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Efficacy of Antibiotic-Coated Intramedullary Nails for Septic Shaft Nonunion: Surgical Technique and Outcomes

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ABSTRACT

Objective: To evaluate the efficacy of a staged protocol using an antibiotic-impregnated cement-coated intramedullary nail (ACCIN) for achieving infection eradication and bone consolidation in the treatment of septic shaft non-union of long bones.

Methods: A retrospective cohort study was conducted on 18 patients treated for septic nonunion of the humerus, femur, or tibia at a single tertiary referral center between January 2018 and January 2024. All patients were managed with a standardized staged protocol involving radical debridement and first-stage stabilization with a custom-made ACCIN, followed by definitive fixation and bone grafting after infection control after an additional spacer Masquelet augmentation and later bone grafting. Data on demographics, injury characteristics, microbiology, and treatment outcomes were collected. The primary outcomes were infection eradication and radiographic union.

Results: The cohort consisted of 14 males (78%) and 4 females (22%) with a mean age of 43 years. The tibia was the most common location (50%). Staphylococcus aureus was the most frequently isolated pathogen (44.4%). Following the staged protocol, both infection eradication and bone union were successfully achieved in 16 of the 18 patients, for an overall success rate of 88%. The mean time to consolidation was 7 months. Unfavorable outcomes were significantly associated with advanced age. Long-term functional complications were significantly associated with advanced age, tobacco use, and failure to control the infection after the first stage.

Conclusion: The use of an antibiotic-impregnated cement nail as part of a staged protocol is a highly effective and reliable strategy for managing septic shaft non-union. This technique successfully addresses the dual challenges of infection and instability, leading to high rates of limb salvage and bone union. Patient-specific factors, particularly age and smoking, remain important predictors of the final outcome.

Keywords: Antibiotic cement nail, Septic non-union, Shaft nonunion, Long bone infection, Intramedullary nailing, Fracture-related infection.

INTRODUCTION

Septic non-union, or infected nonunion, of long bones is a devastating complication following fracture fixation, defined as the failure of bone consolidation after six months in the presence of a persistent infection[1–4]. For the purpose of this study, septic nonunion was defined according to the Fracture-Related Infection (FRI) Consensus guidelines, requiring two or more features such as purulent drainage, fistula, pathogen isolation from deep tissue, or visible hardware infection. It represents one of the most formidable challenges in orthopedic surgery, associated with significant patient morbidity, prolonged disability, substantial healthcare costs, and a diminished quality of life. The incidence of nonunion is estimated to be as high as 10% for all fractures, with infection being a primary contributing factor, particularly in severe open fractures or following internal fixation[1-6]. The complex nature of these cases often places them in the Cierny–Mader Type III or IV categories, requiring radical debridement and specialized reconstruction.

The etiology of septic nonunion is multifactorial, involving a synergistic interplay between mechanical instability and a persistent, deep-seated infection. Bacterial colonization, often in the form of a biofilm on orthopedic implants, creates a protected niche that is resistant to systemic antibiotics and host immune responses[1,5]. Traditional management strategies are often complex and arduous, typically involving multiple staged procedures. These include radical surgical debridement of all infected and necrotic tissue, removal of hardware, stabilization with external fixation, and a prolonged course of systemic antibiotics, followed by delayed bone reconstruction. While effective, this staged approach necessitates multiple surgeries, extended hospitalization, and significant patient discomfort, with unpredictable outcomes[1,4-6].

To overcome these limitations, single-stage procedures combining infection control with definitive skeletal stabilization have been explored. The use of an antibiotic-impregnated cement-coated intramedullary nail (ACCIN) has emerged as a promising therapeutic modality[7-10]. This technique offers the dual advantage of providing immediate and robust mechanical stability to the nonunion site while simultaneously delivering high local concentrations of antibiotics. This localized delivery can achieve levels far exceeding the minimum inhibitory concentration (MIC) required to eradicate biofilm-embedded bacteria, thereby overcoming the poor penetration associated with systemic antibiotic therapy in avascular or necrotic tissue[7,8,10,11].

While the use of ACCIN is gaining acceptance, further clinical evidence is required to solidify its role in the treatment algorithm for septic nonunion. The primary objective of this study was to retrospectively evaluate the efficacy of antibiotic-impregnated cement nails in achieving infection eradication and bony union in patients treated for septic shaft non-union of the femur, tibia, and humerus at our institution. This study is presented in accordance with the STROBE guidelines[12].

MATERIALS AND METHODS

Study Design and Patient Population

This study was designed as a retrospective cohort analysis to evaluate the outcomes of patients treated for septic shaft non-union. The patient cohort was identified from the surgical and medical records of the Department of Orthopedic and Trauma Surgery at the Mohammed VI University Hospital in Marrakech, a tertiary referral center for complex orthopedic trauma. All consecutive patients who received treatment with an antibiotic-impregnated cement-coated intramedullary nail (ACCIN) for this condition between January 2018 and January 2024 were eligible for inclusion. The retrospective nature of the study allowed for the analysis of a complete treatment course, from initial presentation to final follow-up. The study protocol was conducted in full accordance with the ethical standards outlined in the Declaration of Helsinki and received approval from the local institutional review board.

Inclusion and Exclusion Criteria

This study was designed as a retrospecTo ensure a homogeneous study group, strict inclusion and exclusion criteria were applied. Patients were included if they were 18 years of age or older and had a confirmed diagnosis of septic non-union affecting the diaphysis of the humerus, femur, or tibia. The diagnosis was established based on a combination of clinical findings and radiographic evidence of nonunion at least six months after the initial fracture management. Clinical criteria for infection included localized pain, swelling, erythema, or the presence of a draining sinus tract, supported by laboratory findings of elevated inflammatory markers such as C-reactive protein (CRP) or erythrocyte sedimentation rate (ESR). A critical inclusion criterion was the use of a custom-fabricated ACCIN as a central component of the surgical strategy. Furthermore, a minimum clinical and radiographic follow-up of 12 months after the definitive reconstructive surgery was required for inclusion. Patients were excluded from the analysis if they were diagnosed with an aseptic nonunion, if they were lost to follow-up before the minimum period, or if their medical records were incomplete, thereby precluding a thorough and accurate assessment of the treatment and outcomes.

Data Collection

A comprehensive and standardized data collection form was developed to systematically extract pertinent information from each patient's electronic and paper-based medical records, including operative reports, inpatient charts, and outpatient follow-up notes. The collected data encompassed several domains. Demographic data included age at the time of surgery, sex, and the presence of significant comorbidities known to affect bone healing and infection risk, such as diabetes mellitus, tobacco use, and osteoporosis. Details of the initial injury were meticulously recorded, including the mechanism of

trauma, the specific location and type of the fracture (classifying open fractures according to the Gustilo-Anderson system), and the nature of the primary fracture fixation.

Characteristics of the infection were documented, including the clinical presentation, results of microbiological analysis from intraoperative cultures, and serial measurements of inflammatory markers. Surgical details were extensively reviewed, noting the number and type of prior surgical interventions, the specific steps of the ACCIN procedure, the antibiotic agents incorporated into the cement, the necessity for soft tissue reconstruction with flaps, and the details of any subsequent procedures, particularly definitive fixation and bone grafting. Finally, primary and secondary outcomes were tracked, including the time to achieve radiographic and clinical union, evidence of infection eradication, final functional status, and the incidence of any postoperative complications.

