

Septic Non-Union of the Leg: Epidemiological Profile, Reconstruction Strategy and Outcomes - A Retrospective Study of 15 Cases

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Abstract

Case Series

Background: Septic non-union of the leg couples two mutually reinforcing obstacles: failure of bone healing and persistence of a bone infection. The tibia, subcutaneous over most of its length and poorly covered distally, is the long bone most exposed to this complication after high-energy open fracture. Management is long, iterative and functionally hazardous, and no single reconstruction technique has achieved consensus. **Objectives:** To describe the epidemiological, clinical, radiological and microbiological profile of septic tibial non-union in a Moroccan university department, to detail the staged treatment protocol applied, and to assess bone and functional outcomes against recent international series. **Methods:** A retrospective single-centre study was conducted in the Department of Orthopedic and Trauma Surgery A, Mohammed VI University Hospital, Marrakech, over five consecutive years (January 2011 – December 2015). All patients with post-traumatic septic non-union of the leg treated and regularly followed in the department were included; aseptic non-unions, patients lost to follow-up, self-discharges and incomplete records were excluded. Treatment followed a staged protocol: radical debridement with culture-directed antibiotic therapy, external fixation, then delayed osteogenic reconstruction with soft-tissue coverage when required. Outcomes were graded with the ASAMI bone and functional criteria. **Results:** Fifteen patients were analysed among 704 leg fractures treated over the period (incidence 2.13%). Mean age was 41.1 years (18–70) and the sex ratio 4:1 (12 men, 3 women). Road traffic accidents accounted for 80% of injuries; the index fracture was open in 13 patients (86.6%), including six Gustilo type III, and external fixation had been the primary osteosynthesis in 86.6%. Mean interval to non-union was 12.1 months (7–24). Atrophic non-union predominated (8 cases, 53.4%) and bone loss was present in nine patients (60%). Cultures were positive in eight cases only (53.3%), *Staphylococcus aureus* leading (4 cases, two methicillin-resistant). Reconstruction used bone grafting alone or with decortication in nine patients (60%), the induced membrane technique in three (20%) and inter-tibiofibular grafting in one. Patients underwent three to seven procedures. At a mean follow-up of 10.4 months (5–24), union was achieved in 12 patients (80%) after a mean of 8 months (5–12) and infection was eradicated in 14 (93.4%). ASAMI bone results were excellent or good in 60% and functional results satisfactory in 80%. No amputation was performed. **Conclusion:** Radical excision, culture-guided antibiotic therapy, reliable external stabilisation and delayed grafting controlled infection in more than nine of ten patients and achieved union in four of five, at the price of repeated surgery. Correct management of the index open fracture, shorter time to definitive care and control of modifiable risk factors remain the decisive preventive levers.

Keywords: Infected non-union; tibia; open fracture; external fixation; bone graft; induced membrane technique; ASAMI score; osteomyelitis.

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1. INTRODUCTION

The leg segment combines every anatomical condition that favours post-traumatic infection. The anteromedial surface of the tibia lies directly beneath the skin, the muscular envelope becomes scarce in the distal third, and the endosteal blood supply is disrupted by displacement at the moment of injury. Tibial shaft fractures are consequently the most frequent open fractures of the limbs, and the extent of soft-tissue

exposure governs both the septic risk and the residual osteogenic potential of the fracture site [1,2].

When infection settles on a fracture that has not united, the prognosis changes in kind rather than in degree. Septic non-union is not the simple sum of osteomyelitis and delayed union: the two processes sustain one another, devitalised bone providing a substrate for bacterial biofilm while chronic inflammation and repeated excisions progressively

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deplete the osteogenic cell pool [3,4]. This interdependence justifies a specific chronological definition. Whereas aseptic non-union is conventionally accepted only beyond six to eight months, a delayed union occurring in an infected environment should be regarded as a septic non-union from the third month onward, because its spontaneous course is unfavourable and because the therapeutic burden it imposes does not tolerate delay [4,5].

The consequences extend well beyond the bone. Patients are typically young and economically active; they face prolonged immobilisation, repeated admissions, stiffness of the adjacent joints, limb-length discrepancy and, in extreme situations, amputation. In health systems where road trauma already represents a heavy burden, the social and economic cost of this complication is considerable.

Therapeutic strategy remains debated. Five principles are universally accepted systemic antibiotic

therapy guided by microbiological sampling, resection of all infected and devascularised tissue, stabilisation of the site, stimulation of osteogenesis, and musculocutaneous coverage but their sequence, timing and technical means differ widely between schools [1]. Ilizarov distraction osteogenesis, the Masquelet induced membrane technique, inter-tibiofibular grafting and vascularised bone transfer currently share the indications, and no adequately powered comparative trial has separated them.

