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Original Article

Minimally invasive elastic intramedullary nails and external fixation achieved satisfactory outcomes for multi-segment and long-spiral mild-to-moderate comminuted closed tibia-fibula fractures

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Abstract: Background: Treatment of severe comminuted tibia-fibula fractures is often complicated by non-union, delayed union, and malunion. The best surgical approach is controversial. Aim: To compare the clinical outcomes and complications of three methods of fixation: elastic intramedullary nails and external fixation (EINE), plates, and interlocking nails (IN). Methods: This was a retrospective cohort study of 86 diaphysealtibia-fibula fractures in 80 patients treated with EINE, plate, or IN. Treatment outcomes were compared in terms of the length of the hospital stay, time to union, and complication rates (loss of reduction requiring a reoperation, malunion, non-union, refracture, infection, and the need for a reoperation other than routine hardware removal). Mean follow-up was 17.4 months. Results: Length of hospital stay was similar among the three groups. Time to clinical union was longer with plate (P<0.05). Complications were more frequent with the interlocking nail (P=0.004). There was a loss of reduction in 7% of fractures treated with EINE, 11% of fractures treated with plate, and 13% of fractures treated with IN. Time to union was 12.5±5.6 months for EINE, 24.5±9.5 months for plate, and 14.5±8.2 months for IN. During follow-up, three patients (two with IN and one with EINE) had ≥2.0 cm of shortening of the affected limb; 25%, 43%, and 37% of patients treated with EINE, plate fixation, and IN, respectively, required a reoperation. Conclusion: Complication rates were similar between the three treatment approaches. Minimally invasive EINE for multi-segment and long-spiral mild-to-moderate comminuted closed tibia-fibula fractures achieved satisfactory outcomes and fast healing.

Keywords: Tibia-fibula fracture, comminuted fracture, external fixation, elastic intramedullary nails

Introduction

Severe comminuted tibia-fibula fractures are mostly high-energy injuries [1-3]. Due to the characteristics of the fracture site, type of fracture, cause of fracture, limited soft tissue coverage, and limited blood supply, the treatment of these fractures is complicated, and fracture non-union, infectious non-union, delayed union, and malunion are often observed [1-3].

Fusion is indicated when there is severe intra-articular comminution and/or >50% of loss of articular cartilage [1-3]. A number of surgical approaches have been suggested for the treatment of severe comminuted tibia-fibula fractures. A number of approaches using internal fixation, external fixation, and arthroscopic fixation, alone or in combination, have been described, as reviewed by Papagelopoulos *et al.* [4]. Blauth *et al.* [5] suggested a two-step approach involving primary reduction and internal fixation, and then internal fixation with a medial plate; this approach was better than single-step internal plate fixation and one-stage minimally invasive osteosynthesis. Nevertheless, the optimal approach remains controversial.

Some studies suggested that the use of less or minimally invasive approaches could improve the outcomes and decrease the rate of complications [6, 7]. The use of elastic intramedullary nails and external fixation (EINE) is a minimally invasive technique that have shown to have good outcomes and safety [8-10], including for tibia-fibula fractures [11].

Therefore, the purpose of this study was to compare the outcomes and complications of three different methods of fixation for tibia-fibula fractures (EINE, plates, and interlocking nail (IN)).

Patients and methods

Study design and patients

This was a retrospective cohort study of patients with traumatic diaphysealtibia-fibula fractures that were treated from June 2010 to June 2015 at the Second Hospital of the Wenzhou Medical University. The study was approved by the ethics committee of the Wenzhou Medical University. Individual consent was waived by the committee because of the retrospective nature of the study.

Inclusion criteria were: 1) traumatic diaphysealtibia-fibula fractures; 2) treated with EINE, plate, or IN; and 3) followed up at our center until bone union. Exclusion criteria were: 1) the presence of any comorbidity that could affect limb healing such as diabetic neuropathy; 2) any congenital oranquired malformation of the lower limb; 3) any genetic disease known to affect bone turnover; or 4) pathological fractures.

