Treatment of a post-traumatic bone defect following a comminuted metaphyseal tibial fracture using S53P4 bioactive glass: a case report

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ABSTRACT

Background: High-energy fractures of the distal tibia associated with soft tissue defects represent a significant therapeutic challenge due to the high risk of infection and non-union. We demonstrate an effective treatment of such an infection-prone fracture using S53P4 bioactive glass.

Case Report: We present the case of a 53-year-old male patient who sustained a comminuted distal metaphyseal fracture of his tibia and fibula, complicated by extensive burns in the vicinity and a bone defect. Following initial stabilization and soft tissue management, the bone defect was treated with plate osteosynthesis and filled with S53P4 bioactive glass. At the 11-month follow-up (13 months post-injury), the fracture had healed with a good functional outcome, as evidenced by the American Orthopaedic Foot and Ankle Society ankle hindfoot score, and there were no signs of infection.

Conclusion: S53P4 bioactive glass is an effective alternative to autologous bone grafts in high-risk environments due to its osteoinductive and antimicrobial properties.

Keywords: Case report, tibial metaphyseal fracture, bone defect, bioactive glass, S53P4, osteomyelitis prevention, internal fixation.

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Introduction

High-energy fractures of the tibial shaft, particularly in the distal third, pose a significant management challenge due to the limited muscular coverage in this region [1,2]. These injuries are characterized by comminution, simultaneous fractures of the tibia and fibula at the same level, diastasis, and frequent association with open wounds or severe soft-tissue damage. Surgical intervention is almost universally required, except in cases of extreme patient polymorbidity. Acceptable reduction parameters include shortening up to 1 cm, angulation up to 5° in the frontal plane, 10° in the sagittal plane, 10° of rotation, and greater than 50% cortical fragment contact. While intramedullary nailing is the standard of care for shaft fractures, plate fixation is indicated for the most proximal or distal segments [2].

This case report describes a patient with a distal tibial and fibular fracture caused by direct trauma, complicated by limb shortening and adjacent burn injuries. The objective of treatment was to restore tibial length and manage a substantial bone defect. The size of the defect was measured on preoperative computed tomography (CT) imaging, revealing dimensions of ~2.5 cm (craniocaudal) × 2.1 cm (anteroposterior) × 3.1 cm (mediolateral). This resulted in an estimated focal ellipsoidal defect volume of ~8.5 cm^3 (Figure 2). For this defect, we opted to use S53P4 bioactive glass, which provides essential antimicrobial properties in a clinical scenario complicated by burn-damaged soft tissues, where baseline infection rates typically range from 5% to 15% [2].

Case Presentation

A 53-year-old male, non-smoker with no significant comorbidities, sustained a work-related injury on December 26, 2024, when he was struck by hot steel bars. He had multiple injuries, including an open fracture of the right femoral shaft (Gustilo-Anderson Grade I), a comminuted fracture of the distal third of the left tibia, and second- to fourth-degree burns on the right thigh, left leg, and ankle area (Figure 1).

Initially, the femoral fracture was stabilized with an intramedullary nail, and the left lower leg fracture was managed with an external fixator. Due to the burns, necrectomies and split-thickness skin grafting were performed in collaboration with plastic surgeons.

Following prolonged soft tissue healing, the patient was readmitted 2 months later for the definitive surgery. Definitive surgical reconstruction was performed via a combined approach under spinal anesthesia. First, a lateral approach to the fibula was performed. Next, an anteromedial approach to the distal tibia was utilized. To facilitate anatomical restoration of the mechanical axis, an ankle distractor was provisionally placed between the tibia and the talus. Open reduction and internal fixation were executed using a locking compression plate (LCP) acting as a neutralization construct of the fibula. Under distraction, major structural fragments of the tibial metaphysis were provisionally stabilized with Kirschner wires. A large, structurally significant cortical fragment was definitively fixed utilizing a cortical lag screw to maximize interfragmentary compression. The remaining cavitary metaphyseal bone defect estimated at 8.5 cm^3 was then tightly packed with S53P4 bioactive glass granules (BonAlive®). After moistening the granules with saline, all granules were put in the defect, and accidentally spilled granules outside the defect were removed as stated in the BonAlive® instructions for use [3]. Definitive stabilization of the medial column was completed using a second LCP configured as a bridging plate across the metaphyseal defect. Following stable internal fixation, the provisional distractor and K-wires were removed.

