

Novel Piston Technique Versus Ilizarov Technique for The Repair of Bone Defect After Lower Limb Infection

Jiafei Du

Shanghai 6th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

Zifei Yin

The Affiliated Hospital of Nanjing University of Traditional Chinese Medicine: Traditional Chinese Medicine Hospital of Kunshan

Pengfei Cheng

Shanghai 6th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

Pei Han

Shanghai 6th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

Hao Shen (✉ shenhao7212@sina.com)

Shanghai Sixth Peoples Hospital <https://orcid.org/0000-0002-8698-5079>

Research Article

Keywords: Ilizarov technique, Piston technique, Masquelet, induced membrane, bone defect, lower limb infection

Posted Date: August 6th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-749905/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Journal of Orthopaedic Surgery and Research on December 1st, 2021. See the published version at <https://doi.org/10.1186/s13018-021-02844-1>.

Abstract

Background

We described the use of a novel Piston technique versus Ilizarov technique to compare the effectiveness and complications for the repair of bone defect after lower limb infection.

Patients and methods:

We retrospectively reviewed 41 patients who had been treated at our department for lower extremity bone defects following osteomyelitis. They were 38 males and 3 females with a mean age of 43.41 (range 12 to 69 years). The infected bone defects involved 36 tibias and 5 femurs. Piston technique (PT, group A) was used in 12 patients and Ilizarov technique (IT, group B) in 29 ones. The mean duration of follow-up was 28.50 months (PT) and 29.90 months (IT). The modified Application of Methods of Ilizarov (ASAMI) criteria was used to evaluate the bone healing and functional recovery.

Results

Complete eradication of infection and union of docking sites were accomplished well in both groups. The mean external fixator index (EFI) was 42.32 days/cm in group A versus 58.85 days/cm in group B ($p < 0.001$). The bone outcomes were similar between group A and B ($p = 0.558$) [excellent (9 vs. 19), good (3 vs. 10)]; group A showed better functional outcomes than group B ($p < 0.05$) [excellent (7 vs. 6), good (4 vs. 12), fair (0 vs. 10) and poor (1 vs. 1)]. Pain was complained most during follow-up and group A had fewer cases of pin tract infection (1 vs. 6), adjacent joint stiffness (3 vs. 8) and delayed healing of the joint (0 vs. 3).

Conclusions

Satisfactory bone healing can be obtained by using both PT and IT, while PT had better functional results, lower EFI and allowed early removal of the external fixation. We have found that this novel Piston technique can improve the comfort of patients, reduce the incidence of complications, and provide a rapid and convenient rehabilitation.

Introduction

Infectious bone defects of the lower extremity still bring a huge challenge for doctors in clinical practice due to its complicated treatment and unfavourable prognosis. Common causes include acute bone loss, surgical removal of dead or sclerotic bone after infection and ischemic atrophy of nonunion sites (1, 2). There are numerous options of reconstruction, including Ilizarov distraction osteogenesis (3–6), Masquelet technique (7), allogeneic bone grafts (8) and vascularized autogenous bone grafts (such as

ribs, ilium, and fibula) (9). New tissue engineering techniques (10) are also emerging in the field of bone defect treatment.

Ilizarov bone transport technique is widely regarded as the surgical method for the treatment of bone defects (3) and used to treat nonunion, osteomyelitis, deformity, traumatic bone defects and unequal length of lower extremities. Although the Ilizarov technique can achieve satisfactory results in most cases, one of the most common problems with this method is that the external fixator needs to be fixed for a long time until the new bone is completely ossified, which involves many complications, including pin trajectory infection, loosening of the retractor, persistent pain, stiffness of joints, angled tilt, refracture and delayed union (11, 12). In recent years, Masquelet technology (13) has been placed a high value and widely used, a two-stage surgical technique including debridement and filling the bone defect with cement spacer in the first stage to control postoperative infection, and bone remodelling by filling with cancellous bone after removing the cement inside the so-called induced membrane in the second stage. Due to the existence of residual infection after first-stage operation of infectious bone defect, the mixture of bone cement and antibiotics has been widely applied (14–16). The review (3–7, 13, 17) shows many clinical series reports on the reconstruction of bone defects with Masquelet technique. However, in some circumstances, quite a lot of bone graft is needed and donor site injury is also disturbing. To overcome the above technical defects, our department used Masquelet technique combined with Ilizarov bone transport technique, which we name it as Piston technique for the first time, to treat bone defects after lower extremity infection. Piston technique shows the similar procedure in the first stage as Masquelet technique, and we remove the bone cement without disturbing the induced membrane, then using external fixation to perform distraction osteogenesis in the second stage. It is expected to reduce the time of external fixation and avoid bone grafting.

