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Research Article

CLINICAL OUTCOMES OF THE MODIFIED PAPINEAU TECHNIQUE IN CHRONIC OSTEOMYELITIS AND INFECTED NON-UNION OF THE LOWER EXTREMITY: A RETROSPECTIVE STUDY

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Abstract: ***Introduction:*** The treatment of cases involving chronic osteomyelitis and infected non-union of the lower limb is still faced with many problems due to infection, bony defect, multiple surgeries, and disabling factors. It becomes increasingly complicated when a patient suffers from poor soft tissue cover, instability, and extensive bone defect. In such cases, the modified Papineau technique proves helpful in limb salvage.**Methods:**This retrospective observational study was performed in the Department of Orthopaedics, Sree Mookambika Institute of Medical Sciences, from February 2024 to January 2025. Records of 35 patients suffering from chronic osteomyelitis and infected non-union of the lower limb in the previous three years were evaluated. All patients have been managed with the modified Papineau technique by performing radical debridement, external fixation if required, open cancellous bone grafting, and delayed wound closure.**Results:**The mean age of the study population was 46.2 ± 11.4 years, and all patients were male. Open fractures accounted for most primary injuries (77%). The tibia was the most commonly affected site (68.6%), and diffuse Cierny–Mader Type IV osteomyelitis was the predominant pattern. Staphylococcus aureus was isolated in 82.9% of patients. Most patients required only a single debridement and grafting procedure. The mean duration of Ilizarov fixation was 18.4 weeks, while the mean time to radiological union was 5.9 months. Complete infection eradication, successful bone union, and limb salvage were achieved in all patients during follow-up.**Conclusion:**The modified Papineau technique is an effective and biologically reliable method for managing chronic osteomyelitis and infected non-union of the lower extremity. When combined with meticulous debridement and stable fixation, it can provide satisfactory infection control and limb salvage even in complex cases with significant bone and soft tissue involvement.

Keywords: Chronic osteomyelitis, infected non-union, modified Papineau technique, limb salvage, Ilizarov fixation.

INTRODUCTION

Chronic osteomyelitis and infected non-union continue to pose significant challenges in orthopaedic practice because of persistent infection, bone loss, prolonged treatment, and functional impairment [1, 2]. These conditions are frequently encountered following high-energy trauma and open fractures, particularly involving the lower extremity, where poor soft tissue coverage and compromised vascularity predispose to chronic infection and impaired fracture healing [2, 3]. Among long bones, the tibia is especially vulnerable because of its subcutaneous location and limited soft tissue envelope, making both infection control and skeletal reconstruction difficult [1, 4].

The success of the treatment involves clearing the infection while maintaining limb function and establishing solid bony union [5]. Nevertheless, the challenge lies in the complications due to necrotic bone, sinus tract development, failure of implants, dead spaces, and repeated surgery [3]. Besides, other host variables, including diabetes mellitus, smoking habit, and peripheral neuropathy, might affect wound healing adversely and contribute to infection recurrence [1,2]. Chronic colonisation of S. aureus bacteria is another factor that contributes significantly to the chronic nature and the difficulty in treatment [3].

Several approaches can be considered in the reconstruction for the treatment of chronic osteomyelitis and infected pseudoarthrosis, such as antibiotic spacers, vascularised bone grafts, Masquelet, flap reconstruction, bone transport, and Ilizarov limb salvage techniques [5,6]. Nevertheless, the treatment poses considerable

challenges in cases of significant bone defects, infections recurrence, or failures with previous treatments. For such difficult cases, Papineau technique still holds its position as an effective limb-salvage technique especially in under-resourced areas [7].

Papineau modification technique utilizes principles such as extensive debridement, staged treatment of wounds, open cancellous bone grafts, and delayed tissue covering [7]. Recent improvements that include external fixation and staged reconstructive procedures have shown promising results in terms of eliminating infection, saving limb, and achieving bone union [6,8]. Proper debridement and restoration of bone stability are critical in ensuring a successful biological reconstruction and avoiding infection recurrence [5,8].

