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CASE REPORT

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Limb Salvage in Infected Tibial Nonunion with Bone Loss: A Case Report of a Modified Masquelet-Ilizarov Technique

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ABSTRACT

Gustilo-Anderson type III fractures, characterized by extensive soft-tissue damage, require urgent debridement and external fixation to minimize infection risk. Despite these measures, deep infections and osteomyelitis may still develop, sometimes leading to amputation. The Masquelet and Ilizarov techniques have emerged as effective approaches for reconstructing infected bone defects by promoting bone regeneration and soft-tissue healing. A 57-year-old male sustained a Gustilo-Anderson type IIIB open tibial-fibular fracture with severe soft-tissue injury in a traffic accident. Initial treatment included emergency debridement, external fixation, and vacuum sealing drainage (VSD). However, he developed a progressive infection with extensive soft-tissue necrosis and osteomyelitis. A modified Masquelet-Ilizarov technique was employed, involving necrotic bone resection, antibiotic cement spacer implantation, and subsequent bone transport using an Ilizarov frame. At final follow-up, satisfactory bone union and functional limb recovery were achieved.The combined Masquelet-Ilizarov technique offers a viable limb-salvage strategy for infected Gustilo-Anderson type IIIB tibial fractures with bone loss, yielding acceptable clinical and functional outcomes.

Keywords: Masquelet Technique, Ilizarov External Fixator, Bone Transport, Bone Infection, Bone Defect, Open fractures.

INTRODUCTION

Open fractures of the extremities are severe injuries associated with a high risk of complications, including soft tissue loss, bone defects, infection, infected nonunion, and amputation[1,2]. Traumatic amputation represents a significant global public health and economic burden, with a rising incidence and trend toward younger patients in recent decades[3].

Despite advances in debridement, antibiotic prophylaxis, fracture stabilization, and soft-tissue reconstruction, infection remains a serious complication following open fractures[2,4]. Tibial fractures, particularly due to the lack of muscular coverage on the anteromedial aspect, are highly prone to soft-tissue injury and secondary bone infection. Yusuf E et al. indicated that for Gustilo Type III fractures, the bacterial culture positive rate was 53% during the initial surgery, and increased to 88% during the repeat surgery[2]. Severely contaminated Gustilo-Anderson type III open fractures carry an especially high risk, with reported infection rates ranging from 8.0% to 9.9%[5]. And even up to 12.7% in some studies, with nearly half of infected cases involving polymicrobial organisms[6]. However, under conditions of limited medical resources, effective infection control is the prerequisite for the reconstruction and repair of soft tissue and bone defects, as infection significantly increases surgical difficulty and the risk of amputation[7].

The choice between limb-salvage surgery and amputation remains controversial, making it difficult for both patients and surgeons to decide. A Mangled Extremity Severity Score (MESS) ≥7 and a Ganga Hospital Open Injury Severity Score (GHOISS) ≥13 are recognized independent predictors for amputation[8,9]. Successful limb salvage in patients presenting with these high-risk scores is exceptionally difficult, and standardized, effective treatment protocols are lacking.

This report presents a successful limb salvage case in a patient with a Gustilo-Anderson IIIB injury, a MESS of 7, a GHOISS of 13, and an AO/OTA classification of 42A3.2 indicators typically associated with a high

probability of amputation. The patient developed osteomyelitis and infected non-union caused by Acinetobacter baumannii, resulting in a substantial segmental bone defect after debridement. The Ilizarov technique is an established method for managing infected nonunions with bone loss, demonstrating high efficacy in eradicating infection, reconstructing bone defects, and correcting deformities[10,11].

This article describes a combined protocol utilizing a modified Masquelet-induced membrane technique, Ilizarov bone transport, vacuum sealing drainage (VSD), and skin grafting. This strategy represents a logical integration rather than a mere sequential application of techniques: the Ilizarov frame provides mechanical stability for bone transport, while the Masquelet-induced membrane creates a favorable biological environment for regeneration. Based on this successful outcome and a comprehensive literature review, we aim to provide a reference for managing such complex conditions and discuss the potential value of this hybrid approach.

CASE PRESENTATION

Chief complaints

A 58-year-old Chinese male was admitted to our trauma center by ambulance due to right lower leg pain, deformity, and bleeding for 5 hours following a car accident.

History of present illness

The patient was involved in a severe car accident 5 hours ago. The accident resulted in severe crush injuries to both lower limbs, with the right calf as the most affected area. Shortly after the injury, the patient was urgently transported by ambulance to our hospital's trauma center. On-site treatment included pressure bandaging for hemostasis of open fractures and temporary splint fixation. During transport, intravenous access was established for rapid fluid resuscitation. Vital signs were monitored separately.

History of past illness

He has a 5-year history of hypertension. His highest recorded blood pressure is 150/100 mmHg. Recently, he has been irregular in taking antihypertensive medications and does not monitor his blood pressure daily. In 2003, surgery was performed to treat a skull fracture caused by trauma. However, the specific surgical method and related details are unknown because medical records from that time were unavailable.

Personal and family history

The patient is a permanent resident of Zhangye City, Gansu Province, and works as a farmer. He has a 30-year smoking history of approximately 20 cigarettes per day and drinks alcohol occasionally for social purposes. He maintains regular eating habits, with no history of drug abuse or confirmed exposure to industrial toxins or radioactive substances. He is married with one son and one daughter, all of whom are in good health.

Physical examination

On physical examination, the vital signs were as follows: Body temperature, 36.3°C; blood pressure, 98/56 mmHg; heart rate, 124 beats per min; respiratory rate, 33 breaths per min. The patient appears drowsy and shows signs of anemia, with a grimacing pain expression. Upon removing the splint and dressings, an open wound with severe bone deformity is visible on the left lower leg. This wound is accompanied by extensive degloving injury (16 × 14 cm) and partial skin loss in the distal region. Moreover, there is displacement and exposure of the fracture ends of the tibia. The wound margins show signs of necrosis and blackening. Additionally, the surrounding skin, deep fascia, muscles, and other soft tissues are severely contaminated. The dorsalis pedis artery pulse cannot be palpated; the distal toes are cold with diminished circulation.

