Research Square

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Efficacy Comparison of Trifocal Bone Transport Using Unilateral External Fixator for Femoral and Tibial Bone Defects Caused by Infection

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Research Article

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Abstract

Background: This study aimed to evaluate the clinical and functional outcomes of patients with critical femoral and tibial bone defects treated by trifocal bone transport using the Ilizarov method.

Methods: In a retrospective comparative study, 39 patients treated for lower limb bone non-union with bone loss measuring between 6 and 14 cm were included. Depending on the location of bone transport, the patients were divided into the femur group (n =18) and tibia groups (n =21). The demographics data, intraoperative records, and postoperative outcomes were documented and compared between the two groups. At the last follow-up, the bone and functional outcomes were evaluated according to the criterion given by the Association for the Study and Application of the Method of the Ilizarov (ASAMI) and postoperative complications evaluated by Paley classification.

Results: The average follow-up time was 26.1 months (range 17–34 months) since the unilateral external fixators were removed. The mean size of the bone defect was 8.3 cm in the femur group, and 7.5 cm in the tibia group. All bone defects were reconstructed successfully. The mean time in external fixation in the femur group was 334.4 days, and in the tibia group was 344.6 days. The external fixation index (EFI) measured 55.9 days/cm in the femur group and 65 days/cm in the tibia group. A statistically significant difference of bone grade was found between the two groups (excellent/good/fair/poor, 3/11/3/1 vs 2/13/4/2, P<0.05), as well as the function grade in two groups (excellent/good/fair/poor/failure, 3/14/1/0 vs 4/13/3/1, P<0.05). According to the ASAMI classification, the clinical and functional results in the femur group were better than in the tibia group. The complication rate of the two groups was 94.4% vs 76.2% (femur vs tibia). One femur and five tibias were performed additional surgery because of delayed union and axial deviation.

Conclusions: The trifocal bone transport using the unilateral external fixator is a reliable treatment in the management of post-traumatic and post-infection lower limb bone defects (>6cm). In the comparison of the tibia, the trifocal bone transport treatment period of the femur was shorter, the functional recovery was better and the risk of minor complications was higher.

Background

Lower limb injuries, especially the open fracture, are commonly caused by trauma, fall from a height, road traffic accidents, and sporting injuries - mainly involving active outdoor life. Although the majority of fractures heal with conventional treatment, large bone defects and non-unions caused by post-traumatic infections still leave a great challenge for Orthopedic clinicians [1–4]. The treatment objectives of orthopedic surgeons, in this case, include thorough debridement and removal of any obvious or potential sources of infection, to achieve stable fixed target osseointegration, maintain equality and alignment of limb length, and obtain appropriate functions. Recently, several mature treatment options available to manage patients who have lower limb bone defects in the presence of infection were produced by scholars, including bone grafting with autogenous or allogenic bone grafts, tibialization of the fibula, vascularized fibular grafts, the Masquelet induced membrane technique, and conventional and modified Ilizarov methods [5–8].

Reconstructions are often limited by the constraints of bony and soft tissue infections, and the above methods may not allow the surgeon to correct alignment and restore bone length completely and straightforwardly, except the Ilizarov method. This method was presented by Gavril Abramovich Ilizarov to treat the complicated shortening, deformity, bone loss, joint contractures, and some soft tissue defects of long bones in 1950 [9]. Bone transport, one of the Ilizarov methods, is characterized by the gradual translocation of a segment of bone from an adjacent healthy area into the region of bone loss, usually together with its surrounding soft tissue envelope [10]. Of this method, there is no change in the length of the limb, as the result of the length of the distraction is equal to the length of the bone defect. The traditional Ilizarov circular fixator has its disadvantages, such as an unaesthetic appearance and a complicated distraction process. If the postoperative joint exercise is not appropriate, the discomfort and stiffness of the adjacent joints are caused obviously, especially its poor applicability in the thigh and upper arm. To overcome these shortcomings, a unilateral external rail system was introduced [11], which requires less surgical technique and possesses greater patient acceptance.

