

Open Tibial Fractures Part 2: A Narrative Review of Definitive Treatment and Potential Applicability to the Southern African Context

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Abstract: The purpose of this study was to conduct a review of contemporary definitive treatment options, potential complications and clinical outcomes for open tibial shaft fractures and while assessing their relevance and applicability within South African context. Treatment options available in high-income countries may not be accessible in low-resource settings, requiring adaptations to the treatment approach based on local conditions. Only one African country has attempted to establish principal guidelines for the treatment of open tibial fractures through a consensus-based approach. These guidelines cover primary assessment, antibiotics, initial stabilization, referral criteria, debridement and irrigation, documentation, wound closure, soft-tissue management, amputation, and definitive internal fixation. Unfortunately, definitive fracture management recommendations for African low-resource countries are not yet available. There is a lack of data regarding the treatment of open tibial fractures in low-resource countries, particularly in regional and rural areas. Existing guidelines address antibiotic prophylaxis and treatment, debridement and lavage, initial surgical fixation, wound closure (both primary and definitive), soft-tissue management (including flap coverage), and bone fragment retention, all adapted to local resource availability. However, guidelines for definitive treatment remain unavailable. Treatment options recommended by high-income countries are largely unsuitable, and Southern African nations should focus on developing guidelines tailored to their available resources.

Keywords: open tibial fractures, management, low-resource countries, Southern Africa, review

Introduction

Managing open tibial fractures in the initial stages is highly challenging and requires a multifaceted approach.¹⁻⁴ Essential steps include administering intravenous and local antibiotics, performing thorough debridement and irrigation, determining the optimal timing for surgery, selecting appropriate skin closure methods, utilizing temporary wound dressings, managing soft tissue damage, and addressing large bone fragments effectively.^{1-3,5,6} Part one of this review highlighted the lack of data on open tibial fracture treatment in low-resource areas.⁶ Guidelines should prioritize antibiotics, debridement, fixation, wound closure, and soft-tissue management while considering local resources and as high-income country treatments are often unavailable, Southern African nations should develop region-specific protocols.⁶ Definitive treatment involves determining the optimal timing for definitive fixation, transitioning from external fixation, managing bone loss, deciding between limb salvage and amputation, selecting appropriate fixation techniques, addressing complications, and evaluating clinical outcomes.^{1-3,5-9}

The management of open tibial fractures in Africa presents significant challenges, including limited early access to specialist care, a lack of fixation devices and intraoperative radiographic imaging, and delayed presentations, as many patients first seek treatment from traditional healers and bone setters before accessing formal orthopaedic care.¹⁰ Additionally, access to healthcare in rural and regional areas remains a major challenge.¹¹ Recently, Graham et al

established a consensus on research priorities in orthopedic trauma in South Africa, with the treatment of open fractures, particularly open tibial fractures, identified as a top priority.¹² Unfortunately, universal guidelines for low-resource and African countries are lacking, with the only existing guideline published by the Malawi Orthopaedic Association/AO Alliance.¹³ Unfortunately, specific recommendations for definitive fracture management were not provided and the guidelines only suggested that definitive internal stabilization should be performed only when it can be immediately followed by definitive soft tissue coverage.¹³

The purpose of this study was to conduct a review of contemporary definitive treatment options, potential complications and clinical outcomes for open tibial shaft fractures and while assessing their relevance and applicability within Southern African context.

Methods

This study adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines¹⁴ and the updated recommendations outlined in the Cochrane Handbook.¹⁵

Eligibility Criteria

This project included all Level I–IV evidence-based clinical studies on open tibial shaft fractures. Reviews, systematic reviews, and meta-analyses were excluded, although their references were reviewed to identify relevant studies meeting the inclusion criteria. Abstracts and conference proceedings were also excluded from the study.

Literature Search

A systematic review of the literature was performed to identify all publications in English and German, screening the databases Medline, Embase, Scopus, and Google Scholar. These databases were screened using the following terms and Boolean operators: “tibial fractures” AND/OR “open” AND/OR “compound” AND/OR “tibial shaft”; AND/OR “complications” AND/OR “treatment” AND/OR “management”. For the Medline search the MeSH term “tibia” was used with the following qualifiers: “fractures, bone” and “compound fractures”. One reviewer conducted independent title and abstract screening. Disagreements between reviewers were resolved by consensus, and if no consensus was reached, they were carried forward to the full-text review. All eligible articles were manually cross-referenced to ensure that other potential studies were identified. The search period was restricted to studies published between 2000 and 2025 to ensure a contemporary review of current treatment approaches for open tibial shaft fractures.

Data Extraction and Quality Assessment

An electronic data extraction form was used to systematically collect information from each article, including the level of evidence, study location, patient age, and sex. Key areas documented included treatment principles, timing of surgery, management of large fragments, treatment of bone defects, limb salvage versus primary amputation, conversion to definitive treatment, fixation techniques, complications, clinical outcomes, and the applicability of these variables to the African context.

Results

Timing of Surgery

In general, the treatment of open tibial fractures should follow the standard principles of orthopaedic trauma management, and the presence of an open fracture should not justify deviating from established osteosynthesis guidelines.³ Type I and II open fractures can generally be treated with definitive osteosynthesis, and most Type III injuries can follow this approach, except in cases involving large or segmental bone defects, significant soft tissue damage requiring flap coverage, severely contaminated farm injuries, or vascular injuries requiring urgent reperfusion surgery.^{3,16} Treatment options include intramedullary fixation, plating, and external fixation methods like ring fixators and spatial frames, with intramedullary nailing generally being the primary choice for most open diaphyseal and extra-articular metaphyseal fractures, although alternative methods may be necessary in certain cases.^{3,7,8,16}

Although there are no universally established guidelines regarding the optimal timing of surgery for open tibial fractures, the Malawi guidelines may provide a useful framework in this context. These guidelines recommend stabilization with an external fixator at the time of initial debridement, if available, with definitive internal fixation performed once adequate and definitive soft tissue coverage is achievable. This approach is, of course, dependent on the availability of surgical expertise and the necessary hardware, and it can be implemented in rural, regional, and teaching hospital settings.

Conversion from Temporary External Fixation to Definitive Fixation

When a temporary external fixator is used for initial stabilization, transitioning to internal fixation is generally advised for definitive treatment.² However, there is ongoing debate regarding the ideal timing for safe conversion and the earliest point at which internal fixation can be performed.³ Current evidence strongly supports the view that external fixation of tibial fractures should be considered a temporary measure, with early conversion to intramedullary nailing recommended. This approach minimizes the risk of long-term complications associated with external fixation and promotes more efficient bone healing.¹⁷ In general, conversion should be performed at the earliest opportunity to minimize the risk of pin tract infections.¹⁷ Studies suggest that conversion from external fixation to intramedullary nailing is safest within two weeks of the initial procedure, as delayed conversion is associated with higher infection rates.^{18,19} Ye et al demonstrated that early conversion within 5–7 days is preferable, as infection rates were shown to increase significantly with delayed conversion, rising from 5.9% to 23% when performed after 7 days.²⁰ Melvin et al advocated for conversion as soon as the patient can tolerate another procedure and soft tissue coverage is adequate.²¹ A safety interval of less than 10 days should be used if pin tract infections are present, provided they are managed with debridement, irrigation, and antibiotics.²¹ Le Baron et al found that early conversion was associated with a reduction in both superficial and deep infections, higher union rates, and fewer required surgeries.²² Interestingly, Yokoyama et al demonstrated that the most critical factor in preventing deep infections when managing open tibial fractures with temporary external fixation followed by conversion to intramedullary nailing is achieving skin closure within one week.²³ As previously noted, reopening and exploring the wound during definitive fracture fixation, when converting a temporary external fixator to intramedullary nailing, does not appear to increase the risk of complications.²⁴

