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Evaluation of Functional and Radiological Outcomes Following the Masquelet Induced Membrane Technique in Management of Segmental Long Bone Defects

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Abstract

Background: Segmental bone defects resulting from trauma, infection, or tumour resection are difficult to manage and often lead to prolonged disability. The Masquelet Induced Membrane Technique (IMT) is a two-stage reconstructive procedure that has shown promising biological and clinical outcomes.

Objective: To assess the clinical, biochemical, radiological, and functional outcomes of patients with segmental long-bone defects treated using the Masquelet technique.

Materials and Methods: Thirty-three patients with segmental bone defects were treated prospectively using IMT between 2022 and 2024. Data collected included demographic details, biochemical parameters (ESR, CRP), cortical union, bone and functional scores, and patient-reported outcomes using PCS-12, MCS-12, and VAS.

Results: The mean patient age was 34.3 ± 6.1 years, with a male predominance (54.5%). The tibia was the most frequently involved bone (42.4%). ESR and CRP showed significant reduction before second-stage surgery ($p < 0.001$). By 6 months, 94% achieved ≥ grade

3 cortical union, and 88.4% demonstrated excellent functional recovery. PCS-12, MCS-12, and VAS scores improved markedly, confirming both objective and subjective recovery.

Conclusion: The Masquelet Induced Membrane Technique is a reliable, reproducible, and biologically sound method for reconstructing large bone defects. It achieves excellent radiological consolidation, pain relief, and functional restoration with minimal complications when performed with meticulous technique and strict infection control.

Keywords: Masquelet Technique, Bone Defect, Induced Membrane, Long Bones, Bone Graft, Non-Union

Introduction

Large segmental bone loss remains a major problem in orthopaedic reconstruction, often following high-energy trauma, chronic osteomyelitis, or tumour excision. The resulting defects may exceed the bone's intrinsic healing capacity, leading to non-union, deformity, and loss of limb function [1,2].

Historically, reconstructive options such as bone transport (Ilizarov technique), vascularized fibular grafts, and massive allografts have been used. While effective, these are technically demanding and associated with prolonged external fixation time, donor-site morbidity, or graft rejection [3].

The Masquelet Induced Membrane Technique (IMT), introduced by Masquelet et al. in 2000, represents a paradigm shift. This two-stage approach first involves thorough debridement and placement of a polymethylmethacrylate (PMMA) spacer to induce a vascularized membrane. The second stage, performed after 6–8 weeks, involves removal of the spacer and filling of the cavity with autologous cancellous bone graft within the biologically active membrane [4].

The membrane acts as a bioreactor, secreting osteogenic and angiogenic factors such as VEGF, TGF-β1, and BMP-2, preventing graft resorption and promoting osteogenesis[5,6]. This technique has since gained global attention for its simplicity, cost-effectiveness, and adaptability, especially in resource-limited settings.

This study evaluates functional and radiological outcomes of the Masquelet technique in managing long-bone defects, focusing on both clinical and biochemical progression during staged reconstruction.

Aims and Objectives

1. To evaluate functional and radiological outcomes following the Masquelet Induced Membrane Technique.
2. To correlate biochemical markers (ESR, CRP) with infection control and healing progression.
3. To assess pain, limb function, and quality of life using validated outcome measures (PCS-12, MCS-12, VAS).

Materials and Methods

Study Design and Setting

This was a prospective, single-centre, observational study conducted at the Department of Orthopaedics, Nil Ratan Sircar Medical College and Hospital, Kolkata, between January 2022 and March 2024. Institutional ethical clearance and informed patient consent were obtained prior to inclusion.

Patient Selection

A total of 33 patients with post-traumatic segmental bone defects (>2 cm) involving the humerus, radius-ulna, femur, or tibia were included.

Inclusion criteria

- Age 18–60 years.
- Segmental long-bone defects due to trauma or infection.

- Adequate soft-tissue coverage achieved before the second stage.

Exclusion criteria

- Pathological fractures or metabolic bone disorders.
- Persistent infection at time of second stage.
- Poor general condition precluding surgery.

