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ORIGINAL ARTICLE

Clinical and Patient-Reported Outcomes of Braganza-Tan (BT) Pass-Through Stump Incision, Stump-Sparing, and Stump-Sacrificing ACL Reconstruction Techniques Among Filipino Patients: A Randomized Controlled Trial

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ABSTRACT

Background. Anterior cruciate ligament reconstruction (ACLR) aims to restore knee stability and function following ligament injury. Remnant-preserving techniques have gained interest due to their potential benefits in proprioception, graft healing, and early functional recovery.

Objective. To compare the clinical and patient-reported outcomes, knee stability, and complication rates of the Braganza-Tan (BT) pass-through stump incision, the stump-sparing, and the stump-sacrificing techniques in ACLR using hamstring grafts among Filipino patients at the University of Santo Tomas Hospital.

Methodology. A prospective, randomized controlled trial was conducted among 90 Filipino patients aged 18–35 years diagnosed with acute primary anterior cruciate ligament (ACL) tear (< 6 weeks from injury) confirmed by MRI. Participants were block-randomized into three groups: BT pass-through stump incision, stump-sparing, and stump-sacrificing (n = 30 each). All underwent hamstring autograft reconstruction and a standardized rehabilitation protocol. Outcomes were assessed preoperatively and at three, six, nine, and 12 months using the International Knee Documentation Committee (IKDC) Scale, Tegner Activity Scale, Lysholm Score, and Hospital for Special Surgery (HSS) Score. Knee stability was evaluated through the Lachman, pivot shift, and anterior drawer tests, and an instrumented arthrometer. One-way ANOVA, Kruskal-Wallis tests, repeated-measures ANOVA, and mixed-effects models were used for analysis.

Results. All groups showed significant improvement from baseline across all functional scores ($p < 0.001$). However, both the BT and stump-sparing groups consistently demonstrated higher IKDC, Lysholm, HSS, and Tegner scores from three to 12 months compared with the stump-sacrificing group ($p < 0.01$). Knee stability tests showed significantly better early and midterm anterior and rotational control in the BT and stump-sparing groups ($p < 0.05$). Complications were lowest in the BT group, with no graft failures recorded, though this difference did not reach statistical significance. By 12 months, stability outcomes became comparable across all groups, although functional scores remained highest in the BT and stump-sparing groups.

Conclusion. The BT pass-through stump incision and conventional remnant-preserving techniques demonstrated superior early clinical outcomes and improved knee stability within the first 12 months compared with stump-sacrificing reconstruction in acute ACL tears. Longer-term follow-up is required to determine sustained graft durability and functional superiority.

Keywords. anterior cruciate ligament reconstruction, remnant preservation, knee stability, functional outcomes, Filipino patients

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INTRODUCTION

The anterior cruciate ligament (ACL) is essential for knee stability, especially during physical activities such as walking, running, jumping, or rapidly changing direction. It is the most frequently injured ligament in the knee during high-impact movements or sports, which highlights its vital role in proper knee function. The ACL serves as the primary restraint to anterior tibial translation and helps neutralize rotational stresses on the knee when under load.[1]

Besides its stabilizing function, the ACL contributes significantly to proprioception, which allows the brain to recognize the position and movement of the knee. Proprioception is an important part of the sensory-motor system that ensures balance, coordination, and posture during activity involving the knee joint. When the ACL is injured, proprioceptive feedback is disrupted, leading to impaired motor control and balance.[1]

Knee function following an ACL rupture is commonly restored through surgical reconstruction. Surgery remains the most effective means of reconstructing the torn ligament and reestablishing its biomechanical stability. The outcome of ACL reconstruction depends on several factors, including graft type, fixation method, and tunnel positioning. Common graft options include bone-patellar tendon-bone, hamstring, quadriceps tendon, and allografts.[2]

Although reported success rates for ACL reconstruction range from 80% to 90%, biological failure and graft re-rupture still occur in a notable percentage of cases. Failures have been linked to poor graft incorporation, inadequate revascularization, or loss of proprioceptive function—factors potentially addressed by preserving the ACL remnant during reconstruction.[3]

Remnant-preserving or stump-retention techniques have been introduced to enhance biological and functional recovery after ACL reconstruction. Stump retention in ACL reconstruction surgery was originally credited to Adachi et al.[4] Studies have demonstrated that preserving the native stump may promote synovial coverage, graft revascularization, and maintenance of mechanoreceptors such as Ruffini, Pacinian, and Golgi-like endings, all of which contribute to proprioceptive restoration.[5] Despite the technique's proposed biological advantages, there are potential disadvantages. Excessive remnant tissue may obscure visualization during tunnel placement, increase technical difficulty, and potentially contribute to impingement or symptomatic cyclops lesions.[3,6,7] Variability in remnant volume and quality may also lead to inconsistent biomechanical behavior.[8] These concerns underscore the need for controlled comparative studies evaluating the clinical relevance of remnant-preserving techniques.

Stump preservation is also associated with improved quadriceps strength and lower rates of graft failure and revision surgery. The stump-sparing approach retains the entire ACL tibial remnant without incision, maximizing preservation of vascular and sensory structures. The Braganza-Tan (BT) pass-through stump incision technique, developed in the Philippines, represents a distinct modification that involves a controlled incision through the tibial stump to allow graft passage while still preserving its biological and proprioceptive benefits. The BT technique differs from conventional remnant preservation by incorporating controlled stump incision and guided graft passage, aiming to preserve vascular and mechanoreceptor structures while minimizing remnant redundancy. In contrast, the stump-sacrificing technique involves complete removal of the ACL remnant, eliminating potential advantages associated with stump preservation but simplifying graft insertion and tunnel visualization.

Currently, no study has compared the Braganza-Tan (BT) pass-through stump incision, stump-sparing, and stump-sacrificing ACL reconstruction techniques in a single randomized trial. Most orthopedic surgeons in the country continue to perform stump-sacrificing reconstruction as the standard approach for restoring knee stability. However, increasing local interest in stump-preserving methods highlights the need for evidence comparing these evolving techniques. The BT method, first introduced and applied locally, aims to balance remnant preservation with technical feasibility using standard arthroscopic portals. Comparing these three methods in one study will help determine whether the BT technique achieves outcomes comparable to stump-sparing reconstruction and superior to the stump-sacrificing technique in terms of functional recovery and patient satisfaction.

This study hypothesized that the BT and the stump-sparing technique would demonstrate comparable clinical and patient-reported outcomes, both superior to the stump-sacrificing ACL reconstruction among Filipino patients at the University of Santo Tomas Hospital. The study aimed to compare these three techniques in terms of knee stability, functional scores, and complication rates.

