Non-contact locking plate: A useful alternative to external fixation in second-stage treatment of post-traumatic tibial osteomyelitis

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Abstract. The treatment of infected tibial bone defects can be challenging for the orthopedic surgeon. Therefore, the aim of the present study was to compare the fixation endurance, bone union time, lower limb joint function and complications associated with different fixation methods in the treatment of bone defects caused by debridement in the treatment of post-traumatic osteomyelitis. The clinical data of 55 patients with infected bone defects of the lower extremities following traumatic injury, who had undergone radical debridement between January 2017 and September 2020, were retrospectively analyzed. The patients were divided into three groups according to the type of fixation during reconstruction, namely the external fixation (EX), internal fixation (IX) and non-contact locking plate (LP) groups. The demographic data, time to bone union, bacterial culture results, complications and Self-Rating Anxiety Scale (SAS) scores of the patients were compared among the three groups. The results indicated that the differences in time to bone union and recurrence rates of osteomyelitis among the three groups were not statistically significant. By contrast, functional status after surgery was significantly higher in the LP group compared with the EX group. In total, 8/22 patients (36.4%) in the EX group, 4/13 patients (30.8%) in the IX group and 4/20 patients (20.0%) in the non-contact LP group had shortened limbs and deformed tibia. The SAS assessment results revealed that patients in the non-contact LP group had the lowest rates of moderate and severe anxiety. In conclusion, the results of the present study demonstrate that the non-contact locking plate technique provided stable fixation without any contact between the implant and bone tissues. Therefore, this technique may be viable for use during the reconstruction stage of post-traumatic tibial osteomyelitis.

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Introduction

Clinical treatment of post-traumatic chronic osteomyelitis is challenging and complex. The therapeutic options for this condition include the rational use of antibiotics, excision of infected bones and the surrounding tissues, reconstruction of soft tissues, bone stabilization and correction of associated deformities (1). In particular, the two-stage treatment approach of chronic osteomyelitis described by Cierny and Mader has been accepted and clinically used for >40 years (2). Osteomyelitis can be successfully treated with debridement, but this typically results in bone and soft tissue defects (3). The induced membrane technique, also termed the Masquelet technique, and distraction osteogenesis methods such as the Ilizarov technique are widely used after debridement for the reconstruction of bone defects (4,5).

The induced membrane technique is a two-stage procedure, the first of which involves the implantation of a bone cement spacer into the bone defect and surrounding area to induce membrane formation. The second stage involves excision of the spacer and the placement of autologous bone grafts. However, as it is necessary to control infection and reconstruction during the second stage, external fixation of the bone is not the optimal choice, because it is bulky, uncomfortable and cumbersome to the patients, causing inconvenience in day-to-day activities and hindering ambulation. Therefore, although the external fixation device used during the first stage may be retained during the reconstruction of the bone defect, internal fixation may be used instead (6,7). However, there is currently no consensus on the optimum approach.

The application of the non-contact locking plate technique, using locking plates as a unilateral external fixator by percutaneous pinning, for bone defect reconstruction following chronic osteomyelitis debridement has gradually increased (8,9). A major advantage of the locking plate is that it provides angular stability, which effectively promotes bone union by providing optimal biological and mechanical environments. In addition, due to this being a non-contact technique, the blood supply to the bone is protected. Furthermore, the screws can be fixed to the locking plate through the skin and soft tissues, which avoids bacterial colonization and subsequent biofilm

formation. The non-contact locking plate technique has been used in the second-stage treatment of post-traumatic tibial osteomyelitis since 2017 at the Department of Orthopedics of Jinling Hospital (Nanjing, China). Based on these cases at the Department of Orthopedics of Jinling Hospital, the aim of the present study was to determine whether the non-contact locking plate technique is a safe and feasible approach for the surgical reconstruction of tibial segment defects.

