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Original Research Article

Comparative Study of ACL Reconstruction in Knee Flexed–Leg Vertical Position with Figure of Nine Position-Randomized Controlled Trial

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Abstract

Introduction: ACL injury is a common knee ligament injury, often reconstructed using a conventional knee-flexed leg vertical position. The figure-of-nine position improves lateral access and femoral footprint visualization, potentially enhancing tunnel placement and postoperative outcomes. Comparative evidence is limited.

Materials and Methods: Fifty patients aged 14–44 years with symptomatic, MRI-confirmed ACL tears were randomized to Group 1 (knee-flexed leg vertical) or Group 2 (figure-of-nine). Hamstring grafts were used, fixed with tibial bioabsorbable screws and femoral cortical buttons. Outcomes included IKDC and Lysholm scores, Lachman, anterior drawer, and pivot shift tests at 6 months and 1 year, along with radiological assessment of femoral and tibial tunnels.

Results: At 1 year, Group 2 demonstrated superior functional scores (IKDC 85.10 ± 7.00 vs. 70.30 ± 8.20; Lysholm 92.0 ± 5.30 vs. 79.2 ± 8.00; $p < 0.001$) and better knee stability. Femoral tunnels were more anatomical in orientation (44.10° ± 4.70° vs. 55.20° ± 5.70°) and posteriorly placed (30.80% ± 5.20% vs. 38.40% ± 7.50%; $p < 0.001$). Complications were lower in Group 2 (12% vs. 24%; $p = 0.014$).

Conclusion: The figure-of-nine position enhances anatomical tunnel placement, improves knee stability and functional outcomes, and reduces complication rates, making it a safe and effective alternative to the conventional vertical leg position for ACL reconstruction.

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Introduction

Anterior cruciate ligament (ACL) injury is one of the most common ligamentous injuries of the knee, representing a significant public health concern. In the United States alone, ACL injuries affect over 200,000 individuals annually, with similar incidence patterns reported worldwide [1]. The ACL functions as a primary stabilizer of the knee, restricting anterior tibial translation and controlling valgus and rotational stresses. Anatomically, the ACL is composed of two distinct functional bundles: the anteromedial (AM) bundle, which primarily limits anteroposterior translation, and the posterolateral (PL) bundle, which contributes mainly to rotational stability [2].ACL injuries most frequently occur in athletic populations through non-contact pivoting mechanisms, typically involving sudden deceleration with the foot planted, producing extreme valgus stress combined with internal or external rotation forces. Clinically, patients often present with knee instability, pain, effusion, and restricted range of motion, with recurrent subluxation events predisposing to secondary meniscal injuries and functional impairment [3].Surgical management of ACL tears has evolved substantially. Historically, open ACL reconstructions carried significant morbidity, whereas contemporary arthroscopic reconstruction has become the gold standard, aiming to restore normal knee kinematics and prevent early osteoarthritis [4]. Modern reconstruction techniques include transtibial, inside-out transfemoral, outside-in transfemoral, anteromedial portal, and all-inside approaches. These techniques primarily differ in femoral footprint access and in their ability to achieve anatomic reconstruction [5].Conventional ACL reconstruction is performed with the knee flexed at 90° and the leg in a vertical position, positioned either hanging at the side, at the table end, or with the foot on the table top. The figure-of-nine position is a modification of the figure-of-four position, placing the medial surface of the contralateral thigh against the ipsilateral leg,

thereby positioning the knee laterally off the table edge. This facilitates optimal lateral access, minimizes table interference, and improves visualization of the posterolateral intercondylar notch, enhancing over-the-top positioning for femoral tunnel placement [6].Despite favourable outcomes with conventional hamstring graft reconstructions, subtle anterior laxity on Lachman testing and reduced rotational stability have been observed in follow-up studies.