To our best knowledge, there are relatively few reports that describe the outcomes of Piston technique in the treatment of infectious bone defects. Therefore, here we describe this Piston technique and compare it with the reconstruction effect of Ilizarov bone transport technique in bone defect after lower extremity infection. We were intended to determine whether this technique could lower the fixator duration time patients keep and reduce the risk of complications.

Patients And Methods

This retrospective study was reviewed and approved by the institutional review board. All procedures were in compliance with the Helsinki Declaration. Informed consent for participation was obtained from all participants.

Inclusion criteria for this study: (1) Bone defects of 2.5 cm or more caused by osteomyelitis; (2) Osteomyelitis confirmed by bacteriology or histology through intraoperative biopsy based on clinical manifestations and imaging; (3) age < 70 years. Exclusion criteria: (1) patients with non-infectious bone defects; (2) patients who withdrew from treatment early or did not complete treatment; (3) patients who could not be followed up.

From 2013 to 2018, we included 41 patients in total, consisting of 38 men and 3 women, of which 12 cases used Piston technique and 29 cases used Ilizarov technique. These infectious bone defects included 36 tibias and 5 femurs. The detailed information of patients is shown in Table 1 and Table 2 in the supplement.

Surgical Techniques

PT and IT technique are similar in debridement. The patient remains supine on the transmissive operating table. The surgical incision is as consistent as possible with the previous incision, including the sinus. The hardware is removed if there are steel plates, screws or intramedullary nails used in previous surgery. Then the infected bone is completely removed until the so-called “paprika sign” (cortical bone bleeding area) appears (Fig. 1a and b) (18). It is of great importance to ensure that cortex remained after radical debridement is intact and uninfected.

In group A, the bone defect is measured at the first stage after radical debridement and polymethylmethacrylate (PMMA) bone cement spacer is filled (Fig. 1c). We tend to use 4.0g vancomycin + 4.0g meropenem per 40g cement. Types of antibiotics can be adjusted according to the patient's condition if the patient had the result of bacterial culture and drug sensitivity before operation. The fixation method depends on the type and location of the bone infection defect. Choices include monolateral or circular external fixation (Fig. 1d). 6–8 weeks after first operation, the cement spacer is carefully removed without damaging the PMMA-induced membrane. Next, we use an external fixation extender for installation comparison. Under the control of the image intensifier, 2 or 3 suitable hydroxyapatite-covered pins are used to fix the femoral or tibial shaft, which are interposed through a pre-drilled way about 2–3 cm above and below the osteotomy site. A subperiosteally transverse osteotomy is performed then. After suturing the periosteum, the incision is closed with a drainage tube.

In group B, after debridement and removing the infected or necrotic bone we would choose the external fixation for tibial and femoral bone defects. The transverse osteotomy method is similar to group A.

Both groups use open dressing change or vacuum sealing drainage (VSD) to temporarily seal large and complex soft tissue defects at the site of infection. Whether skin grafts or flaps are needed before bone defect repair depends on the condition of the soft tissue.

Postoperative Protocols

Clinical follow-up was conducted every 2 weeks to check the nail path status, skeleton stability, range of motion and damage to adjacent joints. In the distraction phase, the X-ray examination was reviewed every 2 weeks, and once a month during the consolidation period, to assess the fracture healing and the quality of consolidation (Fig. 2). Laboratory indicators such as erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), and blood cell count were tested at the proper time to ensure eradication of

infection. Postoperative complications were recorded. Dahl's grading was used to assess the pin tract inflammation (19). According to the modified Application of Methods of Ilizarov (ASAMI) criteria (Table 1) (20), the results of bone healing and functional recovery were evaluated. The external fixation time (EFT) represented the whole days the external fixation was fixed to the bone. The external fixation index (EFI) was defined as EFT (days) divided by the total amount of lengthening (cm).

Table 1
The criteria for the assessment of bone and function

Bone results	Criteria	Functional results	Criteria
Excellent	Union, no infection, deformity < 7°, limb-length discrepancy (LLD) < 2.5 cm	Excellent	Active, no limp, minimum stiffness (loss of < 15° knee extension / < 15° ankle dorsiflexion), no reflex sympathetic dystrophy (RSD), insignificant pain.
Good	Union plus any two of the following: absence of infection, deformity < 7°, LLD < 2.5 cm.	Good	Active, with one or two of the following: limp, stiffness, RSD, significant pain
Fair	Union plus any one of the following: absence of infection, deformity < 7°, LLD < 2.5 cm.	Fair	Active, with three or all of the following: limp, stiffness, RSD, significant pain
Poor	Nonunion/refracture/union plus infection plus deformity > 7° plus LLD > 2.5 cm	Poor	Inactive (unemployment or inability to return to daily activities because of injury)

Statistical analysis.