The Malawi guidelines recommend converting from external fixation to internal fixation as soon as possible, provided there is minimal contamination and the procedure is performed by an orthopaedic surgeon capable of simultaneously achieving adequate soft tissue coverage.¹³ The authors suggest following the approach described by Gopal et al, who recommended performing soft tissue coverage within 72 hours and advocated for early conversion from external to internal fixation to reduce the risk of pin-tract infections and malunion.^{13,25} Gopal et al also recommended transferring patients to an appropriate centre for definitive care.²⁵ This approach is particularly relevant in the African context, where surgical expertise is concentrated in teaching hospitals and is generally unavailable in regional or rural settings.¹⁰

Bone and Segmental Bone Defects

Bone loss can occur at the time of injury and may involve extruded fragments, partial or complete circumferential bone loss, or segmental defects.²⁵ Critical bone defects are generally defined as those that prevent healing despite surgical stabilization and necessitate further intervention, such as bone grafting, for successful recovery.^{26,27} The SPRINT trial defined a critical-sized bone defect as a fracture gap measuring at least 1 cm in length and encompassing more than 50% of the cortical diameter.²⁶ The primary techniques for addressing critical bone loss include the induced membrane technique (Masquelet), distraction osteogenesis, acute limb shortening and lengthening, vascularized fibular bone grafting, as well as more advanced methods such as plate-assisted bone segment transport and three-dimensional bioprinting.²⁵ Omar et al recommended distinguishing between primary and secondary defect reconstructions.³ For primary reconstruction, defects less than 3 cm can be addressed with limb shortening, defects under 5 cm with bone grafting, and defects greater than 5 cm with vascularized bone transplantation.³ For secondary reconstructions, defects larger than 3 cm are best treated with bone lengthening, while those exceeding 5 cm are ideally managed using the Masquelet technique.³ A simpler approach proposed by Ferreira and Tanwar suggests that bone defects less than 2 cm can be treated with primary shortening or bone grafting; defects between 2–6 cm can be addressed with the induced

membrane technique or acute shortening followed by bone transport and lengthening; and defects greater than 6 cm can be managed with bone transport and lengthening.²⁸

Induced Membrane Technique (Masquelet)

The Masquelet technique offers three key benefits: 1) The PMMA spacer maintains defect space, preventing tissue contracture; 2) The membrane, rich in growth factors enhances graft consolidation by promoting cell proliferation and osteoblastic differentiation; 3) The membrane creates a protective compartment, safeguarding the autograft from resorption.²⁹ The Masquelet technique occurs in two stages: first, bony debridement and placement of a PMMA cement spacer, with stabilization by fixation. The second stage, typically 6 to 12 weeks later, involves removing the spacer, preserving the membrane, and filling the defect with autologous bone graft, possibly supplemented by allograft or other substitutes, ensuring a 3:1 ratio of autograft to allograft.³⁰

Distraction Osteogenesis

Distraction osteogenesis for segmental bone loss involves transporting a bone segment using an external fixator or intramedullary device, initially described by Ilizarov for nonunions.^{30,31} The technique has gained popularity with the use of spatial and monolateral frames. After applying the frame, a corticotomy is performed, and the transport phase begins, progressing at up to 1 mm per day.^{30,31} Once the transported segment reaches the docking site, it is compressed until healing occurs, with the consolidation phase often taking twice as long as the transport phase.^{30,31} Advantages include reliability, weight-bearing during reconstruction, and no size limitations for defects.³² However, disadvantages include the lengthy consolidation process and the physical and psychological burden on the patient.³²

Acute Limb Shortening and Lengthening

Acute limb shortening is the simplest and likely fastest treatment for segmental bone loss, allowing for early primary closure without soft tissue tension, which enables delayed lengthening via distraction osteogenesis once the soft tissue heals.³² A major complication of acute limb shortening, especially with shortening over 3–5 cm, is arterial kinking, necessitating careful pulse monitoring, while excessive alteration of the muscle length-tension relationship can impair muscle function.²⁵

Vascularized Fibular Bone Grafting

Vascularized fibular grafting, developed in the 1970s for defects over 10 cm, has lost favour due to newer techniques like distraction osteogenesis and the Masquelet method.²⁵ Its main drawbacks include donor site morbidity, restricted weight-bearing for up to two years, and graft fractures in up to 20% of cases during the first year.³³

Plate-Assisted Bone Segment Transport

In 2018, Baringa et al described a novel technique for managing bone defects in a case report.³⁴ The method involved the use of an intramedullary limb-lengthening system combined with bridging plate fixation. A variable-angle plate was utilized to span the defect, while a precise intramedullary nail facilitated distraction osteogenesis. This approach was applied to a patient with a Grade IIIb open fracture presenting a 2.5 cm bone defect. This technique has several limitations, including the plate length, which may restrict the corticotomy site to the metaphyseal region, and the stroke distance of the nail, which limits bone transport without adjustments.³⁵ Complications of lengthening nails, including magnetically operated ones, may include nail bending, fractures, superficial infections, mechanism failure, and over-distraction.³⁵

Three-Dimensional Custom Implants

Advances in 3D printing technology now allow for patient-specific implants in orthopedic procedures, including post-traumatic limb reconstruction, by using processed CT data from the injured limb.^{36,37} Tetsworth et al reported the successful use of a 3D-printed custom titanium cage filled with bone graft, inserted into an induced membrane and stabilized with either a lateral locked plate or an intramedullary nail in five cases, achieving union in all cases.^{36,37} Nwankwo et al reported a single case with a 5-year follow-up, demonstrating successful union and satisfactory clinical outcomes.³⁸ These results are undoubtedly promising but require validation through larger case series.

The reported prevalence of bone loss in open long bone fractures is approximately 15%.³⁹ The ORCA Study Group, using a survey, found that the majority of orthopaedic surgeons from 31 African countries work in tertiary referral hospitals.⁴⁰ Although there are no data on whether regional hospitals in Africa manage bone defects, the Malawi guidelines recommend transferring grade III open fractures to the nearest central hospital for treatment and suggest that these injuries should be managed in specialist centres.¹³ Given the limited availability of expertise in regional hospitals across Africa, it is reasonable to assume that bone defects are, and should be, managed in referral hospitals.