The present work reports the experience of a Moroccan university department over five years. Its objectives were to characterise the epidemiological, clinical, radiological and microbiological profile of septic non-union of the leg in this setting, to set out the staged strategy applied, and to evaluate the resulting bone and functional outcomes in the light of recent international data.



Figure 1: Preoperative clinical view septic non-union of the distal third of the leg with a discharging sinus and cutaneous tissue loss

2. MATERIALS AND METHODS

2.1. Study design and setting

This was a retrospective, observational, single-centre study carried out in the Department of Orthopedic and Trauma Surgery A of the Mohammed VI University Hospital, Marrakech, Morocco. The inclusion period covered five consecutive years, from January 2011 to December 2015.

2.2. Eligibility criteria

Inclusion criteria. Adult patients with post-traumatic septic non-union of the leg, managed surgically in the department and followed regularly in the outpatient clinic.

Exclusion criteria. Aseptic non-union; patients lost to follow-up before assessment; discharge against medical advice; incomplete or unusable records.

Of 704 leg fractures recorded during the study period, 15 files met these criteria and form the basis of the analysis.

2.3. Definitions and grading systems

Non-union was defined radiologically by the absence of any significant callus on anteroposterior and lateral views, combined with abnormal mobility at the fracture site. The septic character was retained on a variable combination of a discharging sinus or abscess, radiological features of chronic osteitis (heterogeneous sclerosis, periosteal thickening, intraosseous lucencies, sequestrum), a systemic inflammatory response, and, when obtained, a positive culture from bone biopsy or purulent discharge.

Index open fractures were graded according to Gustilo [6], non-union morphology according to Weber and Cech [7], and final outcomes according to the ASAMI bone and functional criteria [8, 9].

2.4. Data collection

A standardised data-collection form was designed and completed from inpatient charts, operative reports, microbiology reports and outpatient records. Patients whose contact details were available were recalled for clinical and radiographic reassessment. Recorded variables comprised demographic data and

comorbidities, the mechanism and characteristics of the index fracture, its initial management, the clinical, radiological, biological and bacteriological presentation of the non-union, the surgical procedures performed, complications, and outcome at latest follow-up.

2.5. Treatment protocol

A staged protocol was applied to the whole series.

Stage 1 Eradication of infection.

The patient was positioned supine under pneumatic tourniquet. The approach followed the sinus tract or the previous anterior scar. Debridement comprised drainage of collections, excision of all infected or necrotic tissue, sequestrectomy, curettage of the medullary canal, removal of all implants and foreign material capable of sustaining biofilm, and freshening of the bone ends. Multiple deep specimens were sent for microbiological analysis.

Antibiotic therapy.

Started after sampling, treatment was initially empirical and parenteral amoxicillin–clavulanate or a

third-generation cephalosporin and was subsequently tailored to susceptibility testing. Total duration ranged from 4 to 8 weeks according to the severity of bone involvement and the clinical and biological response. Patients carrying multidrug-resistant organisms were placed in technical and geographical isolation.

Stage 2 Stabilisation.

The non-union site was stabilised in every case by external fixation, chosen for its neutrality with respect to the septic focus and for the possibility of secondary axial correction.

Stage 3 Reconstruction.

Once the site was dry (cessation of discharge, skin healing, normalisation or marked decline of inflammatory markers), osteogenesis was stimulated by Judet osteoperiosteal decortication, iliac crest corticocancellous grafting, inter-tibiofibular grafting, or the two-stage induced membrane technique with a cement spacer. When required, soft-tissue coverage used a local muscle flap or directed healing.



Figure 2: Debridement stage wide sequestrectomy, excision of the bone ends and medullary canal curettage with multiple deep microbiological samples

2.6. Outcome assessment and analysis

Outcome was assessed at the latest available follow-up. Union was defined by the disappearance of mobility at the non-union site together with cortical continuity on at least three cortices. Bone and functional results were graded as excellent, good, fair or poor according to ASAMI. Analysis was purely descriptive, using counts, percentages, means and ranges.

2.7. Ethical considerations

The study was conducted in accordance with good clinical practice and the Declaration of Helsinki. All data were anonymised and no identifying information appears in the manuscript or in the iconography.

3. RESULTS

3.1. Frequency and demographics

Among the 704 leg fractures recorded between 2011 and 2015, 15 progressed to septic non-union, an incidence of 2.13%, compared with 32 aseptic non-unions (4.5%).

Mean age was 41.1 years (range 18–70); eight patients (53.3%) were younger than 45 years. Male predominance was marked, with 12 men (80%) and 3 women (20%). Six patients (40%) had at least one notable comorbidity: active smoking in two, and hypertension, diabetes mellitus, previous thyroidectomy and psoriasis in one patient each.