Surgical Technique

Stage 1 (Induction phase)

After meticulous debridement of all necrotic and infected tissue, fracture stabilization was achieved using an appropriate fixation method (locking plate, intramedullary nail, or external fixator). The bone gap was filled with antibiotic-impregnated PMMA cement (with pre added gentamicin). Wounds were closed in layers, ensuring tension-free soft-tissue coverage. [Figure 1]

Stage 2 (Definitive reconstruction phase)

Performed 6–8 weeks later once inflammatory markers normalized and the soft tissue appeared stable. The cement spacer was removed, taking care to preserve the induced membrane. The bone defect was filled with autologous cancellous bone harvested from the iliac crest, with or without a fibular strut graft for mechanical stability. [Figure 2]

Figure 1: Intraoperative steps during first and second stages, showing inserted cement spacer, biological membrane formation, and bone graft placement

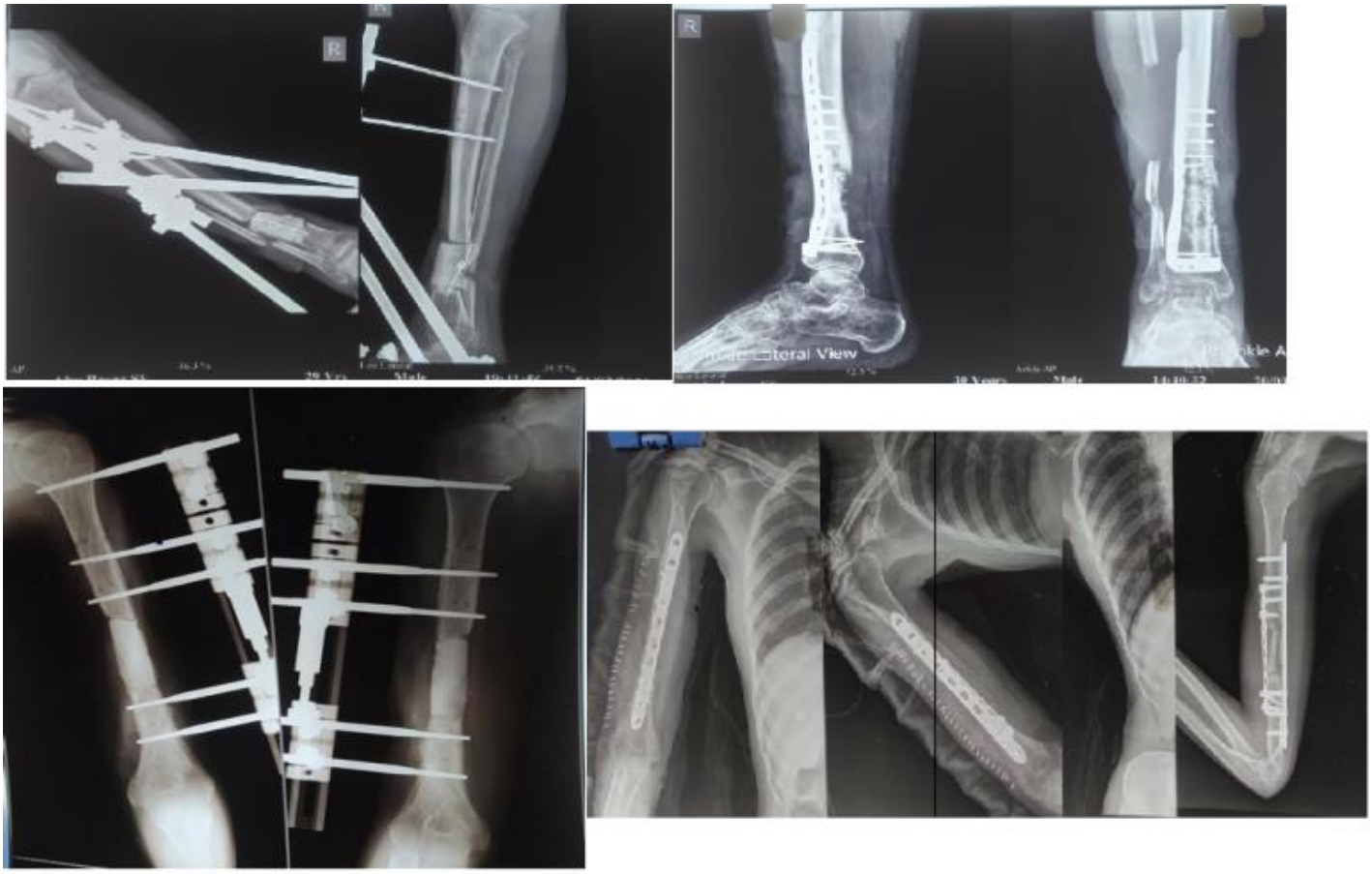

Figure 2: Post Operative Radiographs after first and second stages of Masquelet technique in Tibia and Humerus

Follow-up Protocol

Patients were followed up at 6 weeks, 3 months, and 6 months. Clinical examination, ESR, and CRP were recorded at each visit. Radiographs were analyzed for cortical union (graded 0–4). Functional assessment included Bone Score, Functional Score, PCS-12, MCS-12, and VAS for pain.

