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Original Article

Salvage Treatment of Failed Congenital Pseudarthrosis of the Tibia Using Transcalcaneal Intramedullary Fixation Combined with Ilizarov External Fixation: A Prospective Clinical Series from Bangladesh

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ABSTRACT

Background: Congenital pseudarthrosis of the tibia (CPT) represents one of the most challenging orthopaedic conditions in paediatric practice, characterized by spontaneous anterolateral tibial bowing, pathological fracture, and persistent nonunion resistant to conventional treatment. Salvage management of treatment-failed cases requires a multifaceted approach addressing both the compromised bone biology and mechanical instability. **Objectives:** To evaluate clinical and radiological outcomes of salvage reconstruction for failed CPT using transcalcaneal intramedullary rod fixation combined with Ilizarov external fixation. **Methods & Materials:** A prospective observational cohort study conducted at NITOR, Dhaka, Bangladesh (July 2021–July 2025). Fifteen consecutive patients with failed CPT treated using combined transcalcaneal intramedullary nail fixation and two-ring Ilizarov external fixation were enrolled. Mean age was 6.5 years (range 3–12 years); mean follow-up was 42 months (range 19.2–74.4 months). **Results:** Final radiographic union was achieved in 14 of 15 patients (93.3%), with one case of persistent nonunion (6.7%). No refractures occurred following initial union (0%; 0/15). Acceptable alignment was maintained in all patients (100%; 15/15). Mean time to union was 9 months (range 6–12 months). Pin-tract infection occurred in 5 patients (33.3%), deep infection in 1 (6.7%), delayed union in 2 (13.3%), and implant migration in 2 (13.3%). AOFAS scores improved from mean 40 (preoperative) to 64 (final follow-up). **Conclusion:** Salvage reconstruction combining transcalcaneal intramedullary fixation with Ilizarov external fixation achieved union in 93.3% of failed CPT cases. This combined strategy effectively addresses the complex pathobiology of treatment-failed cases, providing durable stability and acceptable functional outcomes, though pin-tract infection and implant-related complications require careful management.

Keywords: *congenital pseudarthrosis of the tibia; Deformity correctio; failed treatment; transcalcaneal intramedullary fixation; Ilizarov external fixation.*

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INTRODUCTION

Definition and Epidemiology

Congenital pseudarthrosis of the tibia (CPT) is a rare developmental anomaly characterized by spontaneous formation of a false joint within the tibia, typically manifesting as anterolateral tibial bowing, progressive deformity, pathological fracture, and persistent nonunion resistant to healing. The incidence of CPT is approximately 1 in 250,000 live births. The condition occurs in approximately 2–5% of patients with neurofibromatosis type 1 (NF1). [1,2]

Pathophysiology

The pathophysiology of CPT involves multiple interrelated factors: abnormal bone biology with dysplastic bone ends, inadequate vascularity at the pseudarthrosis site, abnormal fibrous tissue interposition, dysostosis of the fibula, and mechanical instability secondary to deformity and limb-length discrepancy. These factors create a challenging biological microenvironment resistant to spontaneous healing and conventional operative interventions. [3,4]

Current Treatment Approaches

Multiple surgical approaches have been described, including intramedullary rodding alone, circular external fixation using the Ilizarov technique, vascularized fibular autografting, and combined fixation constructs. Intramedullary stabilization provides mechanical support and longitudinal stability, while circular external fixation permits graduated compression, deformity correction, and management of limb-length discrepancy. Systematic reviews and meta-analyses suggest that combined fixation strategies may improve union rates and reduce refracture compared with single-modality techniques. [1,2,5]

Salvage Surgery Context

Management of treatment-failed CPT represents a distinct clinical challenge. Prior surgical interventions may have resulted in inadequate pseudarthrosis excision, suboptimal fixation construct, insufficient biological stimulation, or residual deformity. Salvage planning requires comprehensive assessment of previous procedures, current bone stock, infection status, deformity pattern, and functional goals.[6]

Novel Approach and Study Objectives

The transcalcaneal intramedullary rod approach offers a novel trajectory, potentially protecting the proximal tibia

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while avoiding metaphyseal entry and providing protection to the ankle and subtalar joints compared with conventional ante-grade nailing. Combined with Ilizarov circular fixation, this construct theoretically optimizes both mechanical stability and biological factors favouring union. The primary objective of this study was to evaluate radiographic union rates following salvage reconstruction of failed CPT using transcalcaneal intramedullary fixation combined with Ilizarov external fixation. Secondary objectives were to assess: (1) time to radiographic union; (2) maintenance and correction of tibial alignment; (3) limb-length discrepancy correction; (4) functional recovery measured by AOFAS scoring; (5) incidence and management of refracture; and (6) frequency and nature of treatment-related complications.

