E-Da Medical Journal 2022;9(3):14-24

Original Article
DOI: 10.6966/EDMJ.202209_9(3).0002

A Locking Plate as a Definitive External Fixator for Treating Post-Traumatic Tibial Osteomyelitis

Hsing-Chier Hsueh[1,], Chin-Hsien Wu[1,2], Ching-Hou Ma[1,2,*], I-Ming Chou[1,2], Yuan-Kun Tu[1,2]*

Objective: Evaluation of locking plate as a definitive external fixator for post-traumatic tibia osteomyelitis treatment.
Methods: Eighteen consecutive post-traumatic tibial osteomyelitis patients were treated by performing a staged procedure that included hardware removal, radical debridement, locked plate definitive external fixator, and bone and soft-tissue reconstruction.
Results: The follow-up time ranged between 18 – 48 months (mean: 31 months). The time until union ranged between 20 – 72 weeks (mean: 38.2 weeks). All except one patient were successfully treated using our protocol. All bone assessments indicated excellent and good results. The functional results ranged from excellent (14 patients), good (3 patients), and poor (1 patient). One patient had recurrent drainage. Tibiotalocalcaneal fusion was performed on two patients with equinis foot. Parenteral antibiotics was given to one patient who had superficial infections, which resolved with treatment. Length discrepancy greater than 2.5 cm was noted in three patients, and 10° procurvatum was noted in one patient. There were no deep infections due to the external fixator; minor screw track infections were noted in 4 patients.
Conclusions: The locking plate used as a definitive external fixator provided good access for wound management and facilitated the treatment of associated injuries. While the locking plate is not entirely rigid, it is clinically stable and provides the necessary element of flexibility for bone healing. Our patients experienced smooth clinical courses, and had satisfactory functional results and acceptable complication rates.

Key words: tibial osteomyelitis, external fixator, locking plate, posttraumatic

Introduction

Tibial osteomyelitis is a burdensome injury presenting as progressive inflammatory destruction and new appositional bone growth.[1] The treatment for this condition is mainly surgical. Tibial osteomyelitis is a challenging disease because even with surgery and antibiotic treatment, the condition may be difficult to irradicate.[2,3] Adequate disease treatment requires radical debridement, skeletal stabi-

From the [1]Department of Orthopedics, E-Da Hospital; [2]School of Medicine, I-Shou University, Kaohsiung, Taiwan.
Received: October 29, 2020 Accepted: December 25, 2020
* Address reprint request and correspondence to: Hsing-Chier Hsueh and Ching-Hou Ma
Department of Orthopedics, E-Da Hospital, No.1, Yida Road, Jiaosu Village, Yanchao District, Kaohsiung City 82445, Taiwan.
Tel: +886-7-615-0011 ext. 252231, E-mail: emerson.hsueh@gmail.com (HCH)
Tel: +886-7-615-0011 ext. 2765, E-mail: ed100771@edah.org.tw (CHM)

lization, soft-tissue coverage, and addressing bone defects and nonunion. A staged protocol is developed for these treatments.

The use of an internal fixator such as a nail or plate before the infected condition has stabilized should be done cautiously to prevent further infection.[4] For cases with large bone loss or infective nonunion, Ilizarov external fixation is a suitable device.[5,6] However, the technique is laborious and needed prolonged usage that is cumbersome and bulky to the patient. Use on the lower extremities causes problems with dressing and resting, and impedes the contralateral extremity while walking.[7,8]

Low-profile external fixation is suitable for complex injuries during the reconstructive process. Locking plates provide angular stable screw fixation and are used as an internal-external fixator.[9,10] This property makes them suitable as an external plate fixation device. We previously reported successful experiences with locking plate as an external fixator for tibial injury with successful results.[7,8,11-13] Other authors have also reported similarly successful outcomes.[14,15] Based on our successful open tibial injuries management, a treatment protocol was devised for treating these cases of tibial osteomyelitis. This protocol comprises two stages: (1) hardware removal and extensive tissue debridement until viable tissue remains; and (2) bone stabilization using a locked plate low-profile external fixator, with concomitant soft-tissue and bone reconstruction. The benefits of using the locked plate as a low-profile definitive external fixation include immediate osseous stabilization for infection control without crossing the joint, early lower extremity range of motion, easy application and easy access to wounds, and higher convenience and comfort in all aspects of the patient's life during treatment.

We describe our experience of using a locking plate as an external fixator combined with aggressive bone and soft-tissue reconstruction for the treatment of tibial osteomyelitis.

Materials and Methods

Between January 2012 and December 2019, eighteen patients with tibial osteomyelitis (13 male, 5 female), between 21 to 64 years (average age 40 years), with tibia nonunion and bone defect after debridement were managed at our hospital with the above protocol (Table 1). Osteomyelitis was diagnosed both clinically and radiologically. This cohort comprised patients who had received acute care and those who had undergone several debridements before being referred to our hospital. Of these patients, nine had Gustilo and Anderson type III (A:3, B:6), four had type II, three had type I, and two had closed fractures during the initial injury.[16] The Cierny-Mader classification indicated that the site of osteomyelitis was superficial in five, localized in six, and diffused in seven patients.[17] Thirteen patients underwent bacterial cultures, and a total of 13 strains were detected, including 4 strains of methicillin-resistant staphylococcus aureus, 3 *Staphylococcus aureus,* 3 *Pseudomonas,* 2 *Enterobacter cloacae,* and 1 *Klebsiella oxytoca.* Preoperatively, laboratorytesting such as leukocyte count, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) level, were made to assess the severity of infection. The treatment was based on wound size and location, signs of infection, and degree of bone and hardware exposure.