Surgical Technique: Antibioti Coated Cement Nail (ACCIN)

All surgical procedures were performed by a team of senior orthopedic trauma surgeons with expertise in managing complex orthopedic infections. The management was executed following a standardized staged protocol designed to first control the infection and then reconstruct the bony defect.

Radical Debridement

The successful implementation of an Antibiotic-Coated Cement Nail (ACCIN) for the management of long bone osteomyelitis hinges on a meticulous and systematic surgical technique. The procedure begins with a radical debridement of the infected site. This is arguably the most critical stage, involving the aggressive excision of all non-viable and infected tissues, including skin, subcutaneous fat, muscle, and bone until healthy, viable tissue margins are reached. Any sequestra (segments of dead bone) and avascular tissue are thoroughly removed. The bone ends are resected back to healthy, bleeding tissue, which is confirmed by the presence of punctate cortical bleeding, often referred to as the "paprika sign"[1,13–15]. The fundamental goal is to completely remove the established bacterial biofilm and create a clean, well-vascularized environment, which is paramount for infection eradication and subsequent healing (Figure 1).

Intramedullary Reaming

Following the extensive soft tissue and bone debridement, attention is turned to the intramedullary canal. The canal is prepared through sequential intramedullary reaming with progressively larger, sharp reamers. This process is a crucial part of the debridement, as it removes the infected endosteal layer, biofilm, and necrotic debris from the inner cortex. Reaming is continued until the canal is widened to a diameter at least 1 to 2 mm larger than the planned final diameter of the cement-coated nail. This over-reaming is critical to ensure the nail can be inserted without excessive force, which could risk iatrogenic fracture or damage to the cement mantle. The process is complete when healthy cortical bone, indicated by fresh bone shavings (reamings), is consistently observed on the reamer flutes.

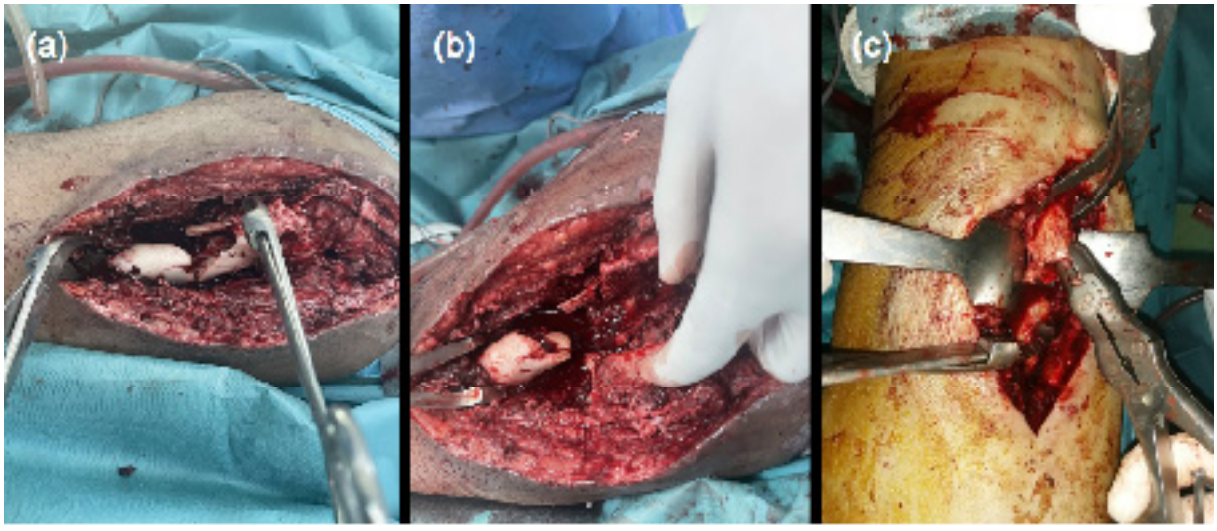

Fig. 1 — Radical debridement steps (a) fibrosis removal (b) loose bodies and sequestrae removal (c) dead tissues removal.

Bacteriological Samples

It is crucial at this juncture, after the canal has been thoroughly cleaned and debrided but before the introduction of any new implants or local antibiotics, that multiple bacteriological samples are obtained. A minimum of five, and preferably six, separate deep tissue and bone samples from various locations within the surgical site (e.g., medullary canal, previous implant tract, abscess walls) are sent for both aerobic and anaerobic culture, as well as fungal cultures if indicated.

Nail Length and Type

The selection of the appropriate intramedullary nail is then made. The nail's diameter must be significantly smaller than the final reaming diameter to allow for a sufficient and robust cement mantle. Typically, a nail 4 mm smaller in diameter than the last reamer used is chosen. For example, if the canal is reamed to 14 mm, a 10 mm nail would be selected. The length is determined by standard preoperative templating and intraoperative measurements to ensure it provides adequate stability, spanning the entire length of the bone from the entry point to a safe distal position. Nail length must exceed intramedullary canal's length and thus be prominent from the entrypoint by at least 20mm to allow an easier extraction afterward in the case of a second stage reconstruction (Figure 2). A fenestrated cannulated nail is preferred as it allows more cement to be embeded within nail's fenestration and thus more mechanical stability. A solid, non-cannulated nail, such as an Ender or Metaizeau nail, might be preferred to prevent any dead space within the implant itself which could harbor bacteria.

Cement Type and Antibiotics Choice

The choice of bone cement and antibiotics is tailored to the clinical situation and, ideally, to preoperative culture results if available. High-viscosity polymethylmethacrylate (PMMA) cement is typically used. The antibiotic selection is critical for achieving high local antimicrobial concentrations. A broad-spectrum, heat-stable, powdered antibiotic is mixed into the cement during its doughy phase. A common and effective combination is Vancomycin (for gram-positive/MRSA coverage) and an aminoglycoside like Tobramycin or Gentamicin (for gram-negative coverage). A standard

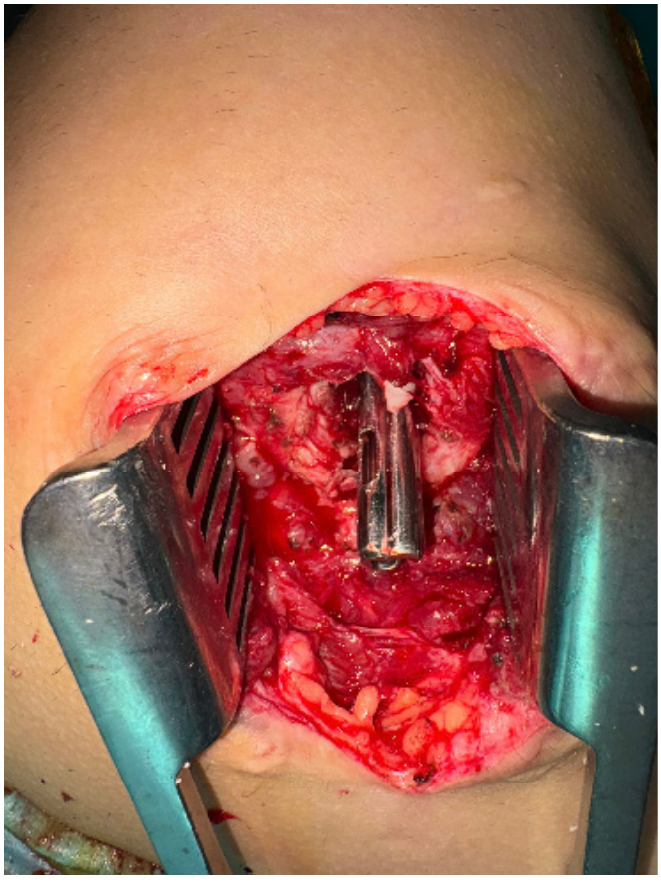

Fig. 2 — Indicative images shows the intramedullary nail protruding from the entrypoint for easy extraction.