Figure 1. Initial thermal burns involving the left ankle and distal lower leg.

Control X-rays were taken at 2.5 weeks, 2, 3.5, and 11 months postoperatively (Figure 3). Close examination with a focus on finding possible infection or non-union was performed in each control. Because the patient consistently demonstrated clean, well-healed surgical wounds, a complete absence of local inflammatory signs (erythema, warmth, fluctuance, or drainage), and a normal systemic presentation, routine utilization of serum inflammatory markers (such as C-reactive protein or erythrocyte sedimentation rate) was deemed clinically unnecessary. There was no sign of infection during rehabilitation. After 11 months, the patient was evaluated using the AOFAS Ankle-Hindfoot Scale. The patient achieved a score of 82 after the procedure and achieved full mobility with ankle dorsiflexion to neutral (Figure 4). However, the patient did not return to full work.

Follow-up is summarized in Table 1.

Discussion

The treatment of bone defects is dictated by their size. While techniques such as the Masquelet procedure or vascularized fibular grafts are reserved for critical-sized defects, smaller defects can be managed with autologous grafts or synthetic substitutes [4].

While the maximal mediolateral diameter reached 3.1 cm, this structural void represented a cavitary, non-segmental defect within the widening metaphysis rather than a complete critical-sized segmental gap (traditionally defined as a circumferential loss of bone continuity exceeding 2 to 3 cm or 1.5 to 2 times the bone's diameter) [5]. Because the structural macro-architecture of the tibia was partially restorable via rigid plate stabilization, a complex, 2-stage Masquelet–induced membrane procedure utilizing temporary PMMA cement was clinically unnecessary [5]. S53P4 bioactive glass was indicated over calcium phosphate cement since the latter lacks antimicrobial properties [4]. We considered antimicrobial properties useful in the setting of soft tissue defects. Autologous bone graft would provide the fastest remodeling but would carry risks of donor site morbidity. If applied to a potentially infected environment, it could become a sequestrum.

S53P4 bioactive glass composed of 53% SiO_2, 23% Na_2O, 20% CaO, and 4% P_2O_5 acts as a scaffold with osteoinductive and antimicrobial properties [6]. Upon contact with body fluids, it releases ions that create a high-pH, hyperosmolar environment inhibiting bacterial growth [7,8]. Calcium and phosphorus ions further promote localized bone turnover [6]. However, its brittleness necessitates stabilization with plate osteosynthesis.