Surgical technique

Staged surgeries were used to manage the patients (Fig. 1). During the first-stage, debridement of the soft-tissue and necrotic bone was performed. During this time, samples was taken for intraoperative microbial cultures. All hardware were removed due to speculation of concealed residual infection or leading to an unacceptable fixation. A provisional external

Table 1. Patient demographics.

Case	Age/Gender	Fracture type (AO/OTA)	Open fracture (Gustilo)	Cierny-Mader classification	Bacterium	Previous operation (time)	Duration of infection (week)	Other fracture
1	28/male	42-C2	IIIA	IIIA	Staphylococcus aureus	4	8	-
2	44/male	41-C3	I	IIA	Enterobacter cloacae	6	12	-
3	34/male	42-C1	IIIB	IIIA	Not found	11	14	-
4	46/male	42-C1/43-A3	IIIB	IVB	MRSA	7	15	Pelvis
5	53/male	43-C1	-	IIB	Staphylococcus aureus	3	9	-
6	49/male	43-C2	II	IIIB	Enterobacter cloacae	6	38	-
7	21/male	41-C2	IIIA	IIA	Pseudomonas	4	6	Patella
8	64/male	41-C2	IIIA	IVB	MRSA	5	22	Raidus
9	36/male	41-A3	IIIB	IIIB	Klebsiella oxytoca	7	15	-
10	58/female	42-B2	I	IIIB	MRSA	8	50	Femur
11	38/male	41-C2	IIIB	IVB	Pseudomonas	9	12	-
12	31/male	42-C1	II	IIIB	Not found	5	14	-
13	55/female	42-B2	II	IVA	Staphylococcus aureus	6	32	Foot (Lisfrancs)
14	25/male	42-C2	IIIB	IIIA	Pseudomonas	6	20	-
15	27/male	43-A3	-	IIB	Not found	3	8	Ankle
16	42/male	42-C3	IIIB	IVB	MRSA	4	4	-
17	39/male	42-A1	II	IIIB	Not found	5	42	Talar
18	26/female	42-B3	I	IIA	Not found	6	36	-

fixator was immediately applied. If the infection was located around the proximal or distal tibia, the external fixator also involved the knee or ankle joint, respectively.

Radical necrotic bone resection along with debridement of the infected scarred soft tissue was performed, and samples for tissue cultures were obtained, including from the wound and the sinus tracts for all dead bones. Cortical bleeding, also known as the paprika sign, suggested presence of viable tissue.[12,13] The dead space resulting from the debridement was filled with custom-made, antibiotic-impregnated polymethylmethacrylate (PMMA) beads, which included 2.4 g of teicoplanin or 2 g of vancomycin in 40 g of PMMA powder. A vacuum-assisted closure device was applied to the open wound, and a repeat debridement was indicated if purulent discharge or extended tissue necrosis was observed.

The second-stage treatment was performed once the wound bed was clear on visual inspection and no pus or fluid accumulation was visualized, along with decrease in the CRP level after repeat testing. In this study, the repeated fracture reduction was performed directly through the debrided wound or extending the wound with a short incision. Orthogonal fluoroscopic views were used for reduction assessment. After reduction of the fracture, we used locked internal fixators, LISS-distal femur (13 holes) [DF] (Synthes, Paoli, PA), or the

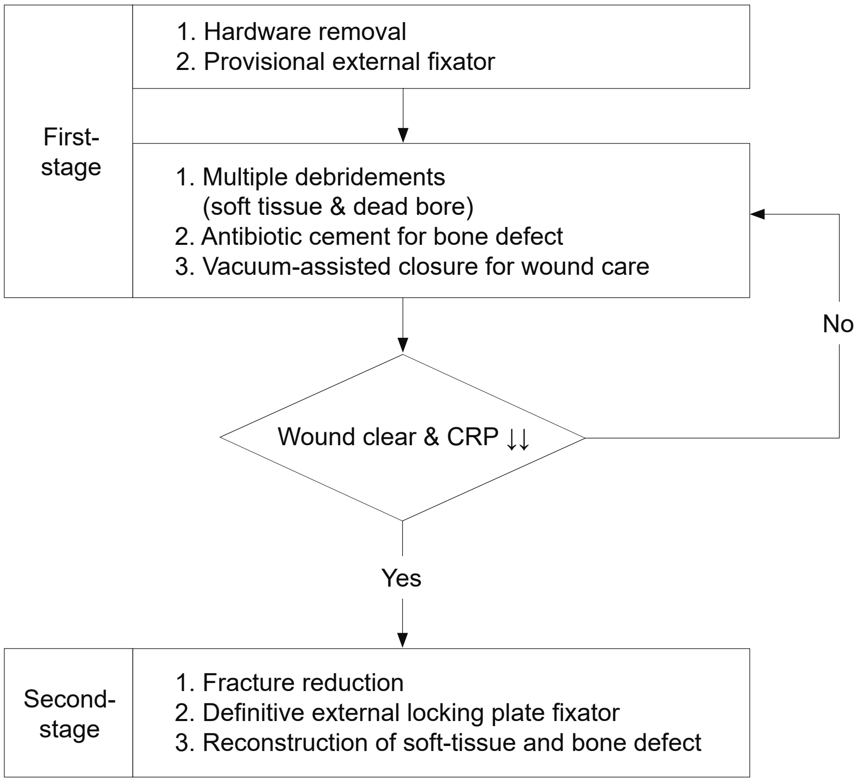

Fig. 1 Flow diagram of treatment protocol.