Materials and methods

Patient selection. The present study was approved by The Ethics Committee for Retrospective Research of Jinling Hospital (Nanjing, China; approval no. 2021NZKY-030-07). All patients with post-traumatic tibial osteomyelitis who underwent surgical treatment using the two-stage treatment approach at Jinling Hospital between January 2017 and September 2020 were included in the study. The patients were divided into three groups according to the method of fixation, namely the external fixation (EX), locking plate (LP) and internal fixation (IX) groups. A total of 22 patients who retained unilateral external fixation during the second stage were assigned to the EX group, 20 patients who changed to non-contact locking fixation were assigned to the LP group, and 13 patients who changed to internal fixation were assigned to the IX group. The inclusion criteria were as follows: i) Patients aged 18-70 years; ii) patients with osteomyelitis initially caused by trauma or surgery; iii) patients with osteomyelitis graded as IIIA/B or IVA/B according to the Cierny-Mader grading system (10); and iv) patients with >4-cm bone defects caused by radical debridement in the first stage of treatment. The exclusion criteria were as follows: i) Patients with osteomyelitis without tibial bone defects; ii) patients with bone defects caused by factors other than trauma or surgery, such as congenital defects, bone tumor resection and simple aseptic non-union; iii) patients with bone defects that required transarticular fixation; iv) patients with serious comorbidities such as septic shock or uncontrolled infections; v) patients who refused surgery; and vi) patients without follow-up data. Based on the bone defects classification proposed by Tetsworth *et al* (11), the bone segment defects were classified as moderate (2-4 cm), major (4-8 cm) and massive (≥8 cm). In the present study, patients with moderate bone defects were not included according to the inclusion criteria.

Treatment procedures. All patients with tibial chronic osteomyelitis underwent the two-stage surgical procedure. In the first stage, surgical debridement was performed to entirely clean the wound bed until bleeding tissue was reached, ensuring that all the foci of infection were removed. Then, antibiotic-impregnated cement spacers were placed in the bone defect area and conventional external fixators were used to stabilize the bone defects. In the second stage, according to the condition of the soft tissue, the bone defect location, the preference of the surgeon and the choice of the patient, the external fixators were either retained or changed to non-contact locking plates or internal plates.

After removal of the cement spacers, granulation tissues were collected for microbial culture, and the bone defects were filled with autogenous cancellous bone grafts. Depending on the outcome of the bacterial culture, corresponding intravenous and oral antibiotics were administered for 2-4 weeks to prevent the recurrence of infection. Other patients with negative bacterial culture were treated with an empirical choice of antibiotics in the perioperative period to prevent infection for 3 days.

Clinical signs were observed and blood tests, including C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) tests, were conducted to assess the infection status of the patient. The limbs were elevated after surgery, and the sutures were removed 2-3 weeks later. Short-term non-weight-bearing exercise was initiated on the second post-operative day while the patient remained in a state of bedrest. Toe-touch weight-bearing exercise with two crutches was initiated at 4-6 weeks post-surgery, once X-rays indicated that the continuous callus passing through the fracture line had become blurred. The exercise intensity and duration were progressively increased until full weight-bearing recanalization of the medullary cavity was accomplished.

Clinical data collection. The primary observational indices included bone healing time and complications, while the secondary observational indices were laboratory results and anxiety assessment. Baseline data, including patient demographics, wound healing conditions, bacterial culture results, complications, CRP levels and the ESR before and 3 days post-surgery were collected. Imaging data, including plain anteroposterior and lateral radiographs of the involved limbs were also obtained. X-ray imaging was used to monitor bone consolidation at 1.5, 3, 6, 9 and 12 months post-surgery. Two surgeons prospectively evaluated the X-rays for each patient. The duration of bone defect malunion and degrees of deformity were also recorded. Clinical union was defined as full-weight bearing ability without pain, and radiological union was defined as the presence of a bridging callus of two cortices visible in two plain X-ray views. The radiographical parameters were assessed using lower leg radiographs obtained at the final follow-up. The mechanical axis deviation, medial proximal tibial angle, lateral distal tibial angle and limb length discrepancy were also assessed. Manual goniometric measurements of the radiographical parameters were performed for patients who were examined by X-ray during the final follow-up at Jinling Hospital, using Healthcare-Centricity RIS CE V3.0 (GE Healthcare) software. For patients who underwent final follow-up X-rays at other hospitals, the radiographical parameters were measured using conventional radiographical hard images by two orthopedic surgeons blinded to patient information. These measurements were performed using a goniometer and repeated three times, with the average value being recorded as the final result to avoid measurement errors.

