

## Early Functional Recovery and Minimal Donor Site Morbidity Following ACL Reconstruction using BTB Autografts in Athletes and Military Personnel: A Prospective Outcome Analysis

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### Abstract:

**Background:** Anterior cruciate ligament (ACL) injuries are increasingly prevalent among athletes and physically active individuals. The bone–patellar tendon–bone (BTB) autograft remains a preferred option for primary ACL reconstruction in high-demand patients due to its superior fixation strength and graft incorporation.

**Objective:** To evaluate the functional outcomes, return to sports, and donor site morbidity following ACL reconstruction using BTB grafts in high-demand individuals over a 12-month follow-up.

**Methods:** In this prospective observational study, 58 patients undergoing primary ACL reconstruction with BTB autograft were enrolled. Functional outcomes were measured using the Lysholm score and return-to-sports scores at regular follow-ups. Donor site morbidity was assessed at the final follow-up.

**Results:** At the end of the 12-month follow-up, patients demonstrated significant improvements in functional outcomes. The mean Lysholm score increased from  $42.0 \pm 13.0$  preoperatively to  $84.0 \pm 5.4$  at 3 months,  $94.8 \pm 2.0$  at 6 months, and reached  $98.7 \pm 2.1$  by 12 months ( $p < 0.001$  across all time points). Return-to-sports scores also showed notable gains, improving from a mean of  $79.4 \pm 9.1$  at 6 months to  $98.3 \pm 2.3$  at the 12-month mark ( $p < 0.001$ ), indicating a successful reintegration into athletic or physically demanding activities. Donor site morbidity was rated as excellent in 72.4% of patients, with no cases of poor outcomes or persistent extensor mechanism dysfunction reported.

**Conclusion:** BTB autografts provide excellent functional recovery and minimal donor site morbidity in high-demand individuals undergoing ACL reconstruction. These findings support the continued use of BTB grafts in athletes and occupationally active patients who require a rapid and reliable return to pivoting sports and physically demanding activities.

**Keywords:** ACL Reconstruction, Bone–Patellar Tendon–Bone Autograft, Functional Recovery, Donor Site Morbidity, Lysholm Score.

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### Introduction

Injury to the anterior cruciate ligament (ACL) is a common and often debilitating event, particularly in young, physically active individuals who participate in pivoting or contact sports such as football, basketball, and martial arts. These injuries not only impair knee stability but also limit performance, increase the risk of meniscal damage, and accelerate degenerative changes if left unaddressed [1,2]. For high-demand individuals—whether competitive athletes, military personnel, or those engaged in physically strenuous occupations—timely surgical reconstruction of the ACL is crucial to restoring

joint function and enabling a confident return to full activity [3].

Among the various graft choices available for ACL reconstruction, the bone–patellar tendon–bone (BTB) autograft has long been favored, particularly in high-performance populations. This preference is largely due to its biomechanical advantages, including rigid bone-to-bone healing, strong initial fixation, and minimal risk of graft elongation [4,5]. These qualities are believed to support more predictable outcomes and an earlier return to high-intensity sport or work [6].

However, the use of BTB grafts is not without its challenges. Donor site issues such as anterior knee pain, kneeling discomfort, and extensor mechanism dysfunction have been reported in varying degrees [7,8]. While many of these concerns can be mitigated through refined surgical techniques and structured rehabilitation, they have prompted consideration of alternative graft options in recent years. The quadriceps tendon (QT) autograft has emerged as one such alternative, offering a thick and robust graft with favorable biomechanical strength. Some studies have highlighted its potential to reduce donor site morbidity, especially anterior knee pain, when compared to the traditional BTB graft [9,10]. In particular, minimally invasive harvest techniques and the use of partial-thickness QT grafts have made this option increasingly attractive.

Furthermore, QT grafts provide a large cross-sectional area and show good mid-term outcomes, especially in recreational athletes [11]. That said, the quadriceps tendon is not without limitations. Concerns have been raised regarding its slower graft incorporation and slightly less rigid fixation—especially when used without a bone block [12]. These factors may influence early rehabilitation and could be less ideal in athletes or military personnel who require robust stability and rapid return to sport. In contrast, BTB grafts continue to offer reliable outcomes in these high-stress scenarios, with well-documented long-term success [13]. Given these considerations, this study was designed to evaluate the clinical utility of BTB autografts in a well-defined population of high-demand patients. We aimed to prospectively assess both functional outcomes and donor site morbidity over a one-year period, thereby providing further insight into the continued relevance of BTB grafts in a clinical landscape that is rapidly evolving toward individualized graft selection.