Supported by previous research and experience, it is confirmed that trifocal bone transport is superior to bifocal bone transport in terms of external fixation index, regenerative consolidation, clinical results in lower limb critical bone defects [12–16]. There were barely descriptions of its complications and clinical outcomes between femoral and tibia critical post-traumatic bone defects. Therefore, our study aimed to compare the clinical efficacy of the trifocal bone transport in the treatment of femoral and tibia post-traumatic defects.

Materials And Methods

Study Design

This non-randomized comparative study was based on retrospective data from treatment sessions recorded in operation planning programs and hospital records in the period 2011–2018 (n = 39). Inclusion criteria for the study were femoral or tibial non-union of minimum duration of half a year and infection at the site of non-union with an addition of either a bone defect between 6 and 14 centimeters or an attempt to obtain bony union that failed to heal following an additional intervention, for an example by doing bone graft. Patients were excluded when they had a follow-up less than 2 years, serious chronic diseases to incomplete the whole treatment, refused to give consent and those with fragmentary medical records. The additional factors related to bone healing at the docking site were ruled out, such as the bone transport direction mode (proximal to distal, distal to proximal, or docking from both sides). All the surgery were conducted by senior orthopedic surgeons with at least five years of experience in Orthopedic and three or more years of experience in the Ilizarov technique. All patients were performed by the proper direction mode(adjusted to the location of the bone defects) of trifocal bone transport using unilateral external fixator (Orthofix limb reconstruction system (LRS),Verona，Italy) after radical debridement, with or without bony spacer filling and soft tissue reconstruction.

Patients’ data

According to the above inclusion criteria, a consecutive series of 39 patients were managed with the Ilizarov technique of trifocal bone transport in the femur (n = 18) or tibia (n = 21) bone defects between March 2011 and January 2017 at our hospital. The questionnaires were applied to collect the patients’ data, including age, gender, location of the injury, the interval between first injuries, and surgical history before bone transport (Table 1). Briefly, there were 26 males and 13 females with a mean age of 46.7 ± 6.79 years (range, 20–52 years). In these patients, modes of bone defects included open fracture caused by trauma (n = 14), osteomyelitis after debridement (n = 16), and developmental deformities after correction (n = 9). Patients were divided into two groups in the light of the location of the bone defect, and minimally invasive osteotomy and trifocal bone transport using unilateral external fixation were performed. Approval from the Ethics Committee of our hospital was received and written informed agreement was obtained from all patients.

Table 1
Comparison of the main indicators of the two groups

	Femur(n = 18)	Tibia(n = 21)	*z* or *t*	P value
Age(years)	46.29 ± 6.29	47.05 ± 7.29	-0.338	0.737
Gender(male, female)	13M,5F	13M,8F	-0.357	0.721
DRL(cm)	8.37 ± 3.48	7.57 ± 2.73	1.768	0.086
Operating time(min)	159.24 ± 13.28	149.91 ± 7.22	2.587	0.016
Surgical bleeding volume(ml)	172.79 ± 15.81	139.44 ± 12.35	7.053	< 0.001
Bone transport time(day)	40.41 ± 8.67	45.45 ± 5.75	-2.115	0.042
CT(day)	231.54 ± 3.31	250.46 ± 2.99	18.110	< 0.001
Duration of bone union(day)	323.72 ± 5.66	344.25 ± 3.69	12.802	< 0.001
EFT(day)	334.49 ± 8.54	344.64 ± 3.64	-4.555	< 0.001
EFI(days/cm)	55.96 ± 2.96	65.02 ± 1.29	11.677	< 0.001
Duration of disease(month)	22.10 ± 5.16	20.63 ± 2.44	1.078	0.293
Follow-up time(month)	27.75 ± 4.06	27.34 ± 3.38	0.083	0.086

DRL distraction regenerate length, CT consolidation time, EFT external fixation time, EFI external fixation index.

