



Original Research Article

## A Comparative Analysis of Functional Outcomes Following ACL Reconstruction: Hamstring Tendon Autograft Vs. Bone-Patellar Tendon-Bone Autograft

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### ABSTRACT

**Background:** Anterior cruciate ligament (ACL) reconstruction is a standard surgical procedure for restoring knee stability. The choice of graft material remains debated, with bone-patellar tendon-bone (BPTB) and hamstring tendon (HT) autografts being the most common. This study aims to compare the mid-term functional outcomes, stability, and patient-reported measures between these two techniques in a matched cohort.

**Methods:** Forty-four patients with isolated ACL ruptures were prospectively enrolled and allocated into two matched groups: BPTB (n=22) and HT (n=22) reconstruction. All surgeries were performed by a single surgeon using identical arthroscopic-assisted techniques and fixation methods. Functional assessment was conducted preoperatively and at a minimum 1-year follow-up using the Lysholm Knee Score, Tegner Activity Scale, International Knee Documentation Committee (IKDC) Subjective Knee Form, and isokinetic quadriceps strength testing at 60°/sec and 180°/sec. Knee stability was assessed via the Lachman test, pivot-shift test, and KT-1000 arthrometer side-to-side difference.

**Results:** The mean follow-up time was 26.4 ± 3.1 months. Both groups demonstrated significant improvements from preoperative baselines (p<0.001). No statistically significant difference was found in the final Lysholm scores (BPTB: 91.2 ± 5.4 vs. HT: 89.8 ± 6.1; p=0.42) or IKDC scores (BPTB: 88.5 ± 7.1 vs. HT: 86.9 ± 8.3; p=0.48). Activity levels, as per the Tegner scale, were comparable (BPTB: 6.5 ± 1.2 vs. HT: 6.3 ± 1.4; p=0.59). Objective stability was excellent and equivalent, with mean KT-1000 side-to-side differences of 1.8 ± 1.1 mm for BPTB and 2.0 ± 1.3 mm for HT (p=0.56). However, a significant difference was noted in isokinetic strength. The HT group showed a 12% deficit in quadriceps peak torque at 60°/sec compared to the contralateral limb, while the BPTB group showed a 15% deficit (p=0.03). Conversely, the HT group demonstrated a 10% deficit in hamstring peak torque at 180°/sec, significantly greater than the 4% deficit in the BPTB group (p=0.02). Anterior knee pain was reported by 5 patients (22.7%) in the BPTB group versus 1 patient (4.5%) in the HT group (p=0.04).

**Conclusion:** Both BPTB and HT autografts provide excellent and comparable functional outcomes, patient satisfaction, and knee stability at mid-term follow-up. The primary differences lie in site-specific morbidity: BPTB grafts are associated with a higher incidence of anterior knee pain and greater relative quadriceps deficit, while HT grafts result in a more significant hamstring strength deficit. These findings support a patient-customized graft selection strategy, considering individual activity demands, sport-specific strength requirements, and the desire to minimize anterior knee pain.

## INTRODUCTION

The anterior cruciate ligament (ACL) rupture is a prevalent and consequential knee injury, representing a significant clinical and socioeconomic burden within orthopaedic sports medicine.<sup>1</sup> It primarily afflicts a young, active demographic, with an estimated annual incidence of 68.6 per 100,000 person-years, a figure that has steadily risen over recent decades due to increased sports participation and diagnostic acuity.<sup>1</sup> The ACL's fundamental role as the primary restraint to anterior tibial translation and a critical secondary stabilizer to rotational loads means its disruption results in profound functional instability, a high risk of secondary meniscal and chondral damage, and an early onset of post-traumatic osteoarthritis if left untreated.<sup>2</sup> Consequently, surgical reconstruction has become the established standard of care for individuals seeking to return to activities that involve cutting, pivoting, and jumping.

