Short Socket ACL Reconstruction Reduces Tunnel Widening While Maintaining Graft Maturation and Comparable Clinical Outcomes: A Prospective Quantitative MRI Study

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INTRODUCTION: Tunnel widening after anterior cruciate ligament reconstruction (ACL-R) may impair postoperative knee stability and complicate revision surgery [1, 2]. All-inside short socket ACL-R techniques preserve bone stock, but their biological healing and tunnel preservation effects remain incompletely understood. The purpose of this prospective study was to evaluate whether short femoral and tibial sockets reduce tunnel widening, support graft maturation assessed by quantitative MRI (qMRI), and maintain clinical outcomes compared to conventional full-tunnel ACL-R.

METHODS: Among patients prospectively enrolled for primary ACL-R with hamstring autografts, 43 patients (30 female, 13 male) completing 12-month follow-up were analyzed (short socket, n=25 [19 female, 6 male]; normal socket, n=18 [11 female, 7 male]). The short socket group underwent retrograde drilling of femoral (7–10 mm) and tibial (10–15 mm) sockets with suspensory fixation [3]. The normal socket group received conventional 15–20 mm femoral tunnels and full tibial tunnels with suspensory femoral fixation and interference screw tibial fixation. Clinical outcomes (KOOS, IKDC, ACL-RSI, Marx) were assessed at 6 and 12 months. Tunnel depth and cross-sectional area (CSA) at the aperture, 5 mm, and 10 mm from the aperture (tibia only) were measured using 3D MRI reconstructions from CUBE sequences. The percentage of tunnel widening was determined by dividing the measured CSA by the initial CSA calculated from the intraoperative drill diameter. Intra-articular graft and bone socket maturation were evaluated using quantitative MRI (qMRI) with T1ρ and T2 mapping sequences. Data distribution was assessed using the Shapiro–Wilk test. Student's t-test, Mann–Whitney U, paired t-test, or Wilcoxon signed-rank tests were used as appropriate. Statistical significance was set at $p<0.05$. IRB approval and informed consent were obtained.

RESULTS: Patient demographics, graft diameter, and meniscal procedure rates showed no significant between-group differences. Eight patients (4 per group) were lost to follow-up between 6-12 months. Both groups demonstrated significant clinical improvement over time with no between-group differences in KOOS, IKDC, ACL-RSI, or Marx scores at 6 or 12 months (Table 1). Tunnel morphology analysis confirmed significantly shorter tunnel depths in the short socket group at 6 months: femoral tunnels (Normal: 17.0±4.7 mm, Short: 10.0±2.4 mm, $p<0.001$) and tibial tunnels (Normal: 37.1±4.7 mm, Short: 18.3±3.4 mm, $p<0.001$) (Figure 1). Tunnel widening was significantly reduced in the short socket group at all measured locations at both timepoints. At 12 months, representative CSA measurements demonstrated: femoral aperture (Normal: 167.6%, Short: 129.4%, $p=0.004$), femoral 5mm depth (Normal: 139.3%, Short: 51.8%, $p<0.001$), tibial aperture (Normal: 182.3%, Short: 114.3%, $p<0.001$), and tibial 5mm depth (Normal: 193.8%, Short: 106.9%, $p<0.001$) (Figure 2). Quantitative MRI analysis demonstrated comparable intra-articular graft maturation between groups (Figure 2). At 12 months, graft T1ρ values (Normal: 39.4±4.2 ms, Short: 38.5±4.6 ms, $p=0.543$) and T2 values (Normal: 27.7±3.6 ms, Short: 28.1±3.3 ms, $p=0.731$) showed no significant differences, with both groups exhibiting decreasing trends from 6 to 12 months. For bone socket maturation, femoral socket qMRI values showed no differences at 6 months but were significantly higher in the short socket group at 12 months: T1ρ (Normal: 45.8±4.9 ms, Short: 49.8±5.7 ms, $p=0.039$) and T2 (Normal: 32.6±4.7 ms, Short: 37.2±5.1 ms, $p=0.011$). Tibial socket qMRI showed no between-group differences at 12 months: T1ρ (Normal: 40.5±3.4 ms, Short: 41.1±5.5 ms, $p=0.778$) and T2 (Normal: 27.9±3.5 ms, Short: 27.8±4.1 ms, $p=0.570$) (Figure 2).