Surgical treatment

Preparation stage

Patient care included changing the wound dressing every two or three days for the wound, improving nutritional status, assessing the affected limb's function and skin condition, and blood monitoring of inflammatory parameters such as WBC, CRP, and ESR. Before bone transport, the debridement of all necrotic and infected bone, soft tissue, and/or implanted antibiotic-impregnated cement spacers were carried out thoroughly to improve axial stability. Intraoperative specimens of the infected area were collected and sent for bacterial culture and susceptibility testing to guide the surgeon in the selection of appropriate postoperative antibiotics. The skin flap for the covering of the small tissue defects was local tissue flap or tension-free direct suture, and for larger defects were flap transfer or free skin grafting. The images of preoperative X-rays and computed tomography (CT) were used to evaluate the size of the defect and plan the structure of the external fixator. Then bone transport surgery was ready to begin when the infectious of bone and skin had been controlled, which was illustrated by the clinical manifestations and laboratory index.

Surgical procedure

Under continuous general or spinal anesthesia, patients were placed in a supine position on a radiologic surgical table and a unilateral external fixator (Orthofix limb reconstruction system (LRS),Verona，Italy) was applied as well. If flap transfer was required, the patient was placed in the supine or lateral decubitus position. On a flap transfer basis, the external fixators were recommended to place on the distal and proximal fragments parallel to the respective joints. For instance, the fixators were placed on the anteromedial aspect of the tibia, but on the lateral of the femur. Next, the sliding clamps were assembled and the external fixator's position was adjusted until acquired the appropriate axial line under the fluoroscopy of an X-ray machine. The Schanz screws were then inserted perpendicular to the mechanical axis of the bone distal end, and the desired bone length and axial alignment were maintained. After these, minimally invasive osteotomy was performed using the Gigli saw and special care was given to preserving the periosteum as much as possible.

Postoperative management

Bone transport started after a latent period of seven days. The proximal fragment and the distal fragment were distracted four times per day at a rate of 0.25 mm retrospectively until the two fragments converged. On the second postoperative day, postoperative rehabilitation was encouraged to start by performing active and passive knee range of motion (ROM) exercises without weight-bearing. Radiographic examination was performed monthly to monitor the progress of bone transport and the quality of bone regeneration during the distraction stage. During the consolidation stage, radiography was also conducted every two months to access the growth of the bone axis and the mineralization of the transport gap. The patient's pain symptoms were monitored closely during the whole treatment and the pin tract care was conducted every two days.

All patients were followed up and the complications were recorded. The unilateral external fixator was removed when radiographs demonstrated solid docking-site union and at least three complete cortices in the regenerate zone. The partial weight-bearing activity of the patient for 2 weeks was recommended after removing the external fixator, then the whole weight-bearing walking.

Statistical methods

The operating time, surgical bleeding volume, distraction regenerate length (DRL), bone transport time, consolidation time (CT), external fixation time (EFT/ET), external fixation index (EFI), and occurrence of complications were recorded and compared between the femur group and the tibia group (Table 2). Bone and functional outcomes were evaluated according to the Association for the Study and Application of the Method of Ilizarov (ASAMI) criteria [12, 17]. The SPSS 20.0 software package was used to perform statistical analysis on the collected data. T-tests were used for continuous variables, and the chi-square test was used for categorical variables. A statistically significant difference was set at $P < 0.05$.

Table 2
Outcomes of ASAMI scores in two groups

ASAMI	Location	Excellent	Good	Fair	Poor	Failure
Bone grade*	Femur	3	11	3	1	-
	Tibia	2	13	4	2	-
Function grade*	Femur	3	14	1	0	0
	Tibia	4	13	3	1	0

*$p < 0.05$

Bone results

Excellent: Union, no infection, deformity < 7°, limb length discrepancy (LLD) < 2.5 cm

Good: Union plus any two of the following: the absence of infection, deformity < 7°, LLD < 2.5 cm.

Fair: Union plus any one of the following: the absence of infection, deformity < 7°, LLD < 2.5 cm.

Poor: Nonunion/refracture/union plus infection plus deformity > 7° plus LLD > 2.5 cm

Functional results

Excellent: Active, no limp, minimum stiffness (loss of < 15°knee extension or < 15°ankle dorsiflexion) no reflex sympathetic dystrophy (RSD), insignificant pain.

Good: Active, with one or two of the following: limb, stiffness, RSD, significant pain.