Limb Salvage versus Primary Amputation

The decision between limb salvage and amputation for patients with severe injuries remains unresolved, despite the findings of the LEAP studies.⁴¹ The findings indicate that soft tissue injury is a more critical factor for function than bone damage, that scoring systems are not useful for decision-making, and that outcomes are influenced by patient factors like smoking, alcohol abuse, social status, and insurance; further, the cost-benefit of amputation is three times higher than limb salvage, with both options resulting in limited overall outcomes.^{3,41} The BOA/BAPRAS guidelines recommend primary amputation in cases of: avascular limbs with more than 4–6 hours of warm ischemia; segmental muscle loss involving more than two compartments; or segmental bone loss exceeding one-third of the tibial length.⁷ Delayed amputation after a failed limb reconstruction is a viable treatment option, leading to satisfactory outcomes similar to those of early amputation or successful limb reconstruction methods.³⁹

The Malawi guidelines recommend that immediate amputation, except in life-threatening emergencies, should not be performed without consultation with another surgical colleague.¹³ Primary amputation may be necessary as damage-control surgery in cases such as uncontrollable haemorrhage, severe crush injuries, or the need for rapid resuscitation.¹³ Early amputation within 48 hours may also be appropriate for limbs deemed unsalvageable.¹³ This decision should involve two surgeons, both to reassure the patient and family that a second opinion has been sought and to allow the operating surgeon to confirm the irreversible nature of the procedure.¹³

Fixation Techniques

The optimal surgical fixation strategy for open tibial shaft fractures remains controversial.⁴⁰ However, current evidence suggests that intramedullary nailing may offer superior outcomes compared to other fixation methods.⁴²

Intramedullary Nailing

Intramedullary nailing (IMN) is the preferred fixation method for open tibial shaft fractures.^{40,42,43} This technique offers several advantages, such as preservation of the periosteal blood supply, minimization of soft tissue trauma, and effective control of alignment, rotational forces, and translational forces.⁴³ Immediate intramedullary nailing for Grade 1–2 fractures is a safe option, provided there has been adequate debridement, irrigation, and appropriate soft tissue coverage.³ Farm injuries or contaminated wounds, however, should initially be managed with temporary fixation.^{3,40,43}

In a randomized controlled trial, Kalkar et al demonstrated that immediate unreamed nailing in patients with Grade 1–3b fractures is safe, provided meticulous soft tissue management is performed. Deep infection rates were found to be 3%, evenly distributed across the Gustilo-Anderson severity grades.⁴⁴ Yokohama et al found that immediate IMN for Grade I–IIIa fractures is not associated with an increased risk of infection, but reported higher infection rates in Grade IIIb and IIIc fractures.⁴⁵ The authors also noted no significant differences between reamed and unreamed nails.⁴⁵ Xue et al conducted a subgroup analysis of randomized trials and similarly concluded that there are no significant differences between reamed and unreamed nails.⁴⁶ The SPRINT trial found no differences in infection rates or reoperations to achieve union between the unreamed and reamed groups in open tibial shaft fractures, but suggested a potential benefit in favour of reamed nailing.⁴⁷ The LEAP study group evaluated immediate nailing for Grade III fractures and found that while infection rates were high, they were significantly lower compared to the external fixator group.⁴⁸ The authors concluded that intramedullary nailing, even for Grade III fractures, may be a more suitable option than external fixation to reduce the incidence of infection.⁴⁸ Based on current evidence, intramedullary nailing appears to be the preferred method for fixation in open tibial fractures.

External Fixation

Definitive external fixation remains a viable and effective treatment choice for open tibial shaft fractures. Beltios et al evaluated the use of a unilateral external fixator as the primary treatment for open tibial fractures in 212 patients, finding union at an average of 25 weeks.⁴⁹ However, they reported a high incidence of non-unions and delayed unions, with a reoperation rate of 20%.⁴⁹ Alsharif et al conducted a meta-analysis comparing external fixation to nailing, revealing higher rates of pin tract and superficial infections, as well as malunion with external fixation, and recommended nailing as the preferred fixation method for open tibial fractures.⁵⁰ Similar to Alsharif et al, Liu et al found that intramedullary nailing significantly reduced the risk of postoperative superficial infection and malunion compared to external fixation in patients with open tibial fractures, leading to the recommendation of intramedullary nailing.⁵¹ These findings were confirmed by Al-Hourani in a later meta-analysis, which reported that nailing resulted in lower reoperation rates and a greater reduction in Type III fractures.⁵²

Ring fixators, are another type of external fixation, and offer the advantage over intramedullary nailing by keeping the hardware away from the fracture site, similar to uniplanar external fixators. Theoretically, this may potentially reduce the risk of deep infection. However, the FIXIT study demonstrated that the risk of at least one complication was higher for the ring fixator compared to nailing, although there were no significant differences in infection, amputation, nonunion, soft tissue issues, malunion, or fracture healing and discouraged the use of ring fixators.⁵³ Earlier, Henley et al compared nailing to half-pin ring fixators and found that nailing resulted in significantly lower rates of malalignment and infection, with comparable outcomes in bone and soft tissue healing.⁵⁴ While external fixation is a viable option, intramedullary nailing appears to be the superior technique.

Plating

Plating remains an uncommon technique for tibial shaft fixation in open fractures.⁴⁰ Galal conducted a randomized controlled trial comparing nailing to percutaneous plating and found no significant differences between the groups in terms of infection or nonunion rates.⁵⁵ Bach and Hansen compared plating to external fixation in Type II–III open fractures and reported higher rates of deep infection (19%) in the plating group, compared to 3% in the external fixation group, though healing rates were similar in both groups.⁵⁶ Aviluca et al compared plating to nailing and found that ORIF resulted in higher rates of nonunion and significantly increased the odds of complications compared to intramedullary nailing (IMN) for open tibial fractures.⁵⁷ Kim et al demonstrated that minimally invasive plating can lead to favorable outcomes. In their study of 34 patients with Grade I–III open tibial fractures, they achieved primary union in 80%, with 9% experiencing superficial infections and 17% experiencing deep infections, none of which required hardware removal.⁵⁸ Based on current evidence, plating—whether minimally invasive or open—should not be considered the primary fixation method for open tibial fractures.

Fixation techniques for open long bone fractures vary widely, largely reflecting differences in available resources. Zubair et al reported that external fixation and Kirschner wires were used for both temporary and definitive fixation.¹⁰ Among the 31 studies reviewed, 10 described the use of K-wires and external fixators, while 7 reported conversion to intramedullary nailing. In 15 studies, intramedullary nails were employed for both initial and definitive fixation. It is recommended that fixation methods follow current published guidelines, provided the necessary resources and surgical expertise are available.¹⁰ Interestingly, a survey by the ORCA group found that only 12% of surgeons had access to external fixation, with almost no access to internal fixation.⁴⁰ When available, 94% of surgeons used intramedullary nailing as their first choice for primary fixation.⁴⁰ Despite this, casting and splint immobilization are still commonly used in these settings.⁴⁰ These findings highlight the significant resource constraints in many African hospitals, which necessitate adaptation of standard fixation strategies and may require reliance on temporary or non-operative methods.