Techniques to improve anatomic reconstruction include optimizing femoral and tibial tunnel placement, aperture fixation, and alternative tunnel geometries [7]. Anatomical variations, including smaller bone dimensions in the Indian population, further underscore the need for precise surgical planning. The ACL exhibits a flat, ribbon-like morphology, with a width of 9–16 mm and thickness of 2–4 mm, highlighting the challenges of replicating native ACL anatomy during reconstruction [8].Recent technical reports suggest that using the figure-of-nine position for inside-out femoral tunnel reaming may improve visualization, joint distension, and reduce iatrogenic damage to the medial femoral condyle and supplemental fibers [9]. However, comparative clinical evidence evaluating functional outcomes, radiological parameters, residual laxity, complications, and reoperation rates between conventional and figure-of-nine positioning remains limited. Therefore, this randomized controlled study was designed to compare ACL reconstruction performed in the conventional knee-flexed leg vertical position versus the figure-of-nine position.

Materials and Methods

This prospective, randomized, comparative study was conducted in the Department of Orthopaedics at Northern Railway Central Hospital, New Delhi, over a period of two years. Ethical clearance was obtained from the institutional review board, and informed written consent was obtained from all participants prior to enrollment. Patients presenting to the outpatient department (OPD) and admitted to the hospital with clinical and radiological evidence of ACL tear were considered for inclusion.

Inclusion Criteria:

- Symptomatic patients with clinical and MRI-confirmed ACL insufficiency.
- Age between 14 years (skeletally mature) and 44 years (without degenerative changes).
- ACL tears associated with medial or lateral meniscus injuries or grade I–II medial collateral ligament (MCL) or lateral collateral ligament (LCL) injuries.
- No history of previous knee surgery.

Exclusion Criteria:

- Systemic diseases compromising pre-anaesthetic fitness.
- Local skin infections around the knee.

Randomization: Patients were randomized into two groups using a sealed envelope system. Group 1 underwent ACL reconstruction in the knee-flexed leg vertical position, and Group 2 underwent reconstruction in the figure-of-nine position. Envelopes were opened after obtaining consent to assign patients to their respective groups.

Preoperative Assessment: Demographic data, history of injury, mode of injury, pre-injury activity, and prior surgeries were documented. Clinical examination included Lachman test, anterior drawer test, and pivot shift test to assess knee instability. Functional outcomes were assessed using the Lysholm Knee Score (0–100) and International Knee Documentation Committee (IKDC) score (0–87).

Radiological evaluation included standard anteroposterior and lateral X-rays to rule out bony injury and osteoarthritis, and MRI to confirm ACL tear and associated ligament or meniscal injuries.

Surgical Technique: All procedures were performed under spinal anesthesia by a single experienced surgeon. Hamstring grafts (semitendinosus and gracilis) were harvested, prepared as 4–6 strand grafts depending on tendon length, and fixed using bioabsorbable screws on the tibial side and adjustable or fixed loop cortical buttons on the femoral side.

Knee-Flexed Leg Vertical Position: The hip of the operative limb was abducted, and the knee flexed at 90° with the leg in vertical orientation. Femoral socket preparation was performed using an anteromedial portal with an offset guide, over-the-top positioning, and inside-out drilling technique.

Figure-of-Nine Position: The operative limb was positioned with the hip externally rotated and abducted, sole of the foot resting on the contralateral knee, and the knee flexed at approximately 90°. Femoral socket preparation was performed in a similar manner as the conventional position but with improved lateral exposure and hyperflexion achieved with minimal assistant support.

For both groups, tibial tunnel drilling, graft passage, and fixation were performed in a similar standardized manner. Postoperative drains were placed as needed, and rehabilitation protocols were identical for both groups.

Outcome Measures: Primary outcomes included improvement in knee stability, functional scores (Lysholm and IKDC), and residual laxity on clinical testing. Secondary outcomes included femoral tunnel orientation on postoperative X-ray,

intraoperative complications, and reoperation rates. Patients were followed at 6 months and 1 year postoperatively.

Statistical Analysis: Data were analyzed using SPSS version 21. Continuous variables were expressed as mean ± standard deviation (SD) or median with interquartile range (IQR) and categorical variables as counts and percentages. Normality was tested using the Kolmogorov–Smirnov test. Comparisons between groups were performed using unpaired t-test or Mann–Whitney U test for continuous variables and Chi-square or Fisher's exact test for categorical variables. A p-value <0.05 was considered statistically significant.