METHODS & MATERIALS

Study Design and Setting

This was a prospective observational cohort study conducted at the National Institute of Traumatology and Orthopaedic Rehabilitation (NITOR), Dhaka, Bangladesh, a 1000-bed tertiary orthopaedic referral centre serving a population of approximately 170 million. The study period extended from July 2021 to July 2025 (48 months). The study received institutional ethical approval from the NITOR Ethics Committee. Written informed consent was obtained from all parents or legally authorized guardians prior to surgical intervention.

Patient Selection and Inclusion Criteria

Patients were eligible for inclusion if they met all of the following criteria: (1) Confirmed diagnosis of congenital pseudarthrosis of the tibia based on clinical presentation and imaging findings; (2) Prior surgical treatment with documented failure to achieve union, defined as absence of bridging callus or cortical continuity on serial radiographs despite 6 months of immobilization; (3) Age ≥ 3 years and ≤ 12 years at time of salvage procedure; (4) Undergone salvage reconstruction using the specified combined technique during the study period; (5) Minimum follow-up duration of 18 months post-salvage surgery.

Exclusion criteria included: (1) Active infection at the pseudarthrosis site at time of salvage surgery; (2) Insufficient skeletal maturity for intramedullary nail placement; (3) Severe soft-tissue compromise or vascular insufficiency precluding safe surgical intervention; (4) Follow-up duration < 18 months post-salvage surgery; (5) Incomplete baseline or outcome data precluding reliable assessment.

Baseline Assessment and Data Collection

Demographic and clinical variables collected at baseline included: age, sex, affected limb, duration of pseudarthrosis, number and type of previous surgical procedures, documentation of previous bone grafting procedures, history of refracture, presence or absence of neurofibromatosis type 1, tibial and fibular involvement pattern, degree of anterolateral deformity measured on radiographs, preoperative limb-length discrepancy measured on full-length radiographs, and preoperative AOFAS ankle-hindfoot scores.

Surgical Technique

All patients underwent salvage reconstruction using a transcalcaneal Rush intramedullary nail combined with Ilizarov external fixation. Patients received general anaesthesia with endotracheal intubation and were positioned supine on the operative table with the affected lower limb prepared and draped in a sterile fashion from the groin to the foot.

A small incision (approximately 1.5 cm) was made at the inferior surface of the calcaneum, medial to the tuberosity. A 5–8 mm diameter Rush intramedullary nail was passed retrograde from the calcaneal entry point through the posterior tibia, bypassing the ankle and subtalar joints, to reach the proximal tibia. The nail trajectory was confirmed fluoroscopically to extend to approximately 2–5 cm distal to the proximal tibial physis, providing longitudinal support across the pseudarthrosis site.

A two-ring Ilizarov frame was applied to the tibia distal to the pseudarthrosis site. Standard 1.8 mm tensioned wires were placed through the mid-distal tibia. The frame was configured to allow gradual compression across the pseudarthrosis site (typically 0.5–1 mm per day) over 7–10 days. Deformity correction was performed acutely or gradually depending on the magnitude of anterolateral bowing. Mean operative time was 1.5 hours (range 1.0–2.5 hours) and mean intraoperative blood loss was approximately 50 mL (range 20–100 mL).

Postoperative Management and Follow-Up

Patients were admitted to high-dependency care for 24–48 hours with limb elevation and regular neurovascular assessment. Pain management included multimodal analgesia with acetaminophen, non-steroidal anti-inflammatory agents, and opioid analgesics titrated to response.

Daily cleansing of the Ilizarov frame pin sites was begun on postoperative day 1 using sterile saline solution. Antibiotic ointment was applied to sites showing inflammation. Intravenous cephalosporin prophylaxis was administered perioperatively, with discontinuation after 24 hours. Weight-bearing status was individualized based on intraoperative assessment. Most patients were progressed to partial weight-bearing after 2–3 weeks and full weight-bearing after 4–6 weeks as tolerated.