Complications

Open tibial fractures are associated with a high risk of complications. In a case series of 173 patients treated over five years, Lua et al reported an 18% postoperative complication rate, with 21% developing deep infections and osteomyelitis of which 40% were caused by hospital-acquired MRSA.⁵⁹ Complications such as non-union, mal-union and delayed

unions was observed in 18%.⁵⁹ Regarding fixation techniques, a meta-analysis concluded that external fixation was associated with a significantly higher risk of complications, including nonunion and infection.⁶⁰

Infection Rates

The overall infection rate for open tibial fractures has shown a slight upward trend over the past four decades. The infection rate by decade was 14% for 1977–1986, 16.2% for 1987–1996, 20.5% for 1997–2006, and 18.1% from 2007 to 2017.⁶¹ Interestingly, the incidence of infections following open tibial fractures did not significantly differ between high-, middle-, and low-income countries.⁶² Papakostidis et al reported infection prevalence in relation to fracture severity.⁶³ Overall infection rates, regardless of treatment method, were 2% for Grade I, 3% for Grade II, 5% for Grade IIIA, 12% for Grade IIIB, and 16% for Grade IIIC fractures.⁶³ Infection rates for fractures treated with intramedullary nailing were 2% for Grade I, 3% for Grade II, 2.5% for Grade IIIA, and 9% for Grade IIIB.⁶³ Infection rates for fractures treated with external fixation were 6% for Grade IIIA, and 19% for Grade IIIB.⁶³ The INFINITI study reported a 12-month post-operative infection rate of 8.0%.⁶⁴ Infection rates varied by fracture grade: 0.6% in Grade 1, 1.8% in Grade 2, and 5.5% in Grade 3 fractures.⁶⁴ Hu et al reported a 17% incidence of superficial infections and a 1.5% incidence of deep infections in a retrospective study of 2,693 patients with open tibial fractures.⁶⁵ Independent risk factors included fracture type, surgery duration exceeding 120 minutes, intraoperative body temperature below 36.4°C, blood glucose levels below 100 mg/dL, platelet count under 288, and WBC count above 9.4.⁶⁵ Obviously, patient comorbidities also significantly influence infection rates.⁶⁶ Saiz et al reported the following odds ratios: 2.26 for alcohol use, 4.5 for bleeding disorders, 3.25 for congestive heart failure, 1.7 for diabetes, 2.17 for psychiatric illness, 1.56 for hypertension, 3.05 for obesity, and 2.09 for chronic obstructive pulmonary disease.⁶⁶ However, smoking and drug use were not associated with an increased risk.⁶⁶ Zhang et al identified predictors for both superficial and deep infections.⁶⁷ Risk factors for superficial infections included obesity (OR 2.08), morbid obesity (OR 4.99), wound contamination (OR 2.04), and Type III injuries (OR 6.12). Risk factors for deep infections included polytrauma (OR 3.6), wound contamination (OR 2.14), and Grade III fractures (OR 2.45).

Non-Union Rates

Santolini et al identified open fractures as the second most significant risk factor for nonunion, with tibial shaft fractures being especially vulnerable due to poor anterior soft-tissue coverage and limited vascularization.⁶⁸ A meta-analysis of 32 studies reported overall non-union rates, irrespective of treatment method, ranging from 0–52% for Grade I, 0–49% for Grade II, 1.6–50% for Grade IIIA, 0–54% for Grade IIIB, and 17–64% for Grade IIIC fractures.⁶³ Due to significant heterogeneity, the authors were unable to pool the data.⁶³ Nonunion rates for intramedullary nailing were 0.9% for Grade I, 4.3% for Grade II, 7.1% for Grade IIIA, and 3.4% for Grade IIIB fractures.⁶³

Other Complications

Malunion rates have been reported to range from 0% to 68%, with rates as high as 20% following intramedullary nailing.⁶⁹ Compartment syndrome in open tibial fractures, with an incidence of 9.1%, is similar to that in closed fractures and is most common in severe Grade III open injuries with comminution, particularly in pedestrian trauma.^{70,71} Patients who underwent external fixation had a 1.9 times higher risk of compartment syndrome, with additional risk factors including younger age, female sex, and more severe fractures.⁷¹ The development of Complex Regional Pain Syndrome (CRPS) following surgery is a significant concern, as it substantially complicates postoperative recovery and has profound negative clinical consequences.⁷² Prospective study on patients with tibial fractures reported a 31% incidence of Complex Regional Pain Syndrome following surgical repair, with rates of 33% for intramedullary nailing, and 29% for both nail-and-screw fixation and external fixation.⁷³ Smith et al reported that 70% of patients with displaced tibial shaft fractures developed acute localized osteoporosis, with 25% of these cases progressing to algodystrophy, and noted that external fixation increased the risk of algodystrophy.⁷⁴ Free flaps are an important reconstructive option for soft-tissue defects, but they are also associated with a risk of failure. The failure rate of a first free flap is reported to be approximately 10%, while the success rate for a second free flap is less favourable, with a failure rate of 17%. The amputation rate following flap failure is 12%, and in cases of partial flap loss, the preferred approach is a split-skin graft,

used in 50% of cases.⁷⁵ In a systematic review, flap necrosis occurred in 7.8% of cases, with partial necrosis in 9.1% and 13.8% requiring re-exploration for suspected vascular issues.⁷⁶

Outcomes

Surprisingly, there is a paucity of studies reporting on patient-reported outcomes, with most research focusing on clinical outcomes such as infection and union rates for various techniques. The LEAP study, however, has addressed both clinical and patient-reported outcomes in severe open tibial fractures, comparing limb salvage and amputation approaches.⁴¹ The LEAP STUDY reported the following findings: at 84 months, only 23% of participants were pain-free. While 58% had returned to work, 20–25% experienced limitations in their job performance. Within 6 months, complication rates included: 4% amputation, 24% non-union, 8% osteomyelitis, and 42% reported psychological distress at 24 months post-injury.^{77,78} Overall, patients who undergo open tibia fracture management face a significant risk of long-term functional, physical, and psychosocial consequences.^{77,78} For example, only 48% with grade 3 of patients returned to full time employment.⁷⁷ Cho et al reported that patients assessed at least one year after treatment had a lower extremity function score of 71, indicating minimal functional limitation or normal function, with outcomes strongly correlated to the occurrence of complications and the size of skin defects.⁷⁸ Giannoudis et al treated distal tibial fractures with circular ring fixation and reported good or excellent outcomes in 62% of patients six months after frame removal. However, they also observed that health-related quality of life assessments revealed significant ongoing effect.⁷⁹ Hari et al reported 66% excellent and 27% good outcomes in patients treated for Grade I–II fractures with intramedullary nailing, using Ketanjian's criteria.⁸⁰ Ferguson et al found that 47% of patients reported work-related disability, while 40% experienced persistent pain.⁸¹ Nightingale et al investigated factors important to patients recovering from an open tibial fracture and found that most were unable to return to previous activities, with key concerns including regaining physical mobility, treatment preferences, fears of poor recovery, and coping strategies to reduce psychological burden.⁸²

Outcomes in Africa

Orthopaedic care in Africa faces numerous challenges, including difficulties in training and retaining doctors in trauma and orthopaedics, inequitable access to healthcare, particularly for rural and impoverished populations, inadequate human resources and budgets, poor management practices, limited use of effective health information systems, and leadership challenges. Additionally, there is a rising burden of non-communicable chronic diseases, such as osteoarthritis, osteoporosis, diabetes, and injuries. For example, in Malawi, the total number of orthopaedic surgeons in 2021 was just 14, and orthopaedic care in district hospitals was primarily provided by orthopaedic clinical officers.⁸³ The Malawi Orthopaedic Association has published guidelines on the management of open tibial fractures, including 16 key statements covering primary assessment based on ATLS principles, antibiotic administration, debridement, documentation, stabilization, amputation, and appropriate patient counselling.¹³ Unfortunately, the implementation of these guidelines has not led to an overall improvement in clinical management. The authors speculated that one possible reason for this is the inadequate hospital facilities and resources, including a lack of water, electricity, radiography, basic orthopaedic equipment, anesthesia, and operating theatres.¹¹ Graham and the Orthopaedic Research Collaboration in Africa (ORCA) recently established a consensus on the top 10 research priorities in orthopaedics and the treatment of open tibial fractures was identified as one of the highest-priority areas for further investigation.¹²