Data was analyzed with SPSS statistical package (version 22.0, IBM). Descriptive statistics were conducted for all variables. Continuous variables were expressed as the mean standard deviation. Dichotomous variables were expressed as percentages and events. Two independent-samples t-test, chi-square test or rank sum test was performed to evaluate the differences between 2 groups. Statistically significant difference was defined as P value of < 0.05.

Results

Detailed intraoperative and postoperative data of groups A and B are shown in Table 2 and Table 3. In both groups, complete eradication of infection and union of docking sites were accomplished well. The

mean bone defect length and EFT did not differ between group A and B, while the mean EFI of group A (42.32 days/cm) was significantly less than group B (58.85 days/cm) ($p < 0.001$).

According to the bone healing and limb function evaluation criteria recommended by ASAMI, the results of bone healing in group A, among which 9 cases were excellent and 3 cases were good, were similar to those of group B, which had 22 excellent cases and 7 good cases ($p = 0.558$). The results of limb function in group A were significantly better than those in group B ($p < 0.05$). Group A had 7 excellent cases, 4 good cases, and 1 poor case. However, group B had 6 excellent cases, 12 good cases, 10 fair cases, and 1 poor case. There was a statistical difference between group A and group B in functional results, but no statistical difference in bone results (Table 4). The relatively worse functional result was mainly due to prolonged external fixation leading to significant pain and restricted movement of adjacent joints.

Pain was the most common complaint during follow-up. For some patients, it was quite severe and intolerable in the first few days after surgery. Whether in group A or group B, almost all patients had dull pain during the distraction phase, especially at night. Most of them were treated with oral analgesics to relieve pain. In the PT group none had delayed healing of the joint, while in the IT group 3 cases occurred. They were admitted to the hospital for bone regraft and adjustment of the external fixation stent, ending up with union of docking sites. Grade II and III pin tract infections according to Dahl's classification were detected in 1 patient of group A and 6 patients of group B. These patients were treated with oral administration of broad-spectrum antibiotics and local injection care. Grade IV or uncontrollable infection was not observed. Though 3 patients of group A and 8 ones of group B suffered from transient adjacent joint stiffness when removing the fixator, all of them could get normal range of motion in the adjacent joint after 2–3 months of rehabilitation physical training.

Table 2
Basic patient data of PT and IT groups

Items	PT group	IT group	P value
Number	12	29	–
Sex ratio(males/females)	11/1	27/2	0.657
Mean age	44.00 ± 11.73	43.17 ± 15.75	0.871
Mean times of previous operations	2.67 ± 1.15	2.52 ± 1.06	0.690
Site of injury(femur/tibia)	2/10	3/26	0.620
Right/left	4/8	17/12	0.181
Type of external fixator(Circular/Monolateral)	8/4	22/7	0.701

Table 3
Comparisons of follow-up data between PT and IT groups

Items	PT group	IT group	P value
Duration of cementation(days)	64	–	–
Bone defect length(cm)	9.96 ± 3.10	7.5 ± 3.04	0.024
External fixator time(days)	425.92 ± 166.35	430.90 ± 165.85	0.931
External fixator index(EFI = days/cm)	42.32 ± 8.31	58.85 ± 13.53	< 0.001
Cases of bone regrant	0	3	–
Follow-up(months)	28.50 ± 8.23	29.90 ± 8.21	0.623

Table 4
Evaluation of the bone and functional results between PT and IT groups

Outcomes	Treatment	Numbers(femur/tibia)/percentage				Total	P values
		excellent	good	fair	poor		
Bone results	PT Group	9(1/8)	3(1/2)	0(0/0)	0(0/0)	2/10	P = 0.558
		75.0%	25.0%	0%	0%		
	IT Group	19(1/18)	10(2/8)	0(0/0)	0(0/0)	3/26	
		65.5%	34.5%	0%	0%		
Functional results	PT Group	7(0/7)	4(1/3)	0(0/0)	1(1/0)	2/10	P = 0.020
		58.3%	33.3%	0%	8.3%		
	IT Group	6(0/6)	12(1/11)	10(2/8)	1(0/1)	3/26	
		20.7%	41.4%	34.5%	3.4%		

Discussion

Treatment of lower limb osteomyelitis is still a thorny problem in orthopedics. Patients who decide to take limb salvage treatment usually require multiple surgical treatments, resulting in soft tissue and bone defects. Nowadays there are many methods for the treatment of bone defects, containing Masquelet and Ilizarov technique. Though both techniques were originally designed to treat bone defects caused by infection, they have been widely applied in the repair of bone defects caused by other diseases nowadays, such as bone defects after trauma (21–23), congenital pseudarthrosis of the tibia (24–26), and bone defects after resection of bone tumor (4, 27, 28).