Fair: Active, with three or all of the following: limb, stiffness, RSD, significant pain

Poor: Inactive (unemployment or inability to return to daily activities because of injury)

Failure: Amputation

Results

There were 26 males and 13 females with lower limb bone defects which were measured between 6 and 13 cm were included in this study, including 18 femurs and 21 tibias. Bone defects in all patients were the result of debridement procedures secondary to trauma and osteomyelitis, or additional resection at the time of established reconstructive surgery. With Cierny and Mader's (CM) classification, 29 cases in type ▯, and 10 cases in type ▯. Of these patients, positive bacteria isolated was in 33 cases (84.6%) by the culture test of secretion. Twenty patients (57.8%) were infected with S. aureus, 7 (21.2%) in P. cuprina, and 6 (18.1%) with E. coli. Full demographics and clinical characteristics of the study cohort are detailed in Table 1. Since the removal of the unilateral external fixator, the average follow-up time was 26.1 ± 3.8 months (range 17–34 months).

A total of 39 limbs were reconstructed successfully. Soft tissue loss was covered with the direct sutures of appropriate tension in 31 patients (79.5%), local propulsive skin flaps in 6 patients (15.4%), and vascularized free flaps in 2 patients (5.1%) after removal of the negative pressure drainage device. Skin or flaps necrosis was not observed. There were no significant differences in age, gender composition, distraction regenerate length (DRL), duration of disease, and follow-up time between the two groups ($P > 0.05$). In contrast, as shown in Table 1, there were several significant differences between the femur and tibia groups in the mean operating time(159.24 min vs 149.41 min, $P < 0.05$), the mean surgical bleeding volume(172.79 ml vs 139.44 ml, $P < 0.001$), the mean distraction time(40.41 days vs 45.45 days, $P < 0.001$), the mean consolidation time(231.54 days vs 250.46 days, $P < 0.001$), the mean bone union time(323.72 days vs 344.25 days, $P < 0.001$), the mean external fixation time(334.49 days vs 344.64 days, $P < 0.001$), the mean external fixation index(55.96 days/cm vs 65.02 days /cm, $P < 0.001$).

In 26 of 39 patients, radiating foot pain occurred during transportation and was relieved by slowing the distraction rate and symptomatic treatment. Furthermore, pin tract infection occurred in 7 patients (4 femurs and 3 tibias), and three of them (Checketts and Otterburn classification 4) progressed to pin loosening. These symptoms were resolved by dressing change combined with oral antibiotic or surgery for the pin track replacement. Axial deviations (3 femurs and 2 tibias) were corrected by adjusting the external fixator radiologically under local anesthesia. Muscle contractures (2 femurs) were managed by the tension-release surgery to reconstruct function. Joint stiffness (2 femurs and 1 tibia), soft tissue incarceration (2 femurs and 1 tibia), and neurological injury (3 femurs and 4 tibias) were treated by drugs, joint rehabilitation training, and physical electromagnetic wave therapy instrument. Delayed unions (1 femur and 5 tibias) were recovered through surgical treatment of autologous bone graft with internal fixation. Refer to Figs. 1–2 for details on the whole procedure of trifocal bone transport, which was described by this study.

Table 2 summarized the details of bone and functional results at the last follow-up (at least 24 months) after removal of the external fixator and the results were evaluated according to the Research and Application Association of the Ilizarov (ASAMI) classification method. A statistically significant difference of bone grade was found between the two groups (excellent/good/fair/poor, 3/11/3/1 vs 2/13/4/2, P <

0.05), as well as the function grade in two groups (excellent/good/fair/poor, 3/14/1/0 vs 4/13/3/1, $P < 0.05$). Additionally, the distribution of complications in the two groups, leading to the above differences of the bone and function grade, were recorded in Table 3. The outcomes of the femur group were better than in the tibia group.