Imaging examinations

Preoperative imaging assessment was performed to evaluate the extent of injuries. Standard anteroposterior and lateral radiographs of both lower limbs were obtained using a digital radiography system immediately upon the patient's emergency admission. The radiographic images (Fig. 1 A&B) clearly demonstrated bilateral tibial and fibular fractures. The right leg sustained a severe, comminuted open fracture of the mid-tibia and fibula, characterized by significant fragment displacement, bone loss, and an associated angular deformity. Notably, the articular surfaces of the ipsilateral knee and ankle joints remained intact, with no evidence of fracture extension to the tibial plateau or distal tibia. In contrast, the left leg presented with a simple, closed transverse fracture of the tibia and fibula. This comprehensive radiographic evaluation was critical for confirming the Gustilo-Anderson type IIIB classification of the right open fracture and for preoperative planning.

Laboratory examinations

Routine laboratory tests conducted upon admission revealed significant abnormalities indicative of

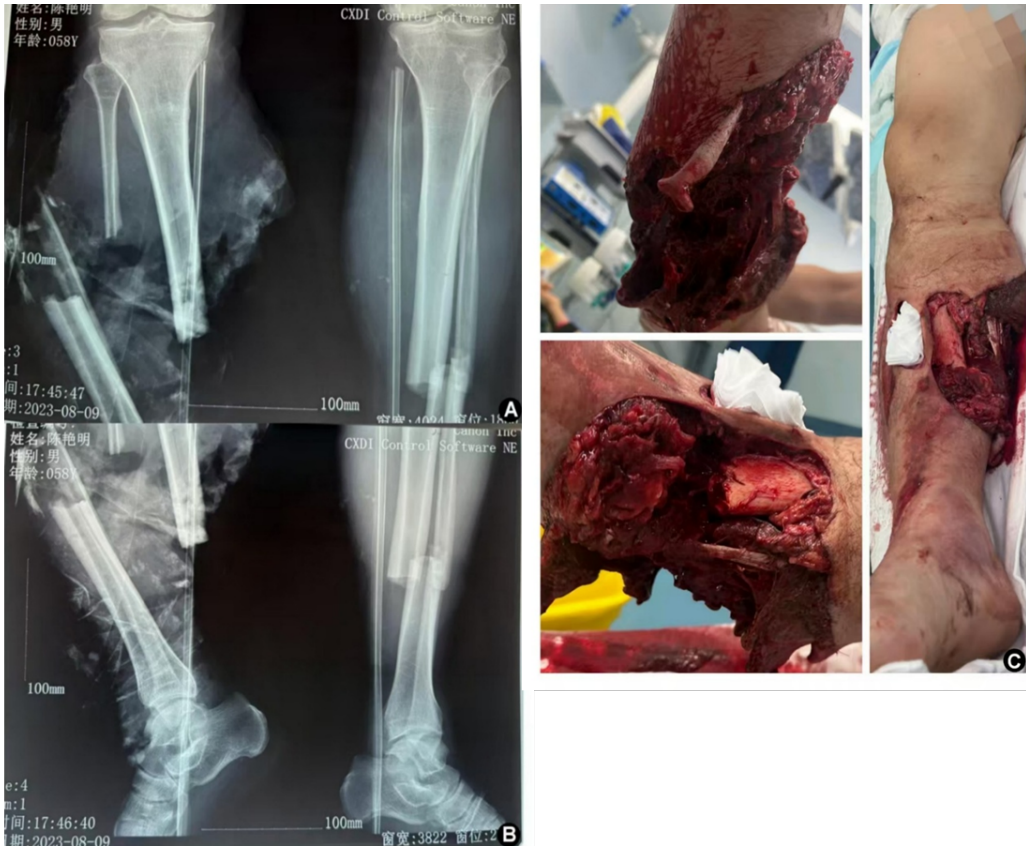

Fig. 1 — (A-B) Preoperative imaging examination: (A) Anteroposterior radiographs of the middle and upper segments of bilateral tibia and fibula: The patient's lower limbs were crushed by a vehicle, resulting in open fractures of the right tibia and fibula and closed transverse fractures of the left tibia and fibula. The right tibia and fibula fracture ends were separated and displaced with soft tissue injuries. No fractures of the tibial plateau or proximal tibia were observed. (B) Radiographs of the middle and lower segments of bilateral tibia and fibula: The open fracture of the right tibia and fibula showed shortening and anteroposterior angular deformity. The fracture ends penetrated the soft tissues. No fractures of the ankle joint or distal tibia were observed. (C) Images taken at the ICU bedside after wound cleaning and hemostasis: Bone exposure was visible at the fracture site of the right tibia and fibula, accompanied by severe circumferential soft tissue avulsion injuries. There were skin and muscle defects, severe damage to the anterior and posterior tibial muscles, and partial muscle and skin margin necrosis.

acute hemorrhage, systemic inflammation, and a hypercoagulable state secondary to the major trauma. The complete blood count showed marked anemia, with a hemoglobin level of 80 g/L, a hematocrit of 23.10%, and a red blood cell count of 2.44 × 10^{12}/L, consistent with substantial blood loss. The white blood cell count was elevated at 10.61 × 10^{12}/L, suggesting an early inflammatory or stress response. The patient's blood type was identified as O, Rh(D) positive. Coagulation studies were notably abnormal, showing a hyper fibrinolytic and consumptive profile: the D-dimer level was significantly elevated at 27.94 µg/mL, accompanied by increased fibrinogen degradation products (63.41 µg/mL), a prolonged thrombin time of 21.56 seconds, and a decreased antithrombin III activity of 56.64%. Plasma fibrinogen was measured at 126.15 mg/dL. This coagulation pattern is characteristic of trauma-induced coagulopathy. The reference ranges of relevant laboratory indicators (Male): Hemoglobin: 130-175 g/L; Hematocrit: 40-50%; Red Blood Cell Count: 4.5-5.9 × 10^{12}/L; White Blood Cell Count: 4.0-10.0 × 10^{12}/L; D-dimer: <0.5 µg/mL; Fibrinogen Degradation Products: <5 µg/mL; Thrombin Time: 14-19 seconds; Antithrombin III: 80-120%; Plasma Fibrinogen: 200-400 mg/dL.