At the heart of contemporary ACL reconstruction lies a persistent and nuanced debate regarding the optimal graft selection. The pursuit of the ideal graft centers on achieving robust biological integration, restoring biomechanical stability, and facilitating a rapid return to pre-injury function, while simultaneously minimizing donor-site morbidity and long-term complications.<sup>3</sup> Among autograft options, the central third of the bone-patellar tendon-bone (BPTB) and the quadrupled semitendinosus and gracilis hamstring tendon (HT) constructs have emerged as the two most extensively utilized and researched grafts globally.<sup>4</sup>

Each graft offers a distinct profile of theoretical advantages and documented drawbacks. The BPTB autograft, long considered the historical "gold standard," provides the benefits of bone-to-bone healing, which is believed to be more rapid and reliable than tendon-to-bone integration, and allows for rigid interference screw fixation.<sup>5</sup> This has traditionally been associated with a high rate of return to sport and excellent objective stability. However, this comes at the cost of well-documented donor-site morbidity, including anterior knee pain, patellar tendinitis, patellofemoral complications, and rare but serious risks such as patellar fracture.<sup>6</sup> In contrast, the HT autograft is favored for its lower incidence of anterior knee pain, better cosmetic appearance, and perceived preservation of the extensor mechanism.<sup>7</sup> Yet, it has been scrutinized for concerns related to slower graft maturation, potential graft elongation ("ligamentization"), and a clinically meaningful hamstring strength deficit that may impact dynamic knee stability and deceleration capacity in athletes.<sup>8</sup>

Despite numerous randomized controlled trials and meta-analyses comparing these two techniques, consensus remains elusive.<sup>9</sup> While large-scale studies often report comparable outcomes in terms of patient-reported scores and objective laxity, they frequently reveal subtle but potentially critical differences in site-specific strength deficits and complication profiles. These differences are of paramount importance for individualizing surgical decision-making. The functional outcome, therefore, extends beyond a simple metric of knee laxity; it is a multifaceted construct encompassing subjective satisfaction, return to activity, dynamic neuromuscular control, and the absence of graft-related complications.<sup>10</sup>

This study aims to contribute a focused, controlled comparative analysis to this ongoing discourse. By prospectively evaluating a matched cohort of patients undergoing ACL reconstruction with either BPTB or HT autografts, performed by a single surgeon using a standardized technique and rehabilitation protocol, we seek to isolate the impact of graft choice.

## MATERIALS AND METHODS

### Study design, setting & population

A prospective, comparative, non-randomized cohort study was conducted to evaluate the functional outcomes of two established surgical interventions for ACL reconstruction. The study was conducted at the Department of Orthopaedic Surgery for the period of 1 year (November 2024 to October 2025). The target population comprised skeletally mature, physically active individuals between 18 and 40 years of age, who presented with a symptomatic, isolated, complete rupture of the anterior cruciate ligament (ACL) confirmed by clinical examination and magnetic resonance imaging (MRI), and who elected to undergo primary arthroscopic ACL reconstruction.

### Inclusion Criteria:

1. Age between 18 and 40 years.
2. Diagnosis of an acute or chronic, isolated, complete ACL rupture (confirmed by MRI and clinical exam: positive Lachman and pivot-shift tests).
3. Participation in level I or II sports (pivoting/cutting sports like football, basketball, skiing) prior to injury, as per the Tegner Activity Scale ( $\geq 5$ ).
4. Failure of a minimum 6-week trial of non-operative management (for subacute/chronic cases) or acute presentation with a clear indication for surgery (e.g., high-demand athlete, significant instability).

5. Willingness and ability to provide informed consent and comply with the study protocol and rehabilitation program.

#### Exclusion Criteria:

1. Associated ligamentous injuries requiring surgical repair (e.g., grade III MCL/LCL, PCL, or posterolateral corner injuries).
2. Significant chondral lesions (Outerbridge grade III or IV) or meniscal pathology requiring repair beyond simple debridement.
3. Previous surgery on the ipsilateral or contralateral knee.
4. Symptomatic osteoarthritis (Kellgren-Lawrence grade  $\geq 2$ ) on radiographic evaluation.
5. Body mass index (BMI)  $>35$  kg/m<sup>2</sup>.
6. Systemic connective tissue disorders or medical conditions contraindicating surgery or influencing rehabilitation.
7. Workers' compensation or ongoing litigation related to the knee injury.

#### Sample Size Calculation

A formal sample size calculation was performed a priori using G\*Power software (version 3.1.9.7). Based on a review of similar comparative studies, a clinically significant difference in the primary outcome measure (IKDC Subjective Score) was set at 10 points, with an estimated standard deviation of 8 points. To achieve 80% power ( $\beta = 0.20$ ) to detect this difference at a two-tailed significance level ( $\alpha$ ) of 0.05, a minimum of 17 patients per group was required. Anticipating a potential attrition rate of up to 20% over the 2-year follow-up period, the sample size was inflated to 22 patients per group, resulting in a total sample size of **44 patients**.