The Hospital for Special Surgery Knee score (12) and the American Orthopedic Foot and Ankle Score (13) were used to evaluate lower limb joint functions following second-stage surgery, and scores >80 were considered to indicate normal function. The Self-Rating Anxiety Scale (SAS) was also assessed during follow-up (14).

Statistical analysis. SPSS software (version 22.0; IBM Corp.) and JMP software (version 14.2; SAS Institute, Inc.) were used

the perform the statistical analyses. Data are presented as the median and interquartile range (IQR) for continuous variables and as percentages for dichotomous variables. The CRP/ESR values and time to union in each group were compared using Kruskal-Wallis analysis. Subsequently, Steel-Dwass post hoc tests were performed to evaluate differences between specific pairs of groups. The χ^2 or Fishers' exact tests were used to analyze dichotomous variables and the estimated P-values after these tests were adjusted by Bonferroni correction. $P<0.05$ was considered to indicate a statistically significant result.

Results

Patient information. A total of 55 eligible patients were included in the study, including 44 (80.0%) males and 11 (20.0%) females (average age, 50 years). Clinical information for all patients is provided in Table SI. In the second treatment stage, patients exhibited no symptoms of infection, including pain, draining sinuses, swelling, local warmth, erythema at the involved site, or necrosis of the wound edge. Furthermore, levels of the inflammatory markers ESR and CRP were normal. The average tibial bone defect of the patients was 5.6 (4.2-12.3) cm and differences in initial bone defects among the groups were not significant (Table I). A total of 41 patients had major defects, while 14 patients had massive defects.

Laboratory results. Prior to the second stage of treatment, no differences in CRP levels were observed among the three groups and the ESR levels in the IX group were higher than those in the EX group (Table II). Furthermore, the ESR levels after the second-stage surgery were significantly higher in the IX group compared with the EX group (P=0.001; Table II). Following the removal of the cement spacers during surgery, granulation tissues were collected from all patients for microbial culture. *Staphylococcus aureus* was detected in 22.7, 30.8 and 20% of patients in the EX, IX and LP groups, respectively. Other bacteria were detected in 18.2, 7.7 and 15% of patients in the EX, IX and LP groups, respectively.

Clinical outcomes and complications. In the EX group during follow-up, 20 patients (90.9%) showed evidence of bone healing and had a median time to union of 13.1 months (Table I). However, 3 patients (13.6%) in this group had infection recurrence, which exhibited as oozing pus in wounds and elevated inflammatory cytokine levels. Also, 5 patients (22.7%) had pin-tract infections, 2 patients (9.1%) had non-union after 12 months of follow-up, and 3 patients (13.6%) had loosened pins (Table I). In addition, 8 patients had shortened limbs and deformed tibia. A total of 5 out of 8 patients had malformations causing limb shortening, with a mean postoperative limb shortening length of 3.2 cm (IQR, 1.5-6 cm). Of these patients, 3 patients also presented with tibial deformity. One patient with limb shortening of 6 cm underwent the Ilizarov procedure, while the other 4 patients did not undergo surgery. The other 3 patients exhibited only tibial deformity. All 6 patients with deformity, including 3 patients with concurrent shortened limbs, had varus or valgus malalignment >2˚. One of these 6 patients had a distal tibial recurvatum of 11˚ but underwent no further surgery. The proportion of cases with satisfactory functional status, which was assessed based on the scores for knee and ankle joint functions of the affected lower limb, were 81.8% before surgery and 86.4% after surgery (Table III). Representative follow-up X-ray images of patients who underwent bone grafting with retained unilateral external fixation are shown in Fig. 1.

In the IX group, 12 patients achieved bone union (92.3%), with a median union time of 13.1 months (Table I), while 1 patient had bone non-union. Only 2 patients (15.4%) in this group had infection recurrence. In addition, 1 patient had 9˚ malrotation of the affected limb but did not undergo further surgery and 3 patients had postoperative leg shortening (1.0-2.3 cm), while no patients had a tibial varus of >2˚. The proportion of patients in the IX group with a satisfactory functional status following surgery was 92.3%, which was significantly higher than that in the EX group (P=0.034; Table III). Representative follow-up X-ray images of patients who underwent bone grafting and changed to internal fixation are shown in Fig. 2.