Final diagnosis

Based on the preoperative X-ray and specialized physical examination results, the patient was preliminarily diagnosed as having an open fracture of the right tibia and fibula; Gustilo-Anderson classification: IIIB; AO/OTA classification: 42A3.2; with a MESS score of 7 and a GHOISS score of 13, as illustrated in Figure1 C.

Treatment

The patient's treatment timeline is detailed in Table I and Figure 2. Upon admission, emergency surgery was performed concurrently with anti - shock fluid resuscitation to debride contaminants, necrotic soft tissues, and fracture ends. Followed by fracture reduction and temporary stabilization using an external fixator to maintain alignment. Thorough debridement of the anterior and posterior leg compartments and fracture fixation alleviated vascular torsion and spasm, restoring blood circulation. Partial necrotic tissues (including the tibialis anterior, extensor digitorum longus, gastrocnemius, and soleus muscles) were excised, with remaining portions repaired via layered suturing (deep to superficial). (First surgery, Table I and Figure 1 C) The wound was covered with VSD dressing for effective drainage. Postoperatively, the patient developed persistent fever (peak 39.5°C) with elevated infection markers (WBC, Absolute Neutrophil Count, Neutrophil percentage, CRP, ESR), as illustrated in Figure 4 A. Copious purulent drainage led to VSD tube blockage, necessitating three additional debridements and infection control procedures. Necrotic muscle was excised, antibiotic - loaded bone cement was placed in infected areas, and cultures identified Acinetobacter baumannii, prompting escalation to cefoperazone - sulbactam. VSD dressings were replaced with gentamicin irrigation. By September 14, 2023, infection markers normalized without fever. VSD removal revealed healthy granulation tissue, prompting stamp skin grafting from the anterolateral thigh for tibial defects. However, fracture ends showed grayish, avascular bone without callus formation (Surgery 5, Figure 4 B). The pivotal surgery on October 27, 2023, combined Masquelet membrane induction with Ilizarov bone transport. A circular fixator ensured limb alignment while 10 cm of necrotic bone was resected, and then followed by medullary canal recanalization and scar tissue excision. According to the method mentioned in the Makhdoom literature[12], the drilling method was used to perform single-plane osteotomy. (Surgery 6, Figure 5A). Antibiotic-impregnated PMMA spacers (PALACOS® R+G, Zimmer Biomet) were placed to maintain space and deliver localized antibiotics.

Postoperative care included anti-inflammatories, wound care, and pin-site management. Markers normalized within a week. Bone transport progressed at 1 mm/day (divided into two steps), with spacer removal every 10 days and radiographic assessments triweekly, the healing status of the fracture and the formation of callus are shown in Figure 5 B-D.

OUTCOME AND FOLLOW-UP

On February 26, 2024, transport ceased after bone docking. Weight-bearing exercises commenced, followed by fixator removal two weeks later. By April 15, 2025, solid union was achieved with equal limb length and mature mineralization, and Paley classification is excellent[13,14] (Fig. 6A - B). Simultaneous soft-tissue distraction addressed skin defects, leaving no exposure at final follow-up (Fig. 6C). No complications (e.g., pin-site infection, hardware loosening) occurred. Follow-up X-rays revealed disuse osteoporosis of the ankle, improving with rehabilitation, though limited mobility required manual release and intensified exercise.

DISCUSSION

The management of Gustilo-Anderson type III open tibial fractures with subsequent infected nonunion and segmental bone defects remains a formidable challenge in orthopedic trauma surgery. These injuries are frequently complicated by deep infection, soft tissue loss, and Osteomyelitis, which significantly necessitate complex reconstructive strategies[11]. Such cases have a long treatment cycle and a high failure rate, and often require multi-stage and multi-technology combined intervention. The standard treatment procedure includes thorough debridement, stable fixation, soft tissue coverage and bone defect reconstruction. However, unfortunately, the treatment outcomes are often disappointing. Additionally, limb preservation may lead to severe complications, often resulting in delayed amputation due to infection, nonunion, or muscle necrosis[2]. In this particular case, after multiple debridements, the patient still faced infectious nonunion, which led to the loss of confidence and the request for amputation on October 25, 2023, abandoning further attempts at limb preservation. However, after the patient requested amputation, through multidisciplinary collaboration, multiple surgeries employing various techniques (Table I), a coordinated treatment strategy, and close postoperative follow-up and guidance, in this case, limb salvage with acceptable functional recovery was achieved. Comprehensive preoperative evaluation, detailed surgical planning, active revascularization, debridement, and complication prevention are key to successful limb preservation.

Similarly, the induced membrane (Masquelet) concept has been discussed in Acta Orthopaedica Belgica for traumatic or infected segmental defects, supporting the biological rationale of staged

Table I. — Timelines of Treatment.