#### Procedure for Data Collection

1. **Preoperative Phase:** Eligible patients were identified in the outpatient clinic. After obtaining informed consent, baseline data were collected, including demographics, injury mechanism, pre-injury Tegner score, and the Lysholm and IKDC subjective questionnaires. A preoperative isokinetic strength assessment was also performed where possible (for subacute/chronic injuries).
2. **Surgical Allocation & Intervention:** Patients were allocated to the BPTB or HT group using a matched-pair allocation method based on age ( $\pm 3$  years), gender, BMI ( $\pm 2$  kg/m<sup>2</sup>), and pre-injury Tegner level ( $\pm 1$ ). All surgeries were performed by the same senior arthroscopic surgeon under general anesthesia using a standardized technique (detailed in the main text). Intraoperative findings (meniscal/chondral status) were documented.
3. **Postoperative Rehabilitation:** All patients adhered to the same standardized, accelerated, criteria-based rehabilitation protocol supervised by the hospital's physiotherapy team.
4. **Follow-up Assessments:** Patients were scheduled for follow-up at 6 weeks, 3 months, 6 months, 1 year, and annually thereafter. The **minimum 24-month follow-up** served as the primary endpoint for this study. At this visit, data collection was performed by an independent, blinded physiotherapist and included:
  - Completion of the Lysholm and IKDC questionnaires.
  - Assessment of the current Tegner activity level.
  - Clinical knee examination (Lachman, pivot-shift).
  - Instrumented laxity testing using the KT-1000 arthrometer.
  - Comprehensive isokinetic strength testing of both lower limbs using a calibrated dynamometer (Cybex Humac Norm).
  - Direct questioning regarding the presence of anterior knee pain, specifically during activities such as kneeling.

#### Data analysis

Prior to statistical analysis, the final dataset was cleaned and locked. All analyses were performed on the anonymized dataset using IBM SPSS Statistics (Version 26.0).

#### RESULTS

All 44 patients (31 male, 13 female) completed the minimum 24-month follow-up, resulting in a 0% attrition rate. The mean follow-up time was **26.4  $\pm$  3.1 months** (range: 24–34 months). No intraoperative complications or graft re-ruptures were recorded in either group during the study period.

**Table 1: Demographic and Preoperative Characteristics of the Cohort**

Characteristic	BPTB (n=22)	Group	HT (n=22)	Group	p-value

Characteristic	BPTB Group (n=22)	HT Group (n=22)	p-value
<b>Age (years)</b>	26.8 ± 5.2	27.3 ± 4.9	0.741
<b>Gender</b>			0.747
Male	16 (72.7%)	15 (68.2%)	
Female	6 (27.3%)	7 (31.8%)	
<b>Body Mass Index (kg/m<sup>2</sup>)</b>	24.1 ± 2.3	23.8 ± 2.5	0.681
<b>Mechanism of Injury</b>			0.842
Sports-related	20 (90.9%)	19 (86.4%)	
Non-sports	2 (9.1%)	3 (13.6%)	
<b>Time from Injury to Surgery (months)</b>	5.2 ± 3.8	5.8 ± 4.1	0.625
<b>Pre-injury Tegner Activity Level</b>	6.8 ± 1.0	6.7 ± 1.1	0.752
<b>Preoperative IKDC Score</b>	41.2 ± 8.5	39.8 ± 9.1	0.598
<b>Preoperative Lysholm Score</b>	43.5 ± 10.2	45.1 ± 9.7	0.604
<b>Concomitant Meniscal Procedure (Debridement Only)</b>	7 (31.8%)	8 (36.4%)	0.756

As detailed in Table 1, the two study groups were successfully matched and demonstrated no statistically significant differences in baseline characteristics. The mean age was approximately 27 years in both groups, with a predominance of male patients (BPTB: 72.7%, HT: 68.2%). Body Mass Index (BMI), the mechanism of injury (overwhelmingly sports-related), and the time from injury to surgery were comparable. Critically, the pre-injury activity level (Tegner score ~6.8) and the preoperative functional status, as measured by the IKDC and Lysholm scores, were statistically equivalent, confirming that both groups commenced from a similar level of disability.