The Ilizarov frame was removed after radiographic evidence of bridging callus formation, typically occurring at 8–12 months post-salvage surgery. The intramedullary rod was left in situ for continued longitudinal support. Clinical and radiological follow-up was performed at 6 weeks, 3 months, 6 months, 12 months, and annually thereafter.

Outcome Measures

The primary outcome was radiographic union status at final follow-up, defined as complete bridging of cortical bone across the pseudarthrosis site on anteroposterior and lateral radiographs with absence of lucency at the healing site, assessed by an independent radiologist blinded to clinical outcomes.

Secondary outcomes included: (1) Time to radiographic union (months); (2) Union status categorized as primary union (achieved without secondary procedure) or final union (status at last follow-up); (3) Persistent nonunion (absence of radiographic bridging callus at ≥24 months); (4) Refracture rate following initial union; (5) Alignment maintenance, defined as <15° deviation from neutral on radiographic assessment; (6) Limb-length discrepancy correction measured on full-length standing radiographs; (7) Functional outcome using AOFAS ankle-hindfoot score (scored 0–100, with 90–100=excellent, 80–89=good, 70–79=fair, <70=poor); (8) Treatment-related complications including pin-tract infection, deep infection, delayed union, malunion, implant failure, rod migration, ankle/subtalar stiffness, and need for reoperation.

Statistical Analysis

Categorical variables were summarized as frequencies and percentages. Continuous variables were described as mean ± standard deviation (SD) for approximately normally distributed data or median and interquartile range (IQR) for skewed distributions. Time-to-event data (time to union) were calculated from the salvage surgery date to the date criteria for radiographic union were first satisfied, as documented in operative and radiological records.

Given the small sample size and observational design, analysis was primarily descriptive. Univariate comparisons between subgroups were performed using two-sample t-tests for continuous variables and Fisher's exact test for categorical

variables, with $p < 0.05$ considered statistically significant. All analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

Ethical Considerations

This study was approved by the Institutional Ethics Committee of NITOR. Informed written consent was obtained from the parent or legal guardian of each child prior to salvage surgery. All data handling adhered to principles of patient confidentiality, with identifying information removed from analytical files and research outputs. Clinical photographs or radiographs potentially containing identifying markers were reviewed before inclusion in manuscripts.

RESULTS

Patient Cohort Characteristics

Fifteen consecutive patients with failed CPT underwent salvage reconstruction during the 48-month study period. The cohort comprised 8 male (53.3%) and 7 female (46.7%) patients. The right tibia was affected in 8 patients (53.3%) and the left tibia in 7 patients (46.7%). Mean age at salvage surgery was 6.5 ± 2.8 years (range 3–12 years). Mean follow-up period was 42.0 ± 18.2 months (range 19.2–74.4 months).

Table I

Baseline Demographic Characteristics.

Characteristic	n / Mean (SD)	Percentage / Range
Total patients	15	100
Male	8	53.3%
Female	7	46.7%
Right tibia	8	53.3%
Left tibia	7	46.7%
Mean age (SD), years	6.5 ± 2.8	3–12 years
Mean follow-up (SD), months	42.0 ± 18.2	19.2–74.4 months

Clinical Characteristics and Prior Treatment

Mean duration of pseudarthrosis prior to salvage intervention was 2.0 ± 1.1 years (range 1–4 years). Patients had undergone a mean of 1.5 ± 0.8 previous surgical procedures per patient (range 1–3 procedures). Previous intramedullary fixation was documented in 10 patients (66.7%). No patients had received prior Ilizarov external fixation. All 15 patients (100%) had undergone previous bone grafting procedures. Prior refracture had occurred in 9 patients (60%). Clinical or radiological signs consistent with neurofibromatosis type 1 were documented in 7 patients (46.7%). Tibial involvement alone was noted in 12 patients (80%), while 3 patients (20%) demonstrated tibial and fibular involvement.

Preoperative tibial deformity in all patients consisted of anterolateral angulation with mean deformity of 35 ± 9° (range 20–50°). Mean preoperative limb-length discrepancy was 2.4 ± 1.2 cm (range 1.5–5 cm). Four patients (26.7%) presented with associated ankle valgus or mild subtalar deformity secondary to the tibial pathology.