A scoping review identified 39 studies from 15 different African countries and documented that the majority of open fractures were the result of high-energy road traffic accidents.¹⁰ Of these, 20% were grade 1, 21% were grade 2, and 59% were grade 3 open injuries. External fixation was the most common method of fixation, with a significant proportion treated non-operatively.¹⁰ Over 49% of patients experienced malunion, 5% had documented non-union, and nearly 6% had delayed union. Wound infection occurred in 9.4% of cases, while pin tract infection was noted in 7.6%.¹⁰

As early as 1996, Steiner & Kotisso investigated the treatment of open fractures in 20 patients using plate fixation, reporting a deep infection rate of 18%.⁸⁴ However, the study was significantly limited by a 50% loss to follow-up, which substantially compromised the validity and clinical applicability of the findings.⁸⁴ Kouassi et al evaluated the use of a locally developed external fixator as definitive treatment for open tibial fractures in 40 cases.⁸⁵ They reported a union rate of 72%, with a mean time to union of 8.5 months.⁸⁵ Malunion occurred in 7.5% of cases, non-union in 10%, pin tract

infections in 32%, and deep infections in 17%.⁸⁵ Ekure et al reported the outcomes of using an intramedullary nail without the need for intraoperative imaging, as part of the Surgical Implant Generation Network (SIGN), in the management of 55 open fractures.⁸⁶ Among these, 60% were classified as Gustilo-Anderson grade IIIA, 14% as grade II, and 14% as grade I open fractures.⁸⁶ The study documented an overall infection rate of 11%, a non-union rate of 3%, and no reported cases of postoperative deformities.⁸⁶ Adesina et al also utilized the SIGN nail for the management of 101 open fractures, the majority of which were classified as Gustilo-Anderson grade IIIA.⁸⁷ They reported an overall infection rate of 15%, with radiographic union achieved in 79% of cases at 12 weeks postoperatively.⁸⁷ Cortez et al followed 240 patients with open tibial fractures, treated with either nailing or external fixation, for a minimum of 3 years.⁸⁸ The authors reported complication rates of 24% in the nailing group and 27% in the external fixation group, with the majority of complications involving chronic infection or non-union.⁸⁸ Masterson et al investigated return-to-work rates following intramedullary nailing of lower extremity fractures.⁸⁹ They reported an overall return-to-work rate of 34% at 6 months and 56% at 18 months. Among patients who were employed pre-injury, 70.1% had resumed work by 18 months postoperatively.⁸⁹

Summary/Conclusions

Regarding surgical timing, grade I and II injuries, as well as grade IIIA fractures, can be definitively treated if the wounds are clean and primary closure can be easily achieved. In contrast, grade III fractures often benefit from temporary fixation before definitive treatment. Intramedullary nailing appears to be the treatment of choice for grade I–IIIa fractures. The management of grade IIIB and IIIC fractures depends on factors such as early debridement, timely conversion from external fixation to nailing, and prompt soft tissue management. Temporary external fixation, if deemed feasible, should be converted to definitive fixation within 14 days of the initial procedure, preferably within 5–7 days, provided adequate soft tissue coverage is achieved. Bone defects of at least 1 cm and involving more than 50% of the cortical diameter are typically treated with the Masquelet technique, distraction osteogenesis, or acute shortening. Defects under 2 cm can be managed with primary shortening or bone grafting, while those between 2–6 cm may require the Masquelet technique or acute shortening followed by bone transport. Defects greater than 6 cm are best treated with bone transport and lengthening. Despite the findings of the LEAP studies, the decision between limb salvage and amputation for patients with severe injuries remains inconclusive. Open tibial fractures are associated with a high risk of complications. Infection rates remain elevated, ranging from 14% to 18%, with higher-grade open fractures exhibiting higher rates of infection. Non-union rates can reach up to 50%, though they are lowest when treated with intramedullary nailing. Other complications associated with open tibial fractures include malunion, compartment syndrome, complex regional pain syndrome (CRPS), fixation failure, and soft tissue complications. Surprisingly, outcome studies are limited, and many patients experience ongoing pain, functional limitations, and a significant reduction in quality of life due to residual symptoms.

In Southern Africa, management of open tibial fractures is often limited by shortages of surgical implants and specialized expertise, particularly for advanced fixation and soft tissue reconstruction. First-world protocols cannot always be applied, forcing reliance on external fixation, splints, or casting. Improving outcomes would require investment in training, better access to implants, and stronger referral networks to ensure timely specialist care. Adapting evidence-based techniques to local resources, rather than attempting to replicate high-income strategies exactly, may be a possible interim solution to reduce complications and optimize healing.

High-income countries typically have >70 hospital beds per 10,000 population, near-universal ICU access, advanced diagnostics (such as routine MRI/CT availability), >20 orthopaedic specialists per 100,000 population, and widespread implant availability (>90% immediate access to specialized orthopaedic hardware such as plates, screws, and joint prostheses in trauma and elective cases).^{90,91} In contrast, Southern African nations average <10 beds per 10,000, with ICU capacity often limited to urban centers and <1 ventilator per 100,000 in rural areas.^{92,93} Orthopaedic specialists are scarce at <1 per 100,000 population, and implant availability is severely constrained (<30% access to advanced hardware in public facilities, with frequent reliance on basic external fixation, recycled implants, or delayed procurement).¹² This contrast underscores the need for low-cost, scalable interventions tailored to resource-constrained settings.

Data Sharing Statement

No datasets were generated or analysed during the current study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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References