Surgical approach for EINE

Tibia fixation: Patients received epidural and spinal anesthesia, or general anesthesia, according to the opinions of the orthopedist and anesthetist. Two elastic intramedullary nails (DePuySynthes Co., Zuchwil, Switzerland) with the same diameter (3.0-3.5 mm, based on patients' conditions) were selected. The shape of the nails was a long arc, with the arch height being about three times the diameter of the medullar cavity. The vertex of the arc was just at the level of fracture line. Under C-arm fluoroscopy, a 0.5-mm incision was cut inside and outside the tibia-fibula tubercle level, until the periosteum. After opening, the nail holder was used to insert the first nail to the fracture line level under C-arm fluoroscopy. In the mean time, the injured limb was pulled to correct the angle and to correct the deformity by manipulative reduction. Afterwards the nail was continuously inserted until reaching cancellous bone at the distal end of the tibia-fibula; the second nail was then inserted, and a "X" shape was formed by the two nails inside the medullary cavity. Two external fixation needles (Orthofix, Lewisville, TX, USA) were then drilled in parallel from the fracture proximal and distal ends, respectively. The needle depth was appropriate to just across the contralateral cortex. The two fixation needles on the same side had to be on the same plane, perpendicular to the long axis of the tibia-fibula, and parallel to knee and ankle joint surface. Fixation needles were used to adjust the reset of fracture proximal and distal ends, and a fixation rod for external fixation was installed for initial fixation. Using C-arm fluoroscopy, the rod was adjusted until achieving ideal fracture reset and the bolts of the fastening system were tightened. All surgeries were performed by the same team of physicians (including one chief physician, one physician-in-charge, and one resident physician).

Fibula fixation: Under C-arm fluoroscopy, a 0.5 cm incision was made longitudinally at the fibula tip, until the periosteum. After opening the incision, a nail was reversely inserted to the fracture line level under C-arm fluoroscopy, and manipulative reduction was then conducted (2.0-3.0 cm incision at the fracture end could be cut to assist reset, if necessary). The nail was then inserted until the fibular neck level, after smoothly passing through the fracture end. The end of the intramedullary nail was cut off, bent to keep 0.3-0.5 cm, and finally buried subcutaneously.

External fixation group: Under fluoroscopy, patients with closed fracture underwent manipulative reduction. If necessary, a small incision was made at fracture end for open reduction, and the fracture was fixed with Kirschner wires or screws. Under C-arm fluoroscopy, reduction of the tibial fracture was performed to guarantee accurate and excellent reduction, followed by fixation with unilateral external fixator (Orthofix): 2-3 outer set screws were inserted at medial tibia, and distal and proximal fracture ends, to ensure proper positions. Then, the external fixator was settled and the screws were tightened.

Plate group: First, the fibular fracture was openly reduced and fixed to restore the length and line of the crus. A 6-8 cm (according to the length of the fracture line) incision was made 3 cm above the medial malleolus, which was extended proximally. Then, the skin was cut open, the great saphenous veins were protected and the tissues were incised to expose the fracture end. Then, larger fracture pieces were fixed with Kirschner wires or screws while protecting the periosteum as much as possible. A plate with an appropriate length was placed at tibial fracture ends. Screws (3-4) were screwed in the distal fracture end according to the fracture and bone conditions, followed by fluoroscopy to confirm satisfactory reduction.

Postoperative treatment

The injured limb was lifted up after surgery to promote venous return and decrease swelling. A soft pillow could be used to keep the rear of the calf level and prevent postoperative rotation and angular deformity. Appropriate antibiotics (ceftriaxone 2.0 g, IV, 2 times/day, for 3 days) could be used based on the wound conditions. Attention was paid to the needle tract and wound dressing change. Needle tract had to be kept clean and dry. Knee and ankle joints active and passive functional exercise were conducted on the 1st day after surgery, and partial weight bearing and ankle functional exercise started 4 weeks after surgery. X-ray was checked regularly after surgery at 1, 3, 6, 9, 12, 18, and 24 months. Removal of external fixations was scheduled when continuous callus growth was observed at the fracture end. Crutches were discarded when the fracture line was blurred and complete healing was achieved. All approaches underwent the same post-operative management.