Table 3
The complications of two groups in the period of bone transport

Complication	Femur(n = 18)	Tibia(n = 21)
Pin tract infection	4	3
Muscle contractures	2	0
Joint stiffness	2	1
Axial deviation	3	2
Soft tissue incarceration	2	1
Neurological injury	3	4
Delayed union	1	5
Nonunion	0	0
Recurrence of infection	0	0

Complications were classified as minor or major [17]. Minor complications did not require additional surgery, and major complications were defined as resolving by additional surgery or true complications that remained unresolved at the end of the treatment period. The complication rate of the two groups was 94.4% vs 76.2% (femur vs tibia). According to Paley's classification, the distribution of minor (n = 26) and major (n = 7) complications was shown in Table 4. In our patients, minor complications (resolved without surgery) per patient were 0.23 and 0.44 in the femur and tibia group respectively ($P < 0.001$), and major complications (required additional surgery) per patient were 0.11 and 0.06 in Table 5 ($P < 0.001$). Permanent complications such as sequelae and unresolved at the end of treatment were not observed.

Table 4 The details of bone transport related complications

Complications	Minor	Major
Pin tract infection or pin loosening	6	1
Muscle contractures	2	0
Joint stiffness	3	0
Axial deviation	4	1
Soft tissue incarceration	2	1
Neurological injury	6	1
Delayed union	3	3
Nonunion	0	0
Recurrence of infection	0	0

Table 5 The treatment results of two group postoperative complications

	Femur	Tibia	P value
Docking Site Revision	1	5	-
Minor complications (per patient)	0.23	0.44	<0.001
Major complications (per patient)	0.11	0.06	<0.001
Sequelae (per patient)	-	-	-
Total Surgeries (per patient)	4	7	-

Discussion

The most important finding of this study was that the duration of the bone union in external fixation was significantly shortened for the femur group compared to the tibia group. In addition, the between-group differences for both bone and functional results were also significant. With this effect size and the number of patients we included, our study was adequately powered (using $P < 0.05$) to detect between-group differences using prior analysis. Generally, the femur group has a physiologically better bone healing response, and lower limb function recovery. The total number of complications per patient was significantly greater in the femur group compared to the tibia group. These findings could be explained as soft tissues and fruitful blood vessels in the thigh have better quality than in the tibia, and this allows for better postoperative rehabilitation and faster bone healing. In turn, the favorable influence of these physiological characteristics brought about comorbidities simultaneously, such as pin tract infection, axial deviation, which increased the number of operations potentially and prolonged the rehabilitation time. Thus, timely and effective detection and management of complications by internet follow-up applications are beneficial for bone healing. This study investigated the clinical efficacy preliminarily of trifocal bone transport in femoral and tibial infected bone defects, recorded and compared the distribution of postoperative complications, and provided the reference for treating infected defects of lower limbs.

Critical bone defects caused by osteomyelitis or trauma are an insurmountable challenge for both patients and orthopedic clinicians, and limb salvage with any technique can be disappointing [14, 16, 18–20]. Masquelet techniques are spacer filling, induced membrane formation, bone grafting, and fixation. It has been reported in the literature about its efficacy in controlling infection and treating nonunion, but this technique requires fruitful coverage of soft tissue at the bone defect site and has poor ability in correcting the deformity. Despite less psychological stress and better acceptance of internal fixation, both plate and intramedullary nailing require operation time to address the problem of suitability and stability of fixation devices and bone. The utilization of automatic intramedullary lengthening devices for lower limb bones is still in the experimental animal stage, and more evidence is needed to support its clinical efficacy.

Based on the spectrum of multi-focal osteosyntheses of the Ilizarov technique, external fixation uses distraction osteogenesis to regenerate bone defects caused by complex etiologies to smooth the way for limb reconstruction and rehabilitation [12]. The reconstruction of soft tissue loss can be resolved effectively by this technique, while addressing bone defects and allows the patient to mobilize on the second postoperative day, accelerating bone mineralization dynamically. Critically, this method allows radiographic and histological analysis easier, whilst standardize the mechanical stability of the defect precisely. Via a recent study [14–16, 21, 22], multi-level bone transport was developed to resolve the reconstruction of the critical bone defects (> 6cm), which enriches the traditional Ilizarov technique. In bone defects, the critical tibia defect caused by trauma has been treated successfully by trifocal bone transport with an external fixator, which could eliminate infection and reconstruct bone and soft tissue defects simultaneously. The main theoretical advantage of trifocal bone transport is to eliminate infection, reconstruct bone and soft tissue defects simultaneously, and connect across the original area of bone loss with the expectation of decreased the whole treatment period [12, 13]. The external fixators are divided into circular fixators and unilateral fixators commonly. The application of a circular external fixator in the treatment of bone defects caused by an infection often has an impact on daily life, nursing, and adjacent joint's range of motion. Besides, the hydroxyapatite-coated screws decrease the risk of pin tract infection, have been used for the treatment of open fracture or osteomyelitis [11]. In this study, all patients were treated by unilateral fixators to minimize external-fixator-nature complications. Bone healing was received in 39 patients (100%), and the rate of excellent and good bone and function was 74.3% and 87.1% respectively.

