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INFECTION

Management of surgical site infection post-open reduction and internal fixation for tibial plateau fractures

J. Shen,
D. Sun,
J. Fu,
S. Wang,
X. Wang,
Z. Xie

From Southwest Hospital, Army Medical University, Chongqing, China

Aims

In contrast to operations performed for other fractures, there is a high incidence rate of surgical site infection (SSI) post-open reduction and internal fixation (ORIF) done for tibial plateau fractures (TPFs). This study investigates the effect of induced membrane technique combined with internal fixation for managing SSI in TPF patients who underwent ORIF.

Methods

From April 2013 to May 2017, 46 consecutive patients with SSI post-ORIF for TPFs were managed in our centre with an induced membrane technique. Of these, 35 patients were included for this study, with data analyzed in a retrospective manner.

Results

All participants were monitored for a mean of 36 months (24 to 62). None were subjected to amputations. A total of 21 patients underwent two-stage surgeries (Group A), with 14 patients who did not receive second-stage surgery (Group B). Group A did not experience infection recurrence, and no implant or cement spacer loosening was noted in Group B for at least 24 months of follow-up. No significant difference was noted in the Lower Extremity Functional Scale (LEFS) and the Hospital for Special Surgery Knee Score (HSS) between the two groups. The clinical healing time was significantly shorter in Group B ($p < 0.001$). Those with longer duration of infection had poorer functional status ($p < 0.001$).

Conclusion

Management of SSI post-ORIF for TPF with induced membrane technique combined with internal fixation represents a feasible mode of treatment with satisfactory outcomes in terms of infection control and functional recovery.

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Keywords: Surgical site infection, Tibial plateau fractures, Induced membrane technique, Internal fixation

Article focus

- Management of surgical site infection (SSI) post-open reduction and internal fixation (ORIF) for tibial plateau fractures (TPFs) with induced membrane technique in combination with internal fixation represents a feasible mode of treatment with satisfactory outcomes in terms of infection control and functional recovery.

Key messages

- Radical debridement forms the basis of using internal fixation as a stabilizing method.
- Usage of antibiotic cement to cover the internal fixation plate is a key step during the first-stage surgery.

Strengths and limitations

- Management of SSI post-ORIF for TPF with internal fixation is beneficial for functional recovery without increasing the recurrence rate of infection.
- The follow-up period of the patients with permanent spacers is relatively short, and complications may occur with increased duration of follow-up.

Correspondence should be sent to Zhao Xie; email: xiezhao54981@163.com

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Introduction

Tibial plateau fractures (TPFs) are prone to postoperative surgical site infection (SSI).[1] The incidence rate was previously reported to be between 2.6% and 45%,[2] which is high in contrast to other fractures managed with open reduction and internal fixation (ORIF).[3] Given its periarticular location, a SSI occurring after ORIF of TPF harbours disastrous consequences.[2,4] Current treatment options include repeated radical debridement,[5,6] irrigation[6] and drainage combined with vacuum sealing drainage (VSD),[7] removal or retention of internal fixation,[6,8] flap or muscle flap coverage,[9,10] and systemic[6,8,11] and/or local[12] antibiotics use. However, due to the relatively long treatment period and recurrent infection, the function of the knee joint is greatly affected.[2]

Orthopaedic implant-associated infection has been documented to be a result of biofilm formation by surface-adhering bacteria.[13,14] Biofilm that has been firmly established on an implant is resistant to host immunity[14] and antibiotics.[15] Evidence shows that once biofilms have formed, the entire tissue bed may continue to contaminate further new implants, thereby propagating infection despite assumed clearance.[16,17] Therefore, previously infected sites were once considered a contraindication for reuse of internal fixation.[18] In 2007, Thonse and Conway[19] reported an effective management of infected nonunion and segmental bone defects with antibiotic cement-coated interlocking nail. In 2017, our centre fashioned temporary internal fixators with an antibiotic cement-coated locking plate for the treatment of femoral osteomyelitis defects with initial induced membrane operation, achieving good clinical results.[20] The current investigation analyzes a series of patients with SSI of TPF after ORIF who were subjected to first-stage internal fixation with antibiotic cement-coated locking plates, followed by second-stage induced membrane technique. We aimed to observe the effect of this method on infection control and the recovery of knee joint function.