In the LP group, 3 patients (15%) had infection recurrence. In addition, 2 patients (10%) had pin-tract infection, which was a significantly lower proportion than that in the EX group (P=0.005; Table I). Furthermore, 1 patient had a loosened screw and was not subjected to any additional surgery. The patients in the LP group had a median union time of 12.3 months (Table I). However, at the 12-month follow-up, 1 patient exhibited non-union. A total of 3 patients experienced tibial shortening, which included a 5˚ mild equinus deformity in one case. In addition, a patient with a 15˚ tibial procurvatum deformity at 2 years post-surgery was treated with internal fixation. The proportion of patients in the LP group with a satisfactory functional status post-surgery was improved to 95% compared with that pre-surgery (75%). Notably, the proportion of patients with a satisfactory functional status after surgery was significantly higher in the LP group compared with the EX group (P=0.046; Table III). Representative follow-up X-ray images of patients who underwent bone grafting and changed to non-contact locking plate fixation are shown in Fig. 3.

SAS assessment. The SAS assessment demonstrated that the proportions of patients with mild, moderate or severe anxiety were 38.5, 53.8 and 7.7% in the IX group, respectively; 55.0, 45.0 and 0.0% in the LP group, respectively; and 18.2, 68.2 and 13.6% in the EX group, respectively (Table III). The proportion of patients with moderate or severe anxiety was lowest in the LP group (45.0%). However, 81.8% of patients in the EX group experienced moderate to severe anxiety.

Discussion

The tibia is the site where infected non-union and chronic post-traumatic osteomyelitis most commonly occurs (15). Furthermore, the repair and reconstruction approaches for infected tibial bone defects are complex and require prolonged treatment and recovery (16). External fixation is widely used for debridement during the first stage of the treatment of post-traumatic tibial osteomyelitis. Compared with conventional internal fixation, external fixation has less impact on soft tissue and markedly reduces bacterial biofilm colonization. However, external fixation is associated with certain risks, including pin infection, deformity, joint stiffness, activity

Table I. Union time and complications in the follow-up interval.

Parameters	Fixation type			P-value
	EX (n=22)	IX (n=13)	LP (n=20)	
Defect size before surgery, cm, median (IQR)	4.5 (4.0-8.0)	5.0 (4.2-8.0)	4.6 (4.2-6.7)	>0.05
Time to union, months, median (IQR)	13.1 (10.0-16.0)	13.1 (12.0-15.0)	12.3 (9.0-14.0)	>0.05
Non-union, n (%)	2 (9.1)	1 (7.7)	1 (5.0)	>0.05
Pin-tract infection, n (%)	5 (22.7)	0 (0.0)	2 (10.0)	0.003[a], 0.005[b]
Pin or screw loosening, n (%)	3 (13.6)	0 (0.0)	1 (5.0)	0.014[a], 0.032[b]
Infection recurrence, n (%)	3 (13.6)	2 (15.4)	3 (15.0)	>0.05

[a]IX group vs. the EX group; [b]LP group vs. the EX group. EX, external fixation group; IX, internal fixation group; LP, locking plate group; IQR, interquartile range.

Table II. Microbes and inflammatory markers in the second stage of treatment.

Parameters	Fixation type			P-value
	EX (n=22)	IX (n=13)	LP (n=20)	
Organisms cultured after surgery, n (%)				
None	13 (59.1)	8 (61.5)	13 (65.0)	>0.05
S. aureus	5 (22.7)	4 (30.8)	4 (20.0)	>0.05
Others	4 (18.2)	1 (7.7)	3 (15.0)	>0.05
Before surgery, median (IQR)				
CRP, mg/l	4.1 (0.7-17.2)	4.0 (0.7-10.5)	3.6 (0.5-5.6)	>0.05
ESR, mm/h	4.9 (2.0-8.0)	8.6 (2.4-34.3)	7.5 (4.0-11.4)	0.019[a]
Day 3 after surgery, median (IQR)				
CRP, mg/l	15.2 (4.4-46.0)	18.6 (2.7-92.7)	9.4 (1.7-43.1)	>0.05
ESR, mm/h	10.8 (8.4-15.6)	16.4 (10.2-34.3)	12.3 (9.3-19.3)	0.001[a]; 0.016[b]