To compare the clinical and patient-reported outcomes of the Braganza-Tan (BT) pass-through stump incision, the stump-sparing and the stump-sacrificing techniques in ACLR using hamstring grafts among Filipino patients at the University of Santo Tomas Hospital.

1. To determine significant differences in clinical and functional scores, specifically:
    a. International Knee Documentation Committee (IKDC) Scale
    b. Tegner Activity Scale
    c. Lysholm Score
    d. Hospital for Special Surgery (HSS) Score
2. To determine significant differences in knee stability, specifically:
    a. Lachman Test
    b. Pivot Shift Test
    c. Anterior Drawer Test
    d. Instrumented Arthrometer

3. To compare the complication rates among patients undergoing the Braganza-Tan (BT) pass-through stump incision technique, the stump-sparing technique, and the stump-sacrificing ACLR.

METHODOLOGY

This study was a prospective, randomized controlled trial involving three parallel groups. The participants were Filipino patients at the University of Santo Tomas Hospital diagnosed with anterior cruciate ligament (ACL) tear confirmed through magnetic resonance imaging (MRI). Eligible patients underwent one of three surgical techniques of ACL reconstruction (ACLR): the Braganza-Tan (BT) pass-through stump incision technique, the stump-sparing technique, or the stump-sacrificing technique. All patients were evaluated preoperatively using standardized functional and knee stability tests and reassessed postoperatively at three, six, nine, and 12 months. This was a single-center, patient- and assessor-blinded trial, with the operating surgeons remaining unblinded due to the nature of the surgical interventions.

Subject selection criteria

Inclusion criteria

1. Filipinos diagnosed with Anterior Cruciate Ligament (ACL) tear confirmed by MRI
2. Male or female patients aged 18 to 35 years old
3. Individuals of any occupation and activity level (sedentary to athletic)
4. Patients able to understand and follow verbal instructions
5. Patients who voluntarily agree to participate and sign the informed consent
6. Participants from private or clinical (charity) divisions of the University of Santo Tomas Hospital
7. Patients with an acute primary ACL tear (< 6 weeks from injury)
8. No prior ACL reconstruction or revision surgery in the affected knee

Exclusion criteria

1. Patients diagnosed with other conditions that may affect knee stability (e.g., meniscus tear, posterior cruciate ligament tear, posterolateral corner injury)
2. Chronic ACL tears (> 6 weeks from injury)
3. Previous ligament surgery on the affected knee
4. Patients who cannot comprehend the questionnaires due to cognitive impairment
5. Unable to follow verbal instructions
6. Patients who did not consent to participate in the study

Limiting enrollment to acute ACL tears minimized confounding factors such as chronic instability, secondary meniscal degeneration, and adaptive inflammatory changes.

Data collection

Patients were selected and recruited according to the inclusion and exclusion criteria. Demographic information, including age, sex, occupation, and activity level were documented. After a general evaluation that included clinical history, past medical history, and physical examination, the patient's eligibility to participate was determined. Written informed consent was obtained before enrollment. Participants were recruited from both the clinical (charity) department and private patient services to ensure equitable distribution of research participation across patient populations.

Institutional Review Board and Ethics Committee approvals were secured before commencing participant enrollment. Each enrolled participant was assigned a unique study code to preserve anonymity and confidentiality of data in compliance with the Data Privacy Act of 2012.

Block randomization was employed to generate equal groups, with allocation concealment maintained through a sealed opaque envelope technique. A total of 90 participants were randomized in a 1:1:1 ratio into one of three groups:

1. Braganza-Tan (BT) pass-through stump incision technique
2. Stump-sparing technique
3. Stump-sacrificing technique

The sample size of 90 participants was chosen to match the requirements of a three-group design with equal allocation. Thirty participants per technique provided enough power to detect meaningful differences in functional outcomes based on commonly reported effects in ACL reconstruction research. This number kept the comparisons reliable while staying realistic for the recruitment capacity of the study site. The adjustment also reflected the shift from the original two-group structure to a three-arm comparison, which prioritized balanced representation across procedures. The revised size supported valid statistical analysis without compromising the study's ability to detect clinically important results. The reduction from 126 participants was therefore a methodological recalibration suited to the updated design.

Randomization was determined on the day of surgery by drawing a sealed envelope to ensure allocation concealment. This three-arm design allowed comparison among stump-preserving and stump-sacrificing techniques, thereby minimizing confounding variables and enabling more comprehensive conclusions regarding the clinical and functional outcomes of the BT method.

All operative procedures were performed by two orthopedic surgeons, both highly experienced in stump-preserving and stump-sacrificing ACL reconstructions. To ensure unbiased evaluation of outcomes, all clinical and functional assessments were conducted by independent consultants who were not part of the surgical team. A single primary assessor evaluated all participants throughout the study, assisted

by a trained research fellow to ensure consistency in data collection. Since Dr. Braganza was the developer of the BT technique, this potential conflict of interest was formally disclosed. To mitigate bias, all postoperative assessments were performed exclusively by blinded, independent assessors with no financial or academic interest in any of the compared techniques.

The primary outcome of this trial was functional recovery, measured using the Lysholm score. Secondary outcomes included other patient-reported measures such as the International Knee Documentation Committee (IKDC) scale, Tegner Activity Scale, and Hospital for Special Surgery (HSS) score, as well as knee stability tests, including the Lachman test, pivot shift test, anterior drawer test, and instrumented arthrometer measurements.

Before surgery, all patients underwent detailed clinical evaluation and magnetic resonance imaging (MRI) to confirm ACL injury and assess for concomitant meniscal or ligamentous lesions. Clinical and functional assessments were conducted preoperatively and postoperatively at three, six, nine, and 12 months.

Possible complications were systematically monitored and recorded throughout the study, including graft failure, infection, knee stiffness or arthrofibrosis, persistent instability, hardware-related issues, neurovascular injury, donor site morbidity, and cyclops lesion formation. Both intraoperative and postoperative complications were documented to enable safety comparisons.

Surgical procedure

All procedures were performed with the patient in the supine position under regional or spinal anesthesia and pneumatic tourniquet control. An examination under anesthesia was conducted to confirm the diagnosis and rule out any concomitant multi-ligamentous injuries.

Hamstring autografts were harvested in all patients. Diagnostic knee arthroscopy was performed using standard anterolateral and anteromedial portals. The intercondylar notch was prepared using an arthroscopic shaver to ensure adequate visualization and graft placement. In Group A (Braganza-Tan pass-through stump incision [BT]) and Group C (stump-sparing), tibial stump fibers were preserved. Specifically, in Group A, the graft was passed through a small incision within the remnant stump to incorporate the native fibers, while in Group C, the tibial tunnel was directed over the center of the remnant without incision or disruption. In Group B (stump-sacrificing), the tibial stump was completely debrided to create a clear tunnel path for conventional ACL reconstruction.