load involves mixing 1-2 grams of vancomycin and 1.2-3.6 grams of tobramycin per 40-gram batch of PMMA. The most frequently used combination in our series was vancomycin (to target Gram-positive organisms, including MRSA) and an aminoglycoside such as amikacine or colimycine (to target Gram-negative organisms).

Nail Cement Coating

The nail cement coating process is performed manually on a separate sterile back table. A common technique involves using a sterile 40 FR chest tube as a mold. The prepared antibiotic-laden PMMA is injected into the chest tube using a cement gun. An alternative method for achieving granular control of the final ACCIN nail diameter consists of applying the cement by hand by molding a consistent 1mm thick layer over the nail using a less viscous PMMA cement. The selected intramedullary nail is then inserted into the center of the cement-filled tube. This ensures the creation of a uniform, circumferential mantle of cement around the nail. The cement is allowed to harden, a process that generates significant heat (an exothermic reaction). Once the cement has fully cured, the chest tube is carefully cut longitudinally with a scalpel and peeled away, revealing the finished antibiotic-coated nail (Figure 3).

Cement Coating Rasping

After the cement has hardened and the mold is removed, it is necessary to perform cement coating rasping. Using a sterile rasp or file, the cement mantle is carefully smoothed and contoured. Any irregularities or excess cement are removed. The primary goal of this step is to ensure the final diameter of the coated nail is consistent and sized appropriately—just slightly less than the final reaming diameter of the intramedullary canal, usually 1.5-2mm less than the upper reamer diameter (Figure 3a).

Nail Placement

With the coated nail prepared, it is carefully inserted into the intramedullary canal using standard insertion techniques. Insertion should be done with gentle hand pressure or light mallet taps. If significant resistance is encountered, insertion should be stopped, the nail removed, and the canal re-reamed to a larger diameter to prevent "cement-nail debonding" (separation of the cement mantle from the nail) or fracture. Once seated at the proper depth, distal and proximal locking screws are placed as needed to ensure rotational and axial stability,

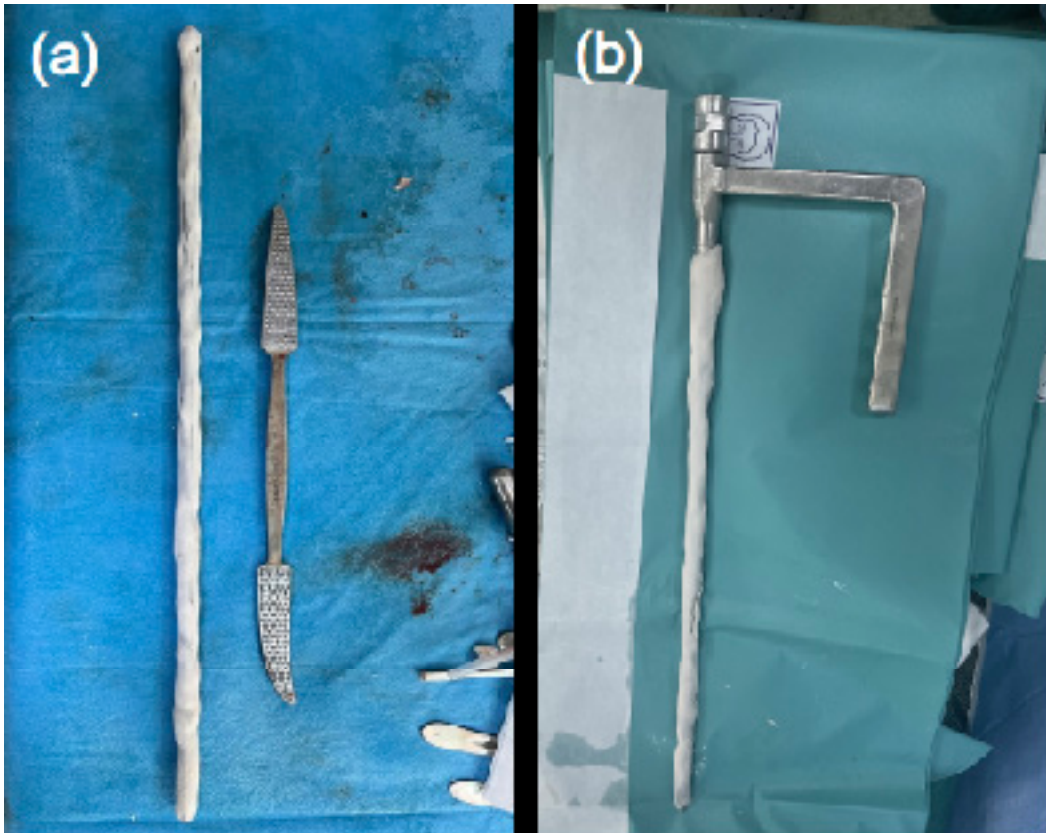

Fig. 3 — Cement coated nail (a) after rasping (b) before rasping.

dictated by the fracture pattern and bone quality (Figure 4).

Spacer Augmentation

In cases with a significant segmental bone defect following debridement, an optional Masquelet augmentation, or induced membrane technique, can be planned. This is a two-stage reconstruction. In the first stage, the ACCIN acts as an antibiotic-releasing spacer, which induces the formation of a robust, biologically active membrane around it. After 6 to 8 weeks, a second surgery is performed. The ACCIN is removed, the induced membrane is carefully preserved, and the resulting cavity is filled with bone graft to achieve bony union (Figure 5).

Wound Closure and Drainage

The final step is wound closure. After confirming hemostasis, the wound is copiously irrigated. Deep fascial layers are closed with absorbable sutures. The skin can be closed with non-absorbable sutures or staples. One or more suction drains are typically placed in the deep space to manage dead space and evacuate any postoperative hematoma, reducing the risk of it becoming a nidus for a new infection. A sterile dressing is applied, and the limb is appropriately splinted or immobilized to protect the soft tissues and fixation (Figure 6).