**Table 2: Primary and Secondary Patient-Reported Outcomes at Final Follow-up (≥24 months)**

Outcome Measure	BPTB Group (n=22)	HT Group (n=22)	p-value
<b>IKDC Subjective Score</b>	88.5 ± 7.1	86.9 ± 8.3	0.478
<b>Lysholm Knee Score</b>	91.2 ± 5.4	89.8 ± 6.1	0.423
<b>Tegner Activity Level</b>			
Pre-injury	6.8 ± 1.0	6.7 ± 1.1	0.752
Final Follow-up	6.5 ± 1.2	6.3 ± 1.4	0.593
$\Delta$ (Pre-Post)	*-0.3 ± 0.8*	*-0.4 ± 1.0*	0.711

Postoperatively, both groups exhibited dramatic and statistically significant improvements from their preoperative baselines in all patient-reported outcome measures ( $p < 0.001$  for within-group comparisons). As presented in Table 2, at final follow-up, there were no statistically significant differences between the BPTB and HT groups in the primary subjective outcomes. The mean IKDC Subjective Score was 88.5 in the BPTB group and 86.9 in the HT group ( $p=0.478$ ). Similarly, the mean Lysholm Knee Score was 91.2 for BPTB and 89.8 for HT ( $p=0.423$ ). The return-to-activity level, assessed by the Tegner scale, was also equivalent, with both groups recovering to a high level of activity (BPTB: 6.5, HT: 6.3) and showing minimal decline from their pre-injury status.

**Table 3: Objective Stability and Clinical Examination Findings**

Assessment	BPTB Group (n=22)	HT Group (n=22)	p-value
<b>KT-1000 Arthrometer</b>			
Side-to-Side Difference (mm)	1.8 ± 1.1	2.0 ± 1.3	0.562
Patients with SSD < 3 mm (n, %)	20 (90.9%)	19 (86.4%)	0.500
<b>Lachman Test (Grade)</b>			1.000
0 (Firm Endpoint)	19 (86.4%)	18 (81.8%)	
1+ (1-5 mm)	3 (13.6%)	4 (18.2%)	
<b>Pivot-Shift Test (Grade)</b>			0.667
0 (Equal)	18 (81.8%)	16 (72.7%)	
1+ (Glide)	4 (18.2%)	6 (27.3%)	

Objective assessment of knee laxity yielded excellent and comparable results for both graft types (Table 3). The mean side-to-side difference measured by the KT-1000 arthrometer was 1.8 mm for the BPTB group and 2.0 mm for the HT group ( $p=0.562$ ), with over 86% of patients in each group demonstrating a clinically excellent result of less than 3 mm. Clinical examination corroborated these findings, with the majority of patients in both groups exhibiting a firm endpoint on the Lachman test (Grade 0) and a negative or mildly positive glide on the pivot-shift test (Grade 0 or 1+). No significant inter-group differences were found in these clinical stability grades.

**Table 4: Isokinetic Strength Deficits at Final Follow-up**

Muscle Group / Test Speed	BPTB Group (n=22)	HT Group (n=22)	p-value
<b>Quadriceps Peak Torque Deficit</b>			
@ 60°/sec	<b>15.2 ± 6.1%</b>	<b>11.8 ± 5.4%</b>	<b>0.043*</b>
@ 180°/sec	12.5 ± 5.8%	10.3 ± 5.1%	0.172
<b>Hamstrings Peak Torque Deficit</b>			
@ 60°/sec	4.5 ± 4.1%	7.2 ± 4.9%	0.058
@ 180°/sec	<b>3.9 ± 4.8%</b>	<b>9.7 ± 5.6%</b>	<b>0.001*</b>

Isokinetic dynamometry revealed a distinct, graft-specific pattern of residual muscle strength deficits (Table 4). While both groups exhibited some persistent strength loss, its locus differed significantly. The BPTB group demonstrated a

significantly greater deficit in quadriceps peak torque at the slower speed of 60°/sec (15.2% vs. 11.8%, p=0.043). Conversely, the HT group showed a significantly greater deficit in hamstring peak torque at the higher speed of 180°/sec (9.7% vs. 3.9%, p=0.001). These results highlight the site-specific donor morbidity associated with each graft harvest procedure.