[a]IX group vs. the EX group; [b]LP group vs. the EX group. EX, external fixation group; IX, internal fixation group; LP, locking plate group; *S. aureus*, *Staphylococcus aureus*; ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; IQR, interquartile range.

limitation, pin-tract loosening and psychological disorders (17). The AO plate was designed according to the concept and principles of the Association for the Study of Internal Fixation, which is also referred to as the Arbeitsgemeinschaft für Osteosynthesefragen (AO). Marti and van der Werken (18) first proposed the AO-plate method as an alternative to the use of conventional external fixators. In addition, Apivat thakakul and Sananpanich (19) reported the case of a large distal tibial defect treated using a locking compression plate (LCP) as an external fixator. The external locking plate has been widely used to manage open fractures and infected non-unions (8,9,18,19). Thus, we hypothesized that the use of non-contact locking plates in the second-stage treatment of tibial osteomyelitis combines the advantages of conventional external and internal fixation.

In the present study, the use of the non-contact locking plate technique provided similar fixation endurance and time to bone-healing as were observed in the EX and IX groups. Furthermore, the differences in the time to bone union and recurrence rates of infection among the three groups were not statistically significant. The SAS scores indicated that the proportions of patients who had moderate or severe anxiety levels were significantly reduced and the functional status after surgery was significantly higher in the LP group compared with the EX group. This difference may be due to the non-contact locking plate technique improving compliance by the patient, since it is less bulky and the device is lighter in weight compared with that used for external fixation. However, following the one-stage debridement surgery and the antibiotic treatment, the IX and LP groups exhibited similar infection rates. In addition, angular malunion occurred more frequently in the LP group compared with the IX group. There may be two reasons for this, specifically selection bias and different outcomes in the tibial force line. In the present study, internal fixation was chosen for patients with greater skin and soft-tissue resolution, which may have outweighed the strengths of the non-contact locking plate technique in infection prevention. In non-contact locking plate surgery, a good reduction of the ends of the bone defect (restoration of the tibial line and correction of the angulation, shortening and

Table III. Functional and SAS assessment of the enrolled patients.

Parameters	Fixation type			P-value
	EX (n=22)	IX (n=13)	LP (n=20)	
Satisfactory functional status, n (%)				
Before surgery	18 (81.8)	11 (84.6)	15 (75.0)	>0.05
After surgery	19 (86.4)	12 (92.3)	19 (95.0)	0.034[a], 0.046[b]
SAS assessment, n (%)				
Mild anxiety	4 (18.2)	5 (38.5)	11 (55.0)	>0.05
Moderate anxiety	15 (68.2)	7 (53.8)	9 (45.0)	0.028[a], 0.017[b]
Severe anxiety	3 (13.6)	1 (7.7)	0 (0.0)	0.021[a], 0.023[b]

[a]IX group vs. EX group; [b]LP group vs. EX group. EX, external fixation group; IX, internal fixation group; LP, locking plate group. SAS, Self-Rating Anxiety Scale.