Follow up and observational index

All patients were followed-up at the outpatient department until December 2015. Follow-up included anteroposterior and lateral X-rays, examination of pin-tract for external fixator (presence or absence of loosening and infection), and local checkup of the fracture as well as wound healing.

Length of hospital stay, time to union, and complications associated with each of the treatment methods. Time to union was defined as the number of weeks until there was radiographic and clinical evidence of union. Radiographic evidence of union was defined as remodeling (mature) callus bridging at least three of the four cortices seen on two orthogonal views of the tibia-fibula, which was considered as the criteria for union in this study. Clinical union was inferred from the absence of tenderness at the fracture site along with full weight-bearing without pain. Complications of interest included loss of reduction, malunion, non-union, refracture, infection, and the need for reoperation. Malunion was defined as one or more of the following: 1) ≥10° of angulation in the coronal plane (varus or valgus); 2) ≥20° of angulation in the sagittal plane (apex-anterior or apex-posterior angulation); 3) clinically obvious malrotation (an asymmetric foot progression angle with corresponding asymmetry of internal or external rotation of the knee); and 4) a limb length discrepancy of ≥2.0 cm. A clinically relevant loss of reduction was defined as any change in the postoperative alignment that prompted surgical intervention or resulted in malunion as defined by the criteria described above. A reoperation was defined as any fracture-related surgical procedure other than routine hardware removal and performed after the initial fixation.

All data were collected from the medical charts of the patients.

Statistical analysis

Continuous data are presented as mean ± standard deviation and were analyzed using analysis of variance and the Bonferroni post hoc test. Categorical data are presented as frequencies were analyzed using the Fisher's exact test. Univariate analyses were first performed, and variables associated with the outcomes with *P*-values <0.10 were included in the multivariate model, which was reported as odds ratio (OR) and 95% confidence intervals (95% CI), SPSS 13.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Two-tailed *P*-values <0.05 were considered statistically significant.

Results

Characteristics of the patients

There were 45 men and 35 women, with a mean age of 43.8 years (range, 19-67 years) and a mean body weight of 68.2 kg (range, 57-76 kg). Age, sex, and weight distributions were similar among the three groups (all P>0.05) (**Table 1**).

Characteristics of the fractures

Fractures were classified based on the AO/OTA classification, with nine cases of B1 type, 14

Table 1. Characteristics of the patients

Characteristic	Total (86 fractures, 80 patients)	Elastic nail and external fixation (28 fractures, 27 patients)	Plate (28 fractures, 24 patients)	Interlocking nail (30 fractures, 29 patients)	P
Age (years)	43.8±7.3	42.4±10.8	39.4±6.8	44.4±7.2	>0.05
Sex					>0.05
Male	45 (56%)	17 (69%)	13 (69%)	15 (70%)	
Female	35 (44%)	10 (31%)	11 (31%)	14 (30%)	
Body weight (kg)	68.2±5.9	67.4±8.6	70.3±7.9	66.6±10.3	>0.05

Table 2. Characteristics of the fractures

Characteristic	All (86 fractures, 80 patients)	Elastic nail and external fixation (28 fractures, 27 patients)†	Plate (28 fractures, 24 patients)†	Interlocking nail (30 fractures, 29 patients)†	P
AO/OTA classification, n (%)					
B1	12 (14%)	6 (21%)*	3 (11%)	3 (10%)	<0.005
B2	19 (22%)	10 (36%)*	6 (21%)	3 (10%)	<0.005
B3	17 (20%)	2 (7%)	7 (25%)	8 (27%)	
C1	19 (22%)	2 (7%)	7 (25%)	10 (33%)	
C2	13 (15%)	7 (25%)*	3 (11%)	3 (10%)	<0.005
C3	6 (7%)	1 (4%)	2 (7%)	3 (10%)	
Comminution, n (%)					
Grade I	19 (22%)	5 (18%)	7 (25%)	7 (23%)	
Grade II	29 (34%)	9 (32%)	10 (36%)	10 (33%)	
Grade III	24 (28%)	8 (29%)	7 (25%)	9 (30%)	
Grade IV	14 (16%)	6 (21%)	4 (14%)	4 (13%)	