Date	Procedure
August 9, 2023 (1st Surgery)	Admitted to our hospital's ICU due to hemorrhagic shock, right open tibiofibular fracture, and left tibiofibular fracture. Received active anti-shock treatment. Condition explained to patient and family. Emergency surgery performed (debridement and suturing + fracture reduction with unilateral VSD + VSD negative pressure suction).
August 17, 2023 (2nd Surgery, 8 days after 1st surgery)	Underwent debridement again due to soft tissue purulent infection and septicemia. Microbial culture of pus from the surgical site indicated Acinetobacter baumannii infection. As infection markers continued to rise and symptoms worsened, a second surgery was performed (debridement + VSD replacement).
August 22, 2023 (3rd Surgery, 5 days after 2nd surgery)	Underwent surgery again due to soft tissue purulent infection, septicemia, and septic shock (debridement + VSD replacement).
August 30, 2023 (4th Surgery, 8 days after 3rd surgery)	Surgery performed due to soft tissue infection, traumatic osteomyelitis, and soft tissue defect (antibiotic bone cement spacer placement).
September 14, 2023 (5th Surgery, 15 days after 4th surgery)	Surgery for skin defect on the lower leg (posterolateral, 6 * 8 cm) (stamp skin graft surgery).
October 27, 2023 (6th Surgery, 43 days after 5th surgery)	Surgery for infected nonunion, bone defect, and soft tissue defect (Masquelet technique, Ilizarov technique, bone transport).
October 28, 2023 - February 28, 2024 (4 months, 123 days)	Transport and repair of a 10 cm bone defect, averaging 0.8 mm per day. One bone cement spacer was removed every 10 days. X-rays were taken every 3 weeks to assess bone reconstruction and repair progress.
February 29, 2024 (124 days after 6th surgery)	Final adjustment of the transported bone segment to approximate the distal osteotomy surface, followed by debridement and suturing of soft tissue.
March 7, 2024 (132 days after 6th surgery)	Removed the ankle portion of the circular external fixator to facilitate ankle joint functional exercise.
April 14, 2024 (170 days after 6th surgery)	Removed the tibial external fixator. Actively guided rehabilitation exercises and gait training without assistance.

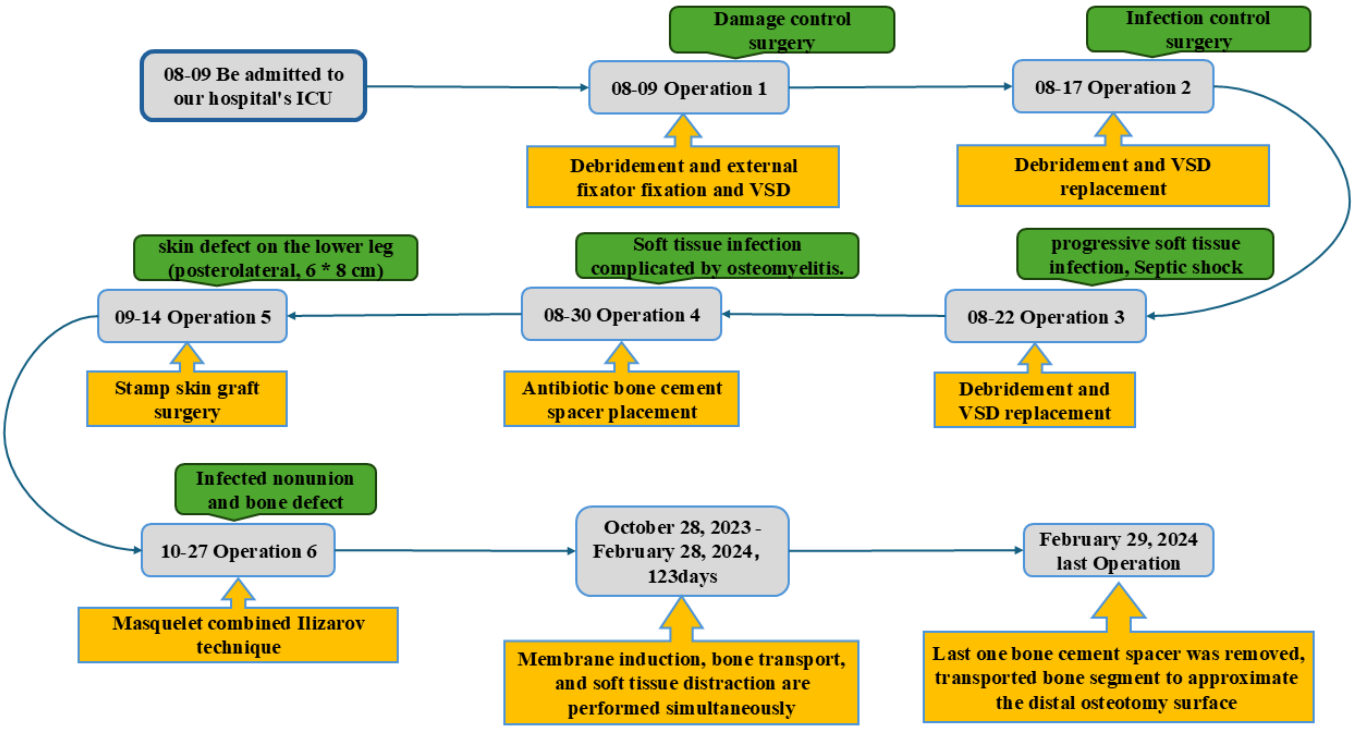

Fig. 2 — Details of the surgical procedure.
The gray marker indicates the date of the procedure. The green marker highlights the operation purpose, while the yellow marker indicates the Surgical strategy.