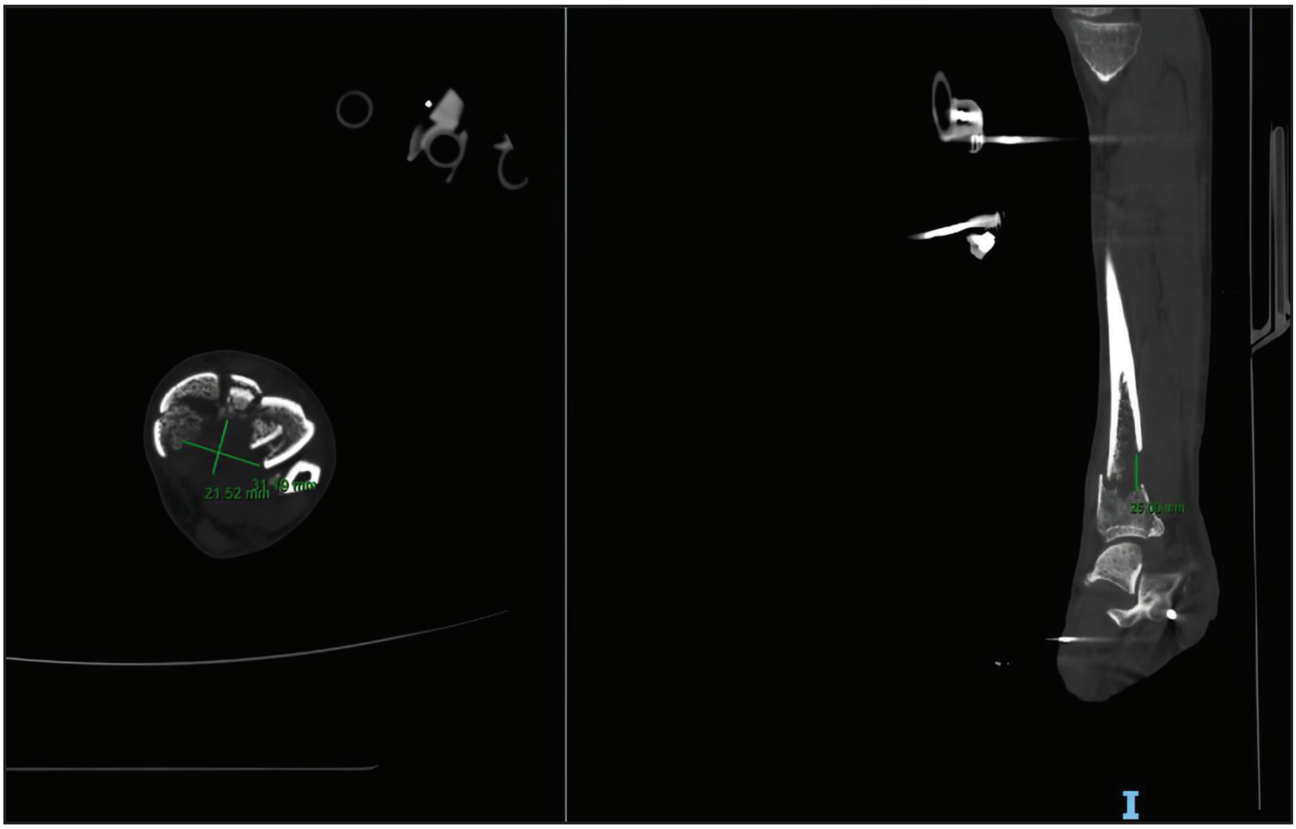

Figure 2. *Preoperative CT imaging demonstrating a metaphyseal bone defect measuring 2.5 cm (craniocaudal) × 2.1 cm (anteroposterior) × 3.1 cm (mediolateral), with an estimated volume of 8.5 cm³.*