*The distributionof fracture patternof types B1, B2, and C2 was significantly higher in the EINE group vs. the plate group (Bonferroni adjusted P=0.005) and the Interlocking nail group (Bonferroni adjusted P=0.005). †Adjusted for other baseline factors in multivariate analysis.

of B2, 22 of B3, 24 of type, 10 of C2, and seven of C3 (P>0.05 among the three groups) (**Table 2**). The level of comminution was graded according to the percentage of the shaft width that was fragmented, adapted from the classification system by Winquist and Hansen [12]. Grade-I fragmentation (<25% of the shaft width) was noted in 19 fractures (22%); grade II (25-49% of the shaft width) in 29 fractures (34%); grade III (50-74% of the shaft width) in 24 fractures (28%); and grade IV (75-100% of the shaft width or segmental) in 14 fractures (16%). The distribution of fracture comminution was similar among the three groups (P>0.05) (**Table 2**).

Soft-tissue damage

The degree of soft-tissue damage was classified based on the AO/OTA classification, with 19 cases of the IC1 type, 27 of IC2, 21 of IC3, 14 of IC4, and five of IC5. There was a significantly lower proportion of the IC1 and IC2 types in the EINE group compared with the other treatment groups (P<0.05). There was a significantly higher proportion of the IC3, IC4, and IC5 types in the EINE compared with the other groups (P<0.05) (**Table 3**).

Operative characteristics

The median hospital stay was eleven days (all P>0.05 among the groups). There was no difference in surgical time, bleeding, and the need for transfusion among the groups (**Table 4**).

Healing

All patients were followed up and the mean follow-up was 17.4 months (8-24 months). The time to union was significantly associated with

Table 3. Degree of soft tissue damage

Degree of soft tissue damage, n (%)	All (86 fractures, 80 patients)	Elastic nail and external fixation (28 fractures, 27 patients)†	Plate (28 fractures, 24 patients)†	Interlocking nail (30 fractures, 29 patients)†	P
IC1	19 (22%)	2 (7%)*	8 (29%)	9 (30%)	<0.005
IC2	27 (31%)	4 (14%)	14 (50%)*	9 (30%)	<0.005
IC3	21 (24%)	10 (36%)*	4 (14%)	7 (23%)	<0.005
IC4	14 (16%)	8 (29%)*	2 (7%)	4 (13%)	<0.005
IC5	5 (6%)	4 (14%)*	0	1 (3%)	<0.005

*The soft-tissue damage degree was significantly higher for types IC3, IC4, and IC5 in the EINE vs. the plate group (Bonferroni adjusted P=0.005) and the Interlocking nail group (Bonferroni adjusted P=0.005). †Adjusted for other baseline factors in multivariate analysis.

Table 4. Characteristics of the surgeries

Characteristics	All (86 fractures, 80 patients)	Elastic nail and external fixation (28 fractures, 27 patients)	Plate (28 fractures, 24 patients)	Interlocking nail (30 fractures, 29 patients)	P
Surgical time (h)	1.9±0.9	1.5±0.5	1.6±1.1	1.5±0.8	>0.05
Bleeding (ml)	236±114	252±35	268±35	239±57	>0.05
Blood transfusion, n (%)					>0.05
Yes	18 (23%)	3 (11%)	3 (13%)	4 (14%)	
No	62 (87%)	25 (89%)	20 (87%)	25 (86%)	

the fixation type (P=0.003). The mean time to union was 11.3±7.2 weeks in the EINE group, 17.3±8.3 weeks in the plate fixation group, and 13.1±7.8 weeks in the IN group (EINE vs. plate, P=0.005; IN vs. Plate, P=0.005; EINE vs. IN, P>0.05). In the multivariate model, the fixation type (P=0.016) remained significantly and independently associated with the time to union after adjustment for baseline differences in risk factors for delayed healing (**Table 5**).