Table II

Clinical Characteristics and Treatment History.

Variable	Value / Mean (SD)	Range / %
Pseudarthrosis duration	2.0 ± 1.1 years	1–4 years
Previous procedures per patient	1.5 ± 0.8	1–3
Patients with ≥2 prior procedures	8	53.3%
Prior intramedullary fixation	10	66.7%
Prior external fixation	0	0%
Prior bone grafting	15	100%
Prior refracture	9	60.0%
Neurofibromatosis type 1	7	46.7%
Tibia only involvement	12	80.0%
Tibia + fibula involvement	3	20.0%
Preoperative deformity (degrees)	35 ± 9	20–50°
Preoperative limb-length discrepancy (cm)	2.4 ± 1.2	1.5–5.0 cm

Operative Characteristics

All patients underwent the standardized combined salvage procedure. Pseudarthrosis excision was performed in all cases (15/15). Corticocancellous autologous bone graft harvested from the contralateral tibia was applied in all patients; mean graft quantity was estimated at 15 ± 5 mL (range 8–25 mL).

Transcalcaneal intramedullary fixation was achieved in all 15 patients. Rush nails with diameters of 5–8 mm was employed: 6 mm in 8 patients, 7 mm in 5 patients, and 5 mm in 2 patients. The intramedullary rod trajectory was confirmed fluoroscopically in all cases, with the proximal extent positioned 2–5 cm distal to the proximal tibial physis.

A two-ring Ilizarov fixation frame was applied in all patients. Standard 1.8 mm tensioned wires were placed in the distal tibia through both rings. Five patients (33.3%) underwent acute deformity correction within the first 48 hours post-operatively, while 10 patients (66.7%) received gradual deformity correction over 7–10 days using the Ilizarov frame's distraction mechanism.

Table III
Operative Characteristics.

Variable	Value / n	%
Pseudarthrosis excision performed	15	100%
Mean graft quantity (mL)	15 ± 5	8–25 mL
Transcalcaneal intramedullary fixation	15	100%
Rush nail diameter: 5 mm	2	13.3%
Rush nail diameter: 6 mm	8	53.3%
Rush nail diameter: 7 mm	5	33.3%
Two-ring Ilizarov frame applied	15	100%
Acute deformity correction	5	33.3%

Primary Outcomes: Union Status and Time to Union
Final radiographic union was achieved in 14 of 15 patients (93.3%). One patient (6.7%) demonstrated persistent nonunion despite 24 months of post-salvage follow-up and was awaiting further intervention at final data analysis. No primary union (i.e., union without secondary procedures) was recorded in any patient; however, 13 of the 14 united patients required no additional operations beyond the index salvage surgery.

The mean time to radiographic union (bridging callus and cortical continuity evident on radiographs) was 9.0 ± 2.2 months (median 9 months, IQR 7–11 months, range 6–12 months). Delayed union, defined as absence of bridging callus at 12 months, occurred in 2 patients (13.3%), both of whom progressed to union by 14–16 months post-salvage.

Secondary Outcomes: Refracture, Alignment, and Limb-Length Discrepancy
No refractures occurred following initial radiographic union in any of the 14 united patients (0/14; 0%) throughout the follow-up period (mean 42 months post-salvage surgery). This is a notable finding given that prior refracture had occurred in 9 of 15 patients (60%) before salvage intervention.

Acceptable alignment (defined as < 15° anterolateral deviation from anatomical neutral on radiographic assessment) was maintained in all 15 patients (100%) at final follow-up, despite the anterolateral deformity present preoperatively. Mean preoperative anterolateral deformity was 35 ± 9°; this was corrected acutely or gradually and maintained through the follow-up period.

Limb-length discrepancy was reduced through the salvage procedure and follow-up management. Mean preoperative limb-length discrepancy was 2.4 ± 1.2 cm (range 1.5–5 cm); this was corrected to a mean of 1.5 ± 0.6 cm (range 1–2 cm) at final follow-up, representing mean correction of 0.9 ± 0.8 cm. The remaining mild discrepancy at final follow-up reflected the challenge of complete correction in the context of prior bone loss.

Table IV
Primary and Secondary Outcomes.