External Locked Plate (15 holes) (E-Da, Kaohsiung, Taiwan) as definitive external fixators to replace the provisional external fixator for stabilizing both ends of the tibial shaft and the tibial metaphysis and diaphysis. When the infected area was around the proximal or distal tibia, the stabilizer did not cross over the knee or ankle joint. The locked plate was placed opposite to the infected wound to circumvent subsequent soft-tissue reconstruction procedure interference. Several 4.5-mm self-drilling and tapping locking screws was applied via stab incisions for fracture stabilization. Four to five screws were fixed to the metaphysis, while three screws were fixed to the diaphysis to ensure secure fixation. We allocated 3 to 5 centimeters of space above the skin for plate position, as this allowed for more straightforward prepping and draping for ensuing procedures.

Shortly after bone stabilization, soft-tissue reconstruction was performed. There was no standardized procedure for soft-tissue coverage. For adequate defect coverage, local muscular flap, fasciocutaneous flap, and free muscle flap were used. If required, thorough debridement may include re-lifting the flap. After confirmation of flap survival and infection control, split-thickness skin graft procedure was performed. Subsequently, the legs were elevated and placed in a soft, mildly compressive dressing in 10° flexion for 2 to 5 days. Screw tracts were cleaned with 75% alcohol 3 to 4 times daily. Physical therapy for the muscles and joints was started on the third to the sixth postoperative day based on the condition of the soft-tissue condition. Appropriate antibiotics were administered according to the bacterial culture and sensitivity until the ESR and CRP levels returned to normal or for a minimum of six weeks. Patients were discharged after the soft tissue had stabilized with ESR and CRP returning to normal. Subsequent physical therapy and outpatient office follow-up was arranged.

In cases with bone defects, where antibiotic beads were placed at the time of the initial sequestrectomy, bead removal and subsequent bone defect filling was performed with cancellous bone graft and unicortical iliac bone transposition. If the defect was greater than 6 cm, a free vascularized fibular graft was used to cover the defect. Bone grafting was performed 6 to 8 weeks after the soft tissue reconstruction. Patients without bone defects were allowed protected, partial weight-bearing starting in the second week. For those with bone grafting, this process was generally initiated at 8 to 12 weeks.

The patients were seen in the outpatient department at 4 to 8 week intervals, keeping detailed records of wound and bone healing. After fracture healing, the external locking plate was removed, and patients were scheduled for yearly follow-up (Fig. 2).

Bone assessment included union, nonunion, malformation, leg shortening, and infection. The definition of bone union was identification of a radiographic bridging callus, without weight-bearing pain at the fracture location.[7,8,12] Nonunion was defined as deficient bone healing that required additional surgical measures such as cancellous bone grafting or a revision osteosynthesis.[12] Excellent result was noted if union without infection, smaller than 7° of deformity, and smaller than 2.5 cm length discrepancy in the tibia. Good result was noted if there was union with two of the other criteria were met. Fair result was noted if there was union and one of the other criteria was met. Poor result was noted if there was nonunion or refracture or none of the criteria was met.