Complications

Table 5 presents the complications encountered during follow-up. There was a loss of reduction of two (7%) of the 28 fractures in the EINE group, three (10.5%) of the 28 fractures in the plate fixation group, and four (13.3%) 30 fractures in the IN group (P<0.005).

At the final follow-up, malunion was noted in one patients of each treatment group (P=0.73). The deformities ranged from 14° varus to 13° valgus and from 22° procurvatum (apex-anterior) to 20° recurvatum (apex-posterior). Three patients (one in the EINE group and two in the IN group) had a limb length discrepancy of 2.0-2.5 cm at the time of fracture union. None of these patients had an externally visible deformity or functional limitations secondary to the misalignment or shortening. Consequently they did not receive any treatment by the time of writing this paper.

Seven of the 28 fractures in the EINE group required a reoperation: two because of loss of reduction and one because of malunion/shortening. One fracture with delayed union was stabilized with plate fixation combined with bone graft seven months after the initial operation; there was a refracture one month after external fixation removal. There were two patients who required replacement of an external pin because of infection.

Twelve of the 28 fractures treated with a plate required reoperation. Loss of reduction in three patients required readjustments of the plate with the patient under general anesthesia (**Figures 1-3**). There was one case of malunion, three with delayed union, two with refracture, and three that required plate replacement because of infection.

Nine of the 30 fractures in the IN group required reoperation. There were two cases of delayed union that were stabilized with plate 18 months after the initial operation. There

Table 5. Surgical outcomes

Characteristics	All (86 fractures, 80 patients)	Elastic nail and external fixation (28 fractures, 27 patients)†	Plate (28 fractures, 24 patients)†	Interlocking nail (30 fractures, 29 patients)†	P
Length of hospital stay (d)					
Median	11	10	12	11	
Mean ± standard deviation	11.3±7.4	9.8±7.8	10.3±8.2	10.8±5.3	>0.05
Time to clinical union (weeks)	15.4±9.4	11.3±7.2	17.3±8.3*	13.1±7.8	<0.05
Union rate (%)	83.8	86.5	87.5	80.2	>0.05
Time to removal of external fixation (months)	18.5±5.5	12.5±5.6	24.5±9.5	14.5±8.2	>0.05
Complications, n (%)	15 (17%)	4 (14%)	4 (14%)	7 (23%)	0.004
Loss of reduction	9 (10%)	2 (7%)	3 (11%)	4 (13%)*	<0.005
Malunion	3 (3%)	1 (4%)	1 (4%)	1 (3%)	0.73
Limb length asymetry >2 cm	3 (3%)	1 (4%)	0	2 (7%)	<0.005
Reoperation, n (%)	28 (33%)	7 (25%)	12 (43%)†	9 (30%)	0.034‡
Loss of reduction	8 (9%)	2 (8%)	3 (11%)	3 (10%)	
Malunion/shortening	3 (3%)	1 (4%)	1 (4%)	1 (3%)	
Delayed union	6 (7%)	1 (4%)	3 (11%)	2 (7%)	
Refracture	4 (5%)	1 (4%)	2 (8%)	1 (3%)	
Infection	7 (8%)	2 (7%)	3 (11%)	2 (7%)	
Johner-Wruhs outcome, n (%)					>0.05
Excellent	59 (69%)	22 (79%)	18 (64%)	19 (63%)	
Good	7 (8%)	1 (4%)	2 (8%)	4 (13%)	
Acceptable	8 (9%)	2 (8%)	3 (11%)	3 (10%)	
Poor	6 (7%)	2 (8%)	1 (4%)	3 (10%)	

