Title

Successful Limb Salvage in an 18.5 cm Infected Tibial Bone Defect Using a Staged Hybrid Biological Reconstruction Strategy: A Case Report

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Abstract

Introduction:

Massive tibial bone defects exceeding 15 cm are among the most challenging conditions in orthopedic reconstruction, particularly when associated with infection, neurovascular injury, and soft-tissue compromise.

Case presentation:

We report the case of a 23-year-old male presenting with an 18.5 cm tibial bone defect following a Gustilo–Anderson type IIIC open fracture complicated by chronic osteomyelitis. The patient had a two-year history of persistent infection requiring multiple debridement procedures, associated with previous vascular bypass of the posterior tibial artery and combined peroneal and tibial nerve injury. He had undergone multiple prior surgeries and requested a below-knee amputation.

Methods:

A staged hybrid biological reconstruction strategy combining the induced membrane (Masquelet) technique, distraction osteogenesis using a modified bilateral external fixation system, and fibular tibialization was performed.

Results:

Bone transport was carried out at a rate of approximately 0.4 mm/day, achieving full defect reconstruction. The external fixation index was approximately 15 days/cm. At 24-month follow-up, complete bone consolidation was achieved with no recurrence of infection. Radiological evaluation demonstrated progressive corticalization and marked hypertrophy of the transposed fibula. Functionally, the patient achieved independent ambulation with full knee range of motion and partial recovery of ankle and toe function despite residual neurological deficits.

Conclusion:

Hybrid biological reconstruction strategies can successfully manage massive infected tibial defects and extend the limits of limb salvage, providing a reliable alternative to amputation in complex clinical scenarios.

Keywords

Tibial bone defect; Limb salvage; Masquelet technique; Distraction osteogenesis; Fibular tibialization; Osteomyelitis

Highlights

- **Reconstruction of an 18.5 cm tibial defect**
- **Hybrid biological-mechanical strategy**
- **Successful fibular hypertrophy and adaptation**
- **Avoidance of amputation**

1. Introduction

Critical-sized segmental bone defects of the tibia represent one of the most challenging conditions in orthopedic trauma and reconstructive surgery, particularly when associated with infection, vascular compromise, and nerve injury. These defects are most commonly encountered following high-energy trauma, such as Gustilo–Anderson type III open fractures, and often present with complex biological and mechanical challenges. When bone loss exceeds 6 cm, spontaneous healing is unlikely, necessitating advanced reconstructive strategies [1,2,3].

Traditional reconstructive options include vascularized bone grafts, massive allografts, and endoprosthetic reconstruction. While these approaches may provide structural restoration, they are associated with significant limitations. Vascularized grafts require advanced microsurgical expertise and are associated with donor site morbidity. Massive allografts are prone to infection, fracture, and delayed incorporation, while endoprosthetic reconstruction carries risks of mechanical failure, aseptic loosening, and limited long-term durability, particularly in young patients [4,5,6,7].

In the presence of previous osteomyelitis, the choice of reconstruction technique becomes even more critical. Methods such as massive allografts and endoprosthetic reconstruction are less suitable due to the increased risk of infection recurrence and poor biological integration. In such contexts, biological reconstruction strategies, including distraction osteogenesis and the induced membrane technique, are considered more reliable as they promote vascularized bone regeneration and may reduce the risk of persistent or recurrent infection [3,4,7,8].

The induced membrane technique described by Masquelet has gained widespread acceptance as a biological reconstruction method. This two-stage procedure induces the formation of a vascularized pseudosynovial membrane that promotes bone regeneration through the secretion of osteoinductive growth factors, including vascular endothelial growth factor (VEGF) and bone morphogenetic proteins (BMPs) [3,9]. However, its application in very large defects (>10–15 cm) is limited by the requirement for substantial volumes of autologous bone graft and concerns regarding structural stability.

Distraction osteogenesis, based on Ilizarov's tension-stress principle, enables gradual regeneration of bone and soft tissues under controlled mechanical conditions[11]. It is particularly advantageous in large defects, as it generates biologically active bone with intrinsic vascularity and mechanical strength. Nevertheless, prolonged treatment duration, patient discomfort, and complications such as axial deviation, regenerate insufficiency, and joint stiffness remain important limitations [9,10,11].