Definitive Reconstruction

After a mean interval of 6 months, and only when the infection was considered clinically and serologically eradicated (as evidenced by a healed wound without drainage, resolution of local inflammatory signs, and normalization of CRP and ESR levels), the patient proceeded to the second stage. During this procedure, the ACCIN was removed, and the medullary canal

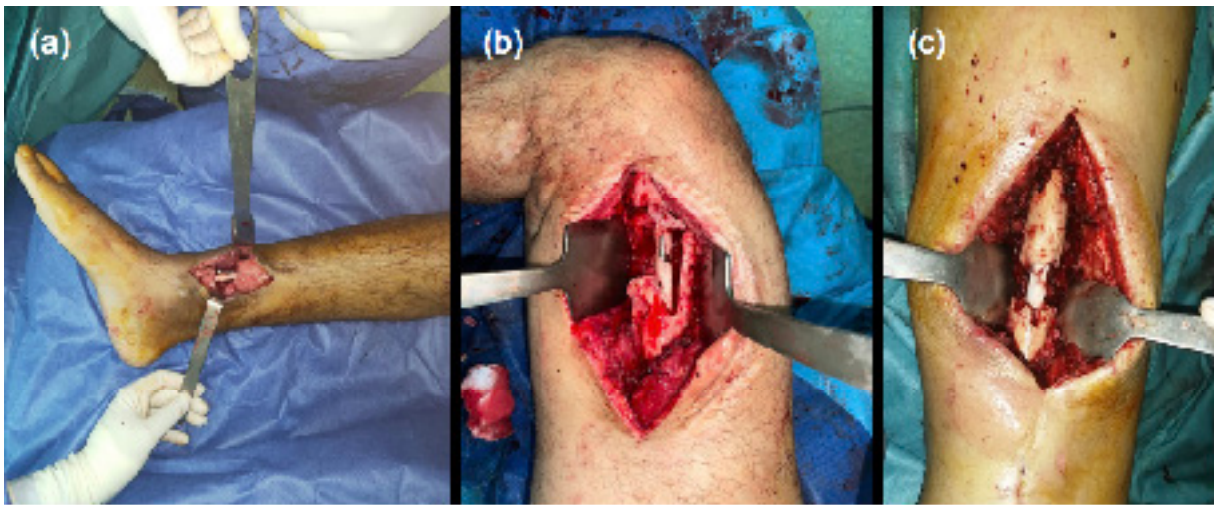

Fig. 4 — Coated nail inserted at different bones (a) distal tibia (b) distal femur (c) femur shaft.

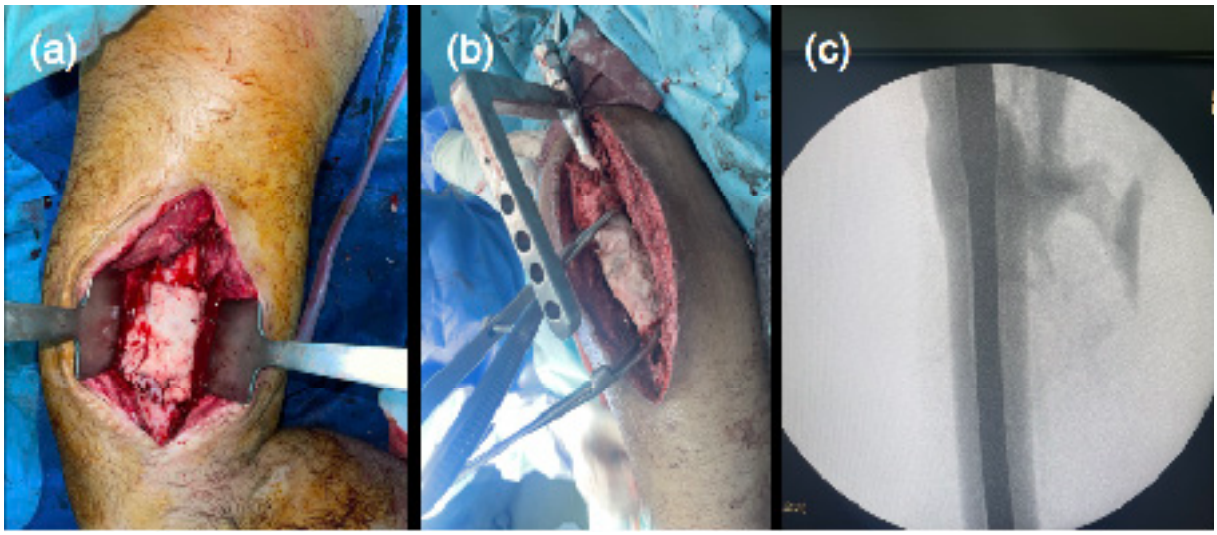

Fig. 5 — Spacer augmentation (a) distal femur (b) proximal femur (c) fluoroscopy of proximal femur spacer augmentation.

Fig. 6 — Wound closure using local flaps (a) pedicled perforated soleus flap (b) anterolateral thigh flap (c) gastrocnemius flap.

was re-reamed to prepare a fresh bony bed. Definitive skeletal stabilization was then achieved using a standard, uncoated intramedullary nail or a locking plate construct. To promote and enhance bone healing, autologous bone grafting was performed in all cases. The graft was typically harvested from the iliac crest (Figure 7).

Outcome Measures and Follow-up

The primary outcome measures for this study were the rates of infection eradication and bone union. Infection eradication was stringently defined as the complete absence of clinical signs of infection (including no draining sinus, pain, erythema, or swelling), sustained normalization of CRP and ESR levels, and no need

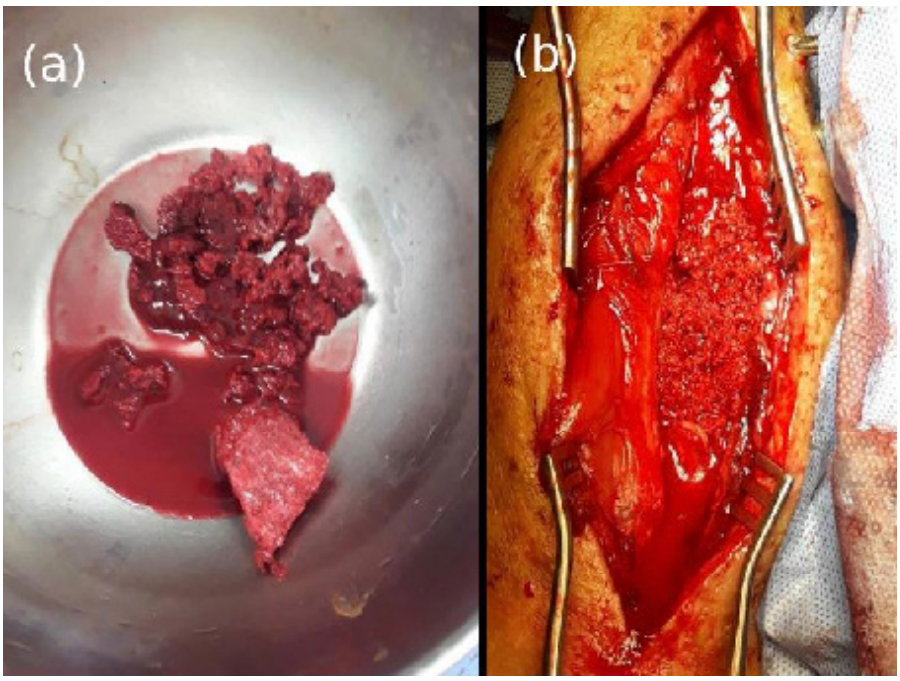

Fig. 7 — Definite reconstruction using an iliac crest autograft (a) graft preparation (b) defect grafting.

for any further surgical or antibiotic treatment for infection at the final follow-up. Bone union was defined using a combination of radiographic and clinical criteria. Radiographically, it required evidence of bridging callus across at least three of the four cortices on orthogonal (anteroposterior and lateral) radiographs (Figure 8). Clinically, it required a stable, non-tender construct that allowed for painless, full weight-bearing on the affected limb.