Anatomic drilling of the femoral tunnel preceded tibial tunnel preparation. With the knee flexed beyond 90°, the femoral insertion was marked approximately at 40% of the proximal-to-distal distance of the lateral notch, centered between the lateral intercondylar ridge and the posterior edge of the lateral femoral condyle. The ACL remnant stump and lateral femoral condyle were visualized during this step (Figure 2). The femoral tunnel was then created (Figure 3).

In Group A (BT), the tibial tunnel was directed toward the center of the tibial stump. A stab incision using a No. 11 blade was made over the ACL remnant stump to prepare the site (Figure 4). The tibial tunnel was then created through the ACL remnant stump, allowing the graft to pass through and maintain continuity with the preserved fibers (Figure 5). In Group B (stump-sacrificing group), where the stump was resected, the tibial tunnel was directed toward the posterior border of the anterior horn of the lateral meniscus, approximately 7 mm anterior to the posterior cruciate ligament (PCL). In Group C (stump-sparing group), the tibial tunnel

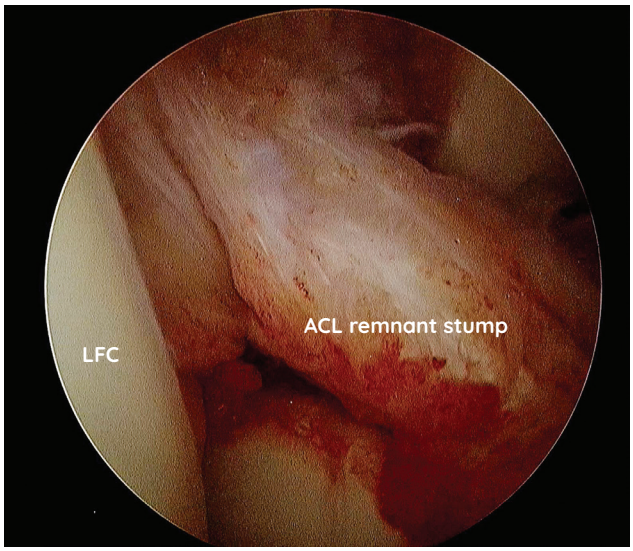

Figure 1. Arthroscopic view of the knee showing the remnant stump adjacent of the anterior cruciate ligament (ACL) adjacent to the lateral femoral condyle (LFC).

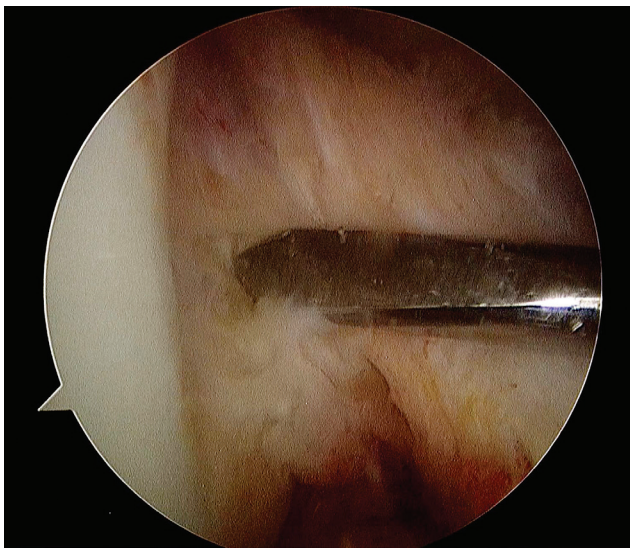

Figure 2. Arthroscopic view demonstrating femoral tunnel creation at the anatomic ACL footprint using a drill guide.

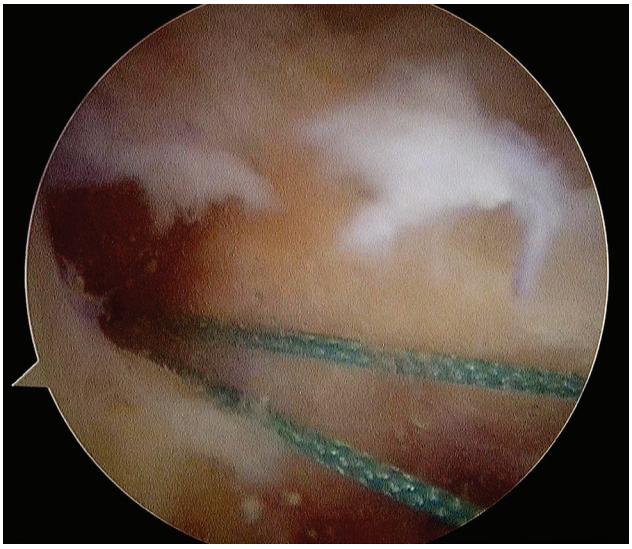

Figure 3. Arthroscopic view of the prepared femoral tunnel before graft passage.

was directed over the center of the tibial stump without incising or disturbing the remnant fibers, preserving the native attachment and proprioceptive elements of the ACL stump.

The tibial tunnel was prepared (Figures 6 and 7). The graft was then passed through both tunnels (Figure 8). The graft was fixed with bioabsorbable interference screws on both the femoral and tibial sides (Figure 9).

Post operative regimen

After surgery, patients were discharged on the same day or within 24 hours. Both groups underwent a uniform rehabilitation program guided by the latest evidence-based protocols to minimize differences in recovery. The initial phase of rehabilitation focused on achieving full active knee extension and allowing full weight-bearing as tolerated, supported with a knee immobilizer. Flexion exercises were limited to less than 90° during the first two weeks, with progressive increases