Recent interest has focused on hybrid reconstruction strategies that combine the biological advantages of the induced membrane technique with the mechanical benefits of distraction osteogenesis. Such approaches aim to overcome the individual limitations of each method and are particularly relevant in complex cases involving infection, soft tissue compromise, and extensive bone loss [12,13].

In this report, we present a complex case of an 18.5 cm infected tibial bone defect following a Gustilo–Anderson type IIIC open fracture complicated by chronic osteomyelitis and neurovascular injury. The defect was successfully reconstructed using a staged hybrid approach combining induced membrane formation, bone transport, and fibular tibialization. This case highlights that limb salvage may be achievable even in extreme conditions traditionally considered indications for amputation.

2. Case Presentation

A 23-year-old male sustained a high-energy trauma resulting in a Gustilo–Anderson type IIIC open fracture of the right tibia, associated with vascular and neurological injury. Emergency vascular repair was performed, followed by soft tissue coverage.

The postoperative course was complicated by chronic osteomyelitis, requiring multiple surgical debridements over a period of approximately two years. Progressive bone loss occurred as a result of repeated resections, ultimately leading to a critical-sized segmental defect.

At the time of presentation to our institution (Fig. 1), clinical and radiological evaluation revealed an 18.5 cm tibial bone defect associated with marked limb instability. The patient demonstrated complete foot drop due to combined peroneal and tibial nerve injury, along with severe functional impairment.

Given the prolonged disease course, persistent infection, and functional deterioration, the patient requested below-knee amputation.

3. Surgical Technique

A staged hybrid reconstruction strategy was employed to address both the biological and mechanical challenges of this complex defect.

3.1 Induced Membrane Technique (Masquelet) (Fig. 2)

The first stage consisted of radical debridement of all necrotic and infected tissues, followed by placement of an antibiotic-loaded polymethylmethacrylate (PMMA) cement spacer to induce membrane formation. Limb stabilization was achieved using a biplanar external fixation system.

3.2 Distraction Osteogenesis (Bone Transport) (Figs. 3–6)

Following membrane maturation, a corticotomy was performed, and distraction osteogenesis was initiated.

Bone transport was carried out over a duration of 162 days, achieving a length gain of 6.5 cm at a rate of 0.4 mm/day. A reduced distraction rate was intentionally adopted to optimize regeneration formation in the context of previous infection and compromised biological conditions.

3.3 Fibular Tibialization (Fig. 7)

Given the residual defect and structural requirements, fibular tibialization was performed. The ipsilateral fibula was transferred into the tibial defect while preserving its vascularity, providing both biological and mechanical support.

The proximal end of the fibula was osteotomized and transposed into the proximal tibial segment, while the surrounding soft tissues and muscular attachments were carefully preserved to maintain vascularity. The distal fibula was left intact and remained in continuity with the ankle joint.

The transposed proximal fibular segment was stabilized within the tibial defect using external fixation pins, as demonstrated in Fig. 7.

Early postoperative evolution was notable for localized soft tissue compromise at the surgical site (Fig. 8). A limited area of superficial skin necrosis developed following fibular transfer, likely related to previous soft tissue damage and surgical dissection. This was managed conservatively with local wound care and healed uneventfully by secondary intention within two weeks.

3.4 Consolidation Phase (Figs. 9)

Following reconstruction, the external fixator was removed, and the limb was immobilized in a cast. Gradual weight-bearing was initiated based on radiological evidence of consolidation.

4. Technical Considerations

A hybrid reconstruction strategy was selected due to the magnitude of the defect and the presence of infection, as no single technique could adequately address both biological and mechanical requirements.

Distraction osteogenesis was performed using a modified bilateral tubular external fixation system rather than a conventional circular Ilizarov frame. This configuration allowed easier application, improved patient tolerance, and sufficient mechanical stability for long-distance transport.

Radiological monitoring focused on regenerate quality, alignment, and union at the docking site throughout the reconstruction process.

5. Results

At a follow-up of 24 months, complete reconstruction of the tibial defect was achieved, with restoration of limb stability and structural continuity.