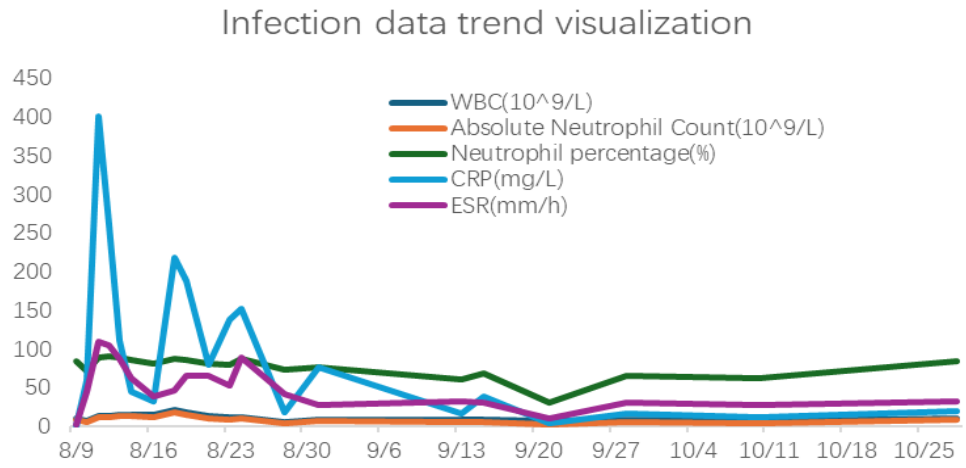

Fig. 3 — Dynamic trends of key infection markers during the perioperative and postoperative period. This line chart visualizes the longitudinal trends of five principal infection-related laboratory parameters: White Blood Cell count (WBC, 10^9/L), Absolute Neutrophil Count (ANC, 10^9/L), Neutrophil Percentage (%, NEUT%), C-Reactive Protein (CRP, mg/L), and Erythrocyte Sedimentation Rate (ESR, mm/h), monitored from August 9 to Otober 25.

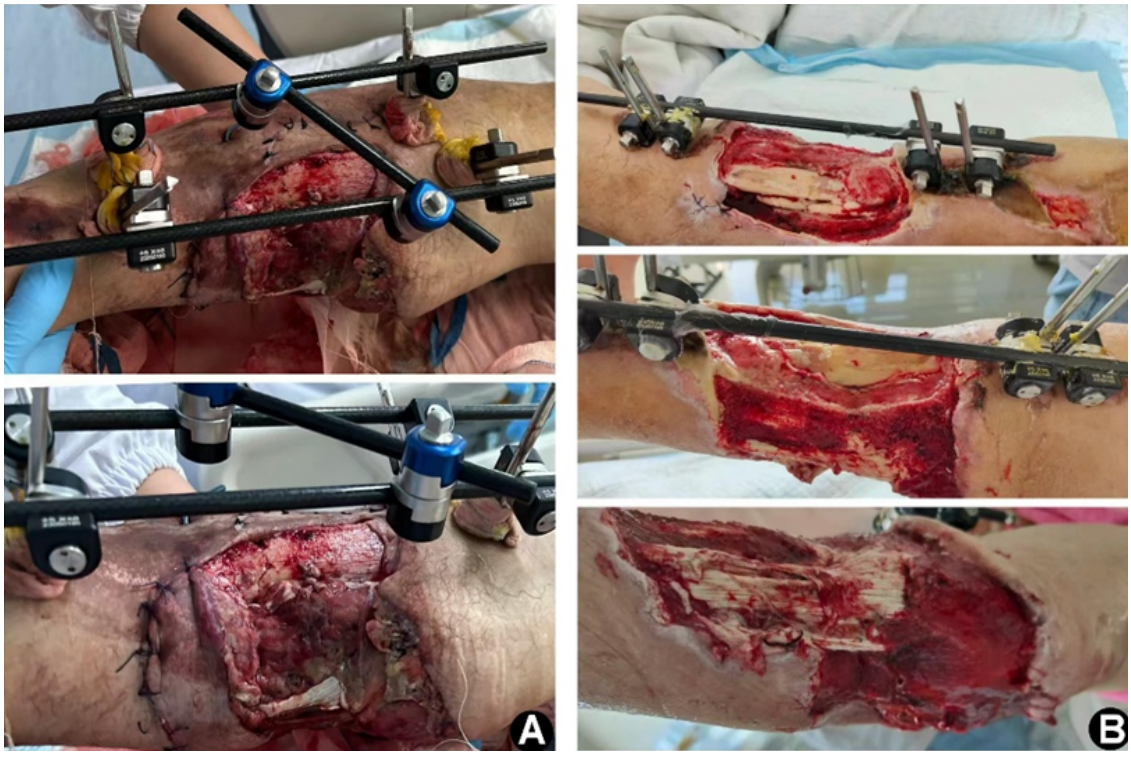

Fig. 4 — Local images after damage control surgery with external fixator.
13 days after the first surgery, (A) In the third surgery, after the VSD dressing was removed, it was observed that the anteromedial soft tissue of the right tibia was infected with defects, showing purulent exudation, with partial skin and muscle necrosis, tibia exposure, periosteal stripping, and no adequate soft tissue coverage. 36 days after the first surgery, (B) In contrast, In the fifth surgery, after multiple debridements and negative - pressure suction therapy using VSD dressings, the infection of skin and muscle soft tissue had significantly improved compared to before, with fresh granulation tissue growth visible; the fracture ends were exposed, no callus formation was seen, and no soft tissue coverage; a large area of skin defect was visible posterior to the tibia.

reconstruction in complex tibial bone loss[7,15]. The Masquelet technique contributes to infection control and promotes a biological environment favorable for bone regeneration. However, the success of this technique relies on adequate soft tissue coverage—typically requiring prior flap transplantation. For patients with poor local blood supply or significant surgical trauma from previous operations, the risk of flap surgery failure is high, potentially triggering a vicious cycle of worsening infection and tissue necrosis, thereby limiting its application. Our reconstructive strategy is consistent with prior limb-