- Nicolaides M, Pafitanis G, Vris A. Open tibial fractures: an overview. *J Clin Orthop Trauma*. 2021;20:101483. doi:10.1016/j.jcot.2021.101483
- Dheenadhaylan J, Nagashree V, Devendra A, Velmurugesan PS, Rajasekaran S. Management of open fractures: a narrative review. *J Clin Orthop Trauma*. 2023;44:102246. doi:10.1016/j.jcot.2023.102246
- Omar M, Zeckey C, Krettek C, Graulich T. Open fractures. *Unfallchirurg*. 2021;124(8):651–665. doi:10.1007/s00113-021-01042-2
- Shafiq B, Hacquebord J, Wright DJ, Gupta R. Modern principles of acute surgical management of open tibial distal fractures. *J Am Acad Orthop Surg*. 2021;29(11):e536–e547. doi:10.5435/JAAOS-D-20-00502
- Hohmann E, Birkholtz F, Glatt V, Tetsworth K. The “road to union” protocol for the reconstruction of isolated complex high-energy tibial trauma. *Injury*. 2017;48(6):1211–1216. doi:10.1016/j.injury.2017.03.018
- Hohmann E, Molepo M, Laubscher M, Tetsworth K. Open Tibial Fractures Part 1: a Narrative Review of Initial Treatment and Potential Applicability to the Southern African Context. *Orth Rev Res*. 2025;2025:427–436.
- British Orthopaedic Association Trauma Committee. British Association Standard for Trauma (BOAST): open fracture management. *Injury*. 2020;51(2):174–177. doi:10.1016/j.injury.2020.06.005
- Orthopaedic Trauma Association. Open Fractures. Available from: <https://ota.org/sites/files/2021-06/General%20B2%20Open%20Fractures.pdf>. Accessed Jan 7, 2025.
- Elniel AR, Giannoudis PV. Open fractures of the lower extremity: current management and clinical outcomes. *EFFORT Open Rev*. 2018;3(5):316–325. doi:10.1302/2058-5241.3.170072
- Zubair AA, Abdullateef R, Davis S, et al. A scoping review on the management of open fractures in African trauma and orthopaedics centres. *Cureus*. 2024;16(9):368925. doi:10.7759/cureus.68925
- Schade AT, Sabawo M, Nyamulani N, et al. Functional outcomes and quality of life at 1-year follow-up after an open tibia fracture in Malawi: a multicentre, prospective cohort study. *Lancet Global Health*. 2023;11(10):e1609–e1618. doi:10.1016/S2214-109X(23)00346-7
- Graham SM, Render L, Maqungo S. Orthopaedic Research Collaboration in Africa (ORCA). Establishing a consensus on research priorities in orthopaedic trauma within South Africa. *Eur J Orthop Surg Traumatol*. 2023;33(3):533–540. doi:10.1007/s00590-022-03413-w
- Schade AT, Yesaya M, Bates J, Martin Jr C, Harrison WJ. The Malawi Orthopaedic Association/AO alliance guidelines and standards for open fracture management in Malawi: a national consensus statement. *Malawi Med J*. 2020;32(3):112–118. doi:10.4314/mmj.v32i3.2
- Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic reviews and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*. 2015;4(1). doi:10.1186/2046-4053-4-1
- Cumpston M, Li T, Page MJ, et al. Updated guidance for trusted symptomatic reviews of the Cochrane handbook for systematic reviews of interventions. *Cochrane Database Syst Rev*. 2019;10:ED000142. doi:10.1002/14651858.ED000142
- Duyos OA, Beaton-Comulada D, Davila-Parilla A, et al. Management of Open Tibial Shaft Fractures: does the Timing of Surgery Affect Outcomes? *J Am Acad Orthop Surg*. 2017;25(3):230–238. doi:10.5435/JAAOS-D-16-00127
- Pairon P, Ossendorf C, Kuhn S, Hofmann A, Rommens PM. Intramedullary nailing after external fixation of the femur and tibia: a review of advantages and limits. *Eur J Trauma Emerg Surg*. 2015;41(1):25–38. doi:10.1007/s00068-014-0448-x
- Della Rocca GJ, Crist BD. External fixation versus conversion to intramedullary nailing for definitive management of closed fractures of the femoral and tibial shaft. *J Am Acad Orthop Surg*. 2006;14(10):S131–135. doi:10.5435/00124635-200600001-00030
- Bhandari M, Zlowodzki M, Tornetta III P, Schmidt A, Templeman DC. Intramedullary nailing following external fixation in femoral and tibial shaft fractures. *J Orthop Trauma*. 2005;19(2):140–144. doi:10.1097/00005131-200502000-00012
- Ye Z, Zhao S, Zeng C, Luo Z, Yuan S, Li R. Study on the relationship between the timing of conversion from external fixation to internal fixation and infection in the treatment of open fractures of extremities. *J Orthop Surg*. 2021;16(1):662. doi:10.1186/s13018-021-02814-7
- Melvin JS, Dombroski DG, Torbert JT, Kovach SJ, Esterhai JL, Mehta S. Open tibial shaft fractures: i. Evaluation and initial wound management. *J Am Acad Orthop Surg*. 2010;18(1):10–19. doi:10.5435/00124635-201001000-00003