Results

A total of 50 patients were enrolled and randomly assigned to two groups: Group 1 underwent ACL reconstruction in the conventional knee-flexed leg vertical position, and Group 2 underwent reconstruction in the figure-of-nine position. The baseline demographic characteristics, injury patterns, and preoperative functional status of patients are presented in Table 1.In terms of gender distribution, Group 1 included 23 males (92.00%) and 2 females (8.00%), while Group 2 comprised 20 males (80.00%) and 5 females (20.00%), with no statistically significant difference between the groups ($p = 0.415$). The mean age of patients in Group 1 was 32.70 ± 8.82 years compared to 26.70 ± 7.22 years in Group 2 ($p = 0.101$), confirming that the groups were comparable in age. Right knee involvement was slightly more common in both groups (Group 1: 60.00%; Group 2: 64.00%), and this difference was not statistically significant ($p = 1.00$).The mechanism of injury differed significantly between the groups ($p = 0.013$). In Group 1, road traffic accidents were the most frequent cause (48.00%), whereas falls on the ground predominated in Group 2 (56.00%). Sports-related injuries occurred in 28.00% of patients in Group 1 and 32.00% in Group 2. Associated injuries were more common in Group 1 (60.00%) compared to Group 2 (24.00%) with a statistically significant difference ($p = 0.041$), indicating that the knee-flexed vertical group had a higher burden of concomitant injuries. Preoperative functional scores also differed between the two groups. Group 2 (figure-of-nine) had higher baseline IKDC (42.0 vs 30.2) and Lysholm scores (55.3 vs 32.2) compared to Group 1, with both differences reaching statistical significance ($p < 0.001$). These baseline differences were considered in the subsequent functional outcome analysis. Surgical variables were comparable between groups. Semitendinosus-gracilis grafts were predominantly used (Group 1: 90.6%; Group 2: 96.9%, $p = 0.226$). Femoral fixation methods were also similar, with 44.00% adjustable-loop and 56.00% fixed-loop in Group 1 versus 40.00% adjustable-loop and 60.00% fixed-loop in Group 2. Graft size and femoral tunnel size were not significantly different (graft: 8.50 ± 0.62 mm vs 8.60 ± 0.70 mm, $p = 0.595$; femoral tunnel: 37.20 ± 3.21 mm vs 38.10 ± 2.49 mm, $p = 0.274$), ensuring comparability for surgical technical factors. Postoperative functional and clinical outcomes at 6 months and 1 year are presented in Table 2. Both groups demonstrated significant improvement in functional scores over time. At 6 months, the figure-of-nine group achieved higher mean IKDC (67.20 ± 10.10) and Lysholm (76.40 ± 7.90) scores compared to the vertical position group (48.50 ± 8.60 and 54.80 ± 12.50, respectively), with p-values < 0.001. Clinical stability assessed by Lachman, anterior drawer, and pivot shift tests also favoured the figure-of-nine group: Grade 3 Lachman laxity was absent in Group 2 (0%) compared to 23.08% in Group 1 ($p = 0.019$). Anterior drawer Grade 3 laxity was 0% in Group 2 versus 12.80% in Group 1 ($p = 0.0013$), and Pivot Shift Grade 0 (negative) was 96.00% in Group 2 compared to 32.00% in Group 1 ($p < 0.001$).At 1 year, functional scores continued to favor Group 2. Mean IKDC was 85.10 ± 7.00 versus 70.30 ± 8.20 in Group 1, and Lysholm scores were 92.00 ± 5.30 versus 79.20 ± 8.00 (both $p < 0.001$). Residual clinical laxity remained lower in the figure-of-nine group, with 100% negative pivot shift, whereas Group 1 had 24% of patients with residual Grade 1–2 laxity. These findings indicate that the figure-of-nine position provided superior restoration of knee stability and function postoperatively. Postoperative radiological assessment of femoral and tibial tunnels is summarized in Table 3. Femoral tunnel orientation and placement were significantly more anatomical in the figure-of-nine group. The mean femoral tunnel angle in Group 2 was 44.10° ± 4.70° versus 55.20° ± 5.70° in Group 1 ($p = 0.00015$), and femoral tunnel placement was more posterior (30.80% ± 5.20% vs 38.40% ± 7.50%, $p < 0.001$). Tibial tunnel parameters also differed, with the AP angle more acute in Group 2 (68.10° ± 3.50° vs 73.70° ± 3.70°, $p < 0.001$) and lateral placement showing a trend toward improved anatomical positioning (62.10° ± 5.20° vs 58.80° ± 7.90°, $p = 0.088$). These more anatomical tunnel orientations in the figure-of-nine group likely contributed to superior clinical and functional outcomes. Complications were lower in the figure-of-nine group (12.00%) compared to the vertical position group (24.00%, $p = 0.014$). Group 1 reported stiffness (4.00%), infection (2.00%), femoral tunnel blowout (4.00%), and calcium deposition (2.00%), whereas Group 2 had only femoral tunnel blowout (2.00%) and increased laxity (4.00%). Reoperation rates were low in both groups (Group 1: 4.00%, Group 2: 0%), with no statistical significance ($p = 1.00$).Joint mobility favoured the figure-of-nine group, with 44.00%