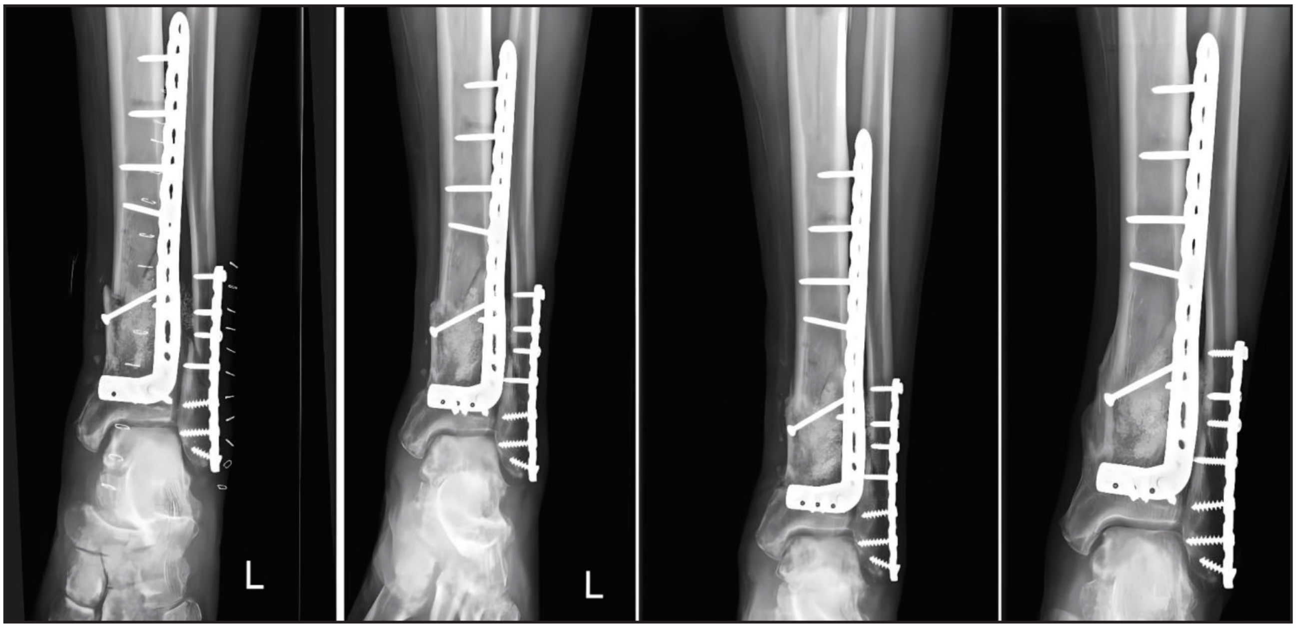

Figure 3. *Radiographic healing progression at 2.5 weeks, 2, 3.5, and 11 months postoperatively, demonstrating progressive integration of the bioactive glass.*

S53P4 is radiodense, which can mask a non-union. Evaluating bone healing when using S53P4 bioactive glass presents a unique radiodiagnostic challenge. Because the material is highly radiodense, it can obscure the fracture gap and mask a potential non-union if traditional orthopedic criteria (such as exuberant periosteal callus) are expected. True integration of S53P4 is characterized by a slow, surface-bound chemical reaction where a hydroxyapatite layer forms, leading to the radiographic "blurring" of granule boundaries and steady bone ingrowth [9]. In our case, we observed such blurring on X-rays taken after 2 months and onwards (Figure 3). The

Table 1. *Treatment milestones of the patient.*

DATE	INTERVENTION
December 26, 2024	Injury; initial stabilization (IM nail for femur, external fixator for tibia).
January 2, 2025	Transfer to a burn center for skin grafting.
February 28, 2025	Definitive surgery: Plate osteosynthesis and bioactive glass filling.
April 28, 2025	2nd month follow-up; bioactive glass integration visible on X-ray.
September 29, 2025	7th month follow-up; full mobility achieved.
January 26, 2026	Final assessment; wounds fully healed, no inflammation.

Figure 4. *Clinical photograph showing maximum dorsiflexion achieved at 11 months postoperatively. Wounds are fully healed with no clinical evidence of infection or non-union.*

absence of clinical signs of non-union, such as no pathological motion, did not prompt us to perform a control CT scan, which would give us a definitive diagnosis of non-union by the absence of bone bridges between granules [8]. Complete loss of granularity may not occur even after 10 years [7]. Further research is needed to study the complete course of resolution of S53P4 bioglass.

Conclusion

S53P4 bioactive glass is an effective option for treating bone defects in high-risk environments due to its antimicrobial and osteoinductive properties. While it requires careful radiographic monitoring for non-union, it avoids donor site morbidity and provides a protective environment against infection.

What is new?

We demonstrated the successful use of S53P4 bioactive glass to reconstruct a relatively high-volume (8.5cm³) cavitary distal tibial metaphyseal defect complicated by adjacent severe thermal burns. We outlined practical radiodiagnostic considerations for differentiating normal bone healing - characterized by the blurring of radiodense bioglass granules - from potential non-union.

List of Abbreviations

AOFAS	American Orthopaedic Foot and Ankle Society
Fig	Figure
IM	Intramedullary
LCP	Locking compression plate
PMMA	Polymethylmethacrylate

Patient perspective

The patient reported a satisfactory return to daily activities and mobility following the 13-month recovery period.

Informed consent

Informed consent was obtained from the patient for the publication of this case report.

Conflict of interests

The authors declare no competing interest in this subject.

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Ethical approval

Ethical approval is not required at our institution for anonymous case reports.

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Summary of the case

1	Patient (gender, age)	Male, 53 years old.
2	Final diagnosis	Comminuted metaphyseal fracture of distal tibia and fibula with post-traumatic bone defect.
3	Symptoms	Pain, deformity, loss of function, thermal burns.
4	Medications	N/A
5	Clinical procedure	Plate osteosynthesis and S53P4 bone substitution.
6	Specialty	Traumatology