Although studies have evaluated different treatment modalities for chronic osteomyelitis and infected pseudoarthrosis, published evidence regarding the clinical outcomes of the modified Papineau technique in lower extremity infections remains limited, particularly from tertiary care centres in developing regions. Therefore, the present study was undertaken to evaluate the demographic characteristics, microbiological profile, surgical management, and clinical outcomes of patients with chronic osteomyelitis and infected pseudoarthrosis of the lower extremity managed using a modified Papineau technique at a tertiary care centre.

MATERIALS AND METHODS

This retrospective observational study was conducted in the Department of Orthopaedics at Sree Mookambika Institute of Medical Sciences between February 2024 and January 2025. Medical records of patients treated for chronic osteomyelitis and infected non-union of the lower extremity during the preceding three years were retrospectively reviewed. Institutional ethics committee approval was obtained prior to commencement of the study.

Patients above 18 years of age with established chronic osteomyelitis or infected pseudoarthrosis involving the tibia, ankle, or foot were included. Diagnosis was based on clinical findings such as persistent pain, swelling, sinus discharge, implant-related infection, and non-healing wounds, along with radiological evidence of infection or non-union. Patients with acute osteomyelitis, pathological fractures, severe peripheral vascular compromise, or incomplete medical records were excluded from the study. A total of 35 patients were included.

Baseline laboratory investigations including complete blood count, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) were assessed in all patients. Plain radiographs were obtained routinely, while computed tomography or magnetic resonance imaging was performed in selected cases to determine the extent of bone and soft tissue involvement.

Details regarding age, sex, mechanism of injury, associated comorbidities, duration of infection, microbiological culture reports, previous surgical procedures, and type of fixation used were collected from hospital records. Patients were followed clinically and radiologically to evaluate wound healing, infection control, and progression towards bony union.

The primary outcome measures assessed were eradication of infection, achievement of radiological union, need for repeat surgical procedures, duration of treatment, and postoperative complications.

Data were entered into Microsoft Excel and analysed using SPSS version 27.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages.

Surgical Procedure

All patients underwent staged surgical management based on the principles of the modified Papineau technique. Under appropriate anaesthesia, thorough debridement of all infected and non-viable soft tissue and bone was performed. Necrotic bone was excised until healthy bleeding bone margins were visualised. Previously inserted implants or fixation devices were removed whenever they were found to be loose or infected. Multiple deep tissue and bone specimens were collected intraoperatively for culture and sensitivity testing. Following debridement, skeletal stability was maintained using external fixation wherever required, particularly in patients with instability or segmental bone loss. The wound was then irrigated thoroughly and left open with sterile moist dressings. Regular dressing changes and serial wound inspections were carried out during the postoperative period. Intravenous antibiotics were administered according to culture sensitivity reports and later converted to oral antibiotics based on clinical improvement. Once a healthy granulating wound bed was achieved and inflammatory markers showed improvement, cancellous bone graft harvested from the iliac crest was placed into the osseous defect. In cases with larger residual cavities or inadequate graft incorporation, repeat grafting was performed when necessary. Final wound management was decided according to the condition of the soft tissues. Smaller wounds were allowed to heal by secondary intention, while larger defects required split-thickness skin grafting or local flap coverage. Patients were reviewed regularly with serial radiographs and clinical examinations until satisfactory infection control and bony union were achieved [7, 9].