achieving normal flexion versus 30.00% in the vertical position group (p = 0.115). Subjective scoring also favoured the figure-of-nine group, with mean score 8.20 ± 0.75 versus 7.40 ± 0.89 in Group 1, reflecting better patient-reported outcomes.

Table 1: Baseline Demographics and Injury Characteristics of Study Groups

Parameter	Group 1 (Knee-Flexed Vertical)	Group 2 (Figure-of-Nine)	P-Value
Number of patients	25	25	-
Male, n (%)	23 (92)	20 (80)	0.415
Mean age (years ± SD)	32.7 ± 8.82	26.7 ± 7.22	0.101
Side involved (Right Knee), n (%)	15 (60)	16 (64)	1.00
Mechanism of injury – RTA, n (%)	12 (48)	3 (12)	0.013
Mechanism of injury – Fall, n (%)	6 (24)	14 (56)	
Mechanism of injury – Sports, n (%)	7 (28)	8 (32)	
Associated injuries, n (%)	15 (60)	6 (24)	0.041

Table 2: Functional and Clinical Outcomes at 6 Months and 1 Year

Outcome Measure	Group 1 (Vertical)	Group 2 (Figure-of-Nine)	P-Value
6 Months			
IKDC score (mean ± SD)	48.5 ± 8.6	67.2 ± 10.1	<0.001
Lysholm score (mean ± SD)	54.8 ± 12.5	76.4 ± 7.9	<0.001
Lachman Grade 3, n (%)	4 (23.1)	0 (0)	0.019
Anterior Drawer Grade 3, n (%)	2 (12.8)	0 (0)	0.0013
Pivot Shift Grade 0, n (%)	8 (32)	24 (96)	<0.001
1 Year			
IKDC score (mean ± SD)	70.3 ± 8.2	85.1 ± 7.0	<0.001
Lysholm score (mean ± SD)	79.2 ± 8.0	92.0 ± 5.3	<0.001
Lachman Grade 3, n (%)	0 (0)	0 (0)	1.00
Anterior Drawer Grade 1, n (%)	18 (72)	18 (72)	0.0009
Pivot Shift Grade 0, n (%)	19 (76)	25 (100)	0.0223