Functional outcomes were systematically assessed using the validated scoring system from the Association for the Study and Application of Methods of Ilizarov (ASAMI) for lower extremity nonunions[16,17], which evaluates bone and functional results. For humeral nonunions, function was assessed using the Stewart and Hundley classification. Following the definitive surgery, patients were followed at scheduled intervals of 6 weeks, 3 months, 6 months, 1 year, and annually thereafter, with clinical and radiographic assessments at each visit (Figure 8).

Statistical Analysis

Descriptive statistics were employed to summarize the demographic and clinical characteristics of the patient cohort. Continuous variables, such as age and time to union, were reported as means and standard deviations (SD). Categorical variables, such as sex and fracture type, were reported as frequencies and percentages. For comparative analysis, the Student's t-test was utilized to compare means for normally distributed continuous variables, while the Chi-square or Fisher's exact test was applied for categorical variables. A p-value of less than 0.05 was established as the threshold for statistical significance. All statistical analyses were conducted using the SPSS software package (Version 25.0, IBM Corp., Armonk, NY).

RESULTS

Demographic characteristics

The study cohort comprised 18 patients who met the inclusion criteria for the treatment of septic shaft non-union. The demographic analysis revealed a significant male predominance, with 14 men (78%) and 4 women (22%), yielding a male-to-female ratio of 3.5:1. The mean age of the patients at the time of their definitive surgical procedure was 43 years (± 16.1), with an age range spanning from 20 to 72 years. A notable concentration of cases was observed in the younger, more active population, with 66% of patients being between 20 and 39 years of age.

An assessment of patient comorbidities showed that the majority of the cohort (11 patients, 61%) had no significant pre-existing medical conditions. Among the remaining patients, active tobacco use was noted in three individuals (16%), and one patient (6%) had a diagnosis of diabetes mellitus. Other recorded conditions included osteoporosis in three patients (16%), hypothyroidism in one (6%), and a pre-existing psychotic disorder in one (6%). All patients were functionally autonomous prior to their injury. The mechanism of the initial trauma was uniformly a high-energy road traffic accident for all 18 patients, with three of these cases (16%) being classified as polytrauma (Table I).

Characteristics of the Initial Trauma and Management

The initial clinical presentation reflected the high-energy nature of the injuries. On admission, 14

Fig. 8 — Follow up series of tibia ACCIN (a) at 6 weeks (b) at 3 months (c) at 6 months (d) at 1 year.

Table I. — Medical History Found in Our Patients.

History	Number	Percentage
None	11	61%
Tobacco / Alcohol	3 / 1	16% / 6%
Diabetes	1	6%
Tuberculosis	1	6%
Osteoporosis	3	16%
Hypothyroidism	1	6%
Psychosis	1	6%

Table II. — Distribution of Cases According to Initial Treatment.

Bone Affected	Fracture Type	Type of fixation	Number of cases	Percentage (%)
Femur	Closed fracture	IM Nail	5	27.77%
	Open fracture II: 1, IIIa: 1	IM Nail	3	16.66%
Tibia	Closed fracture: 3	Locking Plate	1	5.55%
	Open fracture II: 4, IIIa: 2	External Fixator	7	38.88%
Humerus	Open fracture IIIa	External Fixator	1	5.55%
	Closed fracture	Orthopedic	1	5.55%

Table III. — Distribution of Septic Nonunion Cases by Cierny–Mader Classification.

Cierny–Mader Class	Number of cases	Percentage (%)
Type III (Localized)	3	16.7%
Type IVA (Diffuse)	12	66.7%
Type IVB (Diffuse)	3	16.7%
Total	18	100%

patients (78%) were stable. However, four subjects (22%) presented in a state of shock, necessitating stabilization in the intensive care unit prior to their transfer for orthopedic management.

The musculoskeletal examination revealed that the tibia was the most frequently affected long bone, accounting for 50% of cases (9 patients), followed closely by the femur at 44% (7 patients). The humerus was involved in the remaining two cases (11%). The injury was located on the right side of the body in 55% of patients. A majority of the fractures (60%) were open, with most of these being classified as Cauchoix and Duparc type II (56%). Pain and complete functional impotence of the affected limb were universal findings (Table II).

Initial radiological assessment confirmed the severity of the bone injuries. The fractures were predominantly complex (78%), with a high incidence of comminution (56%) and significant displacement (89%). The fracture was most often located at the junction of the proximal and middle thirds of the diaphysis. Surgical intervention was the primary treatment modality for 17 of the 18 patients (94%). The choice of fixation was evenly split between intramedullary nailing (8 cases, 44.4%) and external fixation (8 cases, 44.4%), with a single case being treated with a locking plate. One humeral fracture was managed non-operatively.

Diagnosis and Characteristics of Septic Non Union

The diagnosis of septic non-union was established at a mean interval of 5 months following the initial fracture management. The clinical presentation was consistent with chronic infection in all cases. Every patient (100%) presented with a fistulae, draining sinus tract overlying the fracture site, accompanied by localized pain, signs of inflammation, and functional disability. Abnormal mobility at the fracture site was clinically evident in 78% of patients. Systemic signs of infection were less consistent, with fever being present in 46% of the cohort.

Laboratory investigations supported the clinical diagnosis. C-reactive protein (CRP) levels were

elevated in 15 patients (83%), with values ranging from 16 mg/L to 56 mg/L. Increased WBC was observed in 10 patients (56%), with white blood cell counts ranging from 11,000 to 25,000 cells/mm³. Radiographic evaluation of the nonunion morphology revealed that the atrophic type was the most common, accounting for 53.3% of cases.

The Cierny–Mader staging system provides an anatomical classification for chronic osteomyelitis, which is particularly useful for categorizing the severity and complexity of infected nonunion cases (Table 3). The majority of the infections fell into the diffuse type (Type IV), which is characterized by infection involving the entire circumference of the bone. Specifically, 12 cases (66.7%) were classified as Type IVA (diffuse infection with unstable bone, often associated with atrophic or hypertrophic nonunion morphology), reflecting the dual problems of infection and mechanical failure inherent to septic nonunion. A smaller but significant proportion, 3 cases (16.7%), were categorized as Type IVB, indicating diffuse infection coupled with severe soft tissue compromise, necessitating more complex reconstruction, such as soft tissue coverage with local flaps (Figure 6). The remaining 3 cases (16.7%) were classified as Type III (localized infection), typically corresponding to the eutrophic or early-stage nonunions observed in the cohort. This distribution confirms that the study population comprised predominantly complex, high-grade chronic infections.

Intraoperative sampling for microbiological analysis was a critical component of the diagnostic workup. All patients underwent perioperative sampling, and the distribution of identified pathogens is detailed in Table IV. Gram-positive cocci were the predominant organisms, with Staphylococcus aureus being the most common isolate, found in 8 cases (44.4%). Gram-negative bacilli also constituted a significant proportion of the infections. A notable finding was the identification of one case of osseous tuberculosis, which required a specific therapeutic approach.