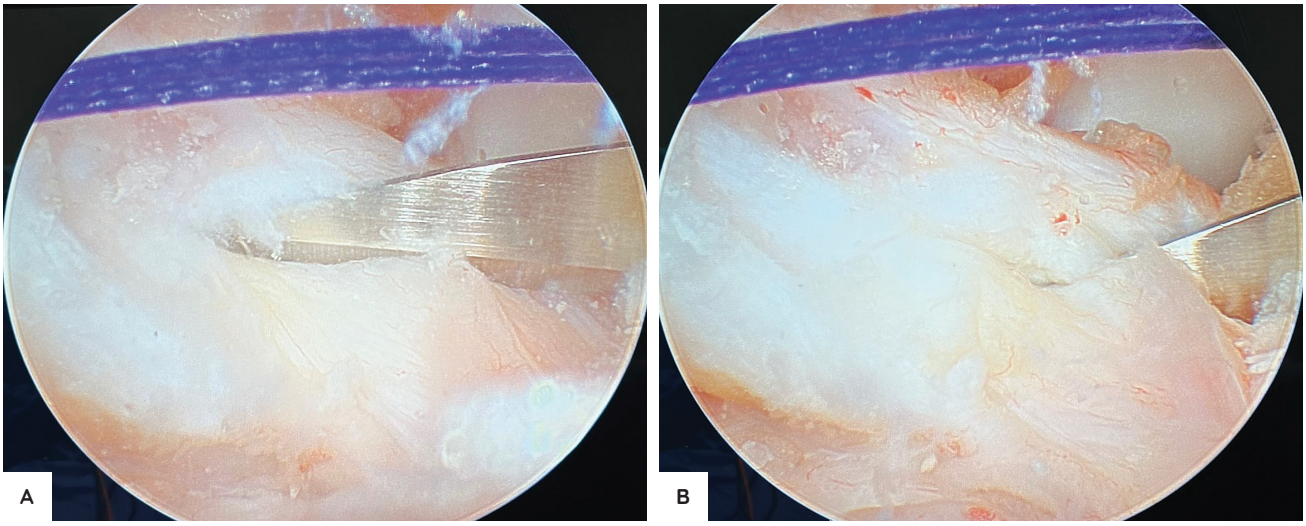

Figure 4. Stab incision using a No. 11 blade over the ACL remnant stump in the Braganza–Tan (BT) stump incorporation technique: initial stab incision over the ACL remnant stump **(A)**; completion of the incision through the remnant tissue **(B)**.

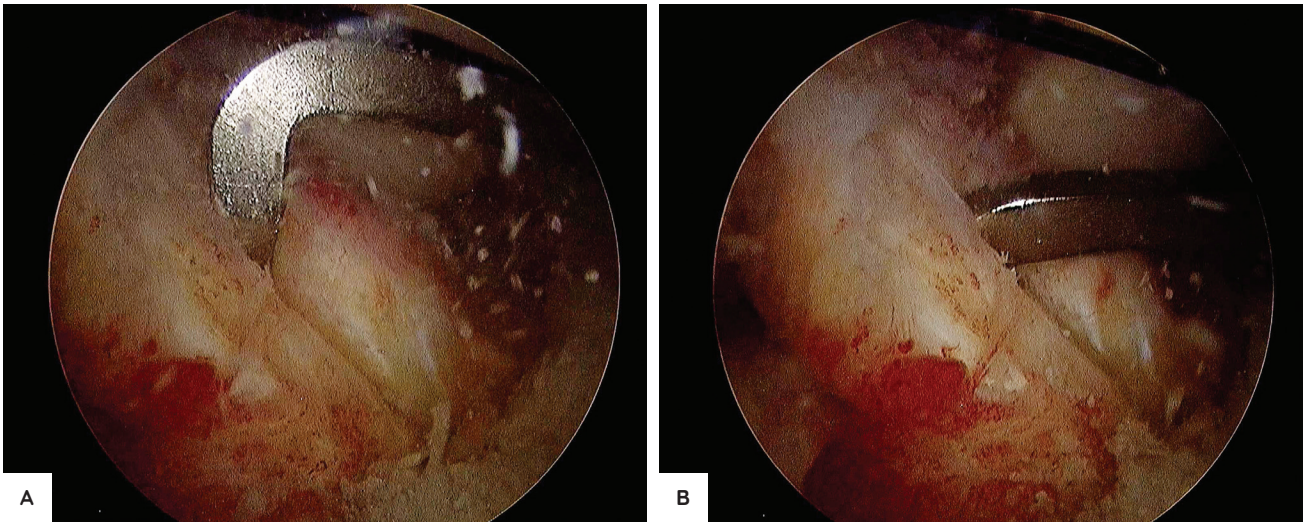

Figure 5. Tibial tunnel creation over the ACL remnant stump: positioning of the tibial guide over the ACL remnant stump **(A)**; drilling of the tibial tunnel through the remnant stump **(B)**.

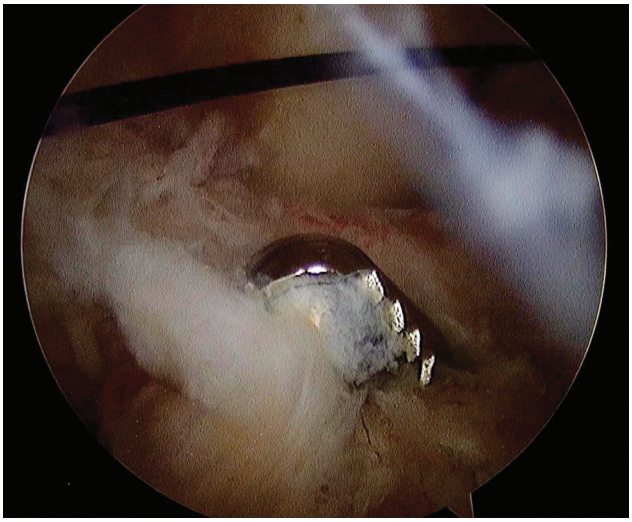

Figure 6. Arthroscopic view of tibial tunnel creation.

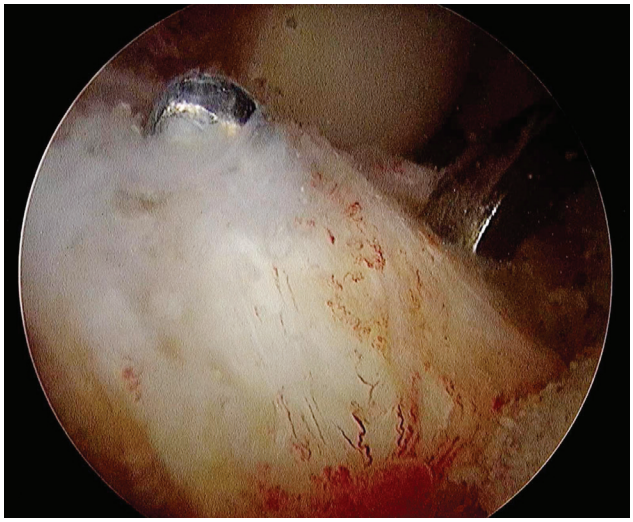

Figure 7. Arthroscopic view demonstrating preparation of the tibial tunnel.