Methods

Digital medical records of 46 consecutive patients with deep SSI after ORIF of TPFs, managed with induced membrane technique in our centre between April 2013 and May 2017, were selected for retrospective analysis. SSI was diagnosed based on a combination of clinical local swelling and bony pain, laboratory, histopathological, and microbiological investigations, as well as via imaging.[21] We excluded 11 patients from the study, including those younger than 18 years or older than 70 years in three cases (source of autogenous bone was limited), Cierny-Mader Host C in two cases (not suitable for surgery),[22] two cases who had less than 24 months of follow-up, treatment with external fixation in two cases, combined with knee joint infection in two cases (impact on knee function assessment). This study finally consisted of a total of 35 subjects. The Schatzker classification[23] of all fractures and patient demographics are presented in Table I. A total of 21 of the 35 patients underwent two-stage surgery (Group A), while the other 14 patients did not receive reconstruction because of individual reasons (Group B). The basic details of each case are presented in Supplementary Table i.

Table I. Demographic analysis (total n = 35).

Variable	Value
Mean age, yrs (range)	46 (19 to 64)
Sex, n (%)	
Male	30 (85.7)
Female	5 (14.3)
Schatzker fracture types, n (%)	
IV	2 (5.7)
V	24 (68.6)
VI	9 (25.7)
Cierny-Mader type, n (%)	
A	6 (17.1)
B	29 (82.9)
Bacterial strains, n (%)	
Negative	4 (11.4)
Positive	31 (88.6)
Staphylococcus aureus (MRSA)	18 (5) (51.4 (14.2))
Pseudomonas aeruginosa	2 (5.7)
Escherichia coli	3 (8.6)
Acinetobacter baumannii	1 (2.9)
> two kinds of bacteria	7 (20)
Mean number of previous operations (range)	2.1 (1 to 6)
Mean duration of infection, wks (range)	55.6 (1 to 468)

MRSA, methicillin-resistant *Staphylococcus aureus.*

Preoperative evaluation. Information regarding history of previous trauma and surgery, present laboratory diagnostic indicators, imaging procedures, and physical examination findings were extracted. In the case of the lack of knee joint infection, an estimate of the debridement scope, fixation mode, and coverage method based on radiography, radionuclide bone scan, MRI, and CT were recorded.

Surgical technique and postoperative treatment: the first stage. Tourniquet was used to ensure a relatively bloodless surgical field. Debridement range of soft-tissue was done with a 2 mm margin of healthy tissue and a 5 mm margin of healthy bone.[24] Sinuses, scars, sequestrum, inflammatory granulation, and foreign bodies (including implants and allograft) were thoroughly cleared until healthy bone was achieved (Figure 1b).[25] After radical debridement, antibiotic polymethyl methacrylate (PMMA) bone cement containing gentamicin (Heraeus, Germany) was used for filling bone defects (with the addition of 5 g vancomycin in 40 g gentamicin PMMA bone cement by our surgical team). Broken ends were stabilized with an antibiotic cement-coated locking plate (Figure 1c). If the skin defect was large, tension-free coverage was carried out through the use of a tissue flap (Figure 1d). Broad-spectrum antibiotics were empirically administered for anti-infective therapy. If bacterial culture was positive,