Treatment Evolution and Outcomes

Treatment Evolution and Outcomes Following the staged treatment protocol with an antibiotic-impregnated cement nail (ACCIN), the majority of patients (16 out of 18, or 88%) demonstrated a favorable evolution, achieving both infection eradication and subsequent bone consolidation. Of the 18 patients, 15 followed the standard two-stage reconstruction pathway (ACCIN removal and definitive fixation), one patient required a four-stage treatment due to underlying tuberculosis, and two patients failed the ACCIN stage and required salvage external fixation. The two patients who experienced an unfavorable evolution and persistent infection were subsequently managed with external fixation and are still undergoing treatment (Table V).

Given the small sample size, this statistical analysis is considered exploratory, suggesting a strong descriptive association rather than a definitive predictor.. Analysis of factors associated with treatment outcomes revealed that patient age was a significant predictor of success. The mean age of patients who had a favorable outcome was 34 years,

Table IV. — List of Germs Identified in the Microbiological Study.

Germs	Number	Percentages
Gram-positive Cocci		
Staphylococcus aureus	8	44.4%
Streptococcus pyogenes	3	16.6%
Enterococcus	2	11.1%
Staphylococcus epidermidis	1	5.5%
Gram-negative Bacilli		
Enterobacter spp.	4	22.2%
Escherichia coli	2	11.1%
Klebsiella pneumoniae	1	5.5%
Pseudomonas aeruginosa	1	5.5%
Gram-positive Bacilli		
Bacillus cereus	1	5.5%
AFB		
Mycobacterium tuberculosis	1	5.5%

compared to 48 years for those with an unfavorable outcome. While other factors such as tobacco use and fracture complexity showed trends toward poorer outcomes, these did not reach statistical significance in this cohort (Table VI).

For the 16 patients who healed, radiological consolidation was achieved at an average of 7 months post-definitive fixation. Biologically, these 16 patients demonstrated a cure of the infection, confirmed by the normalization of inflammatory markers (ESR < 20 mm/h, CRP < 10 mg/L).

The final functional results were assessed for the healed patients in Table VII. For the lower extremity cases, outcomes were variable, with sequelae such as limping, joint stiffness, and persistent pain affecting some patients. The functional results, categorized by the ASAMI score, are presented in Table VIII. Overall, the final therapeutic result for the entire cohort was rated as "Good" in 67% of cases, "Fair" in 22%, and "Poor" in 11%.

Upper Limb Outcomes For the two cases of humeral non union that achieved union, functional outcomes were judged to be satisfactory. A notable improvement in postoperative mobility was observed compared to the preoperative state. Mean active shoulder elevation was 125° (range 80° to 170°), and mean active elbow flexion reached 110° (range 90° to 140°), with a mean extension deficit of 10°. According to the Stewart and Hundley classification, the functional results were rated as "Very good" for one patient and "Good/Fair" for the other (Table IX). The osseous results for both humeral cases were also favorable, achieving solid union without significant deformity (Table X).

DISCUSSION

The management of septic shaft non union remains one of the most significant challenges in orthopedic trauma surgery. This condition, characterized by the

Table V. — Treatment Evolution and Outcomes.

Outcome Category	Number of Patients (n)	Percentage (%)
Standard Two-Stage Reconstruction (ACCIN → Definitive Fixation)	15	83.3%
Complex Four-Stage Reconstruction (Tuberculosis)	1	5.6%
Unfavorable Outcome (Persistent Infection, Ongoing Treatment)	2	11.1%
Total Cohort	18	100%

Table VI. — Factors Associated with the Type of Evolution of Septic Non Union.

Parameters		Favorable (16 cases)	Unfavorable (2 cases)	p-value
Mean age		34 years	48 years	0.018
Gender	Male	13 (92.8%)	1 (7.2%)	0.880
	Female	3 (75.0%)	1 (25.0%)	
Tobacco use	Yes	1 (33.3%)	2 (66.7%)	0.257
	No	15 (100%)	0 (0%)	
Open fracture	Yes	9 (90.0%)	1 (10.0%)	0.257
	No	7 (87.5%)	1 (12.5%)	
Complex fracture	Yes	12 (85.7%)	2 (14.3%)	0.225
	No	4 (100%)	0 (0%)	
Displaced fracture	Yes	14 (87.5%)	2 (12.5%)	0.316
	No	2 (100%)	0 (0%)	

Table VII. — Distribution of Cases According to Functional Results.

Parameters	Tibia	Femur
Limping	2	2
Joint stiffness (Knee)	3	2
Soft tissue dystrophy	2	2
Persistence of pain	2	3
Resumption of normal activity	5	2

Table VIII. — Functional Results of Septic Non Union of Femur and Tibia (ASAMI Score).

Functional Results	Number of cases (Tibia)	Number of cases (Femur)
Very good	5	2
Good / Fair	2	2
Poor	2	3

Table IX. — Functional Results of Upper Limb Septic Non Union.

Functional Results	Number of cases (Humerus)
Very good	1
Good / Fair	1
Poor	0

Table X. — Fracture healing Results of Upper Limb Septic Non Union.

Fracture healing	Number of cases (Humerus)
Very good	1
Good	1
Poor	0

dual problems of persistent infection and mechanical instability, requires a comprehensive treatment strategy that addresses both issues simultaneously[1,2,5,14]. This study retrospectively evaluated the efficacy of a staged protocol using an antibiotic-impregnated cement-coated intramedullary nail (ACCIN) for the treatment of septic nonunions of the humerus, femur, and tibia. Our findings demonstrate that this technique is an effective and reliable method for achieving both infection eradication and bone consolidation, with an overall success rate of 88% in our cohort.

The complexity of this condition is best illustrated by considering the treatment pathways of different patient groups.

- Standard Two-Stage Protocol (15 Patients): This group, representing the majority of the cohort (83%), followed a predictable two-stage pathway. A typical case was a 34-year-old male with an open tibial fracture who presented with a draining sinus and radiographic evidence of an atrophic nonunion. The first stage involved removal of prior fixation, radical debridement, and insertion of the ACCIN. After six months, with inflammatory markers normalized and the fistula healed, he underwent the second stage for ACCIN removal, definitive fixation with a standard intramedullary nail, and autologous iliac crest bone grafting. This two-stage protocol resulted in successful infection control and bone consolidation in all 15 patients in this group.
- Complex Infection with Tuberculosis (1 Patient): This particularly challenging case involved a 42-year-old male with an open tibial fracture whose infection recurred after initial cement spacer and external fixation management. A second, aggressive debridement and ACCIN placement was performed. Subsequent cultures and GeneXpert analysis unexpectedly revealed an underlying Mycobacterium tuberculosis infection, requiring a 9-month course of anti-tuberculous therapy before proceeding to the second stage for definitive plating and grafting, which ultimately resulted in union.
- Recalcitrant Infection Requiring Salvage (2 Patients): These two patients, both with complex tibial nonunions, represent the most difficult cases. They were converted to an ACCIN after initial treatment failure. Unfortunately, the infection persisted. This necessitated a final salvage procedure involving removal of the ACCIN, further radical debridement, and placement of a robust external fixator with a new antibiotic spacer. These two patients remain under treatment, highlighting the extreme difficulty in managing certain highly resistant or polymicrobial infections.