## Materials and Methods

**Study Design and Participants:** This prospective observational study was carried out at a high-volume

tertiary orthopaedic center between January 2022 and January 2024. The primary objective was to evaluate functional outcomes and donor site morbidity in physically active individuals undergoing anterior cruciate ligament (ACL) reconstruction using bone–patellar tendon–bone (BTB) autografts. The study was approved by the institutional ethics committee, and informed written consent was obtained from all participants.

A total of 58 consecutive patients were enrolled based on the following inclusion criteria: aged 18–40 years, engaged in competitive sports, military training, or physically demanding work, and diagnosed with isolated ACL rupture confirmed through clinical examination and MRI. Patients with previous knee surgeries, multiligamentous injuries, chondral defects grade III/IV, or systemic inflammatory arthropathies were excluded. These criteria were aligned with recent studies focusing on high-demand populations undergoing ACL reconstruction [14,15].

**Surgical Technique:** All surgeries were performed arthroscopically by senior orthopaedic surgeons experienced in sports knee reconstruction. A standardized technique was used in all patients. The BTB autograft was harvested from the central third of the ipsilateral patellar tendon, including bony plugs from the inferior patella and tibial tubercle. Careful attention was given to minimize trauma at the donor site, particularly to the paratenon and surrounding soft tissue, as donor site morbidity remains a well-recognized concern [16].

Femoral and tibial tunnels were created anatomically using anteromedial portal drilling. Graft fixation was achieved using titanium interference screws to ensure immediate construct stability. The patellar defect was left unfilled, as supported by recent evidence suggesting spontaneous ossification in most cases [9]. Postoperatively, the surgical site was dressed with compressive bandaging and cryotherapy initiated immediately.



**Figure 1: Surgical technique**

**Postoperative Rehabilitation:** All patients followed a uniform, structured rehabilitation protocol, initiated on the first postoperative day. Emphasis was placed on early quadriceps activation, progressive range- of-motion exercises, and gradual functional loading. Weight bearing was permitted as tolerated, with the aid of crutches for 2–3 weeks. Return to pivoting sports was permitted only after satisfactory functional assessment, typically after 6 months. This rehabilitation strategy aligns with contemporary accelerated protocols shown to reduce complications and improve patient-reported outcomes [17].

**Outcome Measures:** Clinical and functional outcomes were assessed using the following validated tools:

- **Lysholm Knee Scoring Scale:** Used to assess knee function and patient-perceived recovery. Evaluations were conducted preoperatively and at 3, 6, and 12 months postoperatively. This score is widely used in ACL outcome studies and remains a standard in current literature [18].
- **Return to Sport (RTS) Score:** Assessed at 6 and 12 months postoperatively. It evaluated the patient's confidence and level of return to pre-injury sport or activity.
- **Donor Site Morbidity:** Assessed at the 12-month follow-up using a composite scoring

system that incorporated kneeling pain, anterior knee pain during activities, and extensor strength. Outcomes were graded as:

- Excellent ( $\geq 93.3$ ),
- Good (80.0–93.2),
- Fair (50.0–79.9),
- Poor ( $\leq 49.9$ ),

based on methods adapted from previous studies examining BTB graft morbidity [19,20].

**Statistical Analysis:** Data were analyzed using SPSS software version 26.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean  $\pm$  standard deviation (SD). Paired sample t-tests were used to compare changes in Lysholm and RTS scores over time. A p-value of  $<0.05$  was considered statistically significant. The analysis was designed to detect meaningful improvements in function and return-to-activity patterns across the follow-up period.