Radiological evaluation demonstrated progressive regenerate formation during distraction osteogenesis, followed by complete consolidation of the reconstructed segment. Marked hypertrophy of the transposed fibula was observed, consistent with Wolff's law (Fig. 10).

Bone transport was performed over a duration of 162 days, achieving a length gain of 6.5 cm at a distraction rate of 0.4 mm/day. The total external fixation duration was approximately 8–9 months, corresponding to an external fixation index (EFI) of approximately 15 days/cm. Full consolidation was achieved at approximately 24 months.

No recurrence of infection was observed throughout the follow-up period.

Functionally, the patient achieved independent ambulation with progressive weight-bearing. Full recovery of knee range of motion was obtained. Partial recovery of ankle and toe movements was noted; however, residual deficits persisted due to the initial combined peroneal and tibial nerve injury.

A residual limb length discrepancy of approximately 4 cm was present and was effectively compensated using a shoe lift, allowing satisfactory gait. Further surgical limb lengthening remains a potential option if clinically indicated.

Overall, the functional outcome was considered satisfactory given the severity of the initial injury and the extent of bone loss.

Clinical and radiological outcomes are summarized in Table 1.

Table 1. Clinical, radiological, and comparative outcomes of the present case versus literature data.

Parameter	Present case	Literature range	Reference
Defect size	18.5 cm	6–15 cm (typical)	[8],[13]
		up to 25 cm	[9]
Distraction rate	~0.4 mm/day	0.5–1 mm/day	[9],[11]
Monthly distraction	~1.2 cm/month	2–3 cm/month	[9]
External fixation index (EFI)	~15 days/cm	15–30 days/cm	[11],[13]
Time to union	~24 months	6–18 months	[8],[13]
Union rate	Achieved	High (66–100%)	[8],[13]
Infection control	No recurrence	Variable, recurrence possible	[3],[8]
Functional outcome	Independent gait	Acceptable to good	[8],[12]

Knee motion	Full	Usually preserved	[13]
Ankle function	Partial deficit	Variable limitation	[13]
Technique complexity	Hybrid approach	Single-technique approaches	[4],[11]
Biological reconstruction	Yes (combined)	Yes	[3],[5],[13]
Overall outcome	Limb salvage	Limb salvage achievable	[12]

6. Discussion

The management of massive tibial bone defects, particularly those exceeding 15 cm, remains one of the most challenging problems in limb reconstruction [1,11]. In such cases, the decision between limb salvage and amputation is complex and must take into account biological, mechanical, and functional factors. Although amputation may offer faster rehabilitation, limb salvage has been associated with superior long-term functional and psychological outcomes in appropriately selected patients [1,3].

The induced membrane technique has gained widespread acceptance as a reliable biological method for the treatment of segmental bone defects [3,8]. The membrane provides a favorable microenvironment that promotes graft revascularization and osteogenesis through the secretion of growth factors such as VEGF and BMPs [3,8]. However, its application in very large defects is limited by the requirement for substantial graft volume and the lack of immediate structural stability, particularly in infected cases [3,8].

Distraction osteogenesis, based on Ilizarov's principles, represents a cornerstone technique for the reconstruction of large bone defects, as it enables the generation of biologically active bone under controlled mechanical conditions [9,11]. Nevertheless, prolonged external fixation time and complications such as pin tract infection, joint stiffness, and regenerate insufficiency remain important limitations [10,11]. In addition, union at the docking site may represent a critical limiting factor, often requiring adjunctive procedures such as bone grafting to achieve consolidation [11].

In the present case, a hybrid reconstruction strategy was employed to overcome these limitations. The induced membrane technique provided a biologically favorable environment, while distraction osteogenesis enabled gradual reconstruction of the defect without the need for large graft volumes. Furthermore, fibular tibialization introduced a vascularized structural component capable of progressive hypertrophy and long-term remodeling, as previously reported in the literature [5,13].

A key technical aspect of this case was the use of a reduced distraction rate (0.4 mm/day), which is lower than the classical Ilizarov recommendation [9]. This modification was intentionally adopted in response to compromised biological conditions, including prior infection and soft tissue damage. Slower distraction rates have been associated with improved regenerate quality in such environments [9,10].