The demographic profile of our cohort, with a predominance of young, active males injured in high-energy road traffic accidents, is consistent with the epidemiology of severe long bone fractures reported in the literature[3,5,18,19]. These injuries are often associated

with significant soft tissue damage and open wounds, which are primary risk factors for the development of fracture-related infections and subsequent nonunion. This is particularly relevant in the context of developing regions; a systematic review by Kouamé et al. in Acta Orthopaedica Belgica highlighted that open tibia fractures in Sub-Saharan African countries are associated with infection rates as high as 30% and significant challenges in management due to limited resources[20]. The high rate of open fractures (60%) and complex, comminuted patterns (78%) in our series underscores the severity of the initial trauma and the inherent difficulty in achieving primary healing.

A cornerstone of our treatment protocol was the radical surgical debridement of all non-viable and infected tissue. This principle is universally accepted as the most critical step in managing chronic osteomyelitis. The "paprika sign," indicating bleeding from healthy bone, served as our intraoperative endpoint for debridement[1,13–15]. The subsequent insertion of the ACCIN served two crucial purposes. First, it provided immediate mechanical stability to the nonunion site, which is essential for both soft tissue healing and creating an environment conducive to bone regeneration. Second, and equally important, it functioned as a local antibiotic delivery system[7,8,11,21–23]. The high concentrations of antibiotics eluted directly from the cement mantle into the medullary canal are capable of overcoming the resistance of biofilm-forming bacteria, a feat that is often unachievable with systemic antibiotics alone due to poor vascularity at the infected site[22–27]. This aligns with technical insights provided by Samuel et al., who emphasized in this journal that successful local therapy depends on achieving high local antibiotic concentrations, which can be optimized during the manual fabrication of antibiotic-loaded cement by ensuring adequate porosity and surface area[28].

The microbiological profile of our cohort aligns with previous studies, with Staphylococcus aureus being the most frequently isolated pathogen[1,5,10,24,29]. The presence of MRSA in two cases and a significant number of Gram-negative and polymicrobial infections highlights the importance of obtaining multiple, deep intraoperative cultures to guide targeted antibiotic therapy. The unexpected diagnosis of osseous tuberculosis in one patient further emphasizes the need for a high index of suspicion and comprehensive microbiological and histopathological analysis in cases of persistent, culture-negative infection.

Our study demonstrated a union rate of 88%, which is comparable to or exceeds the rates reported in other series utilizing ACCINs for septic nonunions. Thonse and Conway reported union rates of 84%[30–32], while other studies have shown success rates ranging from 70% to 100%[7,8,10,22,25,26,33,34]. This high success rate is often juxtaposed with techniques using circular external fixation (such as Ilizarov or Taylor Spatial Frame) which, while also effective for limb lengthening and deformity correction, can be associated with extended treatment times and frame-related morbidity. The ACCIN provides immediate, rigid internal stabilization, facilitating earlier weight-bearing and patient mobilization. It is also consistent with other local antibiotic strategies published in Acta Orthopaedica Belgica. For instance, Visani et al. reported a cure rate of 80–86% using antibiotic-loaded bone void fillers for chronic osteomyelitis, validating the efficacy of high-dose local antibiotic delivery systems in eradicating deep-seated bone infections[35]. The mean time to consolidation in our series was 7 months, which is also consistent with the literature. The two cases of persistent nonunion in our study occurred in older, smoking patients, reinforcing the well-established negative impact of these factors on bone healing. This finding suggests that while the ACCIN technique is highly effective, patient-specific biological factors remain a critical determinant of the final outcome.

This stability is a key differentiator. The debate between external fixation and intramedullary nailing for infected defects is ongoing. Eralp et al. compared external fixation alone versus combined with nailing for segmental defects, noting that while combined techniques reduced treatment time, they carried risks of deep infection. The ACCIN technique effectively bridges this gap; it provides the patient comfort and mechanical alignment of an intramedullary nail while the antibiotic coating mitigates the risk of deep infection recurrence that Eralp et al. cautioned against[36].

The analysis of factors contributing to long-term functional complications revealed significant associations with advanced age and tobacco use. This is not surprising, as these factors are known to impair microvascular circulation and the overall biological capacity for tissue repair[3,5,6,24,25]. The strong correlation between an unfavorable evolution after the first stage (i.e., persistent infection) and poor functional outcomes underscores the criticality of achieving complete infection eradication before proceeding to definitive reconstruction. The sequelae of joint stiffness and persistent pain, even in healed cases, highlight the long-term morbidity associated

with this condition and the importance of early and aggressive physical therapy.

This study is not without its limitations. Its retrospective nature introduces the potential for selection bias and reliance on the accuracy of medical records. The cohort size, while representative of a single-center experience with a challenging condition, is relatively small, which limits the statistical power of the analysis of contributing factors. Furthermore, the lack of a direct comparative group treated with an alternative method, such as external fixation with the Masquelet technique, prevents a definitive conclusion about the superiority of the ACCIN method. However, the high success rate in a cohort with severe, established infections provides strong evidence for its efficacy.

In conclusion, the findings of this study support the use of a staged protocol involving an antibiotic-impregnated cement nail as a robust and effective treatment strategy for septic shaft nonunion. This technique successfully addresses the fundamental challenges of infection control and mechanical instability, leading to high rates of union and infection eradication. While patient-related factors such as age and smoking influence the final outcome, the ACCIN provides a reliable platform for managing these complex orthopedic problems, facilitating patient mobilization and ultimately improving the chances of a successful limb salvage. Future prospective, comparative studies are warranted to further define the role of this technique in relation to other available treatment options.

CONCLUSION

The use of antibiotic-impregnated cement-coated intramedullary nails represents a significant advance in the formidable challenge of treating septic diaphyseal pseudarthrosis. This staged stabilization and local antibiotic delivery system proved to be a highly effective strategy in our cohort, yielding an 88% success rate for both infection eradication and bone consolidation. This approach effectively addresses the dual pathological pillars of this condition—mechanical instability and persistent, biofilm-protected infection.

Our findings confirm that a staged protocol, centered around radical debridement and the use of an ACCIN, provides a reliable pathway to limb salvage in a patient population with severe, high-energy injuries and established chronic infections. While the technique is robust, the outcomes are still influenced by patient-specific biological factors, with advanced age and tobacco use remaining significant negative predictors of success.

The successful management of these complex cases underscores the necessity of a multidisciplinary approach, combining aggressive surgical debridement, targeted local and systemic antibiotic therapy, and meticulous soft tissue management. The ACCIN technique is a powerful tool in the orthopedic surgeon's armamentarium, offering a promising and effective solution that facilitates early patient mobilization, reduces the number of required interventions compared to traditional multi-stage protocols, and ultimately improves the quality of life for patients afflicted with this debilitating condition.

Statement of Ethics: The study was waived by the Scientific Committee and the Medical Council of Mohamed VI University Hospital for being a retrospective non interventional study. Written informed consent was obtained from the all patients for publication of this report and any accompanying images in accordance with the principles of the Declaration of Helsinki.