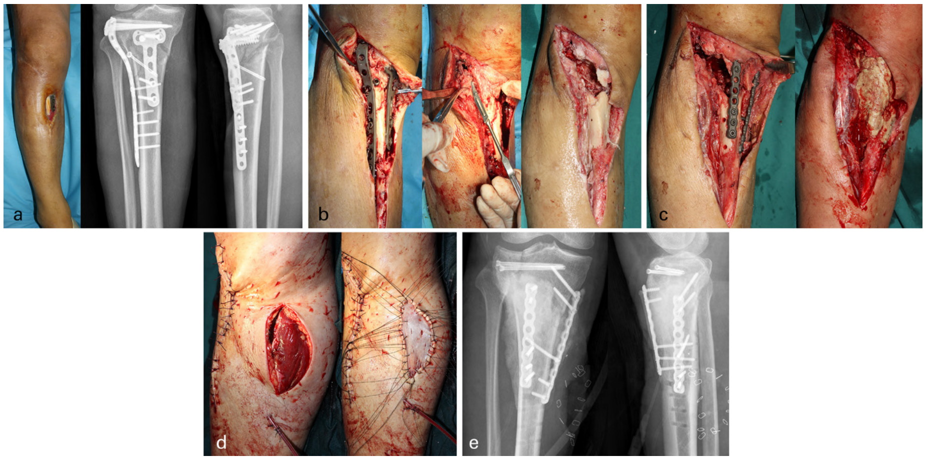

Fig. 1

First-stage surgical procedure. a) Photograph, and anteroposterior (AP) and lateral preoperative radiographs, of a 50-year-old male patient with a Schatzker VI fracture. b) The sinuses, scars, sequestrum, inflammatory granulation, and foreign bodies (including implants and allograft) were thoroughly cleared until healthy bone was achieved. c) An antibiotic bone cement spacer was used to fill the bone defect, followed by application of antibiotic cement coated locking plate. d) The skin defect was large, with tension-free coverage carried out using a flap. e) First-stage postoperative AP and lateral radiographs demonstrated that bone defect was filled with antibiotic bone cement spacer and the locking plate and hollow screw were used as internal fixator to limb stabilization.

the anti-infection plan was adjusted according to drug sensitivity. All patients received intravenous anti-infection therapy for two weeks, followed by four weeks of oral antibiotics. All patients were advised for range of motion knee exercises with strict prohibition of weight-bearing prior to the second operation.

Surgical technique and postoperative treatment: the second stage. Second-stage surgery was planned after six to eight weeks. Complete removal of bone cement and implants under the membrane was done, with the broken ends of the bone cleaned to form fresh wounds prior to fixation with a proper locking plate (Synthes, Switzerland), which was wrapped with antibiotic bone cement afterwards. An autograft was used to fill the bone defect (anterior or posterior iliac crest). All patients subsequently received two weeks of intravenous antibiotics. Non-weight-bearing functional exercises were allowed within three months after surgery. Three months later, radiographs were repeated to determine the feasibility of gradual weight-bearing.

Follow-up. A follow-up evaluation, encompassing radiological and clinical assessments, was done at one, two, three, four, six, nine, 12, 18, and 24 months. The Lower Extremity Functional Scale (LEFS)[26] and Hospital for Special Surgery Knee Score (HSS)[27] were used to quantify clinical results. During each follow-up clinic appointment, assessments of plain radiographs of the affected tibial plateau were carried out (medial-lateral and anterior-posterior planes). Radiological healing was determined by the formation of callus in at least three of four cortices.[28] Patients who were able to fully weight-bear and were free of pain were defined as having achieved clinical healing.[29]

Statistical analysis. The SPSS v22.0 statistical software package (IBM, USA) was used to analyze all data. The chi-squared test and Fisher's exact test were used to contrast categorical variables, while the independent-samples *t*-test was used to analyze continuous variables. Clinical healing times were assessed using Kaplan-Meier survival curves and log-rank test for comparison. A two-sided test that resulted in a p-value of less than 0.05 was taken to indicate statistical significance.