Outcome	n/N or Mean ± SD	% or Range
Final radiographic union	14/15	93.3%
Persistent nonunion	1/15	6.7%
Delayed union (>12 months)	2/14	14.3%
Mean time to union (months)	9.0 ± 2.2	6–12
Refracture post-union	0/14	0%
Acceptable alignment maintained	15/15	100%
Preop limb-length discrepancy (cm)	2.4 ± 1.2	1.5–5.0
Final limb-length discrepancy (cm)	1.5 ± 0.6	1–2
Mean discrepancy correction (cm)	0.9 ± 0.8	—

Functional Outcomes
Functional assessment using AOFAS ankle-hindfoot scores showed improvement. Mean preoperative AOFAS score was 40 ± 8 (range 28–56). At final follow-up, mean AOFAS score was 64 ± 9 (range 52–78). This represented a mean improvement of 24 ± 7 points.

Score distribution at final follow-up was: excellent (90–100) in 0 patients (0%); good (80–89) in 2 patients (13.3%); fair (70–79) in 8 patients (53.3%); and poor (< 70) in 5 patients (33.3%).

Clinical examination at final follow-up revealed: full weight-bearing tolerance in 13 patients (86.7%), pain-limited weight-bearing in 2 patients (13.3%), normal gait pattern in 11 patients (73.3%), mild antalgic gait in 4 patients (26.7%), and active ankle dorsiflexion/plantarflexion maintained within ≥ 80% of contralateral side in 12 patients (80%).

Complications and Reoperations
Pin-tract infection (minor inflammation, purulent drainage, or local cellulitis at Ilizarov frame pin sites) occurred in 5 patients (33.3%). All cases were managed with local pin-site care, topical antibiotics, and temporary frame adjustments; none progressed to systemic infection. Four of five cases resolved with conservative management; one patient required brief course of oral antibiotics.

Deep infection, defined as positive bacterial culture from the pseudarthrosis site or surrounding tissue at the time of frame removal, was documented in 1 patient (6.7%). This patient had undergone 4 previous operations for CPT and developed chronic Staphylococcus aureus at the pseudarthrosis site, diagnosed intraoperatively at frame removal. The infection was managed with irrigation and debridement, extended antibiotic therapy, and continuation of the intramedullary rod. Subsequent radiographs at 12 months post-salvage demonstrated radiographic union.

Rod migration (progressive movement of the transcalcaneal intramedullary nail relative to its anatomical position) was documented in 2 patients (13.3%) by radiographic assessment at 12 months post-salvage. Migration of approximately 5–8 mm with loss of optimal fracture site positioning was observed. One patient's rod remained stable without further progression and was left in situ with continued healing progression. The other patient underwent rod exchange at 18 months post-salvage with a slightly larger diameter implant. No rod breakage was documented.

Ankle/subtalar stiffness, defined as reduction in active ankle plantarflexion/dorsiflexion compared with the contralateral limb, was documented clinically in 7 patients (46.7%) at 12 months post-salvage. The degree of stiffness was mild in 6 cases (10–15% reduction in motion) and moderate in 1 case (25% reduction in motion). None of the patients had onset of symptomatic ankle pain or functional ankle disability directly attributable to this stiffness.

Ankle valgus deformity was present clinically or radiographically in 4 patients (26.7%) at final follow-up. The valgus was mild (5–10° deviation from neutral) in all cases and did not produce functional symptoms.

Reoperations beyond the index salvage surgery were required in 2 patients (13.3%): one for rod exchange and one for frame removal at an earlier timepoint due to pin-site concerns, followed by planned frame re-application. No patient required pseudarthrosis re-excision or repeat bone grafting beyond what was performed during the index salvage procedure.

Table V
Complications and Reoperations.

Complication	n/N (%)
Pin-tract infection	5/15 (33.3%)
Deep infection	1/15 (6.7%)
Total infectious complications	6/15 (40.0%)
Delayed union (>12 months)	2/15 (13.3%)
Persistent nonunion (>24 months)	1/15 (6.7%)
Rod migration	2/15 (13.3%)
Rod breakage	0/15 (0%)
Ankle/subtalar stiffness	7/15 (46.7%)
Ankle valgus	4/15 (26.7%)
Malunion (>15° residual)	0/15 (0%)

Follow-Up Duration and Patient Cohort Status

Mean follow-up duration post-salvage surgery was 42 ± 18 months (median 39 months, IQR 28–56 months, range 19.2–74.4 months; equivalent to 3.5 years). Twelve patients (80%) had completed at least 36 months of follow-up; three patients (20%) had 24–35 months of follow-up. At final follow-up: 14 patients (93.3%) demonstrated radiographic union; 14 patients (93.3%) were fully or nearly fully weight-bearing; 13 patients (86.7%) had returned to normal gait pattern or minimal antalgic gait; and 1 patient (6.7%) had persistent nonunion requiring further intervention.