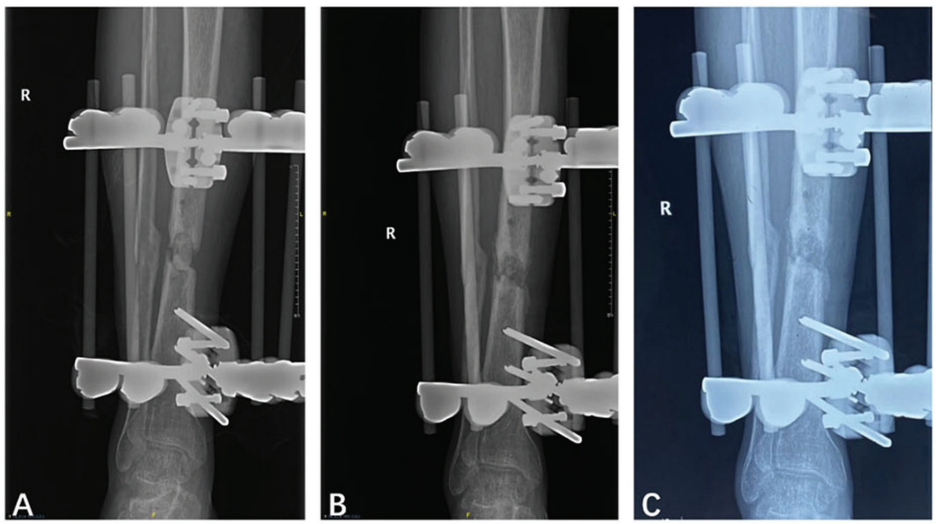

Figure 1. Representative X-rays of a patient (no. 6) who underwent bone grafting with retained unilateral external fixation. (A) Cement spacer placed in the bone defect using unilateral external fixation to maintain tibial stability before the second-stage surgery. (B) Bone defect filled with autogenous iliac bone grafts and callus formation 3 months after the second-stage surgery with external fixation. (C) Increased callus volume 1 year after the second-stage surgery. R, right.

deformity) before screw insertion is important but challenging to achieve. Internal fixation provides additional biomechanical advantages compared with fixation with an external locking plate. Therefore, the non-contact locking plate technique should only be performed when patients meet the surgical indications, but it is not universally suitable.

Compared with internal fixation, the LCP technique has several inherent advantages. First, for patients who require removal of the plate after bone healing, the screws and LCP can be removed in an outpatient setting under local anesthesia, which avoids secondary cut-down surgery. Second, the non-contact plate reduces compression of the periosteum and destruction of the local blood circulation, providing an optimal environment for the bone defect. Third, tibial soft tissue readily forms scars after trauma or defects, resulting in a limited implant volume, which may not provide an effective and complete coverage for internal fixation. In the case of high skin tension after suturing, an external locking plate is more appropriate. Fourth, load-sharing during weight bearing may stimulate the development of calluses until bone union occurs. In patients receiving an LCP, controlled stress distribution or dynamization by removal of the screws closest to the bone graft site is possible, which can provide a certain measure of control of the load-sharing process (20).

There is a risk of secondary infection in external fixation, including the use of conventional external fixators and non-contact locking plates, in which bacterial infection extends from the screws to the tibia. However, the majority of pin-tract infections are superficial and only ~4% of cases present with deep soft tissue infections and osteomyelitis (21). Furthermore, most pin-tract infections can be eradicated by wound care and short-term oral antibiotics. In the present study, 5 patients in the EX group, including the patient shown in Fig. 1 who had an external fixator for >1 year, had pin-tract infections, all of which were resolved by the use of dressings and oral antibiotics. In the LP group, only 2 patients had a