Additionally, distraction osteogenesis was performed using a modified bilateral tubular external fixation system rather than a conventional circular Ilizarov frame. This configuration facilitated easier application, improved patient tolerance, and provided sufficient mechanical stability for long-distance transport, representing a practical alternative in complex cases [11].

Functional outcomes in the present case were satisfactory despite residual limitations. While full knee range of motion was achieved, partial deficits in ankle and toe function persisted due to the initial combined peroneal and tibial nerve injury. These findings are consistent with previous reports, which indicate that neurological injury significantly influences functional recovery even after successful bone reconstruction [8].

Alternative reconstructive options, including vascularized fibular grafts combined with allografts, have demonstrated good outcomes but are associated with high complication rates and require advanced microsurgical expertise [4,5,6]. Similarly, recent limb salvage techniques have shown that complex defects can be successfully managed without amputation, even in severe cases involving both bone and soft tissue loss [12].

When compared with previously reported studies, the present case demonstrates reconstruction of a substantially larger and more complex defect. While most studies report successful outcomes in defects ranging from 6 to 15 cm [8,13], the current case involved an 18.5 cm infected defect with neurovascular compromise. Despite this increased complexity, outcomes were comparable to those reported in the literature, highlighting the effectiveness of the hybrid reconstruction strategy [12,13].

Overall, this case suggests that hybrid biological reconstruction can extend the current limits of limb salvage and may represent a reliable alternative to amputation in carefully selected patients with massive infected tibial defects [3,12].

A comparison with previously reported studies is summarized in Table 2, highlighting the relative magnitude and complexity of the present case.

Table 2. Comparison of the current case with previously reported studies on the reconstruction of large tibial bone defects.

Study	Technique	Defect size (cm)	Bone	Time to union	Outcome	Limitations
Ilizarov (1989) [9]	Distraction osteogenesis	Up to 10–12	Tibia/Femur	Variable	Reliable union	Prolonged treatment
Yin et al. (2015) [13]	Fibula transport (Ilizarov-based)	13–25	Tibia	9–14 months	100% union	Pin complications
Quinnan (2017) [11]	Ring fixation	Variable	Tibia	Variable	Effective	Long frame duration
Grün et al. (2023) [8]	Masquelet technique	Mean 9	Tibia/Femur	Variable	Good union, fair function	High complication rate
Houben et al. (2019) [4]	Allograft + vascularized fibula	>6	Lower limb	Variable	Good outcomes	High complication rate
Plotnikovs et al. (2023) [12]	Ilizarov-based hybrid techniques	Large defects	Tibia	Variable	High union	Limited long-term data
Present case	Hybrid (Masquelet + transport + fibula)	18.5	Tibia	24 months	Limb salvage achieved	Neurological deficit, LLD

7. Conclusion

This case demonstrates that even extreme tibial bone defects exceeding 18 cm can be successfully reconstructed using a staged hybrid biological approach. The combination of the induced membrane technique, distraction osteogenesis, and fibular tibialization provides an effective solution to both biological and mechanical challenges.

This strategy enabled complete bone reconstruction and limb salvage despite the presence of infection, neurovascular injury, and extensive bone loss. Functional outcome was satisfactory, with independent ambulation achieved despite residual neurological deficits and limb length discrepancy.

Hybrid biological reconstruction may expand the current limits of limb salvage and represents a viable alternative to amputation in carefully selected complex cases.

Further studies are required to validate the reproducibility of this approach and to better define its indications and long-term outcomes.

Clinical message:

Massive tibial bone defects exceeding 15 cm, even in the presence of infection and neurovascular injury, can be successfully managed using a staged hybrid biological reconstruction strategy, providing a reliable alternative to amputation.

8-Ethical approval:

Not required.

9-Consent:

Written informed consent was obtained from the patient for publication.

10-Conflict of Interest:

The author declares no conflict of interest.

11-Funding:

No funding was received.