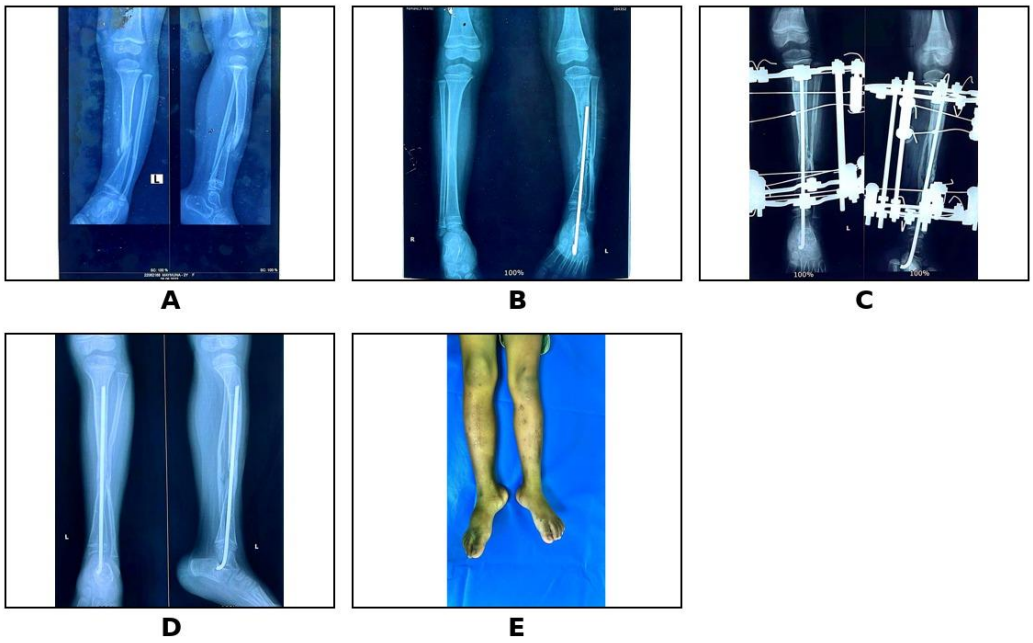


Figure 1 Representative clinical and radiographic sequence: (A) pretreatment tibial deformity; (B) intramedullary rod fixation; (C) Ilizarov external fixation; (D) follow-up radiographs; and (E) clinical appearance at follow-up.