*The time to union was significantly longer in the plate fixation group vs. the EINE group (Bonferroni adjusted P=0.005) and the Interlocking nail group (Bonferroni adjusted P=0.005). †Adjusted for other baseline factors in multivariate analysis. *In the pairwise comparisons, the rate of clinically relevant loss of reduction was significantly higher in the Interlocking nail group vs. the two other fixation groups (Bonferroni adjusted P<0.005 in all three comparisons). †Adjusted for other baseline factors in multivariate analysis. ‡The rate of clinically relevant loss of reduction and/or malunion and/or limb-length discrepancy was significantly higher in the Interlocking nail group in pairwise vs. the EINE group (P=0.004) and the plate group (P=0.005) (all *P*-values are Bonferroni adjusted for multiple comparisons). No significant difference was found between the EINE and the plate groups (P=0.66). †Only the plate fixation group had a significantly higher reoperation rate than the other groups.

was loss of reduction in three cases, malunion/shortening in one, refracture in one, and infection in two cases.

Discussion

Treatment of severe comminuted tibia-fibula fractures is often complicated by non-union, delayed union, and malunion. The best surgical approach is controversial. Therefore, this study aimed to compare the clinical outcomes and complications of three methods of fixation: EINE, plates, and IN. Results that there was a loss of reduction in 7% of fractures treated with EINE, 11% of fractures treated with plate, and 13% of fractures treated with IN. Time to union was 12.5±5.6 months for EINE, 24.5±9.5 months for plate, and 14.5±8.2 months for IN. Complications were similar among the three groups, but the plate approach was independently associated with an increased risk of loss of reduction and/or malunion.

Dynamic compression plate (DCP) may need relatively long surgical incisions, and certain soft tissue and periosteal stripping is necessary, which destroys fracture ends and soft tissue blood supply. Postoperative possibility for soft tissue necrosis due to infection and bone non-union is high. Along with proposal of the new concept of biological-osteosynthesis (BO) by Palmer *et al*. [13], the less invasive stabilization system (LISS) was proposed. Although the operation is performed away from

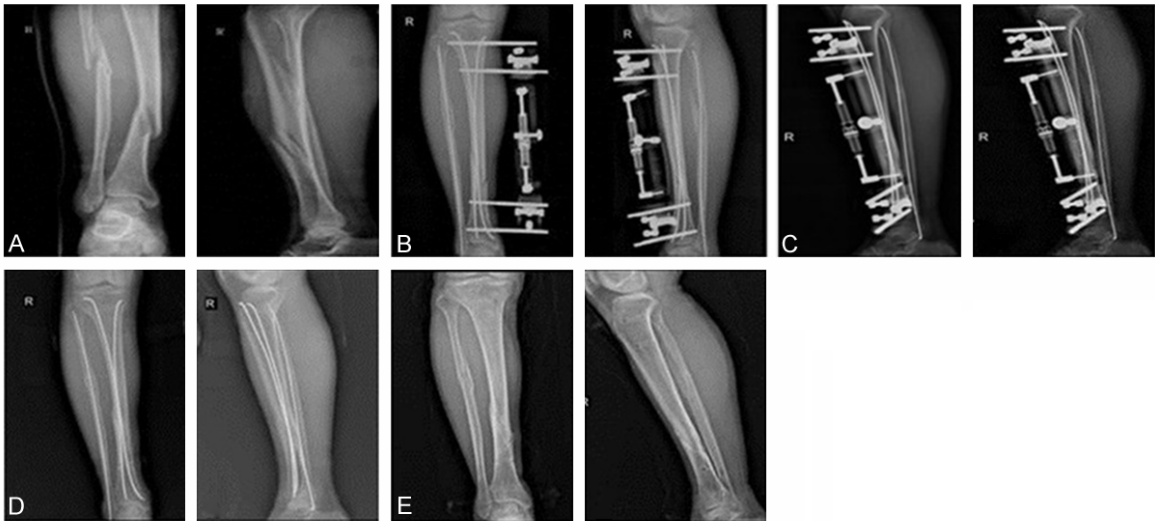

Figure 1. Male patient, 49 years old. A. Anteroposterior and lateral X-rays of the tibia-fibula fracture. B. Anteroposterior and lateral X-rays after tibial intramedullary elastic nail + external fixation, as well as fibular intramedullary elastic nail fixation. C. Anteroposterior and lateral X-rays 6 months after surgery showing bony union of the tibia. D. Anteroposterior and lateral X-rays after removal of external fixator, 6 months after surgery. E. Anteroposterior and lateral X-rays after removal of internal fixations, 7 months after surgery.