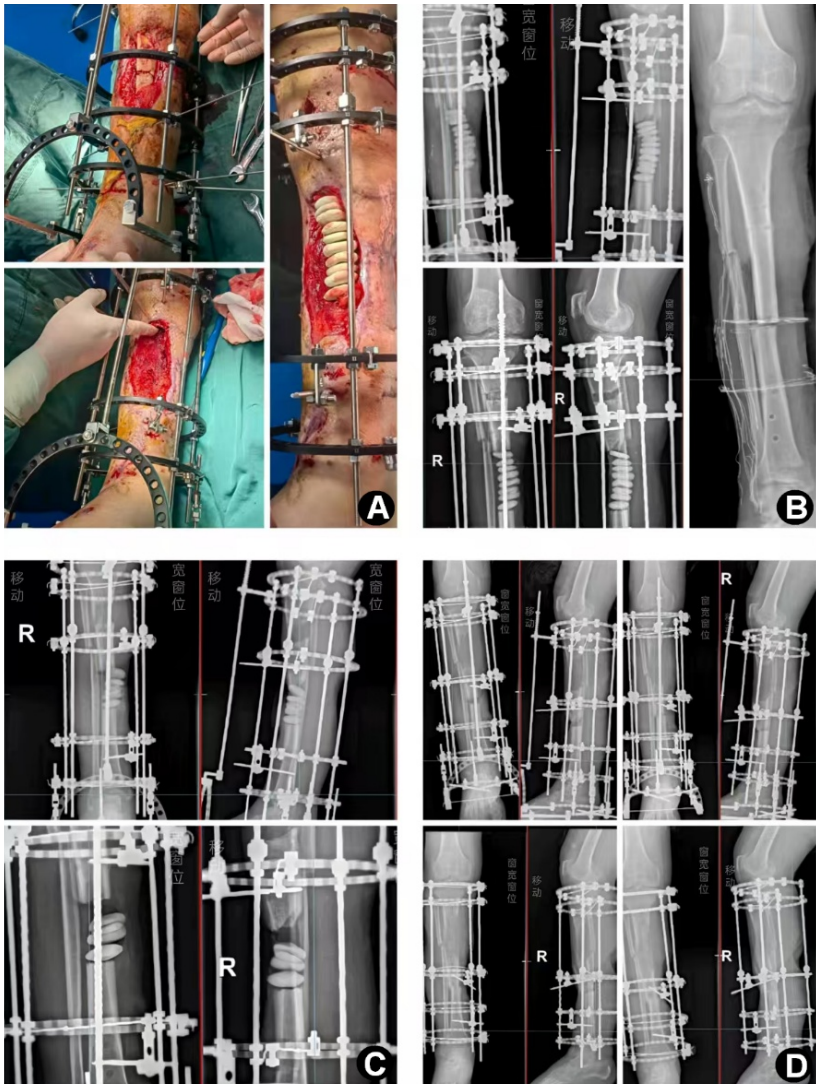

Fig. 5 — Clinical intraoperative and postoperative follow-up data of Masquelet membrane induction and Ilizarov bone transport techniques.
(A) The 6th surgery (Masquelet-Ilizarov operation), performed 80 days after the first surgery, involved resection of approximately 10 cm of necrotic bone tissue centered at the fracture site. The osteotomy surface showed active bleeding. A single-stage bone transport was designed at the proximal tibia, and a circular external fixator with adjustable transport rings was installed. Ten antibiotic-loaded bone cement discs were placed in the bone defect area. (B) The full-length X-ray of the right tibia showed no callus formation at the fracture site. Postoperative X-rays demonstrated proper positioning of the circular external fixator and adjustable transport rings, with good tibial alignment and well-positioned bone cement spacers. Bone lengthening proceeded smoothly. (C) Follow - up X - rays on December 11 and 25, 2023, as well as on February 5, 26, March 4, and September 9, 2024, showed good healing at both the fracture site and the lengthening zone, with no angular deformity. The X - rays on December 2023 also showed stable external fixation. (D) On February 5, 2024, February 26, 2024, March 4, 2024, and September 9, 2024, X-ray follow-ups indicated, the fracture ends and lengthening zone showed good healing with no angular deformity. The newly formed callus in the lengthened segment exhibited good ossification, with mineralization gradually increasing over time, approaching the density of normal cortical bone. Continuous bridging callus was observed at the distal end of the bone transport site.

salvage experiences reported in Acta Orthopaedica Belgica, where infected tibial nonunion has been managed successfully using radical debridement and Ilizarov bone transport[10].

Although skin or flap transplantation remains the gold standard for soft tissue reconstruction, it is inadvisable when the adjacent skin is unhealthy and local blood supply is poor. This patient has a high risk of failure in flap-related soft tissue coverage surgery, and soft tissue necrosis can further exacerbate infection, creating a vicious cycle. Our reconstruction strategy shares similarities with the limb salvage and