3.2. Index injury

Road traffic accidents were the dominant mechanism (80%). The right side was involved in 60% of cases. The fracture was isolated in five patients (33.4%), occurred within a polytrauma in four (26.6%) and was associated with another musculoskeletal injury in six (40%): floating knee, ipsilateral femoral fracture, malleolar fracture, contralateral leg fracture or chest trauma. No vascular or nerve injury was recorded.

The fracture was open in 13 cases (86.6%). Gustilo grading identified two type I injuries (13.4%), five type II (33.4%), five type IIIa (33.4%) and one type IIIb (6.6%); no type IIIc was observed. Both bones of the leg were fractured in all patients and the fracture pattern

was complex in 14 of 15. The distal third was most often involved (5 cases, 33.4%), followed by the middle third and the middle–distal junction (4 cases each, 26.6%), the proximal third being concerned in only two cases (13.4%).

3.3. Initial management

The interval between injury and initial treatment ranged from 1 to 18 days, with a mean of 8 days. Open fractures received emergency tetanus prophylaxis, antistaphylococcal antibiotic prophylaxis, wound lavage and debridement, and temporary splinting. External fixation was the primary osteosynthesis in 13 patients (86.6%); one patient was treated by intramedullary nailing (6.6%) and one woman by traditional splinting known locally as *jbira* (6.6%). A temporary above-knee cast was used in five patients.



Figure 3: Complex bifocal fracture of the middle–distal junction of the left leg in a 36-year-old man injured in a road traffic accident, treated primarily by external fixation. (a) Anteroposterior view. (b) Lateral view

3.4. Presentation of the non-union

Mean interval from injury to the diagnosis of non-union was 12.1 months (range 7–24). Presenting

complaints combined, to varying degrees, pain at the fracture site, complete or partial functional impairment, and a subjective sensation of instability of the leg. Low-grade fever was present in most patients. Local examination showed abnormal mobility of the site in all patients, swelling with local warmth in 10, a discharging sinus in 9, cutaneous tissue loss in 5, angular deformity in 5, limb shortening in 4 (mean 1.5 cm; range 0.5–3 cm) and trophic changes in 1. No neurovascular deficit was found.

Radiologically, the atrophic pattern predominated with eight cases (53.4%), followed by the hypertrophic pattern reactive to infection in four cases (26.6%) and the eutrophic pattern in three (20%). Bone loss, decisive for reconstruction planning, was present in nine patients (60%). Features of chronic osteitis variably associated heterogeneous sclerosis, periosteal thickening, intraosseous lucencies and sequestra.

Laboratory work-up showed a raised C-reactive protein in 10 patients, between 16 and 56 mg/L, an erythrocyte sedimentation rate of 16 to 20 mm in the first hour in three, and leucocytosis in six, from 11,000 to 25,000 cells/mm³.



Figure 4: Anteroposterior radiograph atrophic non-union of the distal third of the right leg with sclerosis and tapering of the bone ends

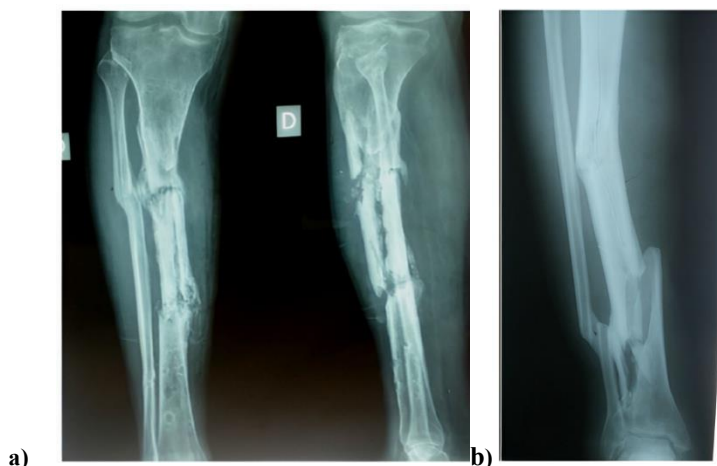


Figure 5: Comparative radiographic patterns: (a) reactive hypertrophic non-union; (b) eutrophic non-union

3.5. Microbiological findings

An organism was identified in only 8 of 15 cases, a culture yield of 53.3%. *Staphylococcus aureus* was the leading pathogen, isolated in four patients two methicillin-susceptible and two methicillin-resistant strains requiring isolation. The four remaining positive cultures were polymicrobial Gram-negative infections, including extended-spectrum beta-lactamase-producing Enterobacteriaceae, *Acinetobacter baumannii*, *Escherichia coli*, *Proteus* spp. and *Pseudomonas* spp. (Table 3).