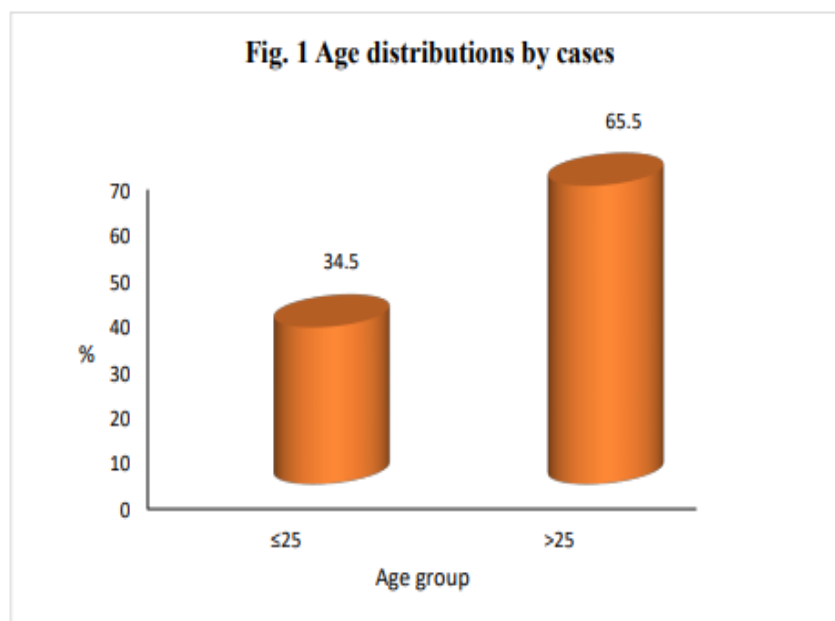
## Results

**Patient Profile:** The study cohort included 58 individuals who met the inclusion criteria for high-demand status, either due to athletic involvement or physically intensive occupations such as military service or manual labor. Among them, 36 were male (62.1%) and 22 were female (37.9%), with a mean age of  $26.6 \pm 4.7$  years. All patients had isolated

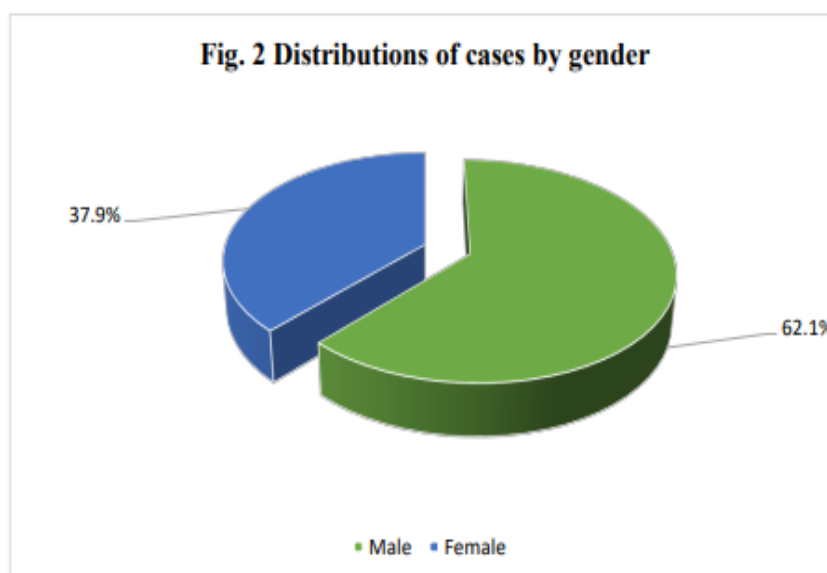
ACL injuries and underwent surgery within a standardized timeline following diagnosis.

**Table 1: Demographic profile of cases**

| Variable  | Category  | No.        | %    |
|-----------|-----------|------------|------|
| Age group | ≤25 years | 20         | 34.5 |
|           | >25 years | 38         | 65.5 |
| Mean ± SD |           | 26.6 ± 4.7 |      |
| Gender    | Male      | 36         | 62.1 |
|           | Female    | 22         | 37.9 |
| Total     |           | 58         | 100  |



**Figure 2: Age distribution by cases**



**Figure 3: Distribution of cases by gender**

**Recovery of Knee Function:** Postoperative functional recovery, as measured by the Lysholm Knee Score, showed a clear and encouraging