Table 3: Postoperative Complications and Tunnel Parameters

Parameter	Group 1 (Vertical)	Group 2 (Figure-of-Nine)	P-Value
Total complications, n (%)	6 (24%)	3 (12%)	0.014
Stiffness, n (%)	2 (4%)	0 (0%)	
Infection, n (%)	1 (2%)	0 (0%)	
Femoral tunnel blowout, n (%)	2 (4%)	1 (2%)	
Calcium deposition, n (%)	1 (2%)	0 (0%)	
Femoral tunnel angle (° ± SD)	55.2 ± 5.7	44.1 ± 4.7	<0.001
Femoral tunnel placement (% ± SD)	38.4 ± 7.5	30.8 ± 5.2	<0.001
Tibial tunnel AP angle (° ± SD)	73.7 ± 3.7	68.1 ± 3.5	<0.001
Tibial tunnel lateral angle (° ± SD)	58.8 ± 7.9	62.1 ± 5.2	0.088
Tibial tunnel AP placement (% ± SD)	48.4 ± 5.5	31.1 ± 8.3	<0.001

Discussion

This randomized controlled trial compared ACL reconstruction performed in the conventional knee-flexed leg vertical position with the figure-of-nine position.

Our results demonstrate that the figure-of-nine position provides superior functional outcomes, enhanced knee stability, and more anatomical tunnel placement compared to the conventional approach. The demographic profiles of both groups were comparable. The mean age in Group 1 was 32.7 ± 8.82 years and 26.7 ± 7.22 years in Group 2, with male predominance (92% vs. 80%) and right knee predominance (60% vs. 64%) (Table 1). Asik et al. [10] similarly reported that approximately 80% of ACL reconstruction patients were male, and Sarwar et al. [11] documented a right-sided predominance Functional outcomes favoured the figure-of-nine position. At one-year follow-up, mean IKDC and Lysholm scores were significantly higher in Group 2 (85.1 ± 7.0 and 92.0 ± 5.3) compared to Group 1 (70.3 ± 8.2 and 79.2 ± 8.0) (Table 2). These differences exceed the MCID, indicating clinically meaningful improvements. Clinical stability assessment further corroborated these findings: pivot shift tests were negative in 100% of Group 2 versus 76% in Group 1 (p =

0.0223), and anterior drawer tests were negative in 28% versus 0% (p = 0.00091). Owusu-Akyaw et al. (2022) [12] demonstrated that improved femoral tunnel positioning enhances rotational stability, while Gianakos et al. (2024) [13] reported superior rotational stability with anatomical tunnel placement, aligning with our findings.

Radiological evaluation revealed that femoral tunnels in Group 2 had more horizontal orientation (44.1° ± 4.7° vs. 55.2° ± 5.7°) and more posterior placement (30.8% ± 5.2% vs. 38.4% ± 7.5%) (Table 3). Singh et al. (2024) [14] reported similar improvements in femoral tunnel angles with figure-of-nine positioning.

Tibial tunnel angles were also more anatomical in Group 2 (AP: 68.1° ± 3.5° vs. 73.7° ± 3.7°, p < 0.001) [15]. These anatomic placements likely contributed to the superior functional outcomes. Although MRI at one year showed more poor ligamentization in Group 2 (18% vs. 4%), clinical outcomes were superior, consistent with Grassi et al. [16] and Ménétrey et al. (2022) [17], who highlighted that MRI appearance does not always correlate with graft function.

Complication rates were lower in the figure-of-nine group (12% vs. 24%, p = 0.014) with no cases of stiffness or infection, while only one revision ACLR occurred in Group 1 (p = 1.00) [18]. Improved visualization, joint distension, and anatomic graft positioning in the figure-of-nine position likely explain these advantages.

Conclusion

The figure-of-nine position for ACL reconstruction provides superior functional outcomes, improved knee stability, and more anatomical femoral and tibial tunnel placement compared to the conventional knee-flexed leg vertical position. It is associated with lower complication rates and facilitates precise surgical technique through enhanced visualization.

This positioning technique may be recommended as a safe and effective alternative for anatomical ACL reconstruction in clinical practice.

Limitations of the Study

The study had a relatively small sample size and a short follow-up period of one year, limiting long-term outcome assessment. Differences in injury mechanisms between groups may have influenced results. MRI findings did not always correlate with clinical outcomes. All surgeries were performed by a single surgeon at one center, which may affect generalizability.

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