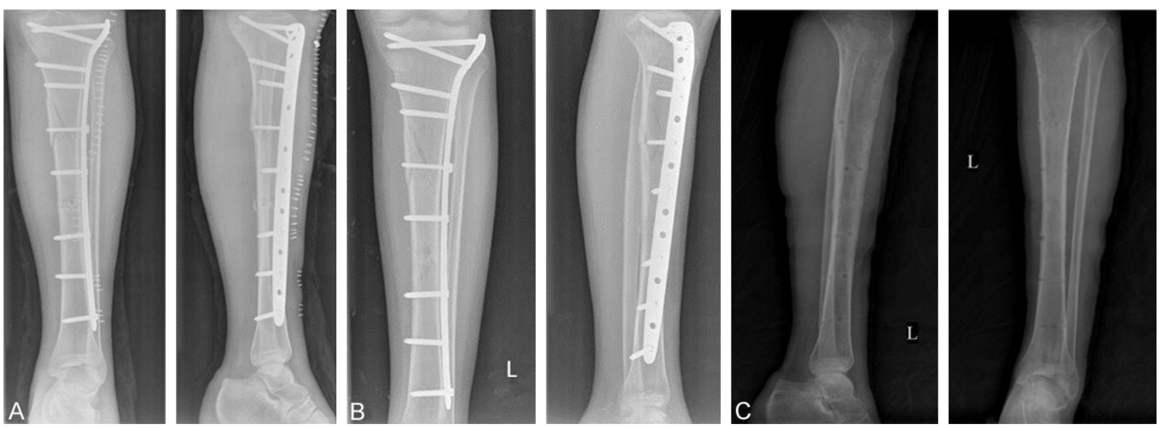

Figure 2. Male patient, 17 year old, treated with plate. A. Anteroposterior and lateral X-rays of the tibial fracture. B. Anteroposterior and lateral X-rays 8 months after surgery, showing blurred fracture line and basic fracture healing. C. Anteroposterior and lateral X-rays after removal of internal fixation, 10 months after surgery.

the fracture site as much as possible and blood supply is well protected, a very long steel plate is usually needed for the treatment of tibia-fibula long-spiral multiple-segment fractures, with some occult fractures. In this case, content on injured limb calf and risk of osteofascial compartment syndrome are increased artificially [14]. Intramedullary nails are for central axis fixation, but the actual operation is relatively difficult, which not only increases surgical time, but also has potential risk of bone splitting during nail insertion. Additionally, closed reduction and enlargement of the medullar space are relatively difficult for comminuted or multi-segment fractures. The reset usually needs to be cut, both intramedullary and extramedullary blood supplies are destroyed, and blood supply at the fracture ends is destroyed. Therefore, intramedullary nail fixation had certain limitations.

On the other hand, external fixation has advantages for protection of fracture local blood supply. This method highlights the characteristics of minimally invasive treatment for fracture and BO. However, the strength of simple external fixation is relatively weak, and cannot maintain the reset and fixation of fracture ends effec-