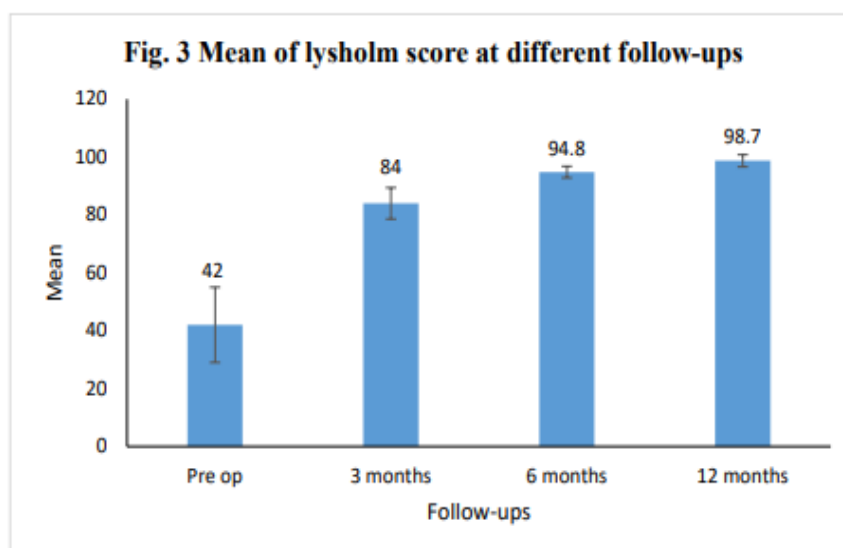
trajectory of improvement over the 12-month follow-up period.

Preoperatively, patients had a mean Lysholm score of  $42.0 \pm 13.0$ , reflecting significant limitations in knee stability and function. By 3 months post-surgery, the score had risen sharply to  $84.0 \pm 5.4$ , indicating rapid early gains. Continued rehabilitation and return to activity further improved

scores to  $94.8 \pm 2.0$  at 6 months and  $98.7 \pm 2.1$  at the 1-year mark. These changes were statistically significant across all time points ( $p < 0.001$ ), underscoring the effectiveness of the BTB graft in restoring knee function in a demanding population.

**Table 2: Pair-wise comparison of Lysholm score at different follow-ups (N = 58)**

| Pair | Follow-up | Lysholm Score (Mean $\pm$ SD) | Paired sample t test (p value) |
|------|-----------|-------------------------------|--------------------------------|
| 1    | Pre-op    | $42.0 \pm 13.0$               | <0.001                         |
|      | 3 months  | $84.0 \pm 5.4$                |                                |
| 2    | 3 months  | $84.0 \pm 5.4$                | <0.001                         |
|      | 6 months  | $94.8 \pm 2.0$                |                                |
| 3    | 6 months  | $94.8 \pm 2.0$                | <0.001                         |
|      | 12 months | $98.7 \pm 2.1$                |                                |
| 4    | Pre-op    | $42.0 \pm 13.0$               | <0.001                         |
|      | 12 months | $98.7 \pm 2.1$                |                                |



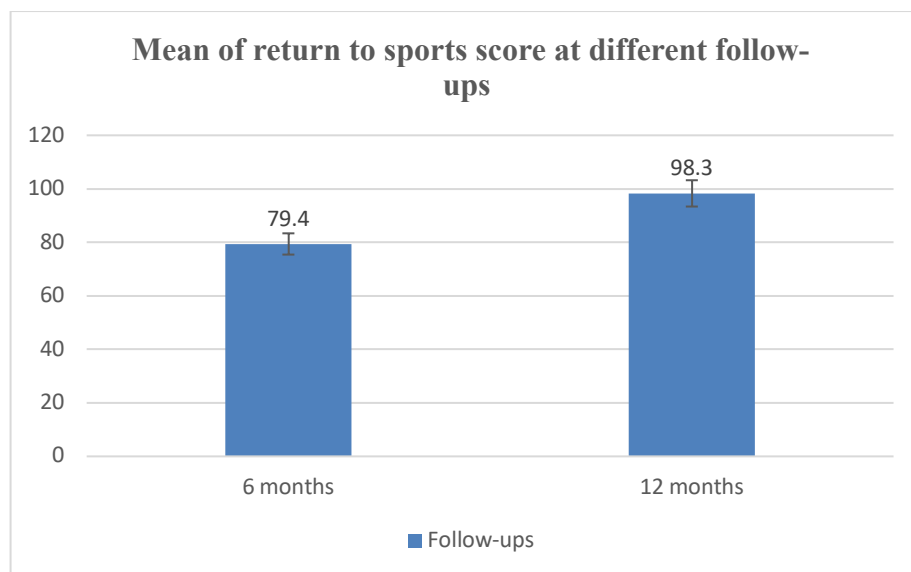
**Figure 4: Mean of lysholm score at different follow-ups**