Results

All 35 patients achieved satisfactory outcomes during the mean follow-up time of 36 months (24 to 62), with none requiring amputation. A total of 21 patients underwent two-stage surgery (Group A), while the other 14 patients did not receive reconstruction (Group B). In Group A, the infection control was obtained through two repeated debridement sessions in two patients, with the remaining 19 undergoing a single debridement session only. After primary debridement, two patients required local flaps to achieve wound coverage. All 21 patients were treated with autografts in the second stage, and median radiological healing was achieved at 16 weeks (interquartile range13.0 to 22.0) after the operation. There was no recurrence of infection after the reconstruction in Group A, and the mean LEFS and HSS at the last follow-up was 65.7 points (40 to 80) and 82.6 points (52 to 100), respectively (Figures 2a and 2b). In Group B, the infection control was obtained through two primary debridements in two patients, and a single primary debridement in the remaining 12 patients. There was no recurrence of infection, and no implant or cement spacer loosening for at least 24 months' follow-up. The mean LEFS and HSS of the last follow-up was 68.9 points (51 to 80) and 86.0 points (67 to 100), respectively (Figures 3a and 3b). Demographic characteristics ($p > 0.05$), previous operations ($p = 0.343$, independent-samples *t*-test) , duration of infection ($p = 0.748$, independent-samples *t*-test) , and bacterial strains (*Staphylococcus aureus*) ($p = 0.305$, Fisher's exact test) were not significantly different between the two groups. LEFS ($p = 0.376$, independent-samples *t*-test) and HSS ($p = 0.404$,

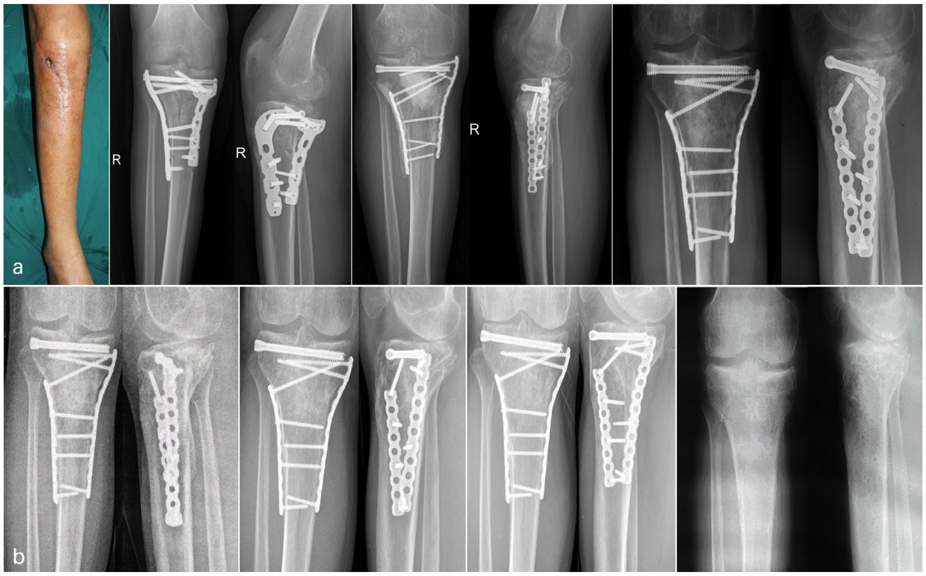

Fig. 2

Two-stage treatment process of a 40-year-old male patient with a Schatzker V fracture. a) Anteroposterior (AP) and lateral radiographs before operation. Plate exposure seen prior to operation (photograph). First-stage postoperative AP and lateral radiograph showed that bone defect was filled with antibiotic bone cement spacer, and the locking plate and hollow screw were used as internal fixator to limb stabilization. Second-stage postoperative AP and lateral radiographs demonstrating placement of iliac crest autograft after removal of spacer and replacement of implant to limb stabilization. b) Radiographs of three, 12, 24, and 30 months after bone grafting, where the implants were removed at 30 months, demonstrating the duration of bony consolidation.