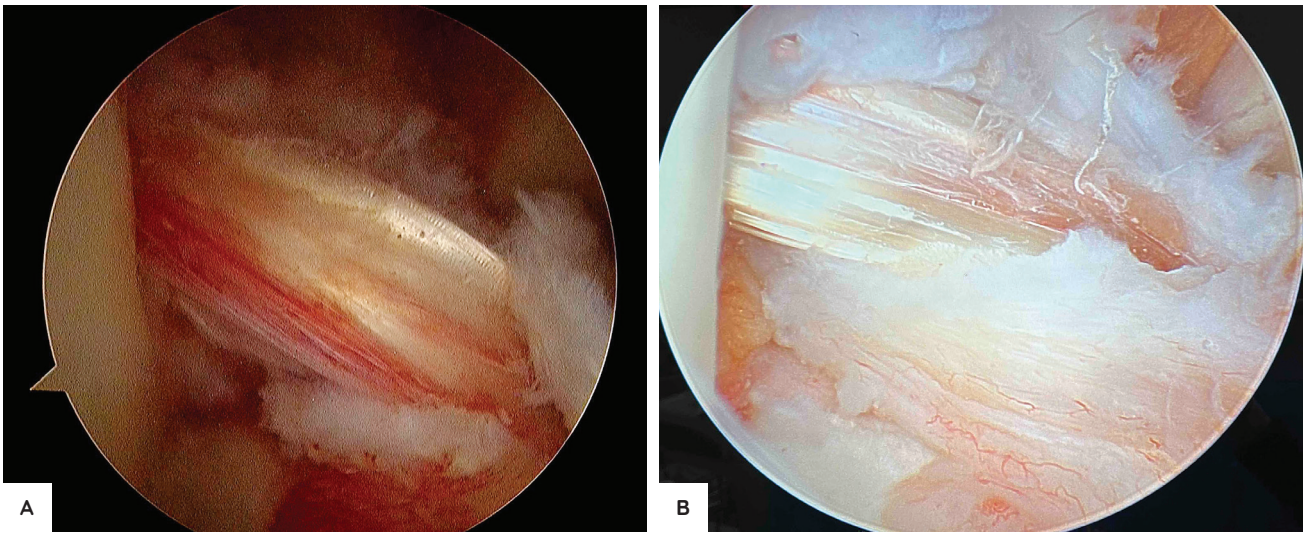

Figure 8. Arthroscopic view demonstrating passage of the ACL graft through the tibial tunnel: initial passage of the ACL graft through the tunnel **(A)**; advancement of the graft within the tunnel **(B)**.

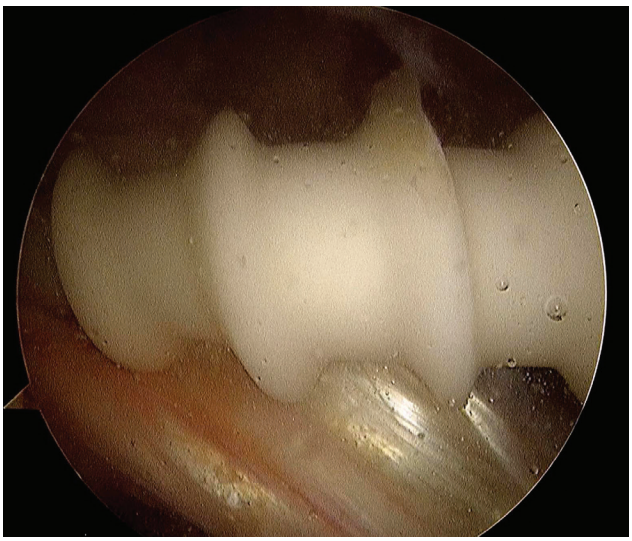

Figure 9. ACL graft fixation using bioabsorbable interference screw.

introduced thereafter until full flexion was attained. Sutures were removed after two weeks, and follow-up visits were scheduled every two weeks throughout the first 12 weeks. Therapy prioritized regaining complete range of motion, progressive weight-bearing, and strengthening the quadriceps and hamstrings.

Four to five months after surgery, patients were allowed to start straight-line running once sufficient strength and stability were demonstrated. Participation in contact or pivoting sports was permitted at nine months post-surgery, contingent upon functional recovery and results of stability assessments.

Stability and standardized outcome scores were assessed at three, six, nine, and 12 months following surgery.

Statistical methods

Descriptive statistics, including mean, standard deviation (SD), frequency, and percentage, were used to summarize the demographic and baseline characteristics of participants, such as age, height, weight, gender, and employment status. Continuous variables are presented as mean ± SD, while categorical variables are expressed as counts and percentages.

To determine differences in continuous outcome scores among the three surgical techniques, a one-way analysis of variance (ANOVA) was performed. The *F* value indicates the ratio of between-group to within-group variance, and a *p*-value less than 0.05 was considered statistically significant. A repeated measures ANOVA was used to evaluate within-group changes in clinical and functional scores over time from preoperative assessment to 12 months postoperatively. The *F* statistic measured overall change across timepoints, and η^2 (eta squared) was used to determine the effect size, representing the magnitude of observed improvements within each group.

For ordinal or non-normally distributed data (such as the Tegner Activity Scale and knee stability tests), the Kruskal-Wallis test was applied. The *H* statistic indicates group variance, while the *p*-value identified significant differences. The η^2 value is reported to show the strength of association and relative effect size.

To account for repeated ordinal data and correlated observations, particularly for changes in activity level over time, an ordinal mixed-effects model was employed. This model simultaneously considers both time and group effects for the Tegner Activity Scale, providing more accurate estimates of progression. The estimate (β) shows the degree of score change per month or per surgical group, and the Z-value tested whether each estimate differed significantly from zero.

For categorical outcomes such as infection, graft failure, stiffness, and other complications, the Chi-square (χ^2) test was used to assess associations between the type of surgical technique and the occurrence of complications. The χ^2 value indicates the strength of association, while the *p*-value determines whether differences were statistically significant.

Statistical significance was set at $p < 0.05$, and all analyses were conducted using standard statistical software.

RESULTS

All three groups had more males than females. All participants were young adults, and most were employed. All groups had similar mean heights and weights (Table 1).