3.6. Treatment of the non-union

Debridement was performed in all patients, and antibiotic therapy, subsequently adjusted to susceptibility testing, was continued for 4 to 8 weeks. The approach was anterolateral in 10 cases, posteromedial in 4 and transpatellar in 1.

The entire series was stabilised by external fixation: an Orthofix-type device in three patients, a double Hoffmann frame in five, and a low-cost frame in three; the type of construct was not specified in the operative report of the four remaining patients.

Reconstruction combined osteosynthesis with stimulation of osteogenesis. Bone grafting, alone or supplemented by decortication, was performed in nine patients (60%); the two-stage induced membrane technique in three (20%); and inter-tibiofibular grafting in one (6.6%). Three patients underwent osteoperiosteal decortication with conversion of the fixation construct, either to intramedullary nailing or to a new external frame. Soft-tissue coverage was required in three patients: a muscle flap in two and directed healing in one (Table 4).

The total number of procedures per patient ranged from three to seven.

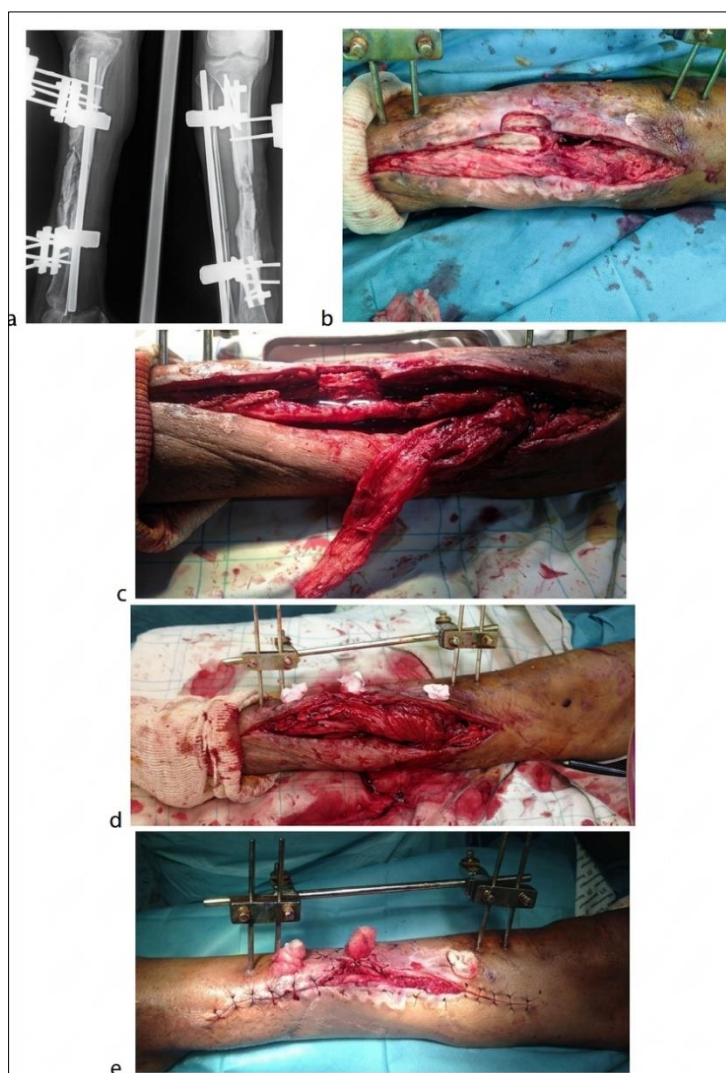


Figure 6: First stage of the induced membrane technique in a 53-year-old man with atrophic non-union of the middle third of the right leg. (a) Preoperative appearance. (b) Sequestrectomy and excision of the bone ends. (c) Medullary curettage and harvesting of a proximal medial hemisoleus flap. (d) Cement spacer inserted in the resulting defect. (e) Skin closure after flap rotation



Figure 7: Revision with iliac crest corticocancellous grafting and low-cost external fixation in a 38-year-old man operated on six times. (a) Preoperative view. (b, c, d) Successive postoperative radiographs

3.7. Complications

The immediate and intermediate postoperative course was uneventful in nine patients (60%). Six complications were recorded: five superficial pin-track infections, controlled by local care, tailored antibiotics and repositioning of the pins, and one necrosis of the

medial hemisoleus flap requiring necrosectomy followed by directed healing.

In the longer term, three patients showed persistent non-union requiring several revision procedures; two of them eventually united. One patient progressed to chronic osteitis.