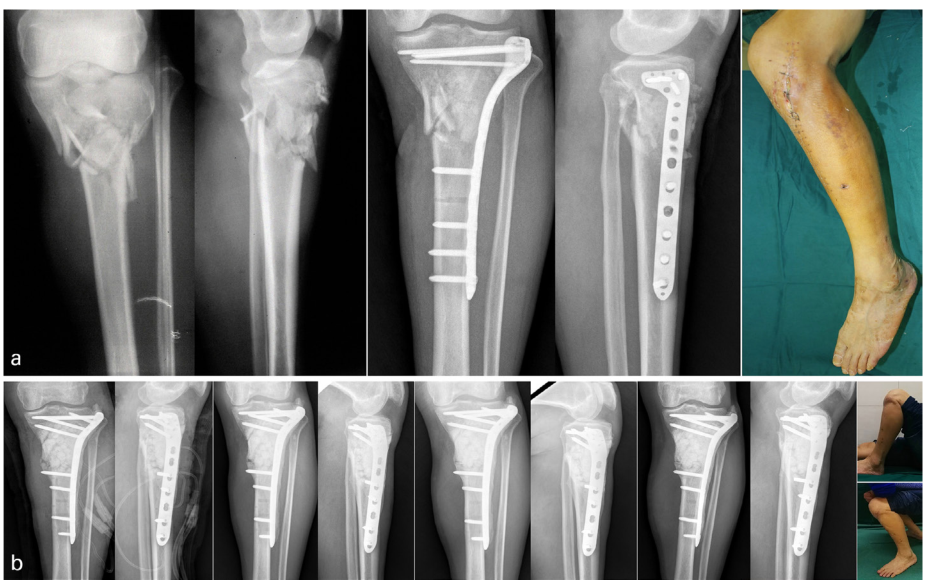

Fig. 3

One-stage treatment process of a 61-year-old male patient with a Schatzker VI fracture. a) Anteroposterior (AP) and lateral radiographs of post-trauma. Photographs and AP and lateral radiographs after open reduction internal fixation demonstrated that knee function was limited and plate was exposed. b) First-stage postoperative AP and lateral radiographs demonstrated that bone defect was filled with antibiotic bone cement spacer, and the locking plate was used as internal fixator to limb stabilization. Radiographs of three, 12, and 24 months after first-stage surgery demonstrating no obvious changes in the proximal tibia. Photos demonstrated function recovery of knee joint at the last follow-up.

independent-samples *t*-test) did not differ markedly between the two groups. Interestingly, our analysis uncovered notable variability in clinical healing time. Through an analysis using the Kaplan-Meier survival curve (Figure 4), the clinical healing time in Group B was significantly less in contrast to that in Group A ($p < 0.001$, log-rank test) (Table II). Factors such as age, duration of infection, and previous operations were analyzed in order to determine factors that were able to predict functional recovery (Table III), and patients with long duration of infection were more likely to suffer poor function ($p < 0.001$, independent-samples *t*-test).

Discussion

Surgical site infection of TPFs after ORIF carries substantial morbidity.[4] In addition to meticulous infection control