**Return to Physical Activity:** Return-to-sport (RTS) performance closely paralleled improvements in functional scores. At the 6-month follow-up, most patients reported partial reintegration into their pre-injury activity levels, with a mean RTS score of  $79.4 \pm 9.1$ . By 12 months, the majority had resumed full

participation in competitive sports or physically demanding work, as evidenced by a mean score of  $98.3 \pm 2.3$ . This highlights the graft's capacity to support not just structural stability but also a confident return to high-intensity tasks.

**Table 3: Pair-wise comparison of return-to-sports score at different follow-ups (N = 58)**

| Pair | Follow-ups | Return-to-sports Score (Mean $\pm$ SD) | Paired sample t test (p value) |
|------|------------|----------------------------------------|--------------------------------|
| 1    | 6 months   | $79.4 \pm 9.1$                         | <0.001                         |
| 2    | 12 months  | $98.3 \pm 2.3$                         |                                |



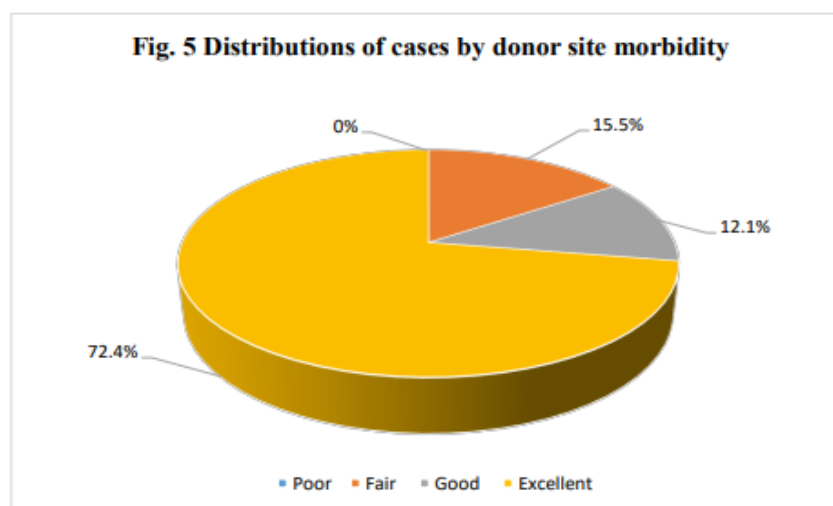
**Figure 5: Mean of return to sports score at different follow-ups**

**Donor Site Tolerance:** Assessment of donor site morbidity at the 1-year follow-up yielded favorable results. A large proportion of patients—42 individuals (72.4%)—reported no significant issues and were classified as having excellent outcomes. Seven patients (12.1%) reported mild kneeling discomfort or transient anterior knee pain, falling

into the "good" category, while nine (15.5%) experienced more noticeable but non-disabling symptoms and were graded as "fair." Importantly, none of the patients were categorized as having poor donor site outcomes. There were no cases of extensor lag, patellar fracture, or chronic anterior knee pain requiring intervention.

**Table 4: Distribution of cases by donor site morbidity (N = 58)**

| Donor Site Morbidity      | No. | %    |
|---------------------------|-----|------|
| Poor ( $\leq 49.9$ )      | 0   | 0.0  |
| Fair (50–79.9)            | 9   | 15.5 |
| Good (80–93.2)            | 7   | 12.1 |
| Excellent ( $\geq 93.3$ ) | 42  | 72.4 |
| Total                     | 58  | 100  |



**Figure 6: Distributions of cases by donor site morbidity**

These findings suggest that, when harvested with care and followed by structured rehabilitation, BTB autografts are not only effective in restoring knee

stability but also well tolerated at the donor site—even in a cohort where functional demands are high.

