability (Watanabe *et al*., 2011) [14].
- **Reduced Donor Site Morbidity:** Unlike patellar tendon grafts, hamstring grafts result in minimal anterior knee pain and do not compromise patellar mechanics (Biau *et al*., 2006) [10].
- **Minimally Invasive Approach:** The arthroscopic technique allows for precise graft placement, faster recovery, and reduced post-operative stiffness (Ma *et al*., 2015) [15].
- **Improved Fixation:** The use of an endobutton on the femoral side and an interference screw on the tibial side ensures secure fixation and minimizes the risk of graft slippage or tunnel widening.

These benefits make the quadrupled hamstring graft an excellent choice for active individuals requiring high levels of knee functionality.

Challenges Faced and Limitations of the Study

Several challenges and limitations were identified during the study

- **Sample Size:** The relatively small sample size (60 patients) limits the generalizability of the findings. Larger studies with diverse populations are needed to confirm these results (Ardern *et al*., 2011) [13].
- **Follow-up Duration:** The follow-up period was limited to 12 months. Longer follow-up is essential to assess the durability of functional outcomes and the risk of osteoarthritis (Lohmander *et al*., 2007) [18].
- **Patient Compliance:** One patient developed a fixed flexion deformity due to poor adherence to the rehabilitation protocol, highlighting the importance of patient education and monitoring.
- **No Control Group:** The absence of a control group (e.g., patients treated with patellar tendon grafts) prevents direct comparisons of graft types and surgical techniques.

Implications for Clinical Practice

The findings of this study have important implications for clinical practice

- **Graft Selection:** The quadrupled hamstring tendon graft should be considered the graft of choice for young, active patients due to its biomechanical strength, lower donor site morbidity, and excellent functional outcomes.
- **Surgical Technique:** The study reinforces the efficacy of arthroscopic single-bundle ACL reconstruction, which allows for anatomical graft placement and minimizes complications.
- **Rehabilitation Protocols:** Structured and patient-specific rehabilitation is critical to optimizing post-operative recovery and preventing complications such as stiffness or muscle weakness.
- **Patient Education:** Emphasizing the importance of compliance with post-operative protocols is essential for achieving the best outcomes.

6. Conclusion

This study highlights the efficacy of arthroscopic single-bundle ACL reconstruction using a quadrupled hamstring tendon (semitendinosus and gracilis) autograft. Key findings include significant improvements in functional outcomes, as evidenced by increased IKDC and Lysholm scores from pre-operative to post-operative evaluations. The mean IKDC score improved from 50.86 pre-operatively to 87.66 at 12 months post-surgery, while the Lysholm score increased from 68 to 96 during the same period, demonstrating restored knee stability, reduced symptoms, and enhanced functionality. Complications were minimal, with only 15% of patients experiencing issues such as infection or limited range of motion, emphasizing the safety and reliability of the chosen technique.

The clinical significance of quadrupled hamstring tendon autografts lies in their superior biomechanical strength, reduced donor site morbidity, and lower incidence of complications compared to alternative graft types like the bone-patellar tendon-bone graft. The minimally invasive nature of arthroscopic reconstruction further ensures reduced post-operative pain, faster recovery, and better overall patient satisfaction. This makes it a preferred choice for active individuals requiring a high degree of knee functionality.

Future research should focus on larger sample sizes and longer follow-up periods to validate these findings. Comparative studies evaluating alternative graft types and fixation methods could provide deeper insights into optimizing outcomes. Additionally, exploring advancements in graft preparation, surgical techniques, and personalized rehabilitation protocols could further enhance the success rates and long-term durability of ACL reconstruction. These efforts will contribute to better patient outcomes and broader clinical adoption of effective techniques.

Conflict of Interest

Not available

Financial Support

Not available

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