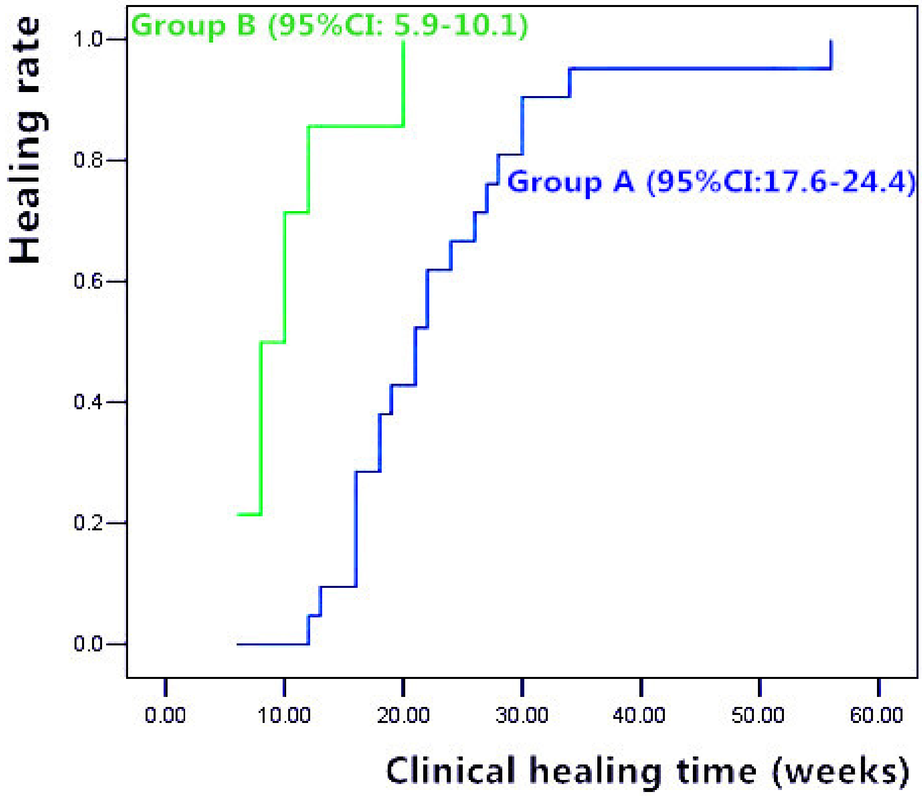

Fig. 4

Kaplan-Meier survival curve for the comparison of clinical healing time between Group A and Group B. The clinical healing time in Group B was significantly less in comparison to that in Group A ($p < 0.001$, log-rank test). CI, confidence interval.

and bone defect repair, it also involves the prolonged rehabilitation to regain knee function. Therefore, the management of SSI of TPF after ORIF is very challenging. The current series of 35 patients with SSI of TPF after ORIF were managed with a two-stage surgery involving a first stage of antibiotic cement-coated locking plates as internal fixation and a second stage using the induced membrane technique. We achieved a high success rate of infection control (100%), bone union (100%), and satisfactory establishment of knee function across all subjects. This is the first study of its kind to demonstrate the successful use of an induced membrane technique in treating infected TPFs.

Bone infection is managed primarily with radical debridement.[30] Incomplete debridement is the major reason of recurrent infection.[20,30,31] Masquelet et al[32] reported that inadequate debridement could be avoided through repeated debridement sessions and the usage of a spacer without antibiotics. Simpson et al[24] suggested that all necrotic and infected bone should be excised with 5 mm or more healthy tissue margin in Cierny-Mader Host B, and less than 5 mm healthy tissue margin in Cierny-Mader Host A. The widely used 'paprika sign' is limited in its ability to determine satisfactory extent of bone resection.[30] Therefore, the extent of bony infection in our study was demarcated using several modes of imaging including radionuclide bone scans, CT scans, and plain radiographs. Based on this system, the whole infected bone area was regarded as a cystic structure that contained sequestrum, pus, and implant, while the junction between infected tissue and normal tissue was regarded as the cyst wall. Radical debridement was done to achieve complete removal of this cystic structure with a 2 mm margin of normal soft-tissue around the cyst wall. Infected wounds were converted contaminated wounds,[18] thereby optimizing conditions for employing internal fixation for stabilization. In this study, 88.6% (31/35) of the participants achieved satisfactory infection control with just a single surgery, indicating the benefits of this radical debridement technique.

In addition to radical debridement, local stabilization as well as microbiological specific local antibiotics application are very important.[33] External fixators represented the first choice for gaining local stabilization in Masquelet's clinical cases involving post-traumatic septic nonunions that occasionally required iterative excisions.[32] The use of a transarticular external fixator often results in joint stiffness,[34] which impacts patients' ability to carry out activities of daily living[35] and negatively affects their mental health.[36] In 2007, Thonse and Conway[19] first reported an effective use of an antibiotic cement-coated interlocking nail in managing infected nonunion and segmental bone defects. A study in 2017 demonstrated good clinical outcomes through first-stage induced

Table II. Comparison of two groups in demographic analysis and final results.