RESULTS

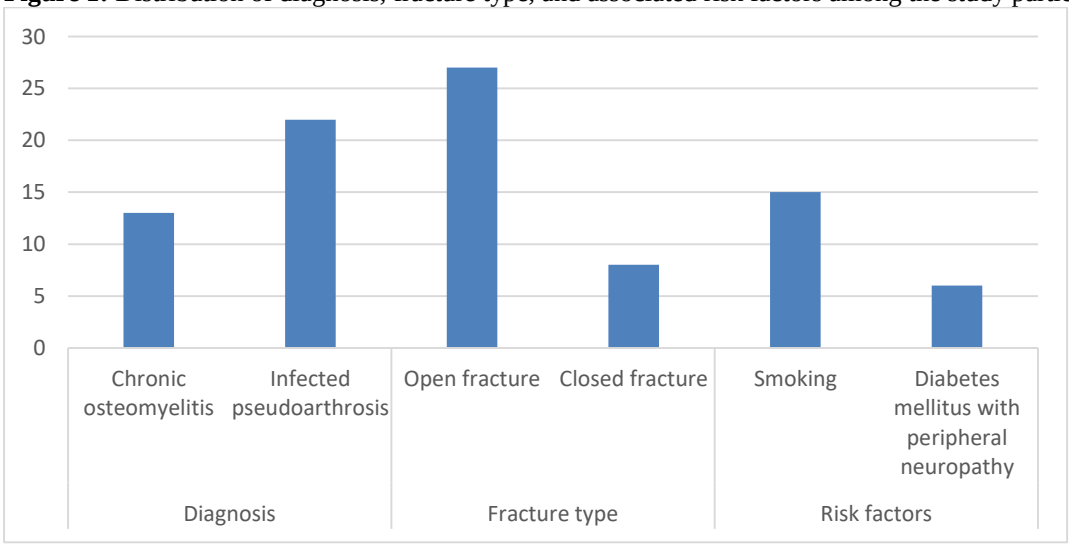
The study included 35 male patients with a mean age of 46.2 ± 11.4 years. Among them, 13 patients (37%) were diagnosed with chronic osteomyelitis, while 22 patients (63%) had infected pseudoarthrosis. Open fractures accounted for the majority of initial injuries, occurring in 27 patients (77%), whereas 8 patients (23%) had sustained closed

fractures. Associated risk factors included smoking in 15 patients (43%) and diabetes mellitus with peripheral neuropathy in 6 patients (17%). The mean duration from injury to referral was 18.2 ± 3.7 months (Table 1, Figure 1).

Table 1: Baseline Patient Demographics and Clinical Characteristics (n = 35)

Variables	Frequency (n) / Mean ± SD	Percentage (%)
Age (years)	46.2 ± 11.4	—
Sex (Male)	35	100
Diagnosis		
Chronic osteomyelitis	13	37
Infected pseudoarthrosis	22	63
Type of fracture		
Open fracture	27	77
Closed fracture	8	23
Associated risk factors		
Smoking	15	43
Diabetes mellitus with peripheral neuropathy	6	17
Mean time from injury to referral (months)	18.2 ± 3.7	—

Figure 1: Distribution of diagnosis, fracture type, and associated risk factors among the study participants.