Figure 8: Unfavourable outcome chronic osteitis of the left leg in a 63-year-old man after comminuted proximal-middle third fracture and multiple operations

3.8. Outcomes

Fourteen of the 15 patients were reassessed in the outpatient clinic; one was lost to follow-up. Follow-

up ranged from 5 to 24 months, with a mean of 10.4 months.

Union was achieved in 12 patients (80%), after a mean of 8 months (range 5–12 months). Infection was eradicated in 14 patients (93.4%). Residual sequelae comprised angular deformity in three patients and limb shortening in six.

According to the ASAMI bone criteria, results were excellent in four patients (26.6%), good in five (33.4%), fair in three (20%) and poor in two (13.4%),

giving 60% satisfactory bone results. The two poor results corresponded to the two failures of union: one persistent non-union and one chronic osteitis.

According to the ASAMI functional criteria, results were excellent in 33.4%, good in 46.6%, fair in 6.6% and poor in 13.4%, giving 80% satisfactory functional results. No amputation was performed in this series (Table 5).

Table 1: Demographic characteristics and features of the index injury (n = 15)

Parameter	Value
Leg fractures managed over the study period	704
Septic non-unions (incidence)	15 (2.13%)
Aseptic non-unions (incidence)	32 (4.5%)
Mean age (range)	41.1 years (18–70)
Patients under 45 years	8 (53.3%)
Men / Women	12 (80%) / 3 (20%)
Notable comorbidity	6 (40%)
Road traffic accident	80%
Right / Left side	60% / 40%
Isolated fracture	5 (33.4%)
Polytrauma	4 (26.6%)
Associated musculoskeletal injury	6 (40%)
Open fracture	13 (86.6%)
— Gustilo I	2 (13.4%)
— Gustilo II	5 (33.4%)
— Gustilo IIIa	5 (33.4%)
— Gustilo IIIb	1 (6.6%)
Closed fracture	2 (13.4%)
Both bones of the leg involved	15 (100%)
Complex fracture pattern	14 (93.4%)
Site: proximal / middle / middle–distal junction / distal third	2 / 4 / 4 / 5
Mean interval to initial treatment (range)	8 days (1–18)
Primary treatment: external fixation	13 (86.6%)
Primary treatment: intramedullary nailing	1 (6.6%)
Primary treatment: traditional splinting (<i>jbira</i>)	1 (6.6%)

Table 2: Clinical, radiological and biological features of the non-union (n = 15)

Parameter	n (%) or value
Mean interval to non-union (range)	12.1 months (7–24)
Abnormal mobility at the site	15 (100%)
Swelling and local warmth	10 (66.6%)
Discharging sinus	9 (60%)
Cutaneous tissue loss	5 (33.4%)
Angular deformity	5 (33.4%)
Limb shortening (mean 1.5 cm; 0.5–3)	4 (26.6%)
Trophic changes	1 (6.6%)
Atrophic non-union	8 (53.4%)
Hypertrophic non-union	4 (26.6%)
Eutrophic non-union	3 (20%)
Bone loss	9 (60%)
Raised CRP (16–56 mg/L)	10 (66.6%)
Raised ESR (16–20 mm/h)	3 (20%)
Leucocytosis (11,000–25,000/mm ³)	6 (40%)

CRP: C-reactive protein; ESR: erythrocyte sedimentation rate.

Table 3: Microbiological documentation (n = 15)

Culture result	Number of cases
Positive culture	8 (53.3%)
— Methicillin-susceptible <i>Staphylococcus aureus</i>	2
— Methicillin-resistant <i>Staphylococcus aureus</i>	2
— <i>Acinetobacter baumannii</i> + <i>Escherichia coli</i> + ESBL <i>Enterobacter</i> spp.	1
— Resistant <i>Enterobacter</i> spp. + <i>Proteus</i> spp.	1
— <i>Enterobacter</i> spp. + <i>Pseudomonas</i> spp.	1
— ESBL <i>Enterobacter</i> spp. + third-generation-cephalosporin-resistant <i>Enterobacter</i>	1
Negative culture	7 (46.7%)

ESBL: extended-spectrum beta-lactamase.