Figure 3. Male patient, 14 year old, treated with plate. Lateral X-rays before surgery (A), after surgery (B), 15 months after operation, the X-ray shows fracture non-union and malunion (C), reoperation with interlocking intramedullary nail fixation (D), 8 months after reoperation, X-ray shows fracture union (E), and after removal of fixation (F). (A) Anteroposterior and lateral X-rays of tibia-fibula fracture. (B) Anteroposterior and lateral X-rays after internal fixation with steel plate. (C) Anteroposterior and lateral X-rays 15 months after internal fixation with steel plate, showing hardening of the fracture end and nonunion. (D) Anteroposterior and lateral X-rays after reoperation with interlocking intramedullary nail fixation. (E) Anteroposterior and lateral X-rays 8 months after reoperation, showing blurred fracture lines and fracture union. (F) Anteroposterior and lateral X-rays after removal of the intramedullary nail.

tively. To solve this problem, many authors have tried to achieve strong fixation by increasing the stiffness of external fixation or limited opening of tensile fixed fracture block [15]. As previously indicated [16], the problem is that strong stress shielding decreases the stress on the bone for a long time, which would finally lead to loss of bone mass of cortical bone and increase fracture healing time. After removal of fixation, there is an increased risk of refracture. External fixation combined with elastic intramedullary nails for treatment of comminuted tibia-fibula, long-range and multi-segment fractures should overcome the above disadvantage: 1) intramedullary and extramedullary double elastic fixation does not occupy the space for soft tissues; the contact area between fixtures and cortical bone is small, which protects the blood supply for fracture ends and soft tissue to the largest extent, and complies with BO principles; 2) surgery is easy, surgical time is short, blooding loss is small, interference to damaged soft tissues is small, and postoperative soft tissue swelling and necrosis rate are decreased; and 3) removal of external fixation can be conducted by stages or slightly in advance to decrease the rate of nail tract infection and inconvenience to patients, compared with simple external fixation.

As observed by Liu *et al*. [17], early loading can accelerate bone healing. If callus formation is delayed, the possibility of delayed union is increased. Studies have shown that in order to stimulate bone callus formation, relatively small fracture block activity (about 0.2 mm) was enough, and could be withstood compared with large fracture block activity (about 1 mm).

Wan *et al*. [18] observed that stress stimulation in the middle to late stage of fracture had significant impact on healing. In this study, external fixation was removed once continuous callus growth was observed at the fracture ends by X-ray review; therefore, time with fixation was largely shortened. On one hand, it decreased the rate of nail tract infection; on the other hand, due to the use of elastic nail and intramedullary elastic splint fixation, transformation of high stiffness fixation to elastic fixation and dynamic fixation of axial movement were conducted. In this case, stress shielding was decreased, and discontinuous longitudinal pressure at the fracture ends was produced, promoting bone healing [19]. The final bone healing time for all the patients in this study was 24-32 weeks, with average 28 weeks, and it was shorter in the EINE group compared with the plate group. Previous studies in tibia-fibula fracture also showed good outcomes with the EINE approach [11, 20, 21].

In the present study, patients with complications (ankle dorsiflexion and plantar flexion dysfunction, delayed union, angulation, and limb shortening deformity) all belonged to level 3 or 4 fractures with high level of comminuting and to the C3 type with large quantity of cortical comminuting. Therefore, for severe fracture block separation and fractures with small and large number of fragments, it could not be concluded that this approach had better biological fixation. In this case, the distance between the fracture line to tibia-fibula superior or inferior joint surface should be more than 4-6 cm. EINE should be particularly suitable for patients with long-spiral, multi-segment, level 1 and level 2 comminuting fracture accompanied or not by relatively long occult fracture line, especially for patients with soft tissue highly swelling and patients who could not undergo early surgery due to contusion.

The present study is not without limitations. It was a retrospective study of cases from a single center. In addition, the sample size was small. Multicenter trials should be performed to assess adequately the value of EINE in these patients.

In conclusion, minimally invasive EINE for treatment of comminuted closed tibia-fibula fractures achieved satisfactory results. There is no commonly accepted fixation technique that can be widely used for the treatment of comminuted tibia-fibula fractures, and selection of fixation still depends on the knowledge and experience of surgeons, patients, and fracture types [22]. Additional studies are required to examine the best fixation approach for these complicated fractures.

Disclosure of conflict of interest

None.

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