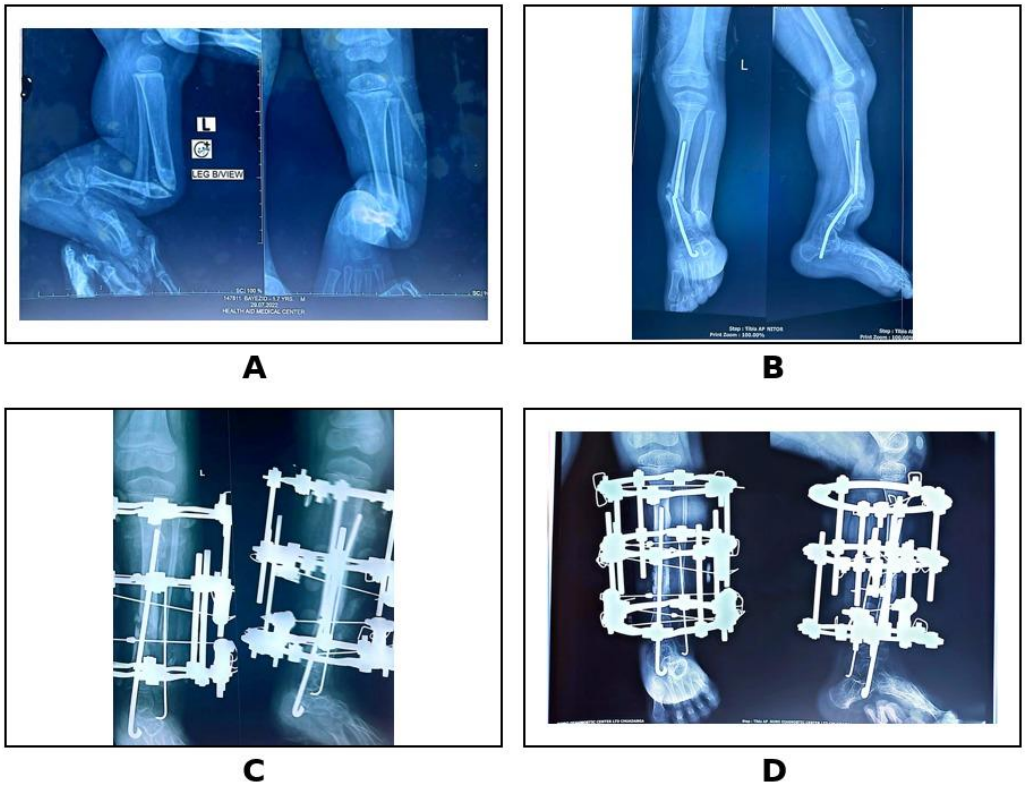


Figure 2 Representative clinical and radiographic images: (A) pretreatment tibial deformity; (B) intramedullary rod fixation; (C) Ilizarov external fixation; and (D) radiographic appearance with the external fixation frame in place.

DISCUSSION

Principal Findings

This prospective observational study evaluated salvage reconstruction of failed congenital pseudarthrosis of the tibia using a combined approach of transcalcaneal intramedullary fixation and Ilizarov external fixation in a cohort of 15 patients. The principal findings demonstrate high union rate (93.3%), zero refracture rate following initial union, excellent alignment maintenance (100%), and meaningful functional improvement (AOFAS 40→64).

Comparison with Existing Evidence

CPT Pathobiology and Treatment Rationale: CPT remains one of the most challenging orthopaedic conditions in paediatric practice. Paley's seminal work emphasized that successful management must address four distinct pathobiological domains: (1) abnormal bone biology preventing spontaneous healing; (2) deformity creating mechanical instability; (3) limb-length discrepancy; and (4) refracture risk even after apparent union.[7] The present study's approach targets all four domains through the combined fixation construct.

Union Rates in Prior Studies: Kesireddy and colleagues, in a systematic review of 33 studies including 1,063 patients with CPT, reported that combined intramedullary rodding and Ilizarov external fixation achieved union in 87–95% of patients across heterogeneous cohorts.[1] The present study's 93.3% union rate is consistent with this range and notably achieved this in a salvage population with 60% prior refracture history, which typically confers worse prognosis.[2]

Refracture Rates: A particularly notable finding is the 0% refracture rate in the present cohort despite 60% of patients having prior refracture history. Most published series report refracture rates of 5–25% following successful union, with highest rates in patients with prior fractures. The absence of refracture in this study likely reflects: (1) long-term presence of both the intramedullary rod and retained Ilizarov frame in most patients; (2) mean follow-up of 42 months; and (3) conservative weight-bearing protocols.

The Transcalcaneal Trajectory: Novel Considerations

The transcalcaneal intramedullary approach employed in this series offers several theoretical advantages over conventional anterograde tibial nailing in CPT: (1) Preservation of Proximal Tibia - the procedure avoids instrumenting or crossing the proximal tibial physis, potentially reducing risk of growth disturbance; (2) Ankle Joint Preservation - the route passes through the posterior tibia and subtalar region distal to the ankle mortise; (3) Mechanical Efficiency - the retrograde trajectory may provide more effective load-sharing with the Ilizarov frame.

The transcalcaneal approach has not been extensively studied in CPT literature, and the present study provides descriptive evidence of safety and efficacy. The calcaneal entry site may theoretically risk subtalar joint involvement or create long-term ankle/subtalar morbidity, though the present cohort did not demonstrate unusual rates of these complications.

Salvage Surgery in Failed CPT: Context and Implications

The present cohort represents a particularly challenging subgroup: patients with failed prior treatment(s). Mean 1.5 previous procedures and 60% prior refracture represent a phenotype associated with higher biological resistance to healing and greater mechanical complexity. Within this context, the 93.3% union rate represents a substantial achievement.