Variables	Group A	Group B	p-value
Number of patients	21	14	
Mean age, yrs (SD)	44.0 (11.8)	48.6 (11.3)	0.268*
Sex, n			0.369†
Female	2	3	
Male	19	11	
Schatzker fracture types, n			0.603‡
IV	1	1	
V	14	10	
VI	6	3	
Cierny-Mader type, n			0.664†
A	3	3	
B	18	11	
Mean previous operations, n (SD)	2.2 (1.4)	1.9 (0.7)	0.343*
Mean duration of infection, wks (SD)	61.2 (122.5)	49.8 (59.5)	0.748*
Bacterial strains (*S. aureus*), n	9	9	0.305†
Mean functional recovery score (SD)			
LEFS	65.7 (10.8)	68.9 (9.7)	0.376*
HSS	82.6 (12.4)	86.0 (10.8)	0.404*
Median bone healing time, wks (IQR)			
Radiological healing	16.0 (13.0 to 22.0)	N/A	N/A
Clinical healing	21.0 (16.0 to 27.0)	8.0 (8.0 to 12.0)	< 0.001§

Group B received no reconstruction and as such had no radiological healing time.
*Independent-samples *t*-test.
†Fisher's exact test.
‡Chi-squared test (linear by linear).
§Log-rank test.
HSS, Hospital for Special Surgery Knee Score; IQR, interquartile range; LEFS, Lower Extremity Functional Scale; N/A, not applicable; *S. aureus*, *Staphylococcus aureus*; SD, standard deviation.

membrane technique in combination of a temporary antibiotic cement-coated locking plate internal fixator in the management of femoral osteomyelitis defects.[20] Wang et al[30] also reported that antibiotic cement should completely envelop the surface of the implant to avoid biofilm formation. In this study, an internal fixator comprising an antibiotic cement-coated locking plate was implanted following radical debridement, which provides antibiotic delivery and bony stability.[37] Compared with an external fixator, this fixation provides greater stability and comfort level without increasing the recurrence rate of infection.[31] One limitation of this technique is the fact that the coating does not protect screws and fixation holes.[38] Additionally, coating efficacy may be hindered by gentamicin/vancomycin resistance. In our series, infection control was obtained through re-debridement in four patients, who may have required the additional procedure either due to incomplete debridement or to the above reason.

In 1986, Masquelet et al[32] serendipitously discovered the efficaciousness of the induced membrane technique in treating large diaphyseal defects. This concept was then further developed in 2010.[39] Compared to the Ilizarov technique and vascularized fibular bone grafting, induced membrane technique mimics natural fracture healing in

Table III. Factors that may be predictive of function recovery.

Variables	Number of patients	LEFS (SD)	HSS (SD)
Duration of infection, wks			
> 10	19	59.9 (8.7)	76.0 (9.7)
≤ 10	16	75.4 (3.8)	93.4 (4.8)
p-value		< 0.001	< 0.001
Age, yrs			
≥ 50	18	65.1 (11.6)	82.1 (13.2)
< 50	17	69.1 (8.7)	85.9 (9.9)
p-value		0.259	0.334
Previous operations, n			
≥ 2	24	65.5 (10.2)	82.4 (11.3)
< 2	11	70.3 (10.4)	87.3 (12.5)
p-value		0.210	0.261

All p-values calculated using independent-samples *t*-test.
HSS, Hospital for Special Surgery Knee Score; LEFS, Lower Extremity Functional Scale.

achieving bony reconstruction. In Group A of this series, all patients were treated with autogenous cancellous bone transplantation in the induced membrane at the second stage. The mean radiological healing time was 16 weeks, which was near to previously reported results.[32] Refracture and infection recurrence are the major complications associated with induced membrane technique.[32]

Incomplete debridement[20,30,32] and use of external fixation[40] were important contributing factors, respectively. In our study, the bone healing rate reached 100%, and no refracture or infection recurrence, which may be a result of the use of combined radical debridement technique and internal fixation.