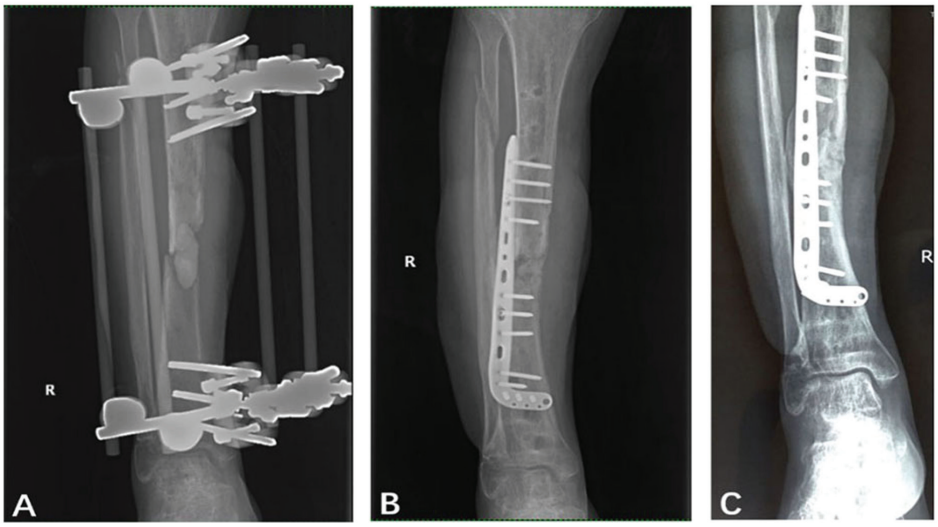

Figure 2. Representative X-rays of a patient (no. 26) who underwent bone grafting and changed to an internal fixator. (A) Cement spacer placed in the bone defect via unilateral external fixation to maintain tibial stability prior to second-stage surgery. (B) Bone defect filled with autogenous iliac bone grafts and callus formation 3 months after the second-stage surgery during which the external fixator was changed to an internal fixator. (C) Recovered continuity of the cortical bone 1 year after the second-stage surgery. R, right.

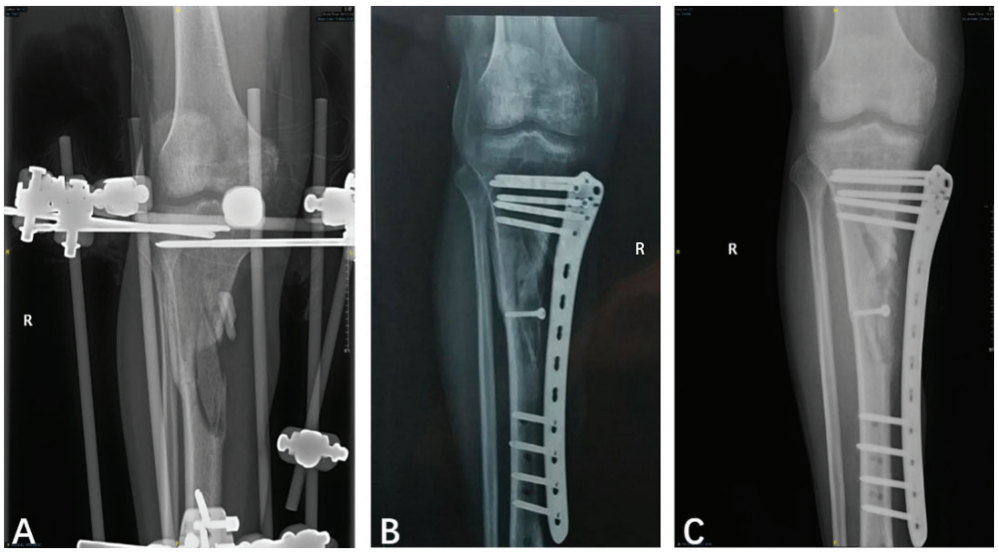

Figure 3. Representative X-rays of a patient (no. 42) who underwent bone grafting and changed to an external non-contact locking plate. (A) Cement spacer placed in the bone defect using unilateral external fixation to provide tibial stability before the second-stage surgery. (B) Bone defect filled with autogenous iliac bone grafts and callus formation 3 months after the second-stage surgery in which the external fixator was changed to an external non-contact locking plate. (C) Recovered continuity of the cortical bone 1 year after the second-stage surgery. R, right.

pin-tract infection, which was a significantly lower incidence compared with that in the EX group. We hypothesize that this may be due to the following: i) Compared with the partially threaded screws of the conventional external fixators, the fully threaded screws of the LCP may attach more easily to subcutaneous tissue and skin; ii) the LCP screws are shorter; and iii) the screw-loosening rate was slightly lower in the LP group. Therefore, the risk of secondary infection caused by biofilms extending from the screws may not be a major issue if frequent daily care of the screws is performed.

However, due to concerns regarding the biomechanical strength of the LCP, the application of this technology is limited. Similar to the biomechanical principle of external fixation, locking screws can directly lock into the plate to provide a stable connection instead of relying on the compressive force provided by the screw head against the plate and the friction between the plate and bone. The length of the plate, the number of screws and the distance from the plate to the bone surface are the main factors affecting locking plate stiffness (22). Liu *et al* (23) conducted a biomechanical comparison study and demonstrated that when an external fixator is used in the treatment of distal tibia fracture, a distal femur LCP is preferred over a distal tibial LCP. In the present study, when non-contact locking plates were used to treat infectious bone defects of the tibia, femoral plates with matching width screws were selected as external fixators. No bending or breakage of plates was observed for any of the patients in the LP group.