Statistical analysis was performed using SPSS v25. Continuous data were expressed as mean ± SD and compared using paired t-tests. A *p* value <0.05 was considered statistically significant.

Results

The mean patient age was 34.3 ± 6.1 years, with a male predominance (54.5%). The tibia was the most frequently involved bone (42.4%). ESR and CRP showed significant reduction before second-stage surgery ($p < 0.001$). By 6 months, 94% achieved ≥ grade 3 cortical unions, and 88.4% demonstrated excellent functional recovery. PCS-12, MCS-12, and VAS scores improved markedly, confirming both objective and subjective recovery.

Table 1: Demographic and Clinical Characteristics of Patients (n = 33)

Parameter	Values / Distribution
Mean Age (years)	34.3 ± 6.1
Sex	Male 18 (54.5 %), Female 15 (45.5 %)
Fracture Site	Humerus 10 (30.3 %), Radius & Ulna 3 (9.1 %), Femur 6 (18.2 %), Tibia 14 (42.4 %)
Fracture Type	Open 15 (45.5 %), Closed 18 (54.5 %)
Bone Graft Used	Cancellous autologous bone 15 (45.5 %), Fibular strut + cancellous 18 (54.5 %)
ESR (mm/hr)	46.9 ± 6.3 → 20.6 ± 2.3 ($p < 0.001$)
CRP (mg/dL)	33.4 ± 5.4 → 1.5 ± 0.2 ($p < 0.001$)

ESR: Erythrocyte Sedimentation Rate, CRP: C-Reactive Protein

Table 2: Radiological and Functional Outcomes

Parameter	Before Stage 1	Before Stage 2	6 Weeks Follow-up	6 Months Follow-up	p value
Cortical Union (Grade 0–4)	0 ≥1 (0%)	0 ≥1 (0%)	28 ≥2 (84.8%)	31 ≥3–4 (94%)	<0.001
Bone Score (Poor–Excellent)	Poor 33 (100%)	Poor 33 (100%)	Good 25 (75.8%)	Excellent 26 (78.8%)	<0.001
Functional Score (Poor–Excellent)	Poor 33 (100%)	Fair 33 (100%)	Good 24 (72.7%)	Excellent 29 (88.4%)	<0.001
PCS-12	26.27 ± 1.77	28.70 ± 1.79	37.61 ± 3.39	49.24 ± 5.93	<0.001
MCS-12	27.45 ± 1.99	31.91 ± 1.86	38.85 ± 3.80	58.97 ± 7.93	<0.001
VAS Score	71.61 ± 2.45	59.99 ± 5.46	41.55 ± 7.83	7.58 ± 15.56	<0.001

PCS-12: Physical Health Summary Scale, MCS-12: Mental Health Summary Scale), VAS: Visual Analogue Scale

Interpretation:

Steady normalization of ESR and CRP confirmed infection control before definitive grafting. Radiological union improved significantly, and most patients regained near-normal function by 6 months. Mean VAS reduction of >60 points reflected substantial pain relief.

Discussion

Our study demonstrates that the Masquelet Induced Membrane Technique provides a predictable and effective method for reconstructing large bone defects, echoing the findings of Masquelet et al. [4] and Karger et al. [7]. The biological activity of the induced membrane — enriched with growth factors and mesenchymal stem cells — enhances graft revascularization and osteoinduction [5,8].

Tibial involvement was most frequent in our series, consistent with Pelissier et al.[9] and Aho et al. [10], likely due to its subcutaneous location and vulnerability to trauma. The infection control achieved before the second stage was reflected by the significant decline in ESR and CRP levels, emphasizing their value as objective indicators for optimal grafting time.

By the 6-month follow-up, 94% achieved solid cortical union, and 88.4% attained excellent functional scores. These outcomes are comparable to those reported by Stafford and Norris[11] and Zhang et al.[8], who documented success rates exceeding 85%.

Compared with bone transport via the Ilizarov method, the IMT avoids complications such as pin tract infection, limb-length discrepancy, and prolonged rehabilitation [1,2]. Furthermore, the IMT allows early soft-tissue recovery, better cosmetic results, and faster rehabilitation.

The main limitations of this study include modest sample size, single-centre nature, and relatively short follow-up (6 months). However, the outcomes suggest IMT as a practical alternative, especially in low-resource environments where advanced reconstructive facilities are limited.

Conclusion

The Masquelet Induced Membrane Technique is a safe, cost-effective, and reproducible method for managing segmental long-bone defects. When performed with meticulous debridement, stable fixation, and adequate infection control, it provides high union rates, excellent pain relief, and functional recovery.

Future studies with larger samples and long-term follow-up are warranted to compare IMT with bone transport and vascularized grafting techniques to establish definitive treatment guidelines

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