Preoperative IKDC scores were similar across the three groups (*F*-value = 0.03, *p*-value = 0.972) (Table 2). The BT and stump-sparing groups consistently had statistically significantly higher scores than the stump-sacrificing group at three, six, nine, and 12 months postoperatively (Table 2). All groups, however, had significant improvements in scores over time ($p < 0.001$), with the effect sizes being largest for the

Table 1. Demographic profile for both groups

	BT (*N* = 30)	Stump-sacrificing (*N* = 30)	Stump-sparing (*N* = 30)
Age (mean ± SD)	25.6 ± 4.2 years	26.1 ± 4.5 years	25.8 ± 4.0 years
Gender (male/female)	28 / 14	27 / 15	26 / 16
Employment (employed/unemployed)	30 / 12	29 / 13	28 / 14
Height (cm)	168.5 ± 7.4	169.2 ± 6.9	168.8 ± 7.1
Weight (kg)	65.8 ± 8.1	66.4 ± 7.6	65.9 ± 8.3

Table 2. Between-group comparison of International Knee Documentation Committee (IKDC) using one-way analysis of variance (*N* = 30 per group)

Timepoint	BT, Mean ± SD	Stump-sacrificing, Mean ± SD	Stump-sparing, Mean ± SD	*F* value	*p*-value	Interpretation
Pre-op	38.8 ± 5.9	38.5 ± 6.2	38.7 ± 6.0	0.03	0.972	No significant difference at baseline
3 months	71.6 ± 6.5	65.4 ± 7.1	70.2 ± 6.8	6.72	0.002	Significant; *BT and stump-sparing higher than ACLR*
6 months	80.5 ± 6.9	74.2 ± 6.8	79.1 ± 7.2	8.41	< 0.001	Significant; *BT and stump-sparing higher than ACLR*
9 months	84.9 ± 6.3	78.1 ± 7.0	83.8 ± 6.5	9.15	< 0.001	Significant; *BT and stump-sparing higher than ACLR*
12 months	87.7 ± 6.7	81.0 ± 7.4	86.9 ± 6.8	8.98	< 0.001	Significant; *BT and stump-sparing higher than ACLR*

Table 3. Longitudinal changes in IKDC Scale

Group	*F* statistic	*p*-value	Effect Size (η^2)	Interpretation
BT Group	68.5	< 0.001	0.62	Significant improvement over time
Stump-sacrificing Group	54.3	< 0.001	0.55	Significant improvement over time
Stump-sparing Group	66.1	< 0.001	0.60	Significant improvement over time

BT group ($\eta^2 = 0.62$) (Table 3). Preoperative Tegner Activity Scale scores were identical across the three groups (median = 3, range 2–3, $H = 0.12$, $p = 0.942$), indicating no significant difference at baseline. At three, six, nine, and 12 months, the BT and stump-sparing groups had statistically significantly higher scores than the stump-sacrificing group (Table 4). When analyzed over time, Tegner scores significantly increased for all patients ($p < 0.001$) (Table 5). When comparing longitudinal improvement between groups, BT was superior to stump-sacrificing ($\beta = +0.82$, $Z = 3.56$, 95% CI = 0.36 to 1.28, $p < 0.001$), stump-sparing was superior to stump-sacrificing ($\beta = +0.75$, $Z = 3.10$, 95% CI = 0.28 to 1.22, $p = 0.002$), and BT was comparable to stump-sparing ($\beta = +0.07$, $Z = 0.33$, 95% CI = -0.34 to 0.48, $p = 0.739$) (Table 5).

Preoperative Lysholm scores were similar across all groups ($F = 0.07$, $p = 0.932$). At three, six, nine, and 12 months, the BT and stump-sparing groups outperformed the stump-sacrificing group ($p < 0.001$) (Table 6). All groups presented significant improvement over time ($p < 0.001$), with the BT group showing the largest effect size ($\eta^2 = 0.64$) (Table 7).

Preoperative HSS scores were similar across the groups ($F = 0.03$, $p = 0.970$). At three, six, nine, and 12 months, the BT and stump-sparing groups had higher scores than the stump-sacrificing group (Table 8). All groups had significant improvement over time ($p < 0.001$), with the BT group having the highest effect size ($\eta^2 = 0.64$).

At baseline, there was no significant difference in Lachman testing among the groups ($H = 0.41$, $p = 0.815$, $\eta^2 = 0.01$). At three, six, nine, and 12 months postoperatively, the BT and stump-sparing groups showed better stability on Lachman testing than the stump-sacrificing group, with the effect size decreasing over time (Table 10).

At baseline, there was no significant difference in pivot shift testing among the groups ($H = 46.0$, $p = 0.694$, $\eta^2 = 0.07$). At three, six, nine, and 12 months postoperatively, the BT and stump-sparing groups showed better stability on pivot shift testing than the stump-sacrificing group (Table 11).

At baseline, there was no significant difference in anterior drawer test results among the groups ($H = 0.47$, $p = 0.789$, $\eta^2 = 0.01$). At three, six, and nine months postoperatively, the BT and stump-sparing groups showed better stability than the stump-sacrificing group. At 12 months, the effect size was small ($\eta^2 = 0.09$), showing comparable stability among the three groups (Table 12).

Table 4. Between-group comparison of Tegner Activity Scale using Kruskal–Wallis test (*N* = 30 per group)

Timepoint	BT, Mean ± SD	Stump-sacrificing, Mean ± SD	Stump-sparing, Mean ± SD	*F* value	*p*-value	Interpretation
Pre-op	3 (2–3)	3 (2–3)	3 (2–3)	0.12	0.942	No significant difference at baseline
3 months	5 (4–6)	4 (3–5)	5 (4–6)	9.25	0.010	Significant; *BT and stump-sparing superior to ACLR*
6 months	6 (5–7)	5 (4–6)	6 (5–7)	11.46	0.004	Significant; *BT and stump-sparing outperform ACLR*
9 months	7 (6–7)	5 (4–6)	7 (6–7)	16.32	< 0.001	Significant; *BT and stump-sparing best*
12 months	7 (6–7)	6 (5–6)	7 (6–7)	13.58	0.001	Significant; *BT and stump-sparing highest Tegner scores*

Table 5. Study characteristics

Fixed Effect	Estimate (β)	SE	*Z*-value	95% CI	*p*-value	Interpretation
Time (months)	+0.43	0.08	5.25	0.27 – 0.59	< 0.001	Significant increase in Tegner scores over time
Group (stump-sacrificing vs BT)	+0.82	0.23	3.56	0.36 – 1.28	< 0.001	BT significantly higher than stump-sacrificing
Group (stump-sacrificing vs stump-sparing)	+0.75	0.24	3.10	0.28 – 1.22	0.002	SSP significantly higher than stump-sacrificing
Group (BT vs stump-sparing)	+0.07	0.21	0.33	-0.34 – 0.48	0.739	No significant difference between BT and stump-sparing

Table 6. Between-group comparison of Lysholm score using one-way analysis of variance (*N* = 30 per group)