Kanchanomai and Phiphobmongkol (24) designed a biomechanical test for tibial fractures externally fixed with an LCP, and reported that an increased distance between the bone and the implant significantly reduced construct stability. The authors recommended that the distance between the bone and the plate should be 2 cm. However, all models in the test were cyclically loaded with >500,000 cycles and did not exhibit any plate failure, indicating that failure of the LCP is not a critical issue in clinical cases. The angular stable interface between the screws and the plate is designed to allow for placement of the plate without contact with the bone, thus preserving periosteal blood supply and bone perfusion, which may not be possible with internal fixation. Notably, once the locking screws are placed on both sides of the defect, it is not possible to adjust the plate as the adjustment may increase the incidence of deformity and non-union (25,26). In the present study, to achieve improved bone-matching, the plate was temporarily secured using two Kirschner wires to provide bicortical fixation and local stabilization. With regards to the anatomy of the tibia and its relationship with peripheral nerves and vessels, the medial tibia is a safe site at which to place the locking screws. Intraoperative fluoroscopy is required to check whether the locking screws penetrate through the joints when bone defects are close to the joints.

There are several limitations associated with the present study. First, this was a retrospective, single-center study and the sample size was small due to the limited availability of patients, which reduced the credibility of the experimental data (type II error). Second, after measurements were repeated three times the average value was determined to avoid measurement errors. However, it may be more reliable to determine the average value after removing the highest and lowest values of five measurements. Third, this was not a randomized trial and selection bias may have occurred. For example, the lower rate of complications in the IX group was likely due to the selection of patients with good soft tissue coverage for internal fixation treatment. Therefore, it is important for the orthopedic surgeon to clearly understand the operative indications when selecting the appropriate fixation modality. Indeed, the selection of an external fixator, internal plate or external non-contact locking plate depends on the inclination of the surgeon and the preference of the patient, which may be influenced by economic factors. The soft-tissue condition and the location of the bone defect are important factors to be considered when selecting the method of surgical reconstruction. In the present study, an external non-contact locking plate was often applied for bone defects in the middle segment of the tibia, while an external fixator or internal plate was considered for bone defects at the end of the tibia. However, there are other criteria that were considered. For example, for patients with soft tissue defects or a poor soft tissue condition, the external fixator was retained after surgery. For patients with specific requirements regarding the appearance and functionality of their limb, the internal plate or external non-contact locking plate were selected. In summary, the choice of fixation is based on the combined effects of multiple factors, and it is challenging to identify the most appropriate treatment for each patient. The fourth limitation of the present study was that the IX group was defined as patients receiving internal locking plate fixation, and several patients with intramedullary nail fixation in the second-stage treatment were not included. However, patients undergoing such treatment will be evaluated in follow-up studies. Finally, the biomechanical differences between the three groups were not analyzed, and this merits further investigation.

In conclusion, the present study indicated that in the second-stage treatment of post-traumatic tibial osteomyelitis, the use of non-contact locking plate technology to treat >4-cm bone defects achieved stable fixation, and reduced pin-tract infections, pin loosening and the risk of biofilm formation. Furthermore, the locking plate lowered the psychological anxiety of the patients. Therefore, the non-contact locking plate technique is a viable alternative for the second-stage treatment of post-traumatic tibial osteomyelitis.

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Availability of data and materials

Datasets of this study are not publicly available due to study participants not giving their consent but may be requested from the corresponding author upon request.

Authors' contributions

YZ participated in the inclusion of patients, research design, collection of data, statistical analysis of the results, and writing and revising the manuscript. PJ contributed to researching the data and writing the discussion. ZH participated in the inclusion of patients, collection of data, statistical analysis of the results, writing and revising the manuscript, and the online submission. HQ contributed to research design, writing and revising the manuscript, online submission and funding acquisition. YZ, PJ, ZH and HQ confirm the authenticity of the raw data. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

The present retrospective analysis was approved by The Ethics Committee for Retrospective Research of Jinling Hospital (Nanjing, China; approval no. 2021NZKY-030-07) and completed in accordance with the Declaration of Helsinki. All patients provided written informed consent to participate.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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