DISCUSSION: Short socket ACL-R achieved equivalent clinical outcomes while consistently reducing tunnel widening compared to conventional ACL-R. qMRI demonstrated comparable intra-articular graft maturation between groups, indicating that graft maturation was not compromised. However, significant differences in femoral socket qMRI values between groups suggest potential variations in bone-tendon healing patterns. Although these differences reached statistical significance, the clinical relevance of a change of this magnitude remains uncertain. Quantitative MRI provides objective graft assessment, but limitations include advanced imaging constraints requiring smaller cohorts, 12-month patient attrition, single-center design, and mixed fixation techniques. Longer-term studies with larger cohorts are warranted to clarify the clinical significance of these findings.

SIGNIFICANCE/CLINICAL RELEVANCE: Short socket ACL reconstruction reduces tunnel widening without compromising graft maturation or outcomes, addressing a key barrier in revision ACL surgery and supporting its use as a bone-preserving alternative.

REFERENCES: [1] Kim et al. Knee Surgery & Related Research 2019, [2] Taketomi et al. Arthroscopy 2021, [3] Sato et al. Video J Sports Med 2014

Table 1. Postoperative Clinical Outcomes Comparison Between Normal and Short Socket ACL Reconstruction

Outcome	Time	Normal socket (6M n=18, 12M n=14)	Short socket (6M n=25 at, 12M n=21)	*P* Value Short vs Normal	*P* value Normal (6M vs 12M)	*P* value Short (6M vs 12M)
KOOS						
Symptoms	6M	82.1 (60.7–89.3)	73.2 (64.3–82.1)	0.443	0.294	0.004
	12M	83.9 (74.1–86.6)	85.7 (78.6–92.0)	0.616		
Pain	6M	83.3 (79.9–94.4)	86.1 (80.6–94.4)	0.792	0.060	0.002
	12M	94.4 (88.9–97.2)	94.4 (92.4–97.2)	0.823		
ADL	6M	94.1 (87.9–97.4)	92.6 (88.2–98.5)	0.906	0.136	0.020
	12M	97.8 (94.5–100.0)	98.5 (95.6–100.0)	0.416		
Sport/Rec	6M	65.0 (48.8–80.0)	65.0 (45.0–75.0)	0.635	0.035	0.003
	12M	80.0 (65.0–87.5)	85.0 (67.5–93.8)	0.592		
QOL	6M	56.3 (50.0–64.1)	50.0 (37.5–62.5)	0.261	0.013	0.001
	12M	68.8 (54.7–70.3)	71.9 (62.5–81.3)	0.120		
IKDC	6M	65.8±11.2	69.4±11.3	0.317	0.007	0.001
	12M	78.7±9.7	83.6±8.7	0.127		
ACL-RSI	6M	59.0±16.2	56.9±15.6	0.715	-	-
Marx	12M	9.0 (1.5–12.3)	8.0 (6.0–9.0)	0.900	-	-

Values are presented as mean ± standard deviation or median (interquartile range) based on data distribution. P values were calculated using Student's t-test or Mann-Whitney U test for between-group comparisons, and paired t-test or Wilcoxon signed-rank test for within-group comparisons (6M vs 12M).

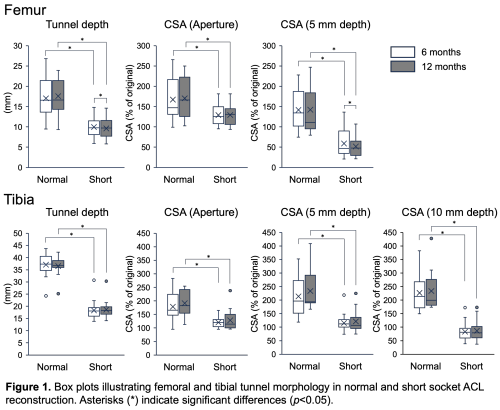

Figure 1. Box plots illustrating femoral and tibial tunnel morphology in normal and short socket ACL reconstruction. Asterisks (*) indicate significant differences ($p<0.05$).

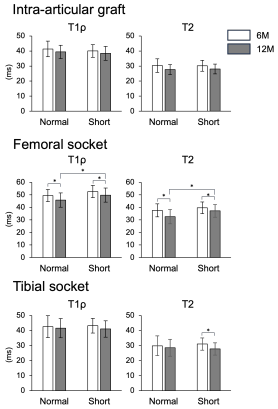

Figure 2. Quantitative MRI assessment of intra-articular graft and bone socket T1ρ and T2 relaxation times at 6 and 12 months following normal socket and short socket ACL reconstruction. Data presented as mean ± standard error. Asterisks (*) indicate significant differences ($p<0.05$).