Salvage planning in failed CPT must consider: (1) Biological Factors - pseudarthrosis excision to healthy bone with removal of fibrous interposition and copious bone grafting; (2) Mechanical Factors - multimodal fixation addressing both stability and flexibility; (3) Deformity Management - acute vs. gradual correction; (4) Infection Control - careful attention to preoperative infection status; (5) Functional Expectations - realistic counseling regarding functional outcomes.

Long-Term Follow-Up and Durability
Mean follow-up of 42 months (3.5 years) in the present cohort provides reasonable medium-term outcome data. Most refractures in the literature occur within 2–5 years post-union; the absence of refracture throughout the present follow-up is encouraging but does not exclude risk in years 5–10. Growth-related issues, ankle development, and functional adaptation may evolve as children mature. Longer follow-up into skeletal maturity and beyond will be essential to characterize true durability of the salvage approach.

Strengths and Limitations
Strengths: (1) Prospective design reducing bias; (2) Defined cohort with clear inclusion/exclusion criteria; (3) Consistent outcome definitions; (4) Focus on failed cases where evidence is particularly limited; (5) Multimodal outcomes assessing union, alignment, function, and complications.

Limitations: (1) Small sample size (N=15) limiting statistical power; (2) No comparison group; (3) Heterogeneous baseline characteristics; (4) Follow-up heterogeneity (ranging from 19.2 to 74.4 months); (5) Transcalcaneal technique novelty with limited comparison cohorts; (6) Potential selection bias as families choosing treatment at a tertiary centre may have better compliance.

Clinical Implications and Future Research
For orthopaedic surgeons managing treatment-failed CPT, the present study provides evidence supporting the combined approach of transcalcaneal intramedullary fixation with Ilizarov external fixation as a reasonable salvage option. The 93.3% union rate compares favourably with published alternatives. However, patient counseling should acknowledge moderate infection risk, need for prolonged frame wear, possible late implant-related complications, and modest functional outcomes.

Future studies should: (1) Conduct multicentre comparative studies of combined fixation approaches vs. alternative salvage strategies; (2) Extend follow-up into skeletal maturity; (3) Investigate biologic adjuncts (BMP, growth factors) combined with dual fixation; (4) Focus specifically on ankle/subtalar outcomes; (5) Develop consensus definitions for union, refracture, and other outcomes to enable meta-analytic synthesis.

CONCLUSION
This prospective observational study examined salvage reconstruction of failed congenital pseudarthrosis of the tibia using combined transcalcaneal intramedullary fixation and Ilizarov external fixation in 15 patients treated at a tertiary orthopaedic centre in Bangladesh. The principal findings demonstrate a high radiographic union rate (93.3%), zero refracture rate following initial union, excellent maintenance of acceptable alignment (100%), and meaningful functional improvement (AOFAS 40→64).

The combined fixation strategy appears effective in addressing the complex pathobiology of failed CPT, providing both biological stimulation (excision, bone grafting) and mechanical optimization (dual fixation, controlled compression). However, treatment remains associated with meaningful morbidity, particularly pin-tract infection (33.3%) and ankle stiffness (46.7%), though serious complications remain uncommon.

These findings should be interpreted within the context of a small observational cohort without a comparison group, and results may not be generalizable to all CPT populations. Longer follow-up and larger comparative studies are needed to establish the optimal role of this salvage approach relative to alternatives such as vascularized fibular grafting or emerging biologic strategies.

Despite limitations, this study contributes evidence-based data from a tertiary orthopaedic centre in the developing world to the limited literature on salvage management of the most challenging CPT cases. The approach represents a reasonable option for centres with expertise in both intramedullary fixation and Ilizarov external fixation techniques.

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ETHICAL APPROVAL
This study was approved by the Institutional Ethics Committee of NITOR, Dhaka, Bangladesh. Written informed consent was obtained from all parents or legally authorized guardians prior to surgical intervention.

FUNDING
No financial support or funding was received for this research.

CONFLICT OF INTEREST
The authors declare no conflicts of interest.

DATA AVAILABILITY
Data supporting this study are available from the corresponding author upon reasonable request, subject to institutional data governance policies and patient confidentiality requirements.

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