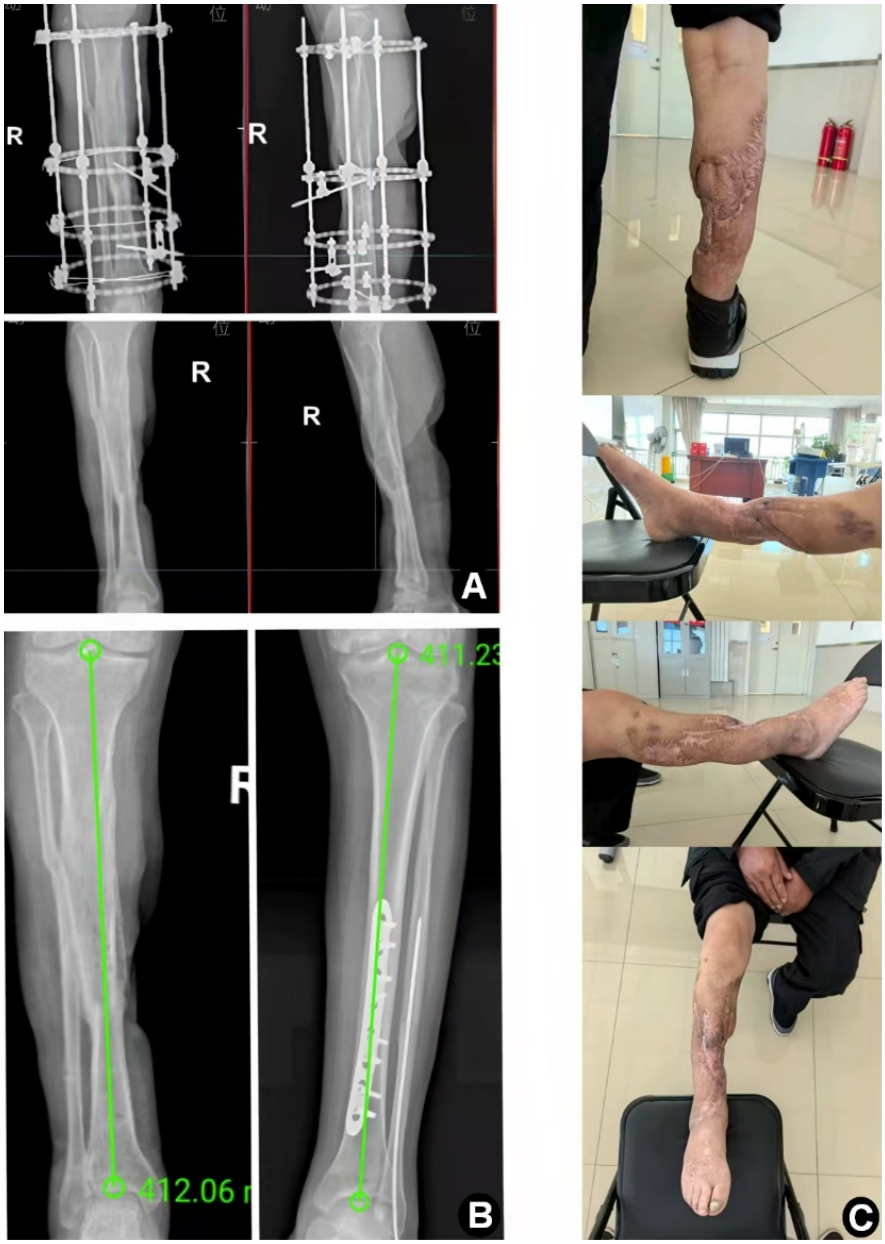

Fig. 6 — Final follow-up X-ray and local calf photographs.
(A - B) X - rays of the right tibia on April 14, 2025, and July 24, 2025: A large amount of callus formation is visible at the fracture ends and the lengthening zone, with the degree of callus mineralization consistent with that of the normal diaphysis. Comparative anteroposterior view of the full - length tibiae of both lower limbs: The lower limbs are essentially equal in length, with no significant abnormalities in the mechanical axis of the right lower limb. Although there is axial deviation, there is no angular deformity perpendicular to the knee - ankle joint line. (C) Local photograph of the lower leg at the final follow - up shows survival of the skin graft area, with no skin defects observed in the anterior or posterior tibial regions. Knee flexion and extension are normal, and ankle range of motion is dorsiflexion -10° (indicating a negative angular change relative to a certain reference position) and plantar flexion 30°.

soft tissue repair experiences previously reported in Acta Orthopaedica Belgica, such as: Waleed Ahmed Mekkiv et al. previously reported that by stabilizing the bone using an Ilizarov external fixator, bone transport could be performed to reconstruct large defects through soft tissue distraction, thereby obviating the need for additional soft tissue reconstructive surgery[16,17]. The Ilizarov method, which employs an external fixation frame, offers remarkable stability while imposing minimal requirements on soft tissue defects. It facilitates bone transport while distracting soft tissues, enabling the repair of both soft tissue and bone defects[17]. Inspired by this approach, we decided to forgo flap transplantation and instead opted to perform segmental

bone transport combined with soft tissue distraction to reconstruct the soft tissue defect simultaneously. This approach provides a viable alternative in patients with poor general condition or compromised vascularity, where traditional flap reconstruction is contraindicated.

There were few literature reports on the combination of Masquelet technique and Ilizarov bone transport[19,20]. Most of these reports discuss the concept of bone transport in two stages from the perspective of combating infection alone. In order to enable the simultaneous application of both techniques, we modified the cement spacer: a technical variation within an established reconstructive strategy. The spacer used in this case consisted of 10 PMMA discs, each approximately 1 cm thick. Compared to a cylindrical long - segment PMMA spacer, this design allows for staged removal according to the bone transport speed, with one disc removed approximately every 10 days. There is almost no relevant literature reporting on this method of spacer placement and removal. This modification may reduce the number of surgical steps, eliminate the need for additional soft tissue or flap reconstruction, but it also prolongs the duration of external fixation use, which may have certain impacts on the patient's recovery, further evaluation in larger series is required in the future. The main disadvantages of Ilizarov bone transport are related to the long - term application of complex devices, such as pin tract infections, joint stiffness, regeneration complications, and nonunion at the docking site[21]. In this case, we observed complications of ankle stiffness and disuse osteoporosis, which improved after partial removal of the external fixator at the ankle joint and weight - bearing exercises. Of course, there are still aspects of this case that remain puzzling to us. Upon admission, aggressive debridement surgery was performed. Multiple uses of VSD devices for drainage combined with antibiotic irrigation were used to control infection[22]. However, the final outcome was suboptimal. However, some literature suggests that Vacuum-Assisted Closure does not reduce the risk of infection in open wounds. In contrast, recombinant human bone morphogenetic protein (rhBMP)-2 has demonstrated promising clinical outcomes in the management of Gustilo-Anderson type III open tibial shaft fractures. These findings offer new insights and potential alternatives for managing similar patients in the future[23].

CONCLUSION

In conclusion, amputation was once common in patients with severe Gustilo-Anderson type III fractures. However, in this case, we productively salvaged the patient's limb using a hybrid surgical technique. This technique may represent a useful option in selected cases managed in experienced centers. More research and case reports are needed to support and validate this technique.