In recent years, the Masquelet technique has gradually become the main method for the treatment of bone defects after lower limb infection due to its significant advantage of induced membrane (29,

30). However, for large segment of bone defect, the classic Masquelet technique cannot obtain a sufficient amount of autologous bone graft, which is also prone to complications in donor site and may not be able to meet the correction of limb length discrepancy (LLD) and limb alignment. The traditional Ilizarov technique still has its classic advantages. Patients can bear weight early after surgery. In addition, IT also has the advantages of continuous adjustment of limb alignment with external fixation and chance of one-stage operation. It is speculated that the process of distraction osteogenesis can trigger a strong vascular response, thereby accelerating the healing of osteomyelitis or distant vascular disconnection (31). Unfortunately, long-time duration of external fixator places restrictions on its use, which would bring a lot of complications. There is no doubt that if the external fixation time can be effectively reduced, it will become very attractive.

The present study here is to investigate a novel hybrid Piston technique combining induced membrane and bone transport technique for the treatment of bone defects after lower extremity infection. We tend to remove the bone cement without disturbing the induced membrane, then performing distraction osteogenesis with external fixation in the second stage. This hybrid technique generally aims to effectively reduce the duration of external fixation and complications.

Our study demonstrated that the average EFI of PT group was significantly less than IT group and the bone healing results was not negatively affected. The traditional studies on the management of infected nonunion with Ilizarov external fixator reported an average EFI of 54.9 days/cm and 54.0 days/cm (32, 33). For induced membrane, the characteristics could be described as a vascularized structure that resembles periosteum, secreting vascular inducible factors (VEGF) (34, 35) and a maturity stage between the 4th and 6th week (36). One of the advantages of Piston technique is that the blood supply of induced membrane in bone defect area and debridement area can promote the migration of the docking sites, thus speeding up the process of distraction osteogenesis.

Delayed union or nonunion of the docking site may occur when the contact area is insufficient or the docking site does not coincide. To address this problem, several feasible options are proposed to prevent this common complication and shorten the duration of the fixator. Some surgeons chose to perform partial autogenous bone grafting, and some preferred the osteotome and curette to polish the bony edges at the docking site (37, 38). Bifocal bone transport was also reported to be effective (39). However, our Piston technique provides an exceptional osteogenic microenvironment compared with Ilizarov technique, where the induced membrane could secrete osteoinductive factors and stimulate bone regeneration. In our study, PT group had none case of delayed docking site union while IT group had 3 cases with further operations of bone graft.

Removal of the entire bone segment and continuous antibiotic release with bone cement can effectively remove the dead bone and biofilm, and so will offer a better chance of eliminating infection compared with the Ilizarov technology. Though none infection recurrence occurred in presented both groups, Sami Roukoz, et al. (40) and Sarita R Shah, et al. (41) reported that antibiotic loaded bone cement could achieve a better anti-infectious effect. A narrative review (42) showed the rate of infectious recurrence in

patients with infected or noninfected critical-sized tibial bone defects treated by Ilizarov methods was 4.58%. Though there was no significant difference in the operation times between two groups, a recent logistic regression analysis (43) discovered that repeated operations, post-traumatic osteomyelitis, and internal fixation at the first stage were risk factors for recurrence of infection treated with the induced membrane technique. Based on these concerns, we recommend that the repeated operations and the surgical design of internal fixation should be carefully considered, to allow patients to receive more benefits of Piston technique.

Though the Piston technique requires two-stage operation, its advantages outweigh the disadvantages. Thanks to the potential benefits of induced membrane, rich blood supply and satisfactory union of the docking site made this Piston technique gather remarkably reduced EFI, satisfactory bone healing results and better functional results. In addition, early removal of external fixator could significantly reduce the risk of complications. In PT group, the percentage and severity of pain, joint stiffness and pin tract infection were low and no complications needed further operation treatment.

Conclusions

The limitations of our study are the relatively small sample size and the short time of follow-up. Nevertheless, the Piston technique group provides an early opportunity to remove the fixator, allowing for earlier rehabilitation exercises and eliminating patient discomfort. We have reason to believe that this new combined technique provides a feasible improvement plan for the treatment of patients with bone defect after lower extremity infection.

Abbreviations

PT

Piston technique

IT

Ilizarov technique

ASAMI

The modified Application of Methods of Ilizarov

EFI

external fixator index

EFT

external fixator time

PMMA

polymethylmethacrylate

VSD

vacuum sealing drainage

ESR

erythrocyte sedimentation rate

CRP

C-reactive protein

Declarations

Ethics approval

This retrospective study was reviewed and approved by the institutional review board of Shanghai Jiao Tong University Affiliated Sixth People's Hospital.