22. Le Baron M, Maman P, Volpi R, Flecher X. External fixation as definitive treatment or external fixation followed by early fixation in open fractures of the tibial shaft: a descriptive study. *Injury*. 2024;55(Suppl 1):111477. doi:10.1016/j.injury.2024.111477
23. Yokohama K, Uchino M, Nakamura K, et al. Risk factors for deep infection in secondary intramedullary nailing after external fixation for open tibial fractures. *Injury*. 2006;37(6):554–560. doi:10.1016/j.injury.2005.08.026
24. Reynolds AW, Garay M, Philip FH, Altman GT, Nwankwo CH. Definitive fixation of open tibia fractures: does reopening the traumatic wound increase complication rates? *J Clin Orthop Trauma*. 2021;24:101715. doi:10.1016/j.jcot.2021.101715
25. Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. *J Bone Joint Surg Br*. 2000;82(7):959–966. doi:10.1302/0301-620x.82b7.10482
26. Andrew A, Meulenkamp B, Wilken G, Papp S. Managing bone loss in open fractures. *OTA International*. 2020;3(1):e059. doi:10.1097/OI9.000000000000059
27. Sanders D, Bhandari M, Guyatt G, et al. SPRINT investigators. Critical-Sized Defect in the Tibia Is it Critical? Results From the SPRINT Trial. *J Orthop Trauma*. 2014;28(11):632–635. doi:10.1097/BOT.0000000000000194
28. Nauth A, Schemitsch E, Norris B, Nollin Z, Watson JT. Critical-Size Bone Defects: is There a Consensus for Diagnosis and Treatment? *J Orthop Trauma*. 2018;32(1):S7–S11. doi:10.1097/BOT.0000000000001115
29. Ferreira N, Tanwar YS. Systematic Approach to the Management of Post-traumatic Segmental Diaphyseal Long Bone Defects: treatment Algorithm and Comprehensive Classification System. *Strategies Trauma Limb Reconstr*. 2020;15(2):106–116. doi:10.5005/jp-journals-10080-1466
30. Masquelet AC, Begue T. The concept of induced membrane for reconstruction of long bone defects. *Orthop Clin North Am*. 2010;41(1):27–37. doi:10.1016/j.ocl.2009.07.011
31. Masquelet AC, Kanakaris NK, Obert L, Stafford P. Bone Repair Using the Masquelet Technique. *J Bone Joint Am*. 2019;101(11):1024–1036. doi:10.2106/JBJS.18.00842
32. Ilizarov GA. The principles of the Ilizarov method. *Bull Hosp Jt Dis Orthop Inst*. 1988;48(1):1–11.
33. Mauffrey C, Barlow BT, Smith W. Management of segmental bone defects. *J Am Acad Orthop Surg*. 2015;23(3):143–153. doi:10.5435/JAAOS-D-14-00018
34. Khira YM, Badawy HA. Pedicled vascularized fibular graft with Ilizarov external fixator for reconstructing a large bone defect of the tibia after tumor resection. *J Orthop Traumatol*. 2013;14(2):91–100. doi:10.1007/s10195-013-0225-3
35. Baringa G, Beason AM, Gardner MP. Novel Surgical Approach to Segmental Bone Transport Using a Magnetic Intramedullary Limb Lengthening System. *J Am Acad Orthop Surg*. 2018;26(22):e477–e482. doi:10.5435/JAAOS-D-17-00487
36. Nolte PB, Kemmerer M, Spranger N, et al. Plate-assisted bone segment transport for bone defects of the lower extremities: possibilities and limitations of treatment. *Unfallchirurg*. 2023;126(3):200–207. doi:10.1007/s00113-023-01291-3
37. Tetsworth K, Block S, Glatt V. Putting 3D modelling and 3D printing into practice: virtual surgery and preoperative planning to reconstruct complex post-traumatic skeletal deformities and defects. *Sicot J*. 2017;3:16. doi:10.1051/sicotj/2016043
38. Tetsworth K, Woloszyk A, Glatt V. 3D printed titanium cages combined with the Masquelet technique for the reconstruction of segmental femoral defects: preliminary clinical results and molecular analysis of the biological activity of human-induced membranes. *OTA Int*. 2019;2(1):e016. doi:10.1097/OI9.000000000000016
39. Mwangi TE, Fabrice LM, Magembe PM, et al. Prevalence, Pattern and Treatment of Traumatic Bone Loss Following Long Bone Open Fractures at Kilimanjaro Christian Medical Centre. *East Afr Health Res J*. 2024;8(3):426–431. doi:10.24248/eahrj.v8i3.813
40. ORCA Study Group. Open tibial shaft fractures: treatment patterns in sub-Saharan Africa. *OTA Int*. 2023;6(2):e228. doi:10.1097/OI9.000000000000228
41. Nwankwo EC, Chen F, Nettles DL, Adams SB. Five-Year Follow-Up of Distal Tibia Bone and Foot and Ankle Trauma Treated with a 3D-Printed Titanium Cage. *Case Rep Orthop*. 2019;7571013. doi:10.1155/2019/7571013
42. Müller CW, Krettek C, Decker S, Hankemeyer S, Hawi N. Limb salvage or amputation after severe trauma to the lower extremities: evidence from the LEAP Study. *Unfallchirurg*. 2016;119(5):400–407. doi:10.1007/s00113-016-0180-6
43. van der Merwe L, Birkholtz F, Tetsworth K, Hohmann E. Functional and psychological outcomes of delayed lower limb amputation following failed lower limb reconstruction. *Injury*. 2016;47(8):1756–1760. doi:10.1016/j.injury.2016.05.027
44. Shen M, Tejwani N. Open tibial shaft fracture fixation strategies: intramedullary nailing, external fixation, and plating. *OTA Int*. 2024;7(4 Suppl): e316. doi:10.1097/OI9.0000000000000316
45. Foote CJ, Guyatt GH, Vignesh KN, et al. Which Surgical Treatment for Open Tibial Shaft Fractures Results in the Fewest Reoperations? A Network Meta-analysis. *Clin Orthop Relat Res*. 2015;473(7):2179–2192. doi:10.1007/s11999-015-4224-y
46. Egol K. Tibia and fibula shaft fractures. In: Kenneth Egol KK, Zuckerman J, editors. *Handbook of Fractures*. Philadelphia, PA: Wolters Kluwer Health; 2020.
47. Kalkar S, Tornetta III P. Open fractures of the tibia treated by immediate intramedullary tibial nail insertion without reaming: a prospective study. *J Orthop Trauma*. 2007;21(3):153–157. doi:10.1097/BOT.0b013e3180336923
48. Yokohama K, Itoman M, Uchino M, Fukushima K, Nitta H, Kojima Y. Immediate versus delayed intramedullary nailing for open fractures of the tibial shaft: a multivariate analysis of factors affecting deep infection and fracture healing. *Indian J Orthop*. 2008;42(4):410–419. doi:10.4103/0019-5413.43385
49. Xue D, Zheng Q, Li H, Qian S, Zhang B, Pan Z. Reamed and unreamed intramedullary nailing for the treatment of open and closed tibial fractures: a subgroup analysis of randomised trials. *Int Orthop*. 2010;34(8):1307–1313. doi:10.1007/s00264-009-0895-x
50. Bhandari M, Guyatt G, Tornetta III P, et al. Randomized trial of reamed and unreamed intramedullary nailing of tibial shaft fractures. *J Bone Joint Surg Am*. 2008;90(12):2567–2578. doi:10.2106/JBJS.G.01694
51. Webb LX, Bosse MJ, Castillo RC, MacKenzie J, Group LEAPS. Analysis of surgeon-controlled variables in the treatment of limb-threatening type-III open tibial diaphyseal fractures. *J Bone Joint Surg Am*. 2007;89(5):923–928. doi:10.2106/JBJS.F.00776
52. Beltios M, Savvidou O, Kovanis J, Alexandropoulos P, Papagelopoulos P. External fixation as a primary and definitive treatment for tibial diaphyseal fractures. *Strategies Trauma Limb Reconstr*. 2009;4(2):81–87. doi:10.1007/s11751-009-0062-3
53. Alsharaf JF, Ghaddaf AA, AlQuhaibi MS, et al. External fixation versus intramedullary nailing for the management of open tibial fracture: meta-analysis of randomized controlled trials. *Int Orth*. 2023;47(12):3077–3097. doi:10.1007/s00264-023-05879-7