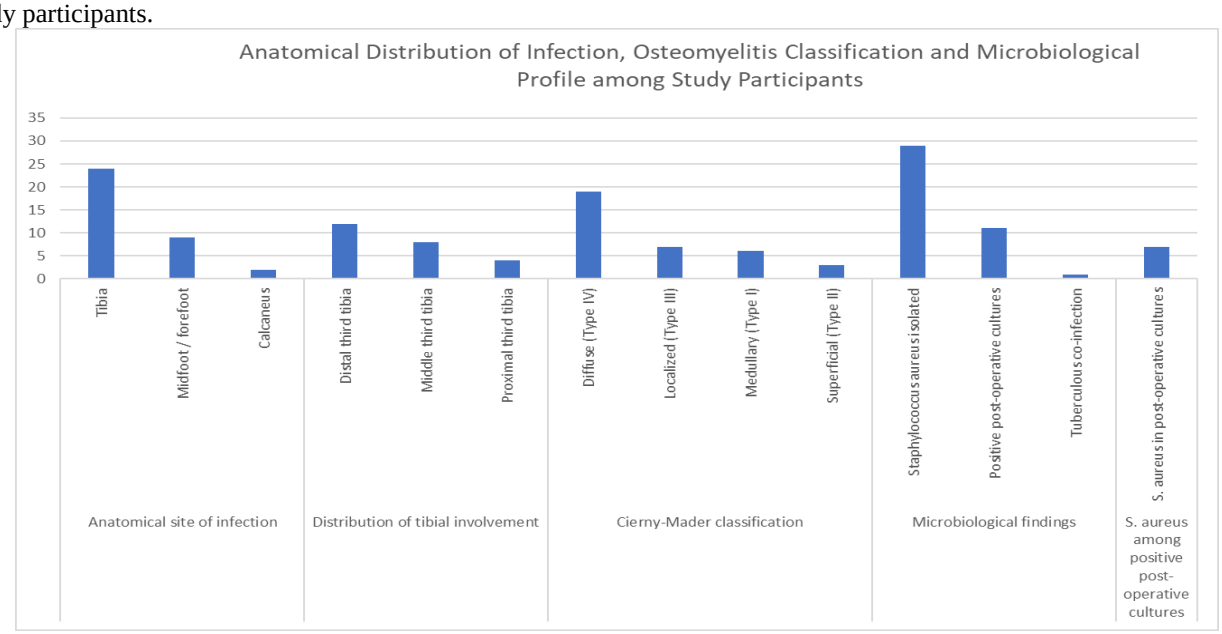
The tibia was the most commonly involved anatomical site, accounting for 24 cases (68.6%), followed by involvement of the midfoot or forefoot in 9 patients (25.7%) and the calcaneus in 2 patients (5.7%). Among patients with tibial involvement, the distal third of the tibia was affected most frequently in 12 cases (50%), followed by the middle third in 8 cases (33.3%) and the proximal third in 4 cases (16.7%). According to the Cierny–Mader classification, diffuse osteomyelitis (Type IV) was the most common pattern, observed in 19 patients (54.3%). Localized osteomyelitis (Type III) was seen in 7 patients (20%), medullary osteomyelitis (Type I) in 6 patients (17.1%), and superficial osteomyelitis (Type II) in 3 patients (8.6%). Microbiological analysis showed isolation of *Staphylococcus aureus* in 29 patients (82.9%). Positive post-operative cultures were observed in 11 patients (31.4%), among whom *Staphylococcus aureus* was isolated in 7 cases (63.6%). One patient (2.9%) had associated tuberculous co-infection (Table 2, Figure 2).

Table 2. Anatomical Distribution, Osteomyelitis Classification and Microbiological Profile among Study Participants (n = 35)

Variables	Frequency (n)	Percentage (%)
Anatomical site of infection		
Tibia	24	68.6
Midfoot / forefoot	9	25.7

Calcaneus	2	5.7
Distribution of tibial involvement (n = 24)		
Distal third tibia	12	50.0
Middle third tibia	8	33.3
Proximal third tibia	4	16.7
Cierny–Mader classification		
Diffuse (Type IV)	19	54.3
Localized (Type III)	7	20.0
Medullary (Type I)	6	17.1
Superficial (Type II)	3	8.6
Microbiological findings (n = 35)		
Staphylococcus aureus isolated	29	82.9
Positive post-operative cultures	11	31.4
Tuberculous co-infection	1	2.9
S. aureus among positive post-operative cultures (n = 11)		
S. aureus in post-operative cultures	7	63.6

Figure 2: Anatomical distribution of infection, Cierny–Mader classification, and microbiological profile among the study participants.