Consent to participate

All the authors agreed to be assigned.

Consent for publication

All the authors agreed to submit to International Orthopaedics.

Availability of data and material

Not applicable.

Conflicts of interest/Competing interests

The authors declare that they have no conflict of interest.

Funding

This study was supported by the National Natural Science Foundation of China (No. 81772364, No.81974325, No. 81702183), Medical Guidance Scientific Research Support Project of Shanghai Science and Technology Commission (Grant No. 19411962600) and the Science and Technology Commission of Shanghai Municipality (No.18ZR1428700).

Authors' contributions

JFD and ZFY designed the research, analyzed the data, and wrote the manuscript. PFC and PH acquired the data and performed the surgical treatment. HS supervised the project and reviewed the manuscript. All authors read and approved the final manuscript.

Acknowledgements

We are indebted to the support from the nursing staff of the Orthopaedic Department, Shanghai Jiao Tong University Affiliated Sixth People's Hospital.

References

1. Kanakaris NK, Tosounidis TH, Giannoudis PV. Surgical management of infected non-unions: An update. *Injury*. 2015;46 Suppl 5:S25-32.
2. Yang KH, Won Y, Kim SB, Oh BH, Park YC, Jeong SJ. Plate augmentation and autologous bone grafting after intramedullary nailing for challenging femoral bone defects: a technical note. *Arch Orthop Trauma Surg*. 2016;136(10):1381-5.
3. Aronson J, Johnson E, Harp JH. Local bone transportation for treatment of intercalary defects by the Ilizarov technique. Biomechanical and clinical considerations. *Clin Orthop Relat Res*. 1989(243):71-9.
4. Demiralp B, Ege T, Kose O, Yurttas Y, Basbozkurt M. Reconstruction of intercalary bone defects following bone tumor resection with segmental bone transport using an Ilizarov circular external fixator. *J Orthop Sci*. 2014;19(6):1004-11.
5. Madhusudhan TR, Ramesh B, Manjunath K, Shah HM, Sundaresh DC, Krishnappa N. Outcomes of Ilizarov ring fixation in recalcitrant infected tibial non-unions - a prospective study. *J Trauma Manag Outcomes*. 2008;2(1):6.
6. Dendrinou GK, Kontos S, Lyritis E. Use of the Ilizarov technique for treatment of non-union of the tibia associated with infection. *J Bone Joint Surg Am*. 1995;77(6):835-46.
7. Selhi HS, Mahindra P, Yamin M, Jain D, De Long WG, Jr., Singh J. Outcome in patients with an infected nonunion of the long bones treated with a reinforced antibiotic bone cement rod. *J Orthop Trauma*. 2012;26(3):184-8.
8. Keating JF, Simpson AH, Robinson CM. The management of fractures with bone loss. *J Bone Joint Surg Br*. 2005;87(2):142-50.
9. Taylor GI, Miller GD, Ham FJ. The free vascularized bone graft. A clinical extension of microvascular techniques. *Plast Reconstr Surg*. 1975;55(5):533-44.
10. Urist MR, Sato K, Brownell AG, Malinin TI, Lietze A, Huo YK, et al. Human bone morphogenetic protein (hBMP). *Proc Soc Exp Biol Med*. 1983;173(2):194-9.
11. Lin CC, Chen CM, Chiu FY, Su YP, Liu CL, Chen TH. Staged protocol for the treatment of chronic tibial shaft osteomyelitis with Ilizarov's technique followed by the application of intramedullary locked nail. *Orthopedics*. 2012;35(12):e1769-74.
12. Khan MS, Rashid H, Umer M, Qadir I, Hafeez K, Iqbal A. Salvage of infected non-union of the tibia with an Ilizarov ring fixator. *J Orthop Surg (Hong Kong)*. 2015;23(1):52-5.
13. Masquelet AC, Fitoussi F, Begue T, Muller GP. [Reconstruction of the long bones by the induced membrane and spongy autograft]. *Ann Chir Plast Esthet*. 2000;45(3):346-53.
14. Lalidou F, Kolios G, Drosos GI. Bone infections and bone graft substitutes for local antibiotic therapy. *Surg Technol Int*. 2014;24:353-62.
15. van Vugt TAG, Arts JJ, Geurts JAP. Antibiotic-Loaded Polymethylmethacrylate Beads and Spacers in Treatment of Orthopedic Infections and the Role of Biofilm Formation. *Front Microbiol*. 2019;10:1626.