Table 4: Reconstruction procedures for the non-union (n = 15)

Procedure	Associated fixation	Number of cases
Osteoperiosteal decortication alone	Intramedullary nail	1
Osteoperiosteal decortication alone	External fixator	1
Decortication with osteosynthesis	Intramedullary nail	1
Inter-tibiofibular graft	External fixator	1
Corticocancellous bone graft	External fixator	3
Corticocancellous bone graft + decortication	External fixator	5
Induced membrane technique (two stages)	External fixator	3
Total		15
Soft-tissue coverage: muscle flap		2
Soft-tissue coverage: directed healing		1
Number of procedures per patient (range)		3–7

Table 5: Outcomes at latest follow-up according to the ASAMI criteria (n = 15)

Grade	Bone result n (%)	Functional result n (%)
Excellent	4 (26.6)	5 (33.4)
Good	5 (33.4)	7 (46.6)
Fair	3 (20.0)	1 (6.6)
Poor	2 (13.4)	2 (13.4)
Satisfactory (excellent + good)	9 (60.0)	12 (80.0)

Mean follow-up: 10.4 months (5–24). Union rate: 12/15 (80%). Mean time to union: 8 months (5–12). Eradication of infection: 14/15 (93.4%). Residual deformity: 3. Residual shortening: 6. Amputation: 0.

Table 6: Summary of the series

Domain	Summary
Period and sample	5 years (2011–2015); 15 septic non-unions among 704 leg fractures (2.13%)
Profile	Young man (sex ratio 4:1; mean age 41.1 years) injured in a road traffic accident (80%)
Index injury	Fracture of both bones, complex (93.4%) and open (86.6%), Gustilo III in 40%
Initial treatment	External fixation (86.6%); mean delay 8 days
Non-union	Atrophic (53.4%); bone loss (60%); mean interval 12.1 months
Microbiology	Culture yield 53.3%; <i>S. aureus</i> predominant (4/8), half methicillin-resistant
Strategy	Debridement + 4–8 weeks of tailored antibiotics + external fixation, then delayed reconstruction
Reconstruction	Graft ± decortication 60%; induced membrane 20%; inter-tibiofibular graft 6.6%; coverage 20%
Morbidity	Pin-track infection 33.4%; flap necrosis 6.6%; 3–7 procedures per patient
Outcome	Union 80% at 8 months; infection eradicated 93.4%; ASAMI satisfactory: bone 60%, functional 80%

4. DISCUSSION

4.1. Frequency and epidemiological profile

The incidence of 2.13% observed in our department falls within the 0.9% to 6.25% range reported for septic complications of leg fractures [1, 10]. This dispersion reflects case-mix rather than surgical quality: the proportion of high-grade open fractures, the delay before admission and the mode of primary osteosynthesis weigh more heavily than any other variable. Our series, in which 86.6% of injuries were open and 40% Gustilo type III, illustrates this dependence on the injury itself.

The mean age of 41.1 years and the 80% male predominance reproduce the profile described in recent literature. Sahu and Ranjan report a mean age of 37.5 years [11], Meleppuram and Ibrahim 38 years [12], Rohilla *et al.*, 31.3 years [13], Megas *et al.*, 39.7 years [14] and Apard *et al.*, 41.6 years [15], with male involvement ranging from 70% to 88.9% (Table 7). This homogeneity reflects the differential exposure of young men to high-energy occupational and road trauma. Road traffic accidents accounted for 80% of our cases, close to the figures of Sahu (100%) [11], Harshwal *et al.*, (92.3%) [16] and Meleppuram (85.7%) [12].

Comorbidities are seldom detailed in published series, although their contributory role is established. Smoking, present in two of our patients, significantly increases the risk of delayed union and non-union, particularly after open tibial fracture [17, 18]. Calori *et al.*, [19] and Pountos *et al.*, [20] have further demonstrated the deleterious effect of corticosteroids, non-steroidal anti-inflammatory drugs, certain anticoagulants and cytotoxic agents on bone repair. Unlike the severity of the index injury, these factors are modifiable and should be addressed systematically from the moment the fracture is first treated.

4.2. Weight of the index injury and its initial management

The severity of soft-tissue exposure remains the principal determinant of septic risk. A type III fracture carries a twenty-fold higher infection risk than a type I or II injury, and grades II and III show non-union rates approaching 14% [1, 21]. Across all grades and causes, infection rates after open tibial fracture range from 13% to 50% [1]. Our data fit this pattern, with 40% Gustilo type III, comparable to Sahu (66.6% type III) [11].

The choice of primary osteosynthesis remains debated. Gustilo type I and II open fractures can usually be internally fixed as though closed [22], and moderately reamed nailing is considered acceptable for limited soft-tissue exposure. Type III injuries classically call for emergency external fixation [22]. Our practice, with 86.6% external fixators, is close to that of Demir *et al.*, (100%) [23], and differs from series with a more favourable case-mix such as that of Harshwal *et al.*, in which nailing accounted for 84.6% [16]. The mean 8-day interval to definitive initial treatment, with outliers at 18 days, is by contrast a weakness specific to our setting: this delay, related to transfer logistics and implant availability, plausibly contributes to secondary contamination and deserves priority organisational attention.