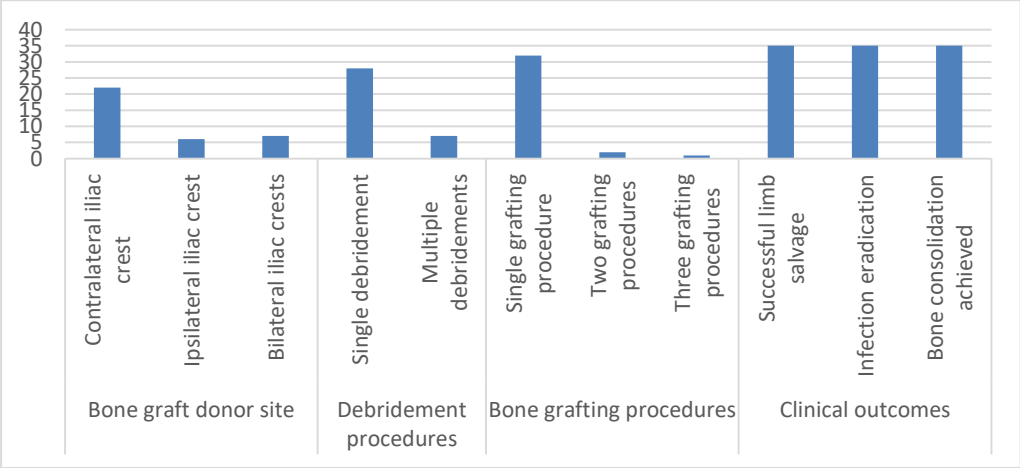


The contralateral iliac crest was the most frequently used donor site for cancellous bone graft harvesting and was used in 22 patients (63%). The ipsilateral iliac crest was used in 6 patients (17%), while grafts from both iliac crests were required in 7 patients (20%). Most patients underwent a single debridement procedure (80%), whereas repeated debridement was necessary in 7 patients (20%). Similarly, a single bone grafting procedure was sufficient in the majority of cases, accounting for 32 patients (91%). Two patients (6%) required repeat grafting, while one patient (3%) underwent three separate grafting procedures. The mean length of the bony defect was 10.2 cm. Patients were followed up for a mean duration of 20.6 months. The average duration of Ilizarov fixation was 18.4 weeks, and the mean time to radiological bone union was 5.9 months. Successful limb salvage was achieved in all patients included in the study. Complete eradication of infection and satisfactory bone consolidation were also observed in all cases during follow-up (Table 3, Figure 3).

Table 3: Surgical Procedures, Treatment Characteristics, and Clinical Outcomes among Study Participants (n = 35)

Variables	Frequency (n) / Mean Value	Percentage (%)
Bone graft donor site		
Contralateral iliac crest	22	63
Ipsilateral iliac crest	6	17
Bilateral iliac crests	7	20
Debridement procedures		
Single debridement	28	80
Multiple debridements	7	20
Bone grafting procedures		
Single grafting procedure	32	91
Two grafting procedures	2	6
Three grafting procedures	1	3
Mean bony defect length (cm)	10.2	—
Mean follow-up duration (months)	20.6	—
Mean duration of Ilizarov fixation (weeks)	18.4	—
Mean time to bone union (months)	5.9	—
Clinical outcomes		
Successful limb salvage	35	100
Infection eradication	35	100
Bone consolidation achieved	35	100

Figure 3: Distribution of bone graft donor sites, debridement procedures, bone grafting procedures, and clinical outcomes among the study participants.



DISCUSSION

The present study evaluated 35 patients with chronic osteomyelitis and infected non-union of the lower extremity managed using a modified Papineau technique at a tertiary care centre. The cohort consisted entirely of males with a mean age in the mid-forties, most presenting following open fractures and delayed referral after the initial injury. Tibial involvement predominated, and Staphylococcus aureus was the most commonly isolated organism. Staged management involving radical debridement, Ilizarov external fixation where necessary, and open cancellous bone grafting was associated with successful infection control, bone union, and limb salvage in all patients.

The significant male preponderance in this study population is supported by current research on post-traumatic osteomyelitis. According to Kharbanda et al, over 80% of patients with open infected fractures of the tibia and fibula were males; this was probably due to higher risk of exposure to high-energy injuries in occupational and road traffic accidents in underdeveloped areas [10]. Also, according to Lam et al, the majority of their patient population suffering from chronic osteomyelitis of the tibia and ankle were males [5]. The late referral of patients in the current study, an average of almost eighteen months after injury, may have contributed to the chronicity of their lesions.