16. Rajendran M, Iraivan G, Ghayathri B, Mohan P, Chandran KR, Nagaiah H, et al. Antibiotic Loaded Nano Rod Bone Cement for the Treatment of Osteomyelitis. *Recent Pat Nanotechnol.* 2020.
17. Tong K, Zhong Z, Peng Y, Lin C, Cao S, Yang Y, et al. Masquelet technique versus Ilizarov bone transport for reconstruction of lower extremity bone defects following posttraumatic osteomyelitis. *Injury.* 2017;48(7):1616-22.
18. Eralp L, Kocaoglu M, Rashid H. Reconstruction of segmental bone defects due to chronic osteomyelitis with use of an external fixator and an intramedullary nail. *Surgical technique. J Bone Joint Surg Am.* 2007;89 Suppl 2 Pt.2:183-95.
19. Dahl MT, Gulli B, Berg T. Complications of limb lengthening. A learning curve. *Clin Orthop Relat Res.* 1994(301):10-8.
20. 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):146-65.
21. Chaddha M, Gulati D, Singh AP, Singh AP, Maini L. Management of massive posttraumatic bone defects in the lower limb with the Ilizarov technique. *Acta Orthop Belg.* 2010;76(6):811-20.
22. Wong TM, Lau TW, Li X, Fang C, Yeung K, Leung F. Masquelet technique for treatment of posttraumatic bone defects. *ScientificWorldJournal.* 2014;2014:710302.
23. Masquelet AC. Muscle reconstruction in reconstructive surgery: soft tissue repair and long bone reconstruction. *Langenbecks Arch Surg.* 2003;388(5):344-6.
24. Meselhy MA, Elhammady AS, Singer MS. Outcome of Induced Membrane Technique in Treatment of failed previously operated Congenital Pseudarthrosis of the Tibia. *Orthop Traumatol Surg Res.* 2020;106(5):813-8.
25. Pannier S, Pejin Z, Dana C, Masquelet AC, Glorion C. Induced membrane technique for the treatment of congenital pseudarthrosis of the tibia: preliminary results of five cases. *J Child Orthop.* 2013;7(6):477-85.
26. Vanderstappen J, Lammens J, Berger P, Laumen A. Ilizarov bone transport as a treatment of congenital pseudarthrosis of the tibia: a long-term follow-up study. *J Child Orthop.* 2015;9(4):319-24.
27. Villemagne T, Bonnard C, Accadbled F, L'Kaissi M, de Billy B, Sales de Gauzy J. Intercalary segmental reconstruction of long bones after malignant bone tumor resection using primary methyl methacrylate cement spacer interposition and secondary bone grafting: the induced membrane technique. *J Pediatr Orthop.* 2011;31(5):570-6.
28. Chotel F, Nguiabanda L, Braillon P, Kohler R, Berard J, Abelin-Genevois K. Induced membrane technique for reconstruction after bone tumor resection in children: a preliminary study. *Orthop Traumatol Surg Res.* 2012;98(3):301-8.
29. Zhang Q, Zhang W, Zhang Z, Zhang L, Chen H, Hao M, et al. Femoral nonunion with segmental bone defect treated by distraction osteogenesis with monolateral external fixation. *J Orthop Surg Res.* 2017;12(1):183.
30. van Niekerk AH, Birkholtz FF, de Lange P, Tetsworth K, Hohmann E. Circular external fixation and cemented PMMA spacers for the treatment of complex tibial fractures and infected nonunions with