Timepoint	BT, Mean ± SD	Stump-sacrificing, Mean ± SD	Stump-sparing, Mean ± SD	*F* value	*p*-value	Interpretation
Pre-op	41.9 ± 6.1	42.3 ± 5.8	42.0 ± 6.0	0.07	0.932	No significant difference at baseline
3 months	74.5 ± 6.9	68.2 ± 7.4	73.1 ± 6.8	8.14	< 0.001	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	84.2 ± 7.1	77.9 ± 6.8	83.0 ± 7.0	9.72	< 0.001	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	88.1 ± 6.5	82.6 ± 7.2	87.0 ± 6.4	7.88	< 0.001	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	91.4 ± 6.2	84.8 ± 7.5	90.3 ± 6.6	10.25	< 0.001	Significant; *BT and stump-sparing better than stump-sacrificing*

At baseline, there was no significant difference in instrumented arthrometer results among the groups ($H = 0.58$, $p = 0.749$, $\eta^2 = 0.01$). At three, six, and nine months postoperatively, the BT and stump-sparing groups showed better stability than the stump-sacrificing group. At 12 months, the effect size was small ($\eta^2 = 0.08$), showing comparable stability among the three groups (Table 12).

Individual complications—including infection, joint stiffness, graft failure, and cyclops lesion—were generally low across all groups with no statistically significant differences. When evaluating the overall complication rate, the BT group had the lowest incidence at 20%, followed by the stump-sparing group at 26.7%, and the stump-sacrificing group at 43.3% ($\chi^2 = 5.42$, $p = 0.066$). Although the difference is not statistically significant, it indicates a clinically meaningful trend, with the BT group demonstrating fewer complications overall.

In summary, while individual complications did not differ significantly, the BT technique shows a favorable safety profile with fewer overall complications.

DISCUSSION

This study evaluated the clinical, functional, and mechanical outcomes of patients undergoing anterior cruciate ligament reconstruction (ACLR) using three techniques: the Braganza-Tan (BT) pass-through stump incision technique, the stump-sparing technique, and conventional stump-sacrificing ACLR. Outcomes were assessed using functional scales, knee stability tests, and complication rates.

Functional and clinical scores

International Knee Documentation Committee (IKDC) scale

Patients who underwent the BT or stump-sparing reconstruction had better overall knee function, improved confidence during movement, and likely a safer return to higher levels of activity or sports. Tibial stump preservation may accelerate functional recovery, may enhance knee stability, and may have superior short-term outcomes compared with conventional ACLR.

Table 7. Longitudinal changes in Lysholm score

Group	*F* statistic	*p*-value	Effect Size (η^2)	Interpretation
BT Group	73.1	< 0.001	0.64	Significant improvement over time
ACLR Group	59.4	< 0.001	0.58	Significant improvement over time
Stump-sparing Group	70.2	< 0.001	0.62	Significant improvement over time

Table 8. Between-group comparison of Hospital for Special Surgery score (HSS) using one-way analysis of variance (*N* = 30 per group)

Timepoint	BT, Mean ± SD	Stump-sacrificing, Mean ± SD	Stump-sparing, Mean ± SD	*F* value	*p*-value	Interpretation
Pre-op	41.0 ± 5.7	41.3 ± 5.9	41.2 ± 5.5	0.03	0.970	No significant difference at baseline
3 months	76.3 ± 7.0	75.1 ± 7.2	70.6 ± 7.8	6.51	0.002	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	84.8 ± 6.6	83.6 ± 6.8	78.9 ± 7.1	8.12	<0.001	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	89.6 ± 6.8	88.3 ± 6.5	83.2 ± 7.3	7.85	< 0.001	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	92.2 ± 6.4	91.0 ± 6.6	86.1 ± 7.0	7.19	0.001	Significant; *BT and stump-sparing better than stump-sacrificing*

Table 9. Longitudinal changes in HSS

Group	*F* statistic	*p*-value	Effect Size (η^2)	Interpretation
BT Group	73.3	< 0.001	0.65	Significant improvement over time
Stump-sacrificing Group	71.1	< 0.001	0.63	Significant improvement over time
ACLR Group	61.1	< 0.001	0.58	Significant improvement over time

Table 10. Kruskal–Wallis test for Lachman test results

Group	*H* statistic	*p*-value	Effect Size (η^2)	Interpretation
Pre-op	0.41	0.815	0.01 (negligible)	Not Significant at baseline
3 months	7.25	0.027	0.14 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	6.68	0.035	0.12 (small–medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	8.54	0.014	0.16 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	5.02	0.018	0.09 (small)	Significant; *Stability becomes comparable across all groups*

Table 11. Kruskal-Wallis test for pivot shift test results

Group	*H* statistic	*p*-value	Effect Size (η^2)	Interpretation
Pre-op	46.0	0.694	0.07 (small)	No difference at baseline
3 months	23.0	0.039	0.31 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	21.0	0.027	0.36 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	32.0	0.049	0.28 (small)	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	26.0	0.048	0.34 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*

Table 12. Kruskal–Wallis test for anterior drawer test results

Group	*H* statistic	*p*-value	Effect Size (η^2)	Interpretation
Pre-op	0.47	0.789	0.01 (negligible)	Not Significant at baseline
3 months	6.95	0.031	0.13 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	7.64	0.023	0.14 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	8.48	0.015	0.16 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	5.16	0.016	0.09 (small)	Significant; *Stability outcomes are comparable*

Table 13. Kruskal–Wallis test for instrumented arthrometer results

Group	*H* statistic	*p*-value	Effect Size (η^2)	Interpretation
Pre-op	0.58	0.749	0.01 (negligible)	Not Significant at baseline
3 months	7.82	0.020	0.14 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
6 months	9.03	0.011	0.16 (medium)	Significant; *BT and stump-sparing better than stump-sacrificing*
9 months	10.21	0.006	0.19 (medium–large)	Significant; *BT and stump-sparing better than stump-sacrificing*
12 months	4.69	0.013	0.08 (small)	Significant; *Comparable among all groups*

Table 14. Comparison of complication rates

Complication	BT, (*n* = 30)	Stump-sacrificing, (*n* = 30)	Stump-sparing, (*n* = 30)	χ^2 (Chi-square)	*p*-value	Interpretation
Infection	1 (3.3%)	3 (10.0%)	2 (6.7%)	$\chi^2 = 1.24$	0.537	Not significant
Joint stiffness	2 (6.7%)	5 (16.7%)	3 (10.0%)	$\chi^2 = 1.89$	0.389	Not significant
Graft failure	0 (0%)	3 (10.0%)	1 (3.3%)	$\chi^2 = 4.26$	0.119	Not significant
Cyclops lesion	2 (6.7%)	0 (0%)	3 (10.0%)	$\chi^2 = 1.52$	0.310	Not significant
Overall complication rate	6 (20.0%)	13 (43.3%)	8 (26.7%)	$\chi^2 = 5.42$	0.066	Not significant; favoring BT

Tegner activity scale

Remnant-preserving techniques enabled a faster and higher rate of return to activity compared with stump-sacrificing ACL reconstruction. These findings underscore the functional advantage of maintaining tibial stump integrity.