The persistence, even marginal, of traditional splinting one case in this series highlights a problem specific to countries where modern medicine and empirical practices coexist. Such contentions delay diagnosis, aggravate skin complications and complicate reconstruction.

4.3. Diagnosis and microbiological documentation

The mean 12.1-month interval to non-union in our series lies within the wide range reported in the literature: 7.8 months for Megas *et al.*, [14], 8 months for Harshwal *et al.*, [16], 8.8 months for Xu *et al.*, [24], 11.9 months for Khan *et al.*, [25] and 13.6 months for Mahaluxmivala *et al.*, [26]. This variability mainly reflects heterogeneous definitions and the difficulty of assigning a date to the transition towards non-union in an infected environment.

The predominance of the atrophic pattern (53.4%) is found by most authors, at 69.3% for Harshwal [16]. It results from the combination of traumatic devascularisation, repeated excision and bacterial aggression of the bone bed.

The weak point of our work concerns microbiological documentation, positive in only 53.3% of cases. This yield is insufficient and is explained by frequent uncontrolled prior antibiotic exposure, by sampling that was at times single and superficial sinus swabbing has poor predictive value and by the absence of techniques adapted to adherent bacteria. Current recommendations insist on multiple deep intraoperative specimens taken after an antibiotic-free window, transported promptly and processed in a laboratory experienced in bone and joint infection [27]. Sonication of explanted hardware and molecular amplification broaden the diagnostic yield and should be incorporated into the protocol. The leading role of *Staphylococcus aureus* in our series is consistent with the literature; the high proportion of methicillin-resistant strains (half of the staphylococcal isolates) and the presence of ESBL-producing Enterobacteriaceae, however, demand particular vigilance and a rigorous isolation policy.

4.4. Therapeutic strategy

Agreement is complete on principles: excision back to healthy tissue, dead-space management, mechanical stability, tailored antibiotic therapy, soft-tissue coverage and osteogenic input. Divergence concerns the means.

Ilizarov distraction osteogenesis dominates publications of the last decade. Meleppuram and Ibrahim in 42 cases [12], Rohilla *et al.*, in 70 cases [13], Khan *et al.*, in 24 cases [25], Xu *et al.*, in 30 cases [24] and Megas *et al.*, in nine cases [14] all report high union rates with this method, which simultaneously addresses bone loss, infection and limb-length discrepancy. Its drawbacks are the duration of frame wear, the burden imposed on the patient and a substantial learning curve.

The induced membrane technique described by Masquelet [28] offers an attractive alternative for segmental defects, with a shorter period of fixation. We applied it in three patients (20%). Inter-tibiofibular grafting [29] and vascularised transfers complete the armamentarium for defects exceeding 6 to 8 cm, beyond which the volume of conventional graft becomes limiting.

Our strategy favoured a pragmatic approach adapted to material constraints: iliac crest corticocancellous grafting, alone or combined with Judet osteoperiosteal decortication, in 60% of patients, with stabilisation by an external fixator including simplified low-cost constructs. This combination, less expensive and technically more accessible than circular frames, achieved 80% union. Conversion to intramedullary

nailing in one patient after the site had been sterilised illustrates the option reported by Piriou *et al.*, [30] and Apard *et al.*, [15].

Soft-tissue coverage, required in three patients, determines the outcome as much as the bone procedure does. The hemisoleus flap necrosis observed here is a reminder of the fragility of such reconstructions in an infected field and argues for early collaboration with the plastic surgery team.

4.5. Outcomes compared with the literature

The 80% union rate obtained here, at a mean of 8 months, is consistent with the times reported by Sahu [11] and Khan [25] (8 months), Xu [24] (8.8 months) and Megas [14] (10 months). The number of procedures per patient three to seven is comparable to the 2 to 5 of Sahu [11], the 2 to 10 of Demir [23] and the 3 to 14 of Xu [24]. Repeated revision is not harmless: each excision depletes the bone stock and delays union, which argues for planning a complete reconstruction strategy from the first stage rather than chaining partial procedures.

Our ASAMI bone results (60% excellent and good) are lower than those of Harshwal (91.3%) [16], Megas (100%) [14] and Khan (83.3%) [25], and close to reported figures around 70% in comparable North African practice. Three factors explain the gap. First, the severity of the case-mix: 60% of our patients had bone loss. Second, the technique used, conventional grafting reaching its limits earlier than bone transport in extensive defects. Third, and above all, the short mean follow-up of 10.4 months, which mechanically penalises the score, since several unions still in progress may have been graded fair or incomplete.

Functional results were more favourable, with 80% satisfactory outcomes, close to those of Khan

(83.3%) [25], Demir (87.5%) [23] and Meleppuram (85%) [12]. This dissociation between bone and functional grading deserves emphasis: return to weight-bearing and to activity may precede the achievement of an optimal radiological result.