Cases of open fractures made up the bulk of primary injuries, as expected since it is known that open tibial fractures are associated with chronic osteomyelitis. Infections have been documented in as many as 30% of open tibial fractures, especially those with higher grades, as noted by Kouassi et al. [11]. In addition, more than

half of the patients in the current investigation showed signs of diffuse Cierny-Mader Type IV disease, which is a sign of advanced infection at the time of diagnosis. As seen in Ozan et al's observation of a prevalence of advanced Cierny-Mader disease in post-traumatic long bone osteomyelitis, with the tibia being the frequently involved bone [12]. The distribution of cases across all four Cierny–Mader stages also demonstrates the applicability of the modified Papineau technique across varying degrees of disease severity.

Tibial involvement accounted for more than two-thirds of all cases, with the distal third being the most frequently affected region. Shastov et al. highlighted the reconstructive difficulty associated with distal tibial infected non-union because of poor vascularity, limited soft tissue coverage, and proximity to the ankle joint [13]. The subcutaneous location and relatively tenuous blood supply of the tibia make it particularly vulnerable to infection and impaired healing following trauma. Involvement of the midfoot, forefoot, and calcaneus in the remaining patients likely reflects the contribution of diabetic foot pathology and peripheral neuropathy.

Staphylococcus aureus remained the predominant organism both at initial and postoperative culture analysis, consistent with its established role in chronic osteomyelitis. Urish et al. described mechanisms contributing to its persistence within bone tissue, including intracellular survival and biofilm formation [14]. Elsheikh et al. similarly identified S. aureus as one of the most common pathogens in chronic long-bone osteomyelitis despite increasing gram-negative infections [15]. The presence of tuberculous co-infection in one patient also highlights the need to consider atypical organisms in endemic regions such as India.

Host-related comorbidities, particularly smoking and diabetes mellitus, are known to adversely affect outcomes in musculoskeletal infection. Sen et al. demonstrated that osteomyelitis significantly increased the risk of amputation in diabetic foot infections, with smoking acting as an additional adverse factor [16]. Winkler et al. further reported poorer limb salvage outcomes in hindfoot diabetic osteomyelitis [17]. Despite these recognised risk factors, all patients in the present study achieved successful limb salvage, although these findings should be interpreted cautiously in view of the absence of formal long-term functional assessment.

Surgical debridement became the backbone of treatment for our current study. The complete removal of all necrotic bone and nonviable soft tissues down to healthy bleeding tissues is always among the critical guidelines in the treatment of osteomyelitis. According to a previous study by Bor et al., a good outcome with excellent control of infection was noted after undergoing extensive debridement and antibiotic-loaded polymethylmethacrylate beads, and the authors concluded that the success of their cases was mainly due to proper surgical debridement [18]. In our study, most of our patients underwent only one round of surgery, probably because of strict adherence to the intraoperative guidelines and allowing bigger defects instead of questionable tissue preservation.

Ilizarov external fixation was used in patients with instability, segmental bone loss, or juxta-articular involvement where conventional fixation was unsuitable. The Ilizarov method provides stable multiplanar fixation without introducing internal implants into an infected field and also permits gradual correction of deformity and management of bone defects when necessary. Shastov et al. reported reliable bone healing and functional improvement using Ilizarov-based reconstruction for infected distal tibial non-union, although treatment duration was considerably longer than that observed in the present study [13]. The relatively shorter duration of external fixation in the current series may be related to the use of cancellous bone grafting as part of the modified Papineau protocol rather than reliance on distraction osteogenesis alone. The mean time to radiological union of approximately six months also compares favourably with outcomes reported in several bone transport studies involving similar defect sizes. Selvaratnam et al. reported treatment success rates exceeding 90% using antibiotic-loaded bioabsorbable carriers in chronic osteomyelitis management [19]. In comparison, complete infection eradication and bone consolidation were achieved in all patients in the present study, although interpretation of these outcomes should consider the relatively shorter follow-up duration.