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Figure 1

Initial clinical and radiological presentation
Preoperative clinical photographs and radiographs showed a massive segmental tibial defect measuring approximately 18.5 cm following a Gustilo-Anderson type IIIC open fracture, with severe soft tissue damage and limb instability

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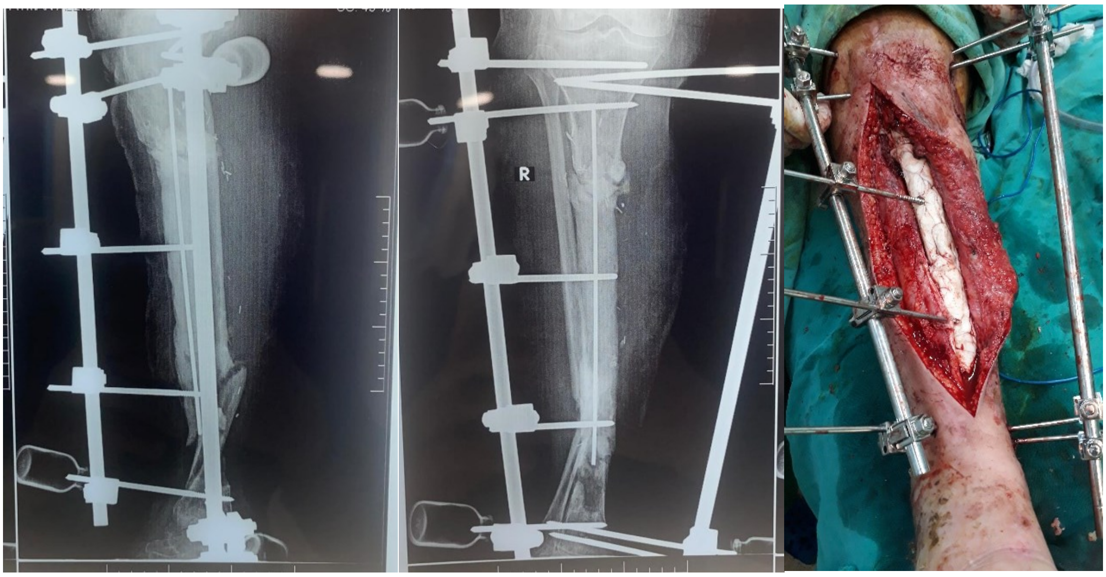

(Fig. 2) First stage – Masquelet technique

Immediate postoperative radiograph after radical debridement and placement of an antibiotic-loaded cement spacer to induce membrane formation, with stabilization using a biplanar external fixator.

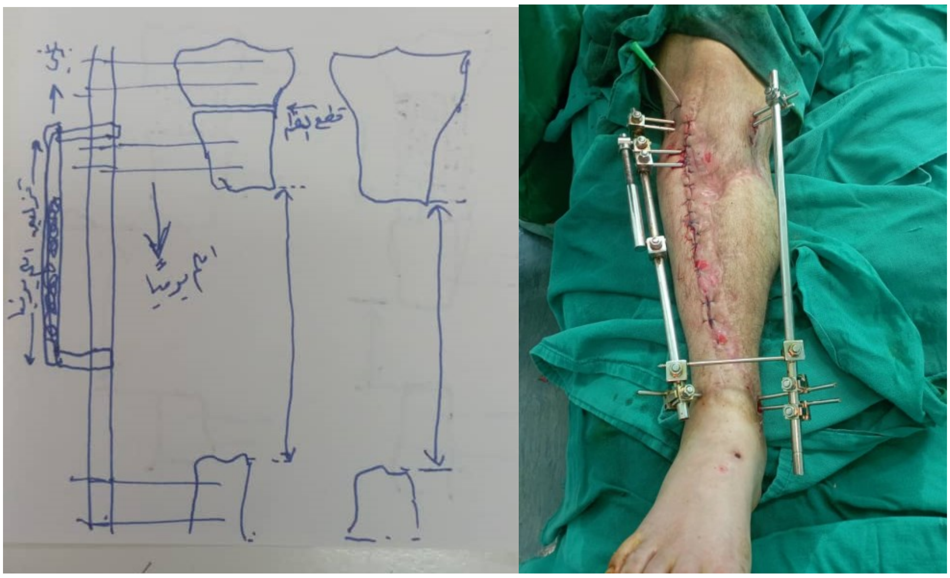

Figure 3

Bone transport planning and corticotomy

-Preoperative planning of corticotomy and transport strategy.

-Intraoperative image showing corticotomy and application of the external fixation system.