Authors contribution: All authors have made substantial contributions to all of the following: the conception and design of the study by Y.FEK., or acquisition of data by Y.FEK., or analysis and interpretation of data by Z.C., drafting the article by Y.FEK., and Z.C. or revising it critically for important intellectual content by A.S., EM.B., MA.B., I.A., all authors approved of the version to be submitted.

Statement of Informed Consent: Written informed consent was obtained from the patient for publication and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

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Availability of data and material: All data generated or analyzed during this study are included in this published article.

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REFERENCES

1. Atkins RM. Principles of management of septic non-union of fracture. Injury. 2007 May 1;38:S23–32.
2. Green SA, Dlabal TA. The Open Bone Graft for Septic Nonunion : Clinical Orthopaedics and Related Research®. [cited 2025 Aug 23]; Available from: https://journals.lww.com/

clinorthop/abstract/1983/11000/The_Open_Bone_Graft_for_Septic_Nonunion.16.aspx
3. Haase L, Moon T, Burcke A, Speybroeck J, Wetzel R, Sontich J, et al. Comparison of outcomes and operative course between septic and aseptic nonunion in long bones. Eur J Orthop Surg Traumatol. 2022 Aug 29;33(5):1929–35.
4. Siboni R, Joseph E, Blasco L, Barbe C, Bajolet O, Diallo S, et al. Management of septic non-union of the tibia by the induced membrane technique. What factors could improve results? Orthop Traumatol Surg Res. 2018 Oct 1;104(6):911–5.
5. Shapiro JA, Stillwagon MR, Tornetta PI, Seaver TM, Gage M, O'Donnell J, et al. Serology and Comorbidities in Patients With Fracture... : JAAOS - Journal of the American Academy of Orthopaedic Surgeons. [cited 2025 Aug 23]; Available from: https://journals.lww.com/jaaos/abstract/2022/09150/serology_and_comorbidities_in_patients_with.11.aspx
6. Lopas LA, Albertson S, Solomon E, Watson DT, Shah AR, Maxson BJ, et al. Outcomes of Various Antibiotic Cement–Coated Intramedullary ... : Journal of Orthopaedic Trauma. [cited 2025 Aug 23]; Available from: https://journals.lww.com/jorthotrauma/abstract/2022/02000/outcomes_of_various_antibiotic_cement_coated.10.aspx
7. Noye NJ. Single stage revision of infected tibia non-union with antibiotic cement coated intramedullary nail (ACCIN) versus Ilizarov methods: A meta-analysis. [cited 2025 Aug 23]; Available from: https://scholar.archive.org/work/gervf6fr5rdxjiktjslguvquem/access/wayback/https://www.researchgate.net/profile/Nick_Noye/publication/339697920_Single_stage_revision_of_infected_tibia_non-union_with_antibiotic_cement_coated_intramedullary_nail_ACCIN_versus_Ilizarov_methods_A_meta-analysis/links/5e601ace4585152ce8090290/Single-stage-revision-of-infected-tibia-non-union-with-antibiotic-cement-coated-intramedullary-nail-ACCIN-versus-Ilizarov-methods-A-meta-analysis.pdf
8. Metsemakers WJ, Reul M, Nijs S. The use of gentamicin-coated nails in complex open tibia fracture and revision cases: a retrospective analysis of a single centre case series and review of the literature. Injury. 2015;46(12):2433–7.
9. Wang S. Antibiotic-impregnated cement temporary spacer for surgical treatment of osteomyelitis and nonunion of bone caused by intramedullary nailing. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi Zhongguo Xiufu Chongjian Waike Zazhi Chin J Reparative Reconstr Surg. 2011;25(8):972–5.
10. Nizegorodcew T, Palmieri G, Marzetti E. Antibiotic-Coated Nails in Orthopedic and Trauma Surgery: State of the Art. Int J Immunopathol Pharmacol. 2011 Jan;24(1_suppl2):125–8.
11. Greco T, Cianni L, Polichetti C, Inverso M, Maccauro G, Perisano C. Uncoated vs. Antibiotic-Coated Tibia Nail in Open Diaphyseal Tibial Fracture (42 according to AO Classification): A Single Center Experience. Jiang N, editor. BioMed Res Int. 2021 Jan;2021(1):7421582.
12. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. Strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. BMJ. 2007 Oct 20;335(7624):806–8.
13. Yoon YC, Oh CW, Cho JW, Oh JK. Early definitive internal fixation for infected nonunion of the lower limb. J Orthop Surg. 2021 Oct 20;16(1):1–13.
14. Kalantar SH, Bagheri N, Khabiri SS, Oghbaee B, Hoveidaei AH. Management of chronic septic nonunion of the femur... : Annals of Medicine and Surgery. [cited 2025 Aug 23]; Available from: https://journals.lww.com/annals-of-medicine-and-surgery/abstract/9900/management_of_chronic_septic_nonunion_of_the_femur.2297.aspx
15. Zhang J, Yin P, Han B, Zhao J, Yin B. The treatment of the atrophic clavicular nonunion by double-plate fixation with autogenous cancellous bone graft: a prospective study. J Orthop Surg. 2021 Jan 7;16(1):1–6.
16. D P, Ma C, F A, A V, Gb B, R C. Ilizarov treatment of tibial nonunions with bone loss. PubMed [Internet]. [cited 2025 Aug 23]; Available from: https://pubmed.ncbi.nlm.nih.gov/2924458/
17. Cierny GI, Mader JT, Penninck JJ. The Classic: A Clinical Staging System for Adult... : Clinical Orthopaedics and Related Research®. [cited 2025 Aug 23]; Available from: https://journals.lww.com/clinorthop/citation/2003/09000/the_classic__a_clinical_staging_system_for_adult.3.aspx
18. Tekin SB, Mert A, Bozgeyik B. Which is superior in the treatment of AO Type 42A tibial shaft fracture? A comparison of talon intramedullary nailing and conventional locked intramedullary nailing. Turk J Trauma Emerg Surg. 2022;28(10):1514.
19. Xu Y, Ma T, Ren C, Li M, Lu Y, Sun L, et al. Treatment of tibial large bone defects: A comparative study of bone transport over an intramedullary nail in combination with antibiotic-impregnated calcium sulphate versus bone transport alone with antibiotic-impregnated calcium sulphate. Injury. 2023;54:S78–85.
20. Kouassi KJE, Manon J, Fonkoue L, Detrembleur C, Cornu O. Treatment of open tibia fractures in Sub-Saharan African countries : a systematic review. Acta Orthop Belg. 2021 Mar 31;87(1):85–92.
21. Lindner JR, Seligson D, Chisena E, Jortani SA, Korte EA. Does an antibiotic nail made in a lubricated tube release antibiotic? Eur J Orthop Surg Traumatol. 2020 Jan;30(1):153–6.
22. Balakrishna B, Pavan K, Harshavardhan S, Amarnath S. The Study of Dual Antibiotic Impregnated cement coated Nails in Infected Nonunion and Chronic Osteomyelitis of Long Bones. Eur J Cardiovasc Med [Internet]. 2023 [cited 2025 Aug 3];13(3). Available from: https://search.ebscohost.com/login.