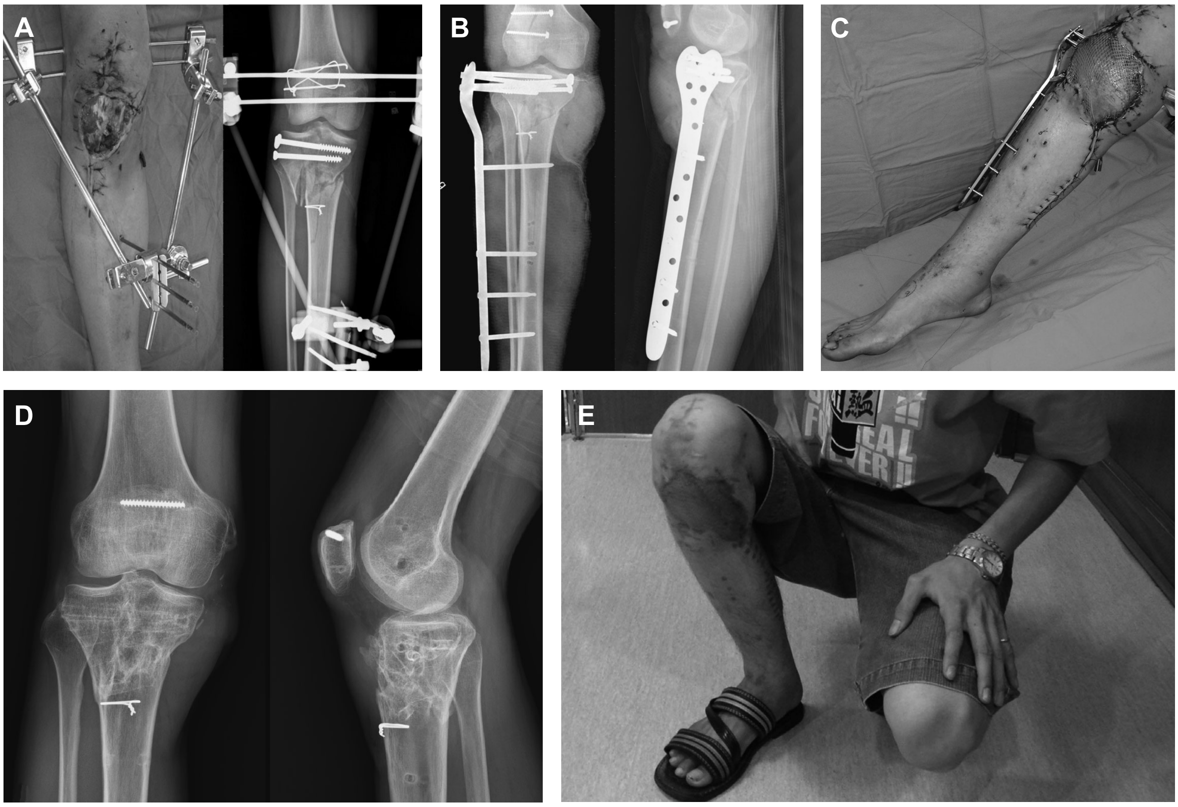

Fig. 2 (A) A 21-year-old man presented with right proximal tibial osteomyelitis with soft tissue defect, bone and tendon necrosis, and improper alignment of the proximal tibia. (B) Post-operative X-ray image shows anatomic reduction of the articular surface, good alignment of the proximal tibia, and stabilization with a locked plate as an external fixator. (C) The fracture was stabilized with a locked plate as an external fixator, and the soft-tissue defect was reconstructed using a pedicle gastrocnemius muscle flap and skin graft. (D) Implants were removed, and the X-ray image shows bone union after 24 weeks. (E) The functional outcomes were excellent at the 3-month follow-up.

The function was evaluated according to Paley et al., based on five criteria: significant limp, equinus rigidity, soft-tissue dystrophy, pain, and inactivity (unable to return to work or daily activity). Excellent results was recorded if 4 criterias was absent. Good result was recorded if presence of one or two of the other four criteria. Fair result was recorded if three or four of the other criteria or the need for an amputation. An inactive individual was asigned poor result regardless of the presence or absence of the other criteria.[6]

Results

Eighteen patients treated according to our protocol were followed for 18 to 48 months (average 31 months) (Table 2). Time to bony union was less than 1 year in 16/18 patients, including the 10 patients who required conventional cancellous bone grafts and iliac bone grafts. One patient who received a free vascularized fibula graft achieved union at 15 months. One patient with a composite bone and soft tissue defect received dual ribs bone graft in combination with latissimus dorsi and serratus anterior free flap achieved union in 18 months (Fig. 3). The mean duration of bone healing was 38.2 weeks (range 20 – 72 weeks). Ten patients were treated using local muscular flaps (4 gastrocnemius muscle flaps, 6 soleus muscle flaps), three were treated using reverse sural artery fasciocutaneous flaps, and four were treated using latissimus dorsi free flaps.

Using the bone assessment, excellent results was recorded in 14 patients and good results in 4. According to the functional result rating established by Paley, the results in 14 patients were rated excellent, 3 were rated good, and 1 was rated poor. One patient resulted in septic knee arthritis after the primary surgery, leading to a limited knee range of motion (15 – 70°). Two patients had lost more than 20 degrees of ankle joint motion and presented with claw feet when we initiated their treatment. Two patients had equinis foot due to anterior leg extensor muscle loss after multiple debridements, resulting in tibiotalocalcaneal fusion as a salvage procedure.

One patient with distal tibial osteomyelitis, in whom soft-tissue reconstruction was performed using a reverse sural artery fasciocutaneous flap, developed recurrent drainage. He underwent a repeat wound debridement for the complete removal of all the necrotic bone tissue. Soft-tissue defects resulting from the repeat debridement required reconstruction with a latissimus dorsi free flap and split-thickness skin grafts. Subsequently, the infection was eradicated, resulting in excellent function and a good radiographic outcome. Three patients healed with a length discrepancy greater than 2.5 cm, and one bone union resulted in a 10° procurvatum. One patient resulted in superficial infections that was successfully treated with parenteral antibiotic treatment. There were no deep infections due to the external fixator, only minor screw tract infections in 4 patients that resolved with oral antibiotics and regular wound care of the screw sites. Two of the four patients also developed an irritation at the site of a locking screw, which was removed under local anesthesia. There was no loosening of the external fixator due to screw tract infections. One patient who received a free latissimus dorsi muscle flap required early revision microsurgery as a result of venous thrombosis and had a partial flap losses over the skin.

Discussion

The management of patients with post-traumatic tibial osteomyelitis pose challenging issues to addressing soft tissue and bone. Patients have commonly undergone several operative interventions, resulting in bone defects and soft-tissue compromise. The main treatment modality osteomyelitis patients is surgical debridement along with antibiotic administra-

Table 2. Patient results.