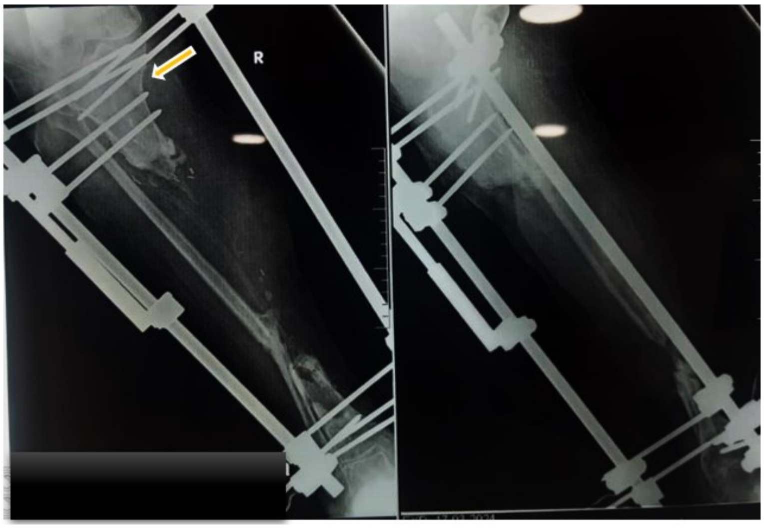

Figure 4

Early postoperative bone transport
Radiograph on the first postoperative day following corticotomy, indicating the site of osteotomy and initiation of distraction.

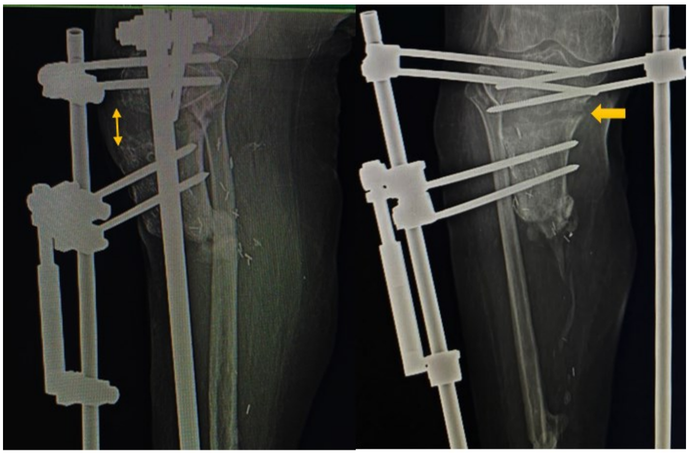

Figure 5

Progressive distraction osteogenesis
Serial radiographs demonstrating progressive bone transport and regeneration formation over time, with a gradual reduction of the bone defect.

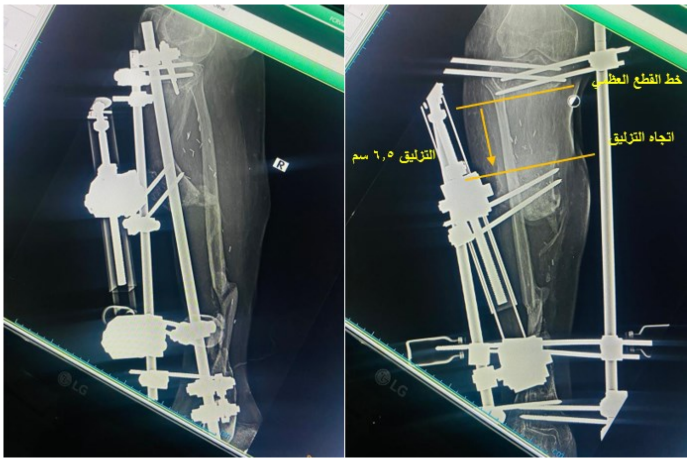

Figure 6

Completion of bone transport
Radiographic appearance after completion of bone transport (approximately 6 months), showing achieved length gain of 6.5 cm and stabilization of the transported segment.