- segmental bone loss. *J Orthop Surg (Hong Kong)*. 2017;25(2):2309499017716242.
31. Aronson J. Temporal and spatial increases in blood flow during distraction osteogenesis. *Clin Orthop Relat Res*. 1994(301):124-31.
 32. Kocaoglu M, Eralp L, Rashid HU, Sen C, Bilsel K. Reconstruction of segmental bone defects due to chronic osteomyelitis with use of an external fixator and an intramedullary nail. *J Bone Joint Surg Am*. 2006;88(10):2137-45.
 33. Sigmund IK, Ferguson J, Govaert GAM, Stubbs D, McNally MA. Comparison of Ilizarov Bifocal, Acute Shortening and Relengthening with Bone Transport in the Treatment of Infected, Segmental Defects of the Tibia. *J Clin Med*. 2020;9(2).
 34. Pelissier P, Masquelet AC, Bareille R, Pelissier SM, Amedee J. Induced membranes secrete growth factors including vascular and osteoinductive factors and could stimulate bone regeneration. *J Orthop Res*. 2004;22(1):73-9.
 35. Cuthbert RJ, Churchman SM, Tan HB, McGonagle D, Jones E, Giannoudis PV. Induced periosteum a complex cellular scaffold for the treatment of large bone defects. *Bone*. 2013;57(2):484-92.
 36. Wang X, Wei F, Luo F, Huang K, Xie Z. Induction of granulation tissue for the secretion of growth factors and the promotion of bone defect repair. *J Orthop Surg Res*. 2015;10:147.
 37. Emara KM, Ghafar KA, Al Kersh MA. Methods to shorten the duration of an external fixator in the management of tibial infections. *World J Orthop*. 2011;2(9):85-92.
 38. Sala F, Thabet AM, Castelli F, Miller AN, Capitani D, Lovisetti G, et al. Bone transport for postinfectious segmental tibial bone defects with a combined ilizarov/taylor spatial frame technique. *J Orthop Trauma*. 2011;25(3):162-8.
 39. Griffith MH, Gardner MJ, Blyakher A, Widmann RF. Traumatic segmental bone loss in a pediatric patient treated with bifocal bone transport. *J Orthop Trauma*. 2007;21(5):347-51.
 40. Roukoz S, El Khoury G, Saghbini E, Saliba I, Khazzaka A, Rizkallah M. Does the induced membrane have antibacterial properties? An experimental rat model of a chronic infected nonunion. *Int Orthop*. 2020;44(2):391-8.
 41. Shah SR, Smith BT, Tatara AM, Molina ER, Lee EJ, Piepergerdes TC, et al. Effects of Local Antibiotic Delivery from Porous Space Maintainers on Infection Clearance and Induction of an Osteogenic Membrane in an Infected Bone Defect. *Tissue Eng Part A*. 2017;23(3-4):91-100.
 42. Aktuglu K, Erol K, Vahabi A. Ilizarov bone transport and treatment of critical-sized tibial bone defects: a narrative review. *J Orthop Traumatol*. 2019;20(1):22.
 43. Wang X, Wang S, Fu J, Sun D, Shen J, Xie Z. Risk factors associated with recurrence of extremity osteomyelitis treated with the induced membrane technique. *Injury*. 2020;51(2):307-11.

Figures

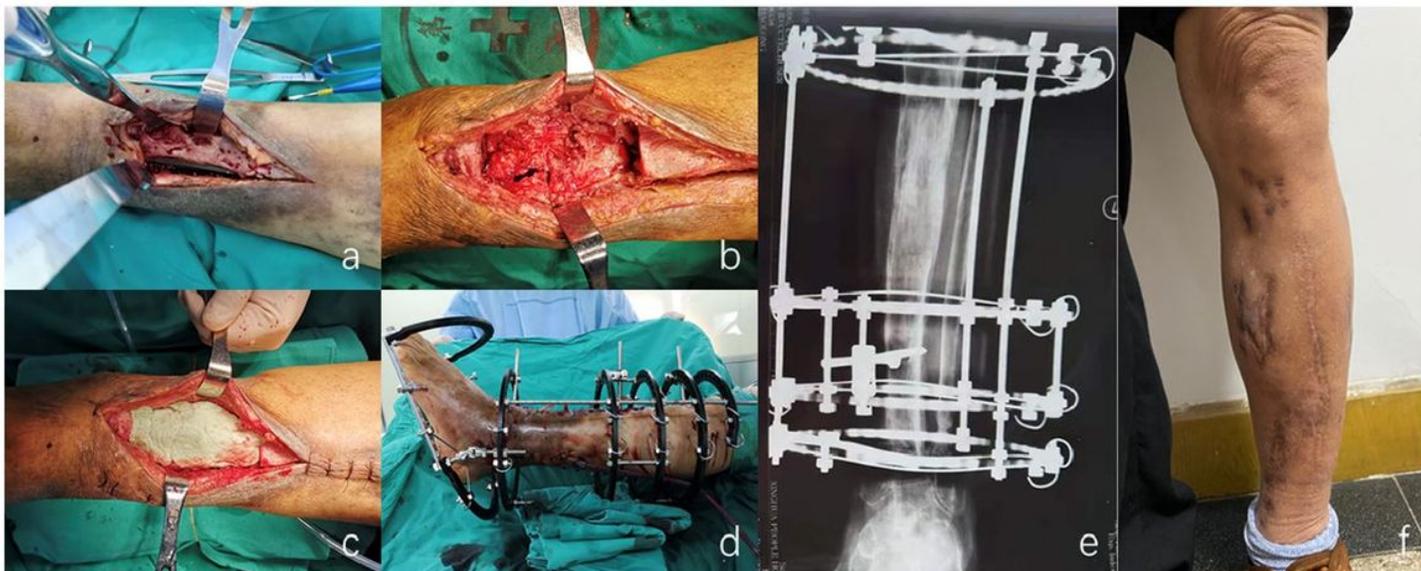


Figure 1

54-year-old man with left tibia osteomyelitis, having a bone defect length of 9.8 cm, was performed with Piston technique. (a-b) During debridement, the infected or necrotic bone was removed radically. (c) Bone cement spacer. (d) External fixation. (e) Bone union was achieved at 19 months after second-stage operation. (f) Patient had removed the external fixator.