Case	Follow-up (months)	Bone union (weeks)	Bone graft	Soft-tissue reconstruction	Bone status at last follow-up	Functional status at last follow-up	Complication
1	48	24	CBG + IBG	S	excellent	excellent	
2	45	36	-	GN	excellent	excellent	
3	43	42	CBG	LD	excellent	excellent	Superficial infection
4	41	38	CBG + IBG	LD	excellent	poor	Flap partial necrosis Ankle fusion
5	41	28	-	RS	excellent	excellent	
6	38	44	CBG	LD	good	excellent	Recurrent discharge
7	38	24	-	GN	excellent	excellent	
8	35	40	CBG + IBG	GN	good	good	Procurvatum 10° Screw tract infection
9	33	26	CBG	GN	excellent	excellent	
10	32	28	CBG	S	excellent	excellent	
11	32	60	FVFBG	RS	good	excellent	Length discrepancy 4 cm
12	30	52	CBG	S	good	excellent	Length discrepancy 2.5 cm Screw tract infection
13	29	42	CBG	S	excellent	good	
14	27	48	CBG + IBG	LD	excellent	excellent	Superficial infection Screw tract infection
15	25	20	-	RS	excellent	excellent	
16	24	72	DRBG	LD + SA	good	excellent	Length discrepancy 4 cm Ankle fusion
17	21	28	-	S	excellent	good	
18	18	36	-	S	excellent	excellent	Screw tract infection

CBG: Cancellous bone graft; IBG: Iliac bone graft; FVFBG: Free vascularized fibular bone graft; DRBG: Double ribs bone graft; S: Soleus local flap; GN: Gastrocnemius local flap; LD: Latissimus dorsi free flap; SA: Serratus anterior; RS: Reverse sural local flap.

tion to assist healing and eradicate infection.[2,3] Successful osteomyelitis management is dependent on careful patient selection, suitable antibiotics usage, and four essential surgical procedures. These include: (1) Radical debridement: removing all contaminated bone and soft tissue, leaving well-vascularized healthy tissue visible. (2) Bone stabilization: instituting adequate stabilization to provide skeletal stability and prevent the local recurrence of infection. (3) Dead space eradication: the bead-pouch application, along with a local or microsurgical free flap transfer to achieve neovascularization of the entire implicated region. (4) Bridging the bone defect: performing a conventional bone graft for short defects (< 6 cm), a vascularized bone graft, or an Ilizarov bone lengthening. A staged protocol is suitable for incorporation of these surgical elements.[2,3,18-20]

We were successful in treating osteomyelitis with a low rate of recurrence (1/18), with timely infection identification and adequate surgical debridement playing a vital role. We debrided all infected and devitalized tissue as much as possible, as would be the case in the treatment of malignant tumors, and were certain that all infected material had been eliminated. Every patient underwent a soft-tissue reconstruction using a local or free flap. There was no consensus for type of soft-tissue coverage. For proximal third defect, a gastrocnemius muscle flap was used; for middle third defect, a soleus muscle flap; for distal third, a reverse sural artery fasciocutaneous flap. A free flap was used to cover extensive defects or when a local flap was unreliable. Soft-tissue reconstruction with a flap decreases dead space, provides soft-tissue coverage, prevents contamination by environmental pathogens, and improves recipient site vascularity.[21,22] Soft-tis-