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REFERENCES

1. Chen SH, Lien PH, Lan CY, Hsu CC, Lin CH, Lin YT, et al. Predicting Union, Osteomyelitis, and Amputation Outcomes of Gustilo IIIC Open Tibial Fractures: A Retrospective Study. Orthop Surg. 2024. 16(1): p. 94–103.
2. Yusuf E, Steinrücken J, Buchegger T, Trampuz A, Borens O. A descriptive study on the surgery and the microbiology of Gustilo type III fractures in an university hospital in Switzerland. Acta Orthop Belg. 2015. 81(2): p. 327–332.
3. Wei B, Zhang J, Cheng Y, Wu H. Global, regional and national burden of traumatic amputations from 1990 to 2021: a systematic analysis of the Global Burden of Disease study 2021. Front Public Health. 2025;13: p. 1583523.
4. Sagi HC, Patzakis MJ. Evolution in the Acute Management of Open Fracture Treatment? Part 1. J Orthop Trauma. 2021. 35(9): p. 449–456.
5. Suzuki T, Inui T, Sakai M, Ishii K, Kurozumi T, Watanabe Y. Type III Gustilo-Anderson open fracture does not justify routine prophylactic Gram-negative antibiotic coverage. Sci Rep. 2023. 13(1): p. 7085.
6. Youbong TJ, De Pontfarcy A, Rouyer M, Strazzula A, Chakvetadze C, Flateau C, et al. Bacterial Epidemiology of Surgical Site Infections after Open Fractures of the Lower Limb: A Retrospective Cohort Study. Antibiotics (Basel). 2021. 10(12): p. 1513.
7. Mathieu L, Potier L, Ndiaye R, Choufani C, Mbaye E, Niang CD. Challenges of the induced-membrane technique in the reconstruction of traumatic tibial defect with limited resources: a cohort study. Acta Orthop Belg. 2020. 86(4): p. 606–613.
8. Fochtmann A, Mittlböck M, Binder H, Köttstorfer J, Hajdu S. Potential prognostic factors predicting secondary amputation in third-degree open lower limb fractures. J Trauma Acute Care Surg. 2014. 76(4): p. 1076–1081.
9. Ndlovu S, Naqshband M, Masunda S, Ndlovu K, Chettiar K, Anugraha A. Clinical effectiveness of the Ganga Hospital Open Injury Severity Score for limb salvage versus amputation in patients with complex limb injuries: a systematic review and meta-analysis. Bone Joint J. 2023. 105-B (1): p. 21–28.
10. Yin P, Zhang Q, Mao Z, Li T, Zhang L, Tang P. The treatment of infected tibial nonunion by bone transport using the Ilizarov external fixator and a systematic review of infected tibial nonunion treated by Ilizarov methods. Acta Orthop Belg. 2014. 80(3): p. 426–435.
11. Laursen MB, Lass P, Christensen KS. Ilizarov treatment of tibial nonunions results in 16 cases. Acta Orthop Belg. 2000. 66(3): p. 279–285.

12. Makhdoom A, Kumar J, Siddiqui AA. Ilizarov External Fixation: Percutaneous Gigli Saw Versus Multiple Drill-hole Osteotomy Techniques for Distraction Osteogenesis. Cureus. 2019. 11(6): p. e4973.
13. Xuming W, Changbao W, Yanping D, Qudong Y, Sheng S. Are the outcomes of bone transport in the treatment of bone defects in the upper- middle and lower-middle tibia similar? Acta Orthop Belg. 2024. 90(3): p. 513–521.
14. Paley D, Catagni MA, Argnani F, Villa A, Benedetti GB, Cattaneo R. Ilizarov treatment of tibial nonunions with bone loss. Clin Orthop Relat Res. 1989. (241): p. 146–165.
15. El-Hadidi TT, Soliman HM, Farouk HA, Radwan MAEM. Staged bone grafting for the management of segmental long bone defects caused by trauma or infection using induced-membrane technique. Acta Orthop Belg. 2018. 84(4): p. 384–396.
16. Mekki WA, Kliushin NM, Sudnitsyn AS. Calcaneogenesis: the use of tibial bone transport for treatment of massively infected hindfoot defects. Acta Orthop Belg. 2022. 88(1): p. 127–134.
17. Dauwe J, Declerck E, Verhulst K, Lammens J. Soft tissue defect closure using an Ilizarov frame: a case series. Acta Orthop Belg. 2024. 90(2): p. 287–292.
18. Schlatterer DR, Hirschfeld AG, Webb LX. Negative pressure wound therapy in grade IIIB tibial fractures: fewer infections and fewer flap procedures? Clin Orthop Relat Res. 2015. 473(5): p. 1802–1811.
19. Li Z, Liu J, Li C, Wu M, Li Y, Cui Y, et al. Advances in the Application of Bone Transport Techniques in the Treatment of Bone Nonunion and Bone Defects. Orthop Surg. 2023. 15(12): p. 3046–3054.
20. Borzunov DY, Kolchin SN, Mokhovikov DS, Malkova TA. Ilizarov bone transport combined with the Masquelet technique for bone defects of various etiologies (preliminary results). World J Orthop. 2022. 13(3): p. 278–288.
21. Iacobellis C, Berizzi A, Aldegheri R. Bone transport using the Ilizarov method: a review of complications in 100 consecutive cases. Strategies Trauma Limb Reconstr. 2010. 5(1): p. 17–22.
22. Yang R, Wang Z, Huang W, Zhao Y, Xu L, Yu S. A Suitable Option for Gustilo and Anderson Grade III Injury. Med Sci Monit. 2016. 22: p. 3018–3024.
23. Rupp M, Popp D, Alt V. Prevention of infection in open fractures: Where are the pendulums now? Injury. 2020. 51 Suppl 2: p. S57–63.