The 93.4% infection eradication rate is the strongest finding of this series. It supports the efficacy of the sequence radical excision – guided antibiotic therapy – external stabilisation, and matches the 100% reported by Meleppuram and Ibrahim with a 4- to 6-week antibiotic protocol [12]. Conversely, persistent infection in eight of the nine patients of Megas *et al.*, [14] illustrates how variable these results can be and how much depends on the quality of debridement.

No amputation was required in our series, whereas Khan reports one case [25]. This extreme solution is now discussed only in the face of a threat to life or of local conditions making union unattainable.

4.6. Limitations

This work carries the limitations inherent to its design: retrospective collection, small sample, absence of a comparison group, and incomplete operative records, notably regarding the exact construct used in four patients. The mean follow-up of 10.4 months is shorter than the 24 months usually recommended before declaring a bone infection cured, so late recurrence cannot be excluded. Finally, the absence of a standardised pre-treatment functional score and of a quality-of-life instrument limits interpretation of the benefit perceived by patients. A prospective multicentre study, with a minimum two-year follow-up and systematised microbiological sampling, would help define the respective indications of conventional grafting, the induced membrane technique and bone transport in this setting.

Table 7: Comparison of principal findings with published series

Author (year)	n	Mean age (years)	Men (%)	Open fractures (%)	Interval to non-union (months)	Number of procedures	Time to union (months)	Satisfactory ASAMI bone result (%)
Sahu and Ranjan (2016) [11]	60	37.5	83.3	91.7	—	2–5	8	—
Meleppuram and Ibrahim (2016) [12]	42	38	76.2	—	8–10	—	—	90
Rohilla <i>et al.</i> , (2016) [13]	70	31.3	88.6	94.3	—	—	—	—
Khan <i>et al.</i> , (2015) [25]	24	38	87.5	41.7	11.9	0–4	8	83.3
Harshwal <i>et al.</i> , (2014) [16]	13	37.4	84.6	84.6	8	—	—	91.3
Xu <i>et al.</i> , (2013) [24]	30	34.1	70	—	8.8	3–14	8.8	—
Karagyris <i>et al.</i> , (2012) [31]	9	37	88.9	—	—	—	—	—
Megas <i>et al.</i> , (2010) [14]	9	39.7	77.8	55.6	7.8	3–6	10	100
Apard <i>et al.</i> , (2010) [15]	7	41.6	85.7	85.7	—	—	—	—
Demir <i>et al.</i> , (2009) [23]	8	—	—	100	—	2–10	—	75
Mahaluxmivala <i>et al.</i> , (2005) [26]	10	—	—	60	13.6	1–4	—	—
Present series	15	41.1	80	86.6	12.1	3–7	8	60

Dashes indicate data not specified in the original publications.

5. CONCLUSION

Septic non-union of the leg remains a formidable complication, the end point of a high-energy open fracture in a young man injured on the road. It confronts the surgeon with two simultaneous and partly contradictory demands: sterilising a bone focus while preserving or restoring its capacity to unite.

In this series of 15 patients treated by a sequence combining radical excision, culture-guided antibiotic therapy, external fixation and delayed reconstruction, infection was eradicated in 93.4% of patients and union achieved in 80%, without recourse to amputation. These results match international series in terms of infection control, remain improvable on the bone side, and are obtained at the cost of iterative surgery three to seven procedures per patient and prolonged disability.

The best treatment of this condition remains its prevention. It depends on the codified and early management of the index open fracture: complete debridement, fixation matched to the injury grade, prompt soft-tissue coverage and rational antibiotic therapy. It also depends on shortening the time to definitive care, on abandoning traditional splinting, and on correcting modifiable risk factors, smoking foremost among them. Diagnostically, systematic multiple deep sampling and the use of modern microbiological techniques represent an immediate margin for improvement, since the relevance of anti-infective treatment depends entirely on culture yield.

ETHICAL DECLARATIONS

Ethics approval and consent to participate:

This retrospective study was conducted on anonymised records in accordance with the principles of the Declaration of Helsinki and with the institutional rules of the Mohammed VI University Hospital, Marrakech. Informed consent was obtained from the patients for the use of clinical and radiological images.

Consent for publication: All patients whose images appear in this article consented to their anonymised publication.

Availability of data: The anonymised dataset supporting the findings of this study is available from the corresponding author on reasonable request.

Conflicts of interest: The authors declare that they have no competing interests.

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in patient management and in the critical revision of the manuscript. R.C. supervised the work and approved the final version. All authors read and approved the final manuscript.

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