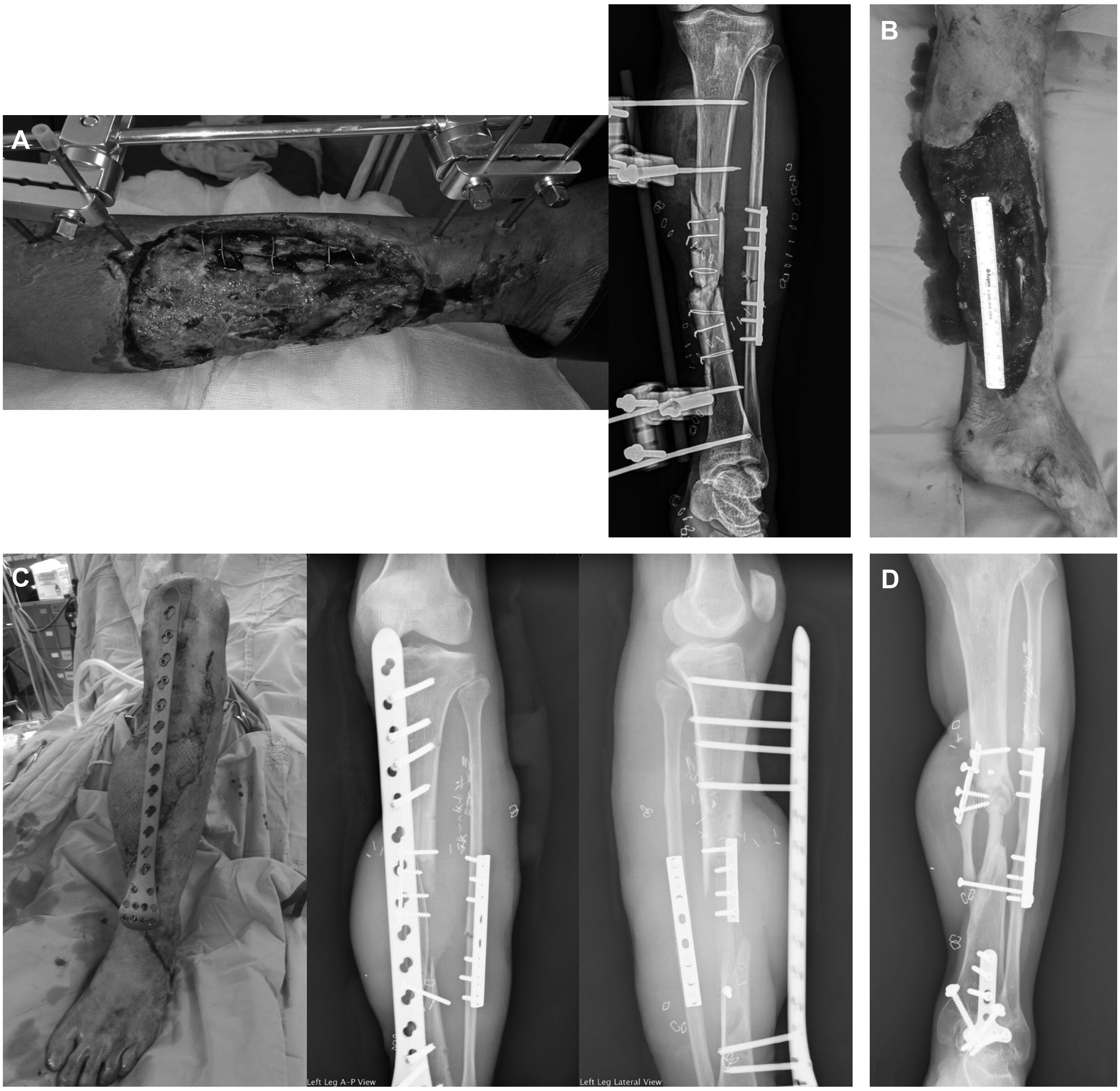

Fig. 3 (A) A 42-year-old man with Cierny-Mader type-IVB osteomyelitis of the right tibia. (B) Pre-operative X-ray image showing huge bone and soft tissue defect after debridement. (C) Photograph and X-ray image show definitive external fixation performed using a locked plate as an external fixator, and the bone and soft tissue defects were reconstructed using a dual ribs bone graft combined latissimus dorsi and serratus anterior free flap. (D) Graft showing hypertrophic solid union and ankle fusion at the 18-month follow-up without recurrent infection.

sue flaps aid the host defense system, improve antibiotic penetration, and encourage healing.[22]

In case of skeletal instability at the site of infection, skeletal stabilization of the non-united fractures is pertinent for infection control, reducing limb pain, and accessing the wound.[4] However, when internal fixation is indwelling, biofilm formation on the implant surface shield microorganisms from eradication. Therefore, the decision to retain or remove the infected implants is case dependent, based on several factors: bone healing status, hardware stability, fracture location, and time since fracture fixation.[23] To eliminate the risks of harboring residual infection from implants, we remove all previous implants and stabilize the fractures using external fixators for bridging the infected area. The standard external fixator is low-cost and quickly applied. However, in cases of knee and ankle infection, these standard external fixators should be applied as a bridging fixation spanning the joint until the infection is restrained and soft-tissue reconstruction is achieved. However, one must be aware of resulting muscle atrophy and joint stiffness.[7,8,11]

An Ilizarov external fixator is important in the treatment of osteomyelitis. This device can address bone defects by distraction osteogenesis at the metaphyseal region, facilitating gradual bone growth.[5,24] Also, it can be used to compress nonunions and to correct malunions. Despite its multiple advantages, the main shortcomings of the Ilizarov method are its extended duration of treatment and the associated long-term disability, an average of 8.5 months.[23] The Ilizarov constructs are often too large and cumbersome for further soft-tissue work and the patient's daily life.[5,23,24] When used in the lower limbs, problems with bedrest, getting dressed, and walking on the contralateral limb are commonly seen.

Successful experiences have been reported by Kerkhoffs et al. in managing infected nonunion or open fractures with standard AO-plates as external fixators.[14] This plate offers good stability in a low profile and simple construct. The newer generation locked plate implants is often utilized for fractures associated with osteoporosis, comminution, and short segment metaphysis. The locked plate biomechanics differ from conventional compression plate by its stable connection of the locking screws to the load carrier (plate). This construct is non-reliant to load carrier-bone interface friction. In other words, the locked plate resembles closely to the external fixator, and are often advocated as internal-external fixators. In recent times, the locking plate has been accepted as an external fixator for treating an open fracture, nonunion, and malunion with satisfactory results.[7,8,11-15] Published biomechanical and clinical studies suggest that locking plate could indeed be used as a definitive external fixator.[25,26] This technique is versatile, low-profile, and well tolerated by patient; it is a useful addition in the armament in the staged treatment of complex reconstructive cases.