In addition to controlling infection and reconstructing defects, restoring knee function is another important goal. Joint immobility for more than three to four weeks can lead to permanent knee stiffness in some patients.[41,42] Prasarn et al[43] noted that a long duration of infection resulted in compromised knee function. In our study, the longer the duration of infection, the worse the postoperative functional recovery ($p < 0.001$, independent-samples *t*-test), which was similar to the reported results.[43] However, all of the 35 patients in our study achieved good mid-term functional outcomes, and the mean LEFS and HSS of the last follow-up were 65.7 (40 to 80) and 82.6 points (52 to 100) in Group A, and 68.9 (51 to 80) and 86.0 points (67 to 100) points in Group B, respectively. One of the important factors is the choice of stabilization method. The antibiotic cement-coated locking plate as internal fixation functioned as a stabilizing internal structure without severely impacting knee joint function. Early non-weight-bearing functional exercises were feasible after the first-stage surgery.

Individualized treatment programmes are important for patients.[30] Cierny et al[44,45] reported a method of permanent spacers to treat osteomyelitis successfully. The permanent spacers were composites of various antibiotic-impregnated bone cements (poly-methylmethacrylate) reinforced with a nail, pin, or plate.[45] The rationale for these choices was not elaborated in the literature. In our study, 14 patients did not receive secondary surgery (Group B) because of individual reasons, such as economic reasons or patient refusal (fear of reoperation and satisfaction with pre-existing functional status). Antibiotic cement-coated locking plate was used to stabilize fractures as permanent spacers. Through at least two years' follow-up, there were no marked differences in LEFS and HSS between Group A and Group B. The clinical healing time in Group B was markedly reduced in contrast to that of Group A ($p < 0.001$, log-rank test). The patients (Group B) had no bone healing time, and the antibiotic cement-coated locking plate as internal fixation functioned as a stabilizing internal structure, which could provide enough support to allow full weight-bearing earlier without refracture. The results were encouraging and similar to the literature.[44,45] Nevertheless, permanent spacers, like prosthetic joints, often have a predetermined service life that requires further scrutiny through studies with longer follow-up durations.

This study is limited in its retrospective design and lack of a control group, with future prospective randomized controlled trials required. Our small case number and short follow-up period may also limit the ability of this study to fully capture the extent of long-term outcomes, especially for the patients of no secondary surgery.

Management of SSI post-ORIF for TPF with internal fixation is a reliable method, especially for infection control and functional recovery. The premise of using internal fixation as a stabilizing method is radical debridement, and usage of antibiotic cement to cover the internal fixation plate is a key procedure during the first-stage surgery.

Supplementary material

Table displaying the basic details of each case.

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Author information:
- J. Shen, MD, Orthopaedic Surgeon
- D. Sun, MD, PhD, Orthopaedic Surgeon, Associate Professor
- J. Fu, MD, Orthopaedic Surgeon
- S. Wang, MD, Clinical Researcher
- X. Wang, MD, Orthopaedic Surgeon
- Z. Xie, MD, PhD, Professor
  National & Regional United Engineering Laboratory of Tissue Engineering, Department of Orthopaedics, Southwest Hospital, Army Medical University, Chongqing, China.

Author contributions:
- J. Shen: Performed the operations and the statistical analysis, Wrote the manuscript.
- D. Sun: Performed the operations and the statistical analysis, Reviewed and revised the manuscript.
- J. Fu: Performed the operations, Reviewed the manuscript.
- S. Wang: Collected the clinical data.
- X. Wang: Performed the operations.
- Z. Xie: Designed the study, Performed the operations, Reviewed the manuscript.

- J. Shen and D. Sun are joint first authors.

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