54. Liu J, Xie L, Liu L, et al. Comparing external fixators and intramedullary nailing for treating open tibia fractures: a meta-analysis of randomized controlled trials. *J Orthop Surg.* 2023;18(1):13. doi:10.1186/s13018-022-03490-x
55. Al-Hourani K, Donovan R, Stoddart MT, Foote CJ, Kelly MB. Definitive Fixation Outcomes of Open Tibial Shaft Fractures: systematic Review and Network Meta-analysis. *J Orthop Trauma.* 2021;35(11):561–569. doi:10.1097/BOT.0000000000002090
56. Major Extremity Trauma Research Consortium (METRC). Modern External Ring Fixation Versus Internal Fixation for Treatment of Severe Open Tibial Fractures: a Randomized Clinical Trial (FIXIT Study). *J Bone Joint Surg Am.* 2022;104(12):1061–1067. doi:10.2106/JBJS.21.01126
57. Henley MB, Chapman JR, Agel J, Harvey EJ, Whorton AM, Swiontowski MF. Treatment of type II, IIIA, and IIIB open fractures of the tibial shaft: a prospective comparison of unreamed interlocking intramedullary nails and half-pin external fixators. *J Orthop Trauma.* 1998;12(1):1–7. doi:10.1097/00005131-199801000-00001
58. Galal S. Minimally invasive plate osteosynthesis has equal safety to reamed intramedullary nails in treating Gustilo-Anderson type I, II and III-A open tibial shaft fractures. *Injury.* 2018;49(4):866–870. doi:10.1016/j.injury.2018.03.008
59. Aw B, Hansen Jr ST. Plates versus external fixation in severe open tibial shaft fractures. A randomized trial. *Clin Orth Relat Res.* 1989;241:89–94.
60. Aviluca FR, Sathiyakumar V, Greenberg SE, Ghiam M, Thakore RV, Francois E. Open distal tibial shaft fractures: a retrospective comparison of medial plate versus nail fixation. *Eur J Trauma Emerg Surg.* 2016;42(1):101–106. doi:10.1007/s00068-015-0519-7
61. Kim JW, Oh CW, Jung WJ, Kim JS. Minimally invasive plate osteosynthesis for open fractures of the proximal tibia. *Clin Orthop Surg.* 2021;4(4):313–320. doi:10.4055/cios.2012.4.4.313
62. Lua J, Tan VH, Sivasubramanian H, Kwek E. Complications of Open Tibial Fracture Management: risk Factors and Treatment. *Malay Orthop J.* 2017;11(1):18–22. doi:10.5704/MOJ.1703.006
63. Giovannini F, de Palma L, Panfigi A, Marinelli M. Intramedullary nailing versus external fixation in Gustilo type III open tibial shaft fractures: a meta-analysis of randomised controlled trials. *Strategies Trauma Limb Reconstr.* 2016;11(1):1–4. doi:10.1007/s11751-016-0245-7
64. Castillo IA, Heiner JA, Meremikwu RI, Kellam J, Warner SJ. Where are we in 2022? A summary of 11,000 open tibia fractures over 4 decades. *J Orthop Trauma.* 2023;37(8):e326–e334. doi:10.1097/BOT.0000000000002602
65. Chebli D, Dhaif F, Ridha A, Schade A, Khatri. A meta-analysis of the incidence of infections following open tibia fractures and the microorganisms that cause them in high-, middle- and low-income countries. *Trop Doct.* 2024;54(3):272–281. doi:10.1177/00494755241232171
66. Papakostidis C, Kanakaris NK, Pretel J, Faour O, Morell DJ, Giannoudis PV. Prevalence of complications of open tibial shaft fractures stratified as per the Gustilo-Anderson classification. *Injury.* 2011;42(12):1408–1415. doi:10.1016/j.injury.2011.10.015
67. Doshi P, Gopalan H, Sprague S, Pradhan C, Kulkarni S, Bhandari M. Incidence of infection following internal fixation of open and closed tibia fractures in India (INFINITI): a multi-centre observational cohort study. *BMC Musculoskelet Disord.* 2017;18(1):156. doi:10.1186/s12891-017-1506-4
68. Hu Q, Zhao Y, Sun B, Qi W, Shi P. Surgical site infection following operative treatment of open fracture: incidence and prognostic risk factors. *Int Wound J.* 2020;17(3):708–715. doi:10.1111/iwj.13330
69. Saiz Jr AM, Stwalley D, Wolinski P, Miller AN. Patient Comorbidities Associated With Acute Infection After Open Tibial Fractures. *J Am Acad Global Res Rev.* 2022;6(9):e22.00196. doi:10.5435/JAAOSGlobal-D-22-00196
70. Zhang J, Lu V, Zhou AK, Stevenson A, Thahir A, Krkovic M. Predictors for infection severity for open tibial fractures: major trauma centre perspective. *Arch Orthop Trauma Surg.* 2023;143(11):6579–6587. doi:10.1007/s00402-023-04956-1
71. Santolini E, West R, Giannoudis PV. Risk factors for long bone fracture non-union: a stratification approach based on the level of the existing scientific evidence. *Injury.* 2015;46(8):S8–S19. doi:10.1016/S0020-1383(15)30049-8
72. Patel I, Young J, Washington A, Vaidya R. Malunion of the Tibia: a Systematic Review. *Medicina.* 2022;58(3):389. doi:10.3390/medicina58030389
73. Blick SS, Brumback RJ, Poka A, Burgess AR, Ebrahim NA. Compartment syndrome in open tibial fractures. *J Bone Joint Surg Am.* 1986;68(9):1348–1353.
74. Beebe MJ, Auston DA, Quade JH, et al. OTA/AO Classification Is Highly Predictive of Acute Compartment Syndrome After Tibia Fracture: a Cohort of 2885 Fractures. *J Orthop Trauma.* 2017;31(11):600–605. doi:10.1097/BOT.0000000000000918
75. Goh EL, Chidambaram S, Ma D. Complex regional pain syndrome: a recent update. *Burs Trauma.* 2017;5:2. doi:10.1186/s41038-016-0066-4
76. Sarangi PP, Ward AJ, Smith EJ, Staddon GE, Atkins RM. Algodystrophy and osteoporosis after tibial fractures. *J Bone Joint Surg Br.* 1993;75(3):450–452. doi:10.1302/0301-620X.75B3.8496220
77. Smith EJ, Ward AJ, watt I. Post-traumatic osteoporosis and algodystrophy after external fixation of tibial fractures. *Injury.* 1993;411–415. doi:10.1016/0020-1383(93)90108-i
78. Koster ITS, Borgdorff MP, Jamaludin FS, de Jong T, Botman M, Driessen C. Strategies Following Free Flap Failure in Lower Extremity Trauma: a Systematic Review. *JPRAS Open.* 2023;36:94–104. doi:10.1016/j.jpra.2023.03.002
79. Serra PL, Boriani F, Khan U, Atzeni M, Figus A. Rate of Free Flap Failure and Return to the Operating Room in Lower Limb Reconstruction: a Systematic Review. *J Clin Med.* 2024;13(15):4295. doi:10.3390/jcm13154295
80. Higgins TF, Klatt JB, Beals TC. Lower Extremity Assessment Project (LEAP)—the best available evidence on limb-threatening lower extremity trauma. *Orthop Clin North Am.* 2010;41(2):233–239. doi:10.1016/j.ocl.2009.12.006
81. Higgin RP, Palmer J, Qureshi AA, Hancock NJ. Patient reported outcomes after definitive open tibial fracture management. *Injury.* 2022;53(11):3838–3842. doi:10.1016/j.injury.2022.09.015
82. Cho JH, Lee IJ, Bang JY, Song HK. Factors affecting clinical outcomes after treatment of extra-articular open tibial fractures. *J Orthop Sci.* 2016;21(1):63–67. doi:10.1016/j.jos.2015.10.022
83. Giannoudis VP, Ewins E, Taylor DM, Foster P, Harwood P. Clinical and Functional Outcomes in Patients with Distal Tibial Fracture Treated by Circular External Fixation: a Retrospective Cohort Study. *Strategies Trauma Limb Reconstr.* 2021;16(2):86–95. doi:10.5005/jp-journals-10080-1516
84. Hari K, Srinath KM, Daddimani RM. A Prospective Study on Clinical Outcome of Primary Nailing in Open Type I to Type IIIA Tibial Diaphyseal Fractures. *J Orthopaedic Diseases Traumatology.* 2022;5(2):56–60. doi:10.4103/jodp.jodp_37_21
85. Ferguson M, Brand C, Lowe A, et al. Outcomes of isolated tibial shaft fractures treated at level 1 trauma centres. *Injury.* 2008;39(2):187–195. doi:10.1016/j.injury.2007.03.012
86. Nightingale J, Shu'an KL, Scammell BE, Leighton P, Ollivere BJ. What Is Important to Patients Who Are Recovering From an Open Tibial Fracture? A Qualitative Study. *Clin Orth Relat Res.* 2022;480(2):263–272. doi:10.1097/CORR.0000000000002031

87. Schade AT, Sabawao M, Jaffry Z, et al. Improving the management of open tibia fractures, Malawi. *Bull World Health Organ.* 2024;102(4):255–264. doi:10.2471/BLT.23.290755
88. Steiner AK, Kotisso B. Open fractures and internal fixation in a major African hospital. *Injury.* 1996;27(9):625–630. doi:10.1016/s0020-1383(96)00107-6
89. Kouassi KJE, Akobe JR, Kouassi AA, et al. Locally developed external fixators as definitive treatment of open tibia diaphyseal fractures: a clinical prospective study conducted in Ivory Coast. *Int Orthop.* 2022;46(1):79–87. doi:10.1007/s00264-021-05073-7
90. OECD. *Health at a Glance 2023: OECD Indicators.* Paris: OECD Publishing; 2023.
91. American Academy of Orthopaedic Surgeons. *Orthopaedic Practice in the U.S. (OPUS) Survey Report 2022.* Rosemont, IL: AAOS; 2023.
92. World Health Organization. *Global Health Observatory: Hospital Beds (per 10,000 Population) and Critical Care Capacity in Africa.* Geneva: WHO; 2023.
93. Ekure J, Akellot D, Amuron N. Short-Term Outcomes of Treatment of Open Fracture of Long Bone Using Surgical Implant Generation Network Nail at Kumi Orthopaedic Center, Uganda. *J Med – Clin Res & Rev.* 2020;4(8):1–3.

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