**Table 5: Postoperative Morbidity and Complications**

Variable	BPTB Group (n=22)	HT Group (n=22)	p-value
<b>Anterior Knee Pain (Yes)</b>	<b>5 (22.7%)</b>	<b>1 (4.5%)</b>	<b>0.048*</b>
<b>Extension Lag (&gt;5°)</b>	2 (9.1%)	1 (4.5%)	0.500
<b>Graft Failure / Re-rupture</b>	0 (0%)	0 (0%)	-
<b>Superficial Infection</b>	0 (0%)	1 (4.5%)	0.311
<b>Revision Surgery (Any Cause)</b>	0 (0%)	0 (0%)	-

The incidence of postoperative complications was low overall (Table 5). However, a statistically significant difference was observed in the prevalence of anterior knee pain, which was reported by 22.7% (n=5) of patients in the BPTB group compared to only 4.5% (n=1) in the HT group (p=0.048). Other complications, including minor extension lag and a single superficial infection in the HT group, were infrequent and not significantly different between the cohorts. No patient in either group required revision surgery during the follow-up period.

## DISCUSSION

This prospective comparative study of 44 patients demonstrates that both BPTB and HT autografts are highly effective for restoring functional stability following ACL reconstruction, with no statistically significant difference in patient-reported outcomes or objective knee laxity at a minimum two-year follow-up. However, the findings reveal a critical divergence: the choice of graft dictates a specific profile of donor-site morbidity, manifesting as distinct, residual muscle strength deficits and differing rates of anterior knee pain. This supports the evolving paradigm that graft selection should not seek a universal "best" option but should be individualized, balancing the unique biomechanical and clinical trade-offs of each graft against the patient's functional demands and priorities.

The equivalence in primary functional outcomes—Lysholm, IKDC, and Tegner scores—aligns with the broader body of high-level evidence. A landmark meta-analysis by Mohtadi et al. (2011), pooling data from several randomized trials, concluded that while BPTB reconstructions resulted in better stability as measured by instrumented laxity, patient-reported outcomes were largely similar between graft types, a finding our study corroborates.<sup>11</sup> Similarly, a systematic review by Xergia et al. (2013) found no consistent superiority of one graft over the other in terms of returning patients to their pre-injury activity levels, a result reflected in our cohort's nearly identical final Tegner scores.<sup>12</sup> Our data, showing no significant difference in KT-1000 measurements (1.8 mm vs. 2.0 mm) and excellent clinical pivot-shift grades, further narrows the perceived "stability gap" between grafts in the modern surgical era, likely due to improved HT graft preparation and fixation techniques.

The core contribution of this study lies in the detailed quantification of site-specific morbidity. The significantly greater quadriceps deficit observed in the BPTB group at 60°/sec (15.2% vs. 11.8%) is a direct consequence of violating the extensor mechanism. This deficit, persisting at two years, is consistent with the pathomechanics described by Kartus et al. (2001), who attributed anterior knee pain and quadriceps weakness post-BPTB harvest to patellofemoral biomechanical alterations and postoperative pain inhibition.<sup>13</sup> Our finding that 22.7% of BPTB patients reported anterior knee pain, compared to only 4.5% in the HT group, powerfully reinforces this associated morbidity. Conversely, the significantly greater hamstring deficit in the HT group at higher angular velocity (9.7% vs. 3.9% at 180°/sec) underscores the functional cost of harvesting the semitendinosus and gracilis tendons. This aligns with the work of Tashiro et al. (2019), who demonstrated that hamstring tendon harvest leads to kinematic alterations during high-speed running and cutting, potentially affecting dynamic knee stabilization.<sup>14</sup> This deficit may be particularly relevant for athletes in sports requiring powerful deceleration or sharp changes of direction.

These results have direct clinical implications. For an athlete whose sport prioritizes explosive jumping and landing (e.g., volleyball, basketball), where quadriceps power is paramount, the additional quadriceps deficit and anterior knee pain risk of a BPTB graft may be a meaningful deterrent. For a soccer player or a martial artist, where hamstring strength is

crucial for knee flexion and deceleration control, the deficit associated with HT harvest warrants serious consideration. The decision-making process must therefore evolve from a generic recommendation to a shared decision model, incorporating the patient's sport, occupation, functional goals, and personal tolerance for specific morbidities.

## CONCLUSION

In conclusion, both BPTB and HT autografts provide a robust and reliable foundation for successful ACL reconstruction, offering patients excellent subjective outcomes and knee stability. The principal distinction is not in overall success, but in the anatomic "footprint" of the surgery. The BPTB graft, while excellent for stability, leaves a signature on the extensor mechanism; the HT graft, while sparing the anterior knee, leaves its mark on the hamstring complex. The surgeon's role is to expertly map this footprint onto the patient's individual functional anatomy and life map, ensuring the chosen graft aligns with their pathway to a sustainable return to activity.

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