We presented an alternative protocol for tibial osteomyelitis treatment. Based on our protocol, following the hardware removal and radical resection of the dead bone with debridement of the infected scarred soft tissue, a good reduction of the articular surface and adequate alignment of the length and rotation of the diaphysis are performed using an open technique through the debrided wound or a short incision. It is easier to achieve a good correction. Subsequently, a LISS-DF locking plate or an External Locked Plate is used as the definitive non-spanning external fixator to stabilize the fractures. The frame is relatively low-profile, has a simple construction, and provides good stability to maintain the reduction better than that with a standard external fixator.[7,8,11-13] Although the mean duration of bone healing in this study was 38.2 weeks (range 20 – 72 weeks), most patients experienced relative convenience and felt comfortable during the fixation.

There is less stability in using a locking plate as an external fixator than as an internal fixator. However, good relative stability was evidenced by the formation of good periosteal callus and hypertrophy of the vascularized fibula graft in our study.[11-13] Recent studies reported that locked plating constructs could be too stiff and consequently suppress the interfragmentary movement to a level inadequate for optimal secondary bone healing.[27,28] This concern is supported by some case studies on locked plates describing inadequate callus formation, delayed union, and nonunion with late hardware failure. Based on these theoretical and clinically emerging concerns, several strategies to reduce the stiffness of locked plating constructs have been used, including reducing the plate thickness, increasing the plate elevation, and increasing the plate span.[29] While these methods effectively reduce locking plate construct stiffness, subsequent plate strength decrease was also unavoidable. In our study, we used a locking plate as an external fixator to provide adequate relative stability for enhanced bone healing.

The use of external fixation was associated with increased rate of malunion and the need for repeat surgery.[30] Malunion might result from improper reduction and progressive loss reduction due to unstable fixation provided by an external fixator. However, in our study, we achieved good reduction directly through wound debridement or a short incision extending from the wound. The number of screws used with the locking plate was more than that used for standard external fixators; however, the stability was consequently improved. Otherwise, the locking plate is a simple construct in which the locking head screw connects directly with the plate hole. Standard external fixators require clamps to connect the screws with the bars, and the clamps must be hand-tightened. These are not secure and create the risk of looseness.

Pin tract infection is still the most common complication when using external fixation; this was also observed in our study. In recent publications, the pin tract infection incidence ranges from 32 – 80%, while deep infection incidence is 16.2%.[30] In this study, we recorded 4 cases of pin tract infection out of 18 patients amounting to 22.22% incidence. We recorded no cases of deep infection. There is difficulty to prevent pin tract infection, especially with the prolonged use of an external fixator. We emphasized this problem to educate the patients and aggressively treated instances of screw tract infection to reduce the rate of infection.

We encountered some disadvantages when using the locking plate as an external fixator. When four to five screws were inserted into the metaphyseal component of the fracture, the density of the screws were too high. This had a negative impact on the care of the screw tract. This problem can be resolved by using a multidirectional locking screw system to increase the distance between each screw. We noted three patients with limb length discrepancies greater than 2.5 cm. Using a locked plate as an external fixator cannot correct these problems and repair the fractures at the same time, which is possible with an Ilizarov-type device.

In conclusion, the management of tibial osteomyelitis should target radical resection of all necrotic and infected tissue, including the skin, soft tissues, and bone. Subsequent bone and soft tissues reconstruction should be performed in a stages. We described an alternative protocol using a locking plate as a definitive external fixator for post-traumatic tibial osteomyelitis, which offers good access for wound management and facilitates the treatment of associated injuries. While the locking plate is not entirely rigid, it offers sufficient stability while providing the necessary flexibility for bone healing. Our patients also had a comfortable clinical course, satisfactory functional results, and an acceptable complication rate.

Funding

Fund from E-Da Hospital (EDAHP 106051) was received in support of this work.

References

1. Lew DP, Waldvogel FA: Osteomyelitis. N Engl J Med 1997;336:999-1007. doi: 10.1056/NEJM199704033361406.
2. Guelinckx P, Sinsel N: Refinements in the one-stage procedure for management of chronic osteomyelitis. Microsurgery 1995;16:606-11. doi: 10.1002/micr.1920160906.
3. Tu YK, Yen CY, Ueng SWN: Reconstruction of post-traumatic bone defect with vascularized iliac bone graft: eight-year follow-up. J Reconstr Microsurg 2002;18:427.
4. Tu YK, Lin CH, Su JI, et al: Unreamed interlocking nail versus external fixator for open type-III tibial fractures. J Trauma 1995;39:361-7. doi: 10.1097/00005373-199508000-00029.
5. Edwards CC: Staged reconstruction of complex open tibial fractures using Hoffmann external fixation. Clinical decisions and dilemmas. Clin Orthop Relat Res 1983;178:130-61. doi: 10.1097/00003086-198309000-00017.
6. Paley D, Catagni MA, Argnani F, et al: Ilizarov treatment of tibial nonunions with bone loss.