Lysholm score

ACL tibial stump preservation provided lasting improvements in pain control, knee stability, and overall functional capacity compared with conventional stump-sacrificing reconstruction. While all three surgical techniques led to significant improvements in Lysholm scores over time, the stump-preserving techniques consistently provided higher functional gains and more robust recovery.

Hospital for Special Surgery (HSS) score

Remnant-preserving ACL reconstruction provided better overall functional restoration, improved knee stability, and more effective pain control compared with the stump-sacrificing technique.

These patients achieved faster, greater, and more sustained functional recovery throughout the first postoperative year.

Although statistically significant differences were observed among groups, the between-group differences in IKDC and Lysholm scores did not consistently reach the established minimal clinically important difference (MCID) threshold of 10–15 points.[9,10] Therefore, while remnant-preserving techniques demonstrated measurable statistical benefit, the clinical relevance of these differences within the first postoperative year should be interpreted cautiously.

Knee stability

Lachman test

The BT and stump-sparing groups demonstrated significantly better anterior knee stability than the stump-sacrificing group from three to nine months postoperatively, with the difference diminishing by twelve months. Early gains in stability are clearly more pronounced in the stump-preserving groups, though conventional ACL reconstruction catches up in mechanical stability as healing and rehabilitation progress.

Pivot shift test

BT and stump-sparing groups showed superior rotational stability compared with stump-sacrificing ACLR from three to twelve months, demonstrating consistent preservation of rotational control throughout the first postoperative year.

Anterior drawer test

BT and stump-sparing groups maintained better anterior stability than stump-sacrificing ACLR from three to nine months, reflecting superior graft control and anterior knee stability. Differences decreased by one year.

Instrumented arthrometer

Knee laxity was lower in the BT and stump-sparing groups compared with stump-sacrificing ACLR during early and midterm follow-up, confirming improved mechanical stability with tibial stump preservation. Advantages diminished slightly by twelve months.

The BT technique may have offered potential advantages over conventional remnant-preserving approaches by allowing controlled incision and guided graft passage through the tibial stump. This approach may optimize graft-remnant contact while preventing excessive remnant bulk, theoretically balancing biological preservation with mechanical precision. Several remnant-preserving techniques have been described, including selective tibial stump preservation and tensioned remnant-retaining reconstruction. Lee et al. reported improved graft synovialization in remnant-preserving ACL reconstruction.[11] Kim et al. demonstrated improved anterior stability and early functional recovery without increased complication rates.[12] A systematic review by Takazawa et al. concluded that remnant preservation may enhance early knee stability and graft maturation, although long-term outcomes remain comparable to conventional techniques.[3] Nevertheless, some authors have noted an increased risk of cyclops lesions when excessive remnant tissue is retained.[7] Overall, evidence suggests that remnant preservation is at least non-inferior to stump-sacrificing reconstruction when performed with meticulous technique.

Complication rates

Postoperative complications were generally low across all groups. Overall complication rates were lowest in the BT group (20%), followed by stump-sparing (26.7%), and stump-sacrificing ACLR (43.3%). These results indicate that tibial stump preservation may reduce postoperative complications through enhanced graft protection and biological healing.

While early postoperative outcomes in this study are promising, medium- and long-term follow-up (5–10 years) will be necessary to determine graft durability and re-rupture rates. The degree of remnant retention has been proposed as a factor influencing both biological integration and the risk of cyclops lesion formation. Excessive remnant bulk may theoretically predispose to anterior impingement and fibrous nodule development. In our surgical technique, controlled remnant incision and guided graft passage were performed to preserve biologically valuable tissue while minimizing redundancy. Importantly, direct arthroscopic visualization of the remnant stump in full knee extension was routinely undertaken before graft fixation to confirm the absence of anterior impingement. This technical step may have contributed to the low incidence of symptomatic cyclops lesions observed and may explain the non-inferior early clinical outcomes of the BT technique.

LIMITATIONS OF THE STUDY

First, the follow-up period was limited to 12 months and therefore reflects early clinical and functional outcomes. Long-term graft durability, re-rupture rates, and potential degenerative changes could not be evaluated within this timeframe. Medium- and long-term follow-up studies are necessary to determine whether the observed early findings are sustained.

Second, although this was a prospective randomized controlled trial, it was conducted at a single tertiary referral center with procedures performed by a limited number of surgeons. While this enhances surgical consistency, it may limit generalizability to other practice settings.

Lastly, the study was powered primarily for functional outcome measures and may not have been sufficiently powered to detect small differences in less frequent complications such as cyclops lesions or graft failure. In addition, variability in remnant tissue volume and quality was not quantitatively assessed, which may influence biological incorporation and mechanical behavior. Future studies incorporating objective remnant grading and longer follow-up are warranted.

CONCLUSION

The study showed that tibial stump-preserving techniques, including the Braganza-Tan (BT) and stump-sparing methods, produced better outcomes than conventional stump-sacrificing ACL reconstruction. Patients who had BT or stump-sparing surgery consistently scored higher on IKDC, Lysholm, Tegner Activity, and HSS assessments throughout the first postoperative year, showing faster and greater recovery. Knee stability was also better in these groups, as measured by Lachman, pivot shift, anterior drawer, and instrumented arthrometer tests. Complications were lowest in the BT group, suggesting that preserving the tibial stump reduced postoperative risks, though this difference was not statistically significant. Overall, tibial stump preservation improved functional recovery, stability, and long-term clinical outcomes compared with traditional ACL reconstruction. Longer-term (5–10 year) follow-up studies are warranted to evaluate graft survival, re-rupture rates, and sustained functional outcomes.

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STATEMENT OF AUTHORSHIP

All authors certified fulfillment of ICMJE authorship criteria.

CREDIT AUTHOR STATEMENT

DST: Conceptualization, Methods, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing, Visualization, Supervision, Project Administration, Funding Acquisition; **CLB:** Conceptualization, Investigation, Resources, Supervision, Funding Acquisition; **BSA:** Conceptualization, Investigation, Resources, Supervision, Funding Acquisition; **CFF:** Conceptualization, Investigation, Supervision, Funding Acquisition.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed in this study are included in the published article.

AUTHOR DISCLOSURE

The authors declared no conflict of interest.

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