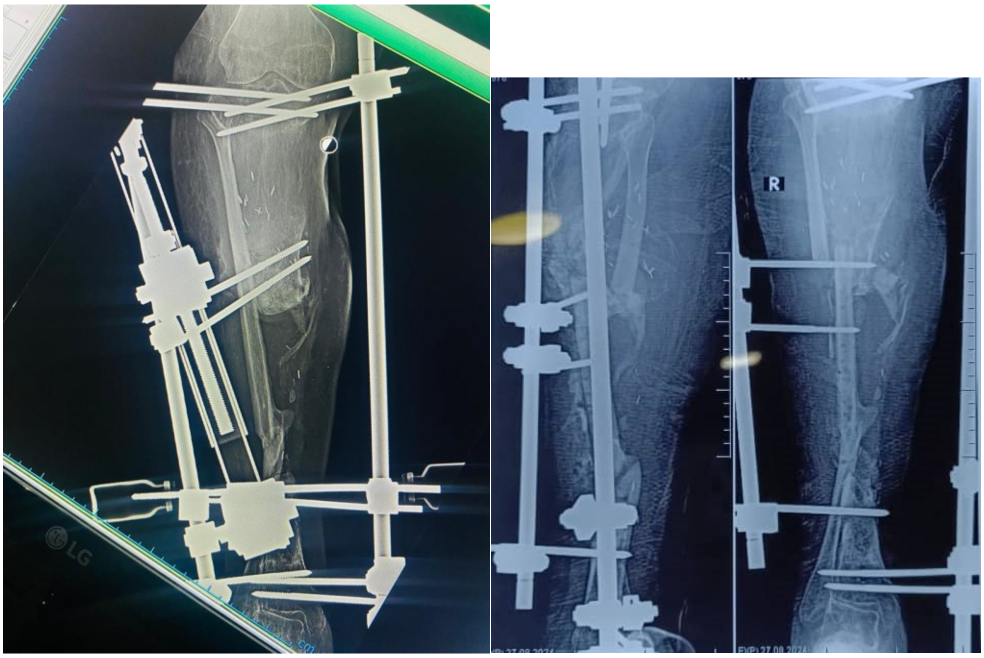

Figure 7

Fibular tibialization

-Preoperative radiograph before fibular transfer.
-Immediate postoperative radiograph showing transposition of the fibula into the tibial defect and fixation.

Figure. 8: Postoperative soft tissue condition

Clinical photograph demonstrating a localized area of superficial skin necrosis following fibular transfer, which healed with conservative management within two weeks.

Figure 9

Functional recovery at 6 months
Clinical images demonstrating progressive recovery of limb mobility and stability six months after fibular transfer. With the initiation of partial weight-bearing

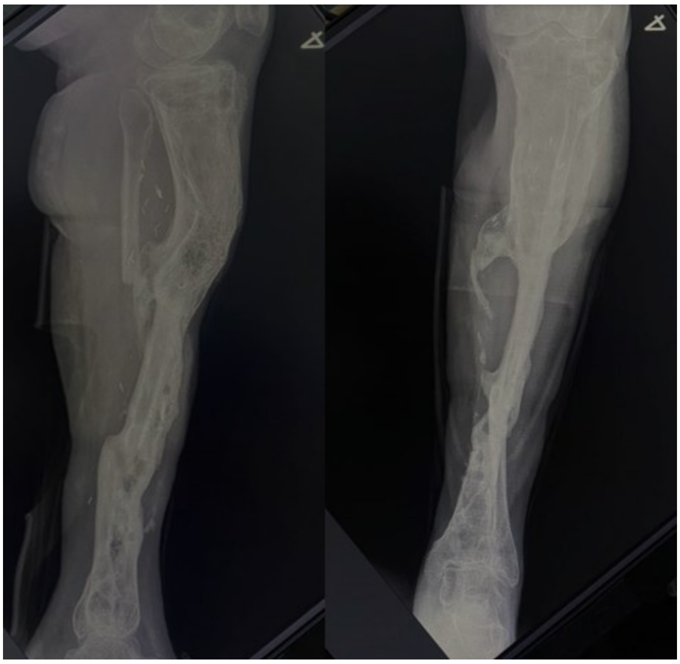

Figure 10:

Final radiological outcome

Final radiographs at two-year follow-up show complete reconstruction of the tibia, integration of the fibular graft, and significant hypertrophy consistent with Wolff's law.

Figure 11

Final clinical outcome
Clinical photographs demonstrating restoration of limb alignment and the ability to ambulate with progressive weight-bearing.