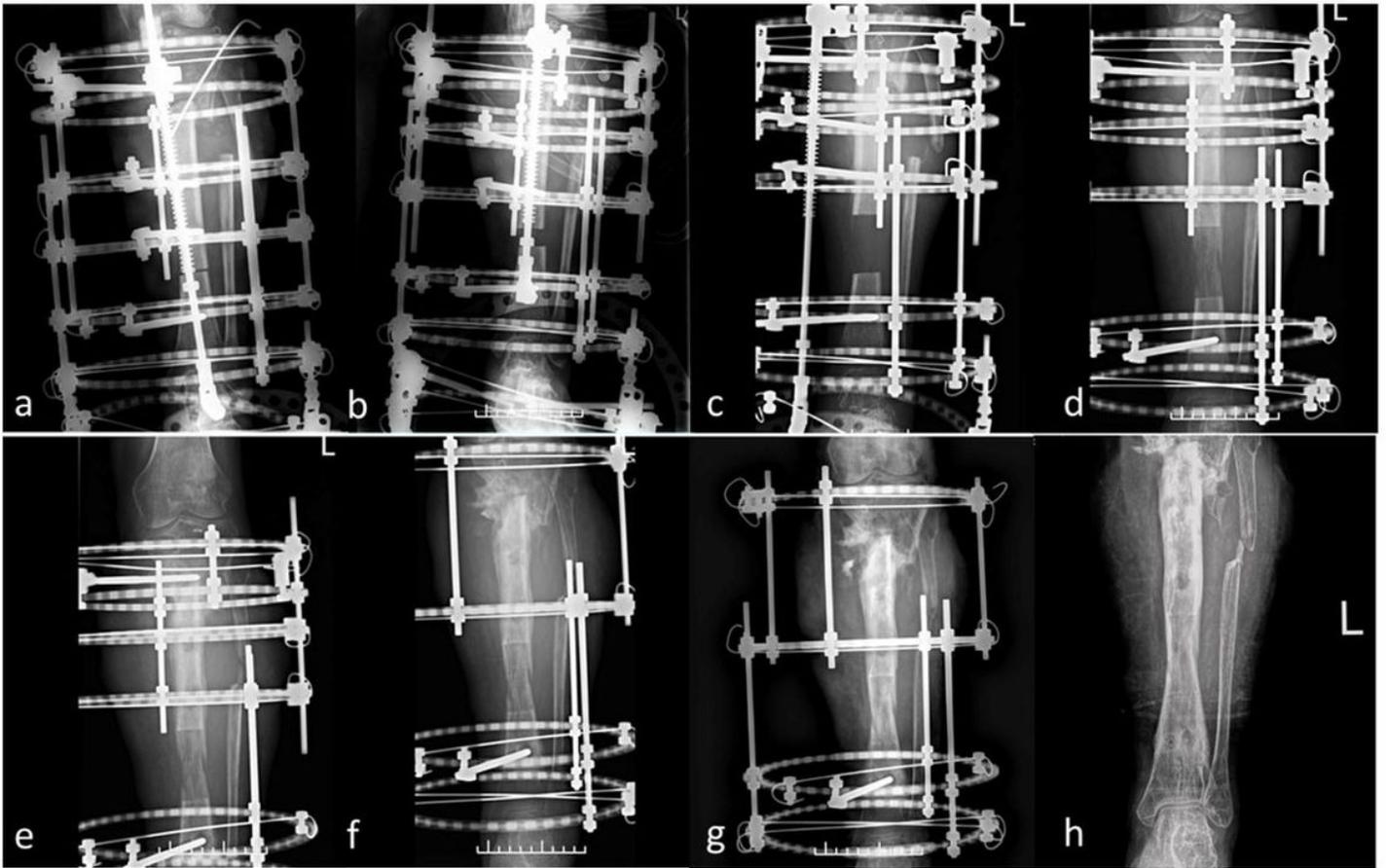


Figure 2

The bone transport process of a 50-year-old woman who had an infected left tibia bone defect with traditional Ilizarov technique. (a) Radiograph of a 50-year-old woman who had an infected left tibia bone defect with the start of transverse osteotomy. (b) Three weeks after operation. (c) Two months after operation. (d-f) Having the regenerated bone begun to be mineralized at the docking site at seven, nine months and one year after operation. (g) Good consolidation and mineralization of the regenerated bone at 17 months after operation. (h) Completing bone union and removing the external fixation at 24 months after operation.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementtable14.xls](#)