## Discussion

This prospective study evaluated the functional outcomes and donor site morbidity following ACL reconstruction using BTB autografts in a high-demand Indian population. Our findings add to the growing body of literature supporting BTB as a dependable graft option, particularly for athletes, military personnel, and physically active individuals. In our cohort of 58 patients, the mean Lysholm score improved significantly from  $42.0 \pm 13.0$  preoperatively to  $84.0 \pm 5.4$  at 3 months,  $94.8 \pm 2.0$  at 6 months, and  $98.7 \pm 2.1$  at 12 months ( $p < 0.001$ ), indicating robust functional recovery. These outcomes are consistent with long-term studies by Shelbourne et al., who reported high patient satisfaction and excellent functional results in athletes undergoing BTB ACL reconstruction [6]. Furthermore, return-to-sport scores improved from  $79.4 \pm 9.1$  at 6 months to  $98.3 \pm 2.3$  at 12 months, reflecting successful reintegration into sports and occupational activity—a crucial parameter in high-demand individuals.

Notably, 72.4% of patients in our study reported excellent donor site outcomes, while none experienced poor results. There were no cases of extensor lag or persistent anterior knee pain, and only mild, transient kneeling discomfort was noted in a small subset. This aligns with the earlier findings who reported that anterior knee pain is significantly reduced when graft harvest is performed with care and followed by a structured rehabilitation program [14, 23].

Our results reaffirm the biomechanical advantages of BTB autografts, particularly their high initial fixation strength and rigid bone-to-bone healing, which may facilitate earlier rehabilitation and safer return to pivoting sports [4]. Tashman et al. reported improved joint kinematics post-BTB ACL reconstruction, highlighting better rotational control and lower laxity compared to other grafts [5].

When viewed alongside comparative studies, BTB autografts appear to outperform hamstring tendon (HT) grafts in certain key parameters for high-performance individuals. Several meta-analyses have shown lower graft failure rates and superior stability in BTB reconstructions compared to HT, especially in patients under 30 years of age and involved in competitive sports [14,21].

Although quadriceps tendon (QT) autografts are gaining popularity, especially due to their favorable donor site profile, data regarding their use in elite or high-demand populations remain limited. Earlier studies suggest that QT autografts offer comparable outcomes to BTB grafts in moderate activity groups, but may lack the rigid fixation and consistent early return seen with BTB in more demanding populations [9,11].

Our study contributes to this ongoing debate by offering real-world, prospective evidence from an Indian context, emphasizing both early functional gains and tolerability of BTB graft harvest. Importantly, the high RTS scores and absence of major complications strengthen the case for using BTB autografts in patients where predictable return to full activity is a surgical priority.

This study is among the few recent prospective investigations focusing exclusively on high-demand Indian patients using BTB grafts. Strengths include the uniform surgical technique, structured postoperative rehabilitation, and use of validated outcome measures. However, the study is limited by the lack of a comparative arm involving hamstring or quadriceps tendon grafts. Additionally, while short-term outcomes were excellent, longer follow-up is needed to assess graft durability, osteoarthritic changes, and revision rates.

**Clinical Implications:** In high-demand individuals requiring strong fixation and early return to activity, BTB autografts remain a preferred choice for ACL reconstruction due to their biomechanical advantages, including rigid bone-to-bone healing, superior pullout strength, and reduced graft elongation, which support early mobilization and functional stability [3,4]. Our study showed marked improvements in Lysholm and RTS scores over 12 months, consistent with existing evidence of BTB efficacy in athletes and occupationally active populations [15,16]. Donor site morbidity was minimal, with over 70% reporting no significant discomfort, aligning with reports that careful surgical harvest and structured rehabilitation reduce complications [7,14]. Comparative research indicates BTB grafts provide greater rotational control, stability, and lower failure rates than hamstring grafts in young, competitive individuals [3,8], though hamstrings may be preferable when anterior knee pain is a concern. Quadriceps tendon (QT) grafts show promise [9,10], but fixation strength and long-term outcomes remain less established. Despite the absence of a control group and limited follow-up, our findings reinforce BTB as a reliable graft for rapid recovery and acceptable morbidity in high-demand patients.

## Conclusion

This study demonstrates that bone-patellar tendon-bone (BTB) autografts are highly effective for anterior cruciate ligament (ACL) reconstruction in physically demanding individuals. Most patients achieved rapid functional recovery and returned to pre-injury activity levels within a year, with minimal donor site morbidity and little anterior knee discomfort. These outcomes highlight the graft's biomechanical advantages and emphasize the role of precise surgical technique and structured rehabilitation. Overall, BTB autografts offer a

reliable option for athletes, military personnel, and others requiring dependable knee stability and long-term success.

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