Open cancellous bone grafting became one of the crucial elements in modified Papineau technique in the current research. After obtaining healthy granulation bed and reduction in inflammatory markers, the autologous cancellous graft derived from iliac crest represented an advantageous scaffold for the development of new bone. The most frequently used donor area was the contralateral iliac crest; bilateral harvesting of the cancellous grafts was needed in case of larger bone defects. In the majority of patients, only one procedure of bone grafting was performed, which helped to obtain good results in bone consolidation in all cases. Cuvillier et al., applying the modified Masquelet technique based on reamer-irrigator-aspirator bone graft harvest and intramedullary fixation, were also able to obtain good results in treatment of chronic diaphyseal osteomyelitis, with significantly smaller mean defect sizes in comparison with the present study [20]. The ability to treat larger defects without using intramedullary fixation became another advantage of open cancellous bone grafting in the modified Papineau technique.

The favourable outcomes observed in this series, including infection eradication, bone consolidation, and limb salvage in all patients, compare well with previously published studies evaluating the modified Papineau technique. Cho et al. reported encouraging mid-term outcomes in patients with chronic osteomyelitis and infected non-union managed using a staged Papineau protocol [21]. Similarly, Gunawan et al demonstrated satisfactory results using the Papineau

technique for tibial bone defect reconstruction, particularly in resource-limited settings [7]. Polyzois et al. also reported reliable infection control and limb preservation in both diabetic and non-diabetic patients undergoing Papineau-based reconstruction for lower extremity osteomyelitis and pseudoarthrosis [9]. The absence of amputation in the present study is clinically significant given the recognised risk of limb loss in patients with advanced tibial osteomyelitis, diabetes mellitus, and multiple failed prior procedures [11].

From a practical perspective, the modified Papineau technique offers a staged and biologically driven approach to reconstruction that does not rely heavily on microsurgical expertise or advanced implant systems. This makes it particularly useful in tertiary care centres with limited reconstructive resources. The use of autologous cancellous graft provides osteogenic and osteoconductive advantages, while open wound management permits continued monitoring and early identification of residual infection.

Several limitations of the present study should be acknowledged. The retrospective single-centre design introduces the possibility of selection bias and limits the generalisability of the findings. Although representative of the institutional case volume, the sample size remained relatively small, limiting the statistical strength of subgroup analyses. In addition, the absence of a comparative treatment group prevented direct comparison of the modified Papineau technique with other reconstructive strategies such as Masquelet technique, vascularised bone grafting, or isolated Ilizarov bone transport. Functional outcomes were not assessed using validated scoring systems, thereby limiting evaluation of long-term quality of life and functional recovery. Furthermore, the duration of follow-up may not fully capture late recurrence of osteomyelitis. Future prospective multicentre studies with larger sample sizes, longer follow-up, and standardised functional outcome measures would help further define the role of the modified Papineau technique in complex lower extremity reconstruction.

CONCLUSION

The modified Papineau technique remains an effective limb salvage option in the management of chronic osteomyelitis and infected non-union of the lower extremity, particularly in complex cases associated with bone loss, recurrent infection, and compromised soft tissue conditions. In the present study, staged management involving radical debridement, external fixation where required, and open cancellous bone grafting achieved satisfactory infection control, successful bone union, and limb preservation in all patients during follow-up. The technique demonstrated favourable outcomes across varying stages of disease severity while avoiding dependence on advanced microsurgical reconstruction or extensive implant use. Despite the limitations inherent to the retrospective design and relatively small sample size, the findings support the continued role of the modified Papineau technique as a practical and biologically sound reconstructive strategy for chronic lower extremity osteomyelitis, particularly in resource-constrained tertiary care settings

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