Clin Orthop Relat Res.1989;241:146-65. doi: 10.1097/00003086-198904000-00017.
7. Ma CH, Wu CH, Yu SW, et al: Staged external and internal less-invasive stabilisation system plating for open proximal tibial fractures. Injury 2010;41:190-6. doi: 10.1016/j.injury.2009.08.022.
8. Ma CH, Yu SW, Tu YK, et al: Staged external and internal locked plating for open distal tibial fractures. Acta Orthopaedica 2010:81 382-6 doi: 10.3109/17453674.2010.487244.
9. Cole PA, Zlowodzki M, Kregor PJ: Less Invasive Stabilization System (LISS) for fractures of the proximal tibia: indica-tions, surgical technique and preliminary results of the UMC Clinical Trial. Injury 2003; 34: A16 - A29 doi: 10.1016/S0020-1383(03)00254-7.
10. Schütz M, Müller M, Krettek C, et al: Minimally invasive fracture stabilization of distal femoral fractures with the LISS: a prospective multicenter study. Results of a clinical study with special emphasis on difficult cases. Injury 2001;32:SC48-54. doi: 10.1016/S0020-1383(01)00183-8.
11. Ma CH, Tu YK, Yeh JH, et al: Using external and internal locking plates in a two-stage protocol for treat-ment of segmental tibial fractures. J Trauma 2011;71:614-9. doi: 10.1097/TA.0b013e3182041175.
12. Ma CH, Chiu YC, Tsai KL, et al: Masquelet technique with external locking plate for recalcitrant distal tibial nonunion. Injury 2017;48:2847-52. doi: 10.1016/j.injury.2017.10.037.
13. Ma CH, Chiu YC, Wu CH, et al: Ipsilateral vascularised fibula with external locking plate treat-ment of massive tibial bone defects. Injury 2021;52:1629-34. doi: 10.1016/j.injury.2021.02.052.
14. Kerkhoffs GMMJ, Kuiper MM, Marti RK, et al. External fixation with standard Ao plates: technique, indications and results in 31 cases. J Orthop Trauma 2003;17:61-4. doi: 10.1097/00005131-200301000-00010.
15. Kloen P: Supercutaneous plating: using of a locking compression plate as an external fixator. J Orthop Trauma 2009 23:72-5. doi: 10.1097/BOT.0b013e31818f8de4.
16. Gustilo RB, Mendoza RM, Williams DN: The management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 1984;24:742-6. doi: 10.1097/00005373-198408000-00009.
17. Cierny G III, Mader JT, Penninck JJ: A Clinical staging system for adult osteomyelitis. Clin Ortho Relate Res 2003;414:7-24. doi: 10.1097/01.blo.0000088564.81746.62.
18. Green SA: Osteomyelitis: the Ilizarov perspective. Orthop Clin North Am 1991;22:515-21. doi: 10.1016/S0030-5898(20)31679-5.
19. Mckee MD, Wild LM, Schemitsch EH, et al: The use of an antibiotic impregnated, osteoconductive, bioabsorbable bone substitute in the treatment of infected long bone defects: early results of a prospective trail. J Ortho Trauma 2002;16:622-7. doi: 10.1097/00005131-200210000-00002.
20. Tu YK, Yen CY, Yeh WL, et al: Reconstruction of posttraumatic long bone defect with free vascularized bone graft: good outcome in 48 patients with 6 years' follow-up. Acta Orthop Scand 2001;72:359-64. doi: 10.1080/000164701753542014.
21. May JW, Gallico GG III, Lukash FN: Microvascular transfer of free tissue for closure of bone wound of the distal lower extremity. N Engl J Med 1982;306:253-7. doi: 10.1056/NEJM198202043060501.
22. Patzakis MJ, Abdollahi K, Sherman R, et al: Treatment of chronic osteomyelitis with muscle flaps. Orthop Clin North Am 1993;24:505-9. doi: 10.1016/S0030-5898(20)31824-1.
23. Patzakis MJ, Zalavras CG: Chronic posttruamtic osteomyelitits and infected nonunion of the tibia: current management concepts. J Am Acad Orthop Surg 2005;13:417-27. doi: 10.5435/00124635-200510000-00006.
24. Kocaoglu M, Eralp L, Rashid HU, e al: Reconstruction of segmental defect due to chronic osteomyelitis with use of an external fixator and an intramedullary nail. J Bone Joint Surg Am 2006;88:2137-45. doi: 10.2106/JBJS.E.01152.
25. Ma CH, Wu CH, Tu YK, et al: Metaphyseal locking plate as a definitive external fixator for treating open tibial fractures—clinical outcome and a finite element study. Injury 2013,44: 1097-101. doi: 10.1016/j.injury.2013.04.023.
26. Ma CH, Wu CH, Jiang JR, et al: Metaphyseal locking plate as an external fixator for open tibial fracture: clinical outcomes and biomechanical assessment. Injury 2017,48:501-5. doi: 10.1016/j.injury.2016.11.031.
27. Bottlang M, Doornink J, Fitzpatrick DC, et al: Far cortical locking can reduce stiffness of locked plating constructs while retaining construct strength. J Bone Joint Surg Am 2009;91:1985-94. doi: 10.2106/JBJS.H.01038.
28. Lujan TJ, Henderson CE, Madey SM, et al: Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. J Orthop Trauma 2010;24:156-62. doi: 10.1097/BOT.0b013e3181be6720.
29. Ahmad M, Nanda R, Bajwa AS, et al: Biomechanical testing of the locking compression plate: when dose the distance between bone and implant significantly reduce construct stability? Injury 2007;38:358-64. doi: 10.1016/j.injury.2006.08.058.
30. Giannoudis PV, Papakostidis C, Roberts C: A review of the management of open fractures of the tibia and femur. J Bone Joint Surg Br 2006;88:281-9. doi: 10.1302/0301-620X.88B3.16465.