For the operative procedure, the principles of the Ilizarov technique of percutaneous osteotomy should be followed to conserves the periosteum. The osteotomy was conducted minimally along with the predesigned bone cutting position (the bone cutting position should be considered in combination with the factors away from the lesion, metaphysis, skin, and soft tissue conditions, etc.), and low-speed drill, low-energy, subperiosteal bone cutting are used to reduce the incidence of iatrogenic fracture nonunion. Trifocal osteotomy was given the meaning of dividing the residual large segmental bone defect into two segments for stretching into the bone and reducing the length of each distraction area. Thereby, it could double the distraction speed because two-level osteotomies divided lengthening (and healing) into two locations. In our cohort, an earlier start to distraction (7 days after surgery) at the rate of 2 mm per day was achieved in all patients by the above surgical method. However, the operating time and surgical bleeding volume were significantly different between femur and tibia, which illustrated that the multilayered physiological anatomy and thicker subcutaneous superficial fascia of the thigh adds significantly to the difficulty of the procedure and increases the risk of postoperative complications, such as pin tract infection and axial deviation. Despite it seems like an elegant solution for the management of bone defects, there is a great problem for clinicians to manage postoperative care, including pin tract care, radiographic follow-up. In this study, 39 bone defects were salvaged and the docking site was connected. Some complications occurred inevitably during the bone transport period. The rate of complications was 0.84 per patient (0.67 of minor and 0.17 of major). Pin tract infection was a common complication in the process of bone transport [23–26], the rate varied from 6–70%. In our study, seven patients (17.9%) had different symptoms of pin tract infection, including four cases in the femur group (22.2%) and three cases in the tibia group (14.2%). Similarly, the complications related to the rich soft tissue of the thigh, especially muscle contractures were also in higher occurrence than the calf.

Another significant observation from this study is the high incidence of delayed or non-union of the docking site in the tibia group. There were delayed unions in 5 cases (23.8%) in the tibia group, compared to the delayed union in one case (5.5%) in the femur group. There was also a significant difference between the two groups about the complications per patient (minor 0.44 vs 0.23, major 0.06 vs 0.11, $P < 0.05$). One of the similarities in these delayed unions was that the bone defects were greater than 8 cm and at least four previous surgical procedures were conducted before bone transport surgery. In our consideration, previous surgeries and invasive osteotomies may disturb the vascular capacity of the affected limb, and give a negative impact on bone regeneration. And the tibia anatomical structure changes in the middle and lower third [23], which results in fewer nutrient vessels here, increasing the risk of delayed union or even nonunion. The basis for the greater incidence of these is also likely related to a temporary imbalance between bone resorption and apposition at a time when loading rapidly increases due to bone transport, which causes few cortical layers to bridge the middle regenerate zone in the consolidation stage. The same phenomenon was noticed by Borzunov et al.[27, 28], they recommended using imaging to monitor the status of regenerated bone and adjust the distraction rate timely to avoid bone ischemia. Thus, the chief surgeon should fully understand the anatomical structure of the lower extremities and make a correct approach for the protection of the periosteum at the osteotomy site before the operation to reduce the probability of delayed union. Besides, the method was recommended by scholars that autologous cancellous bone grafting of the docking site at the end of distraction do a favor to avoid the occurrence of delayed union[6, 29–31]. In our study, the patients with delayed union managed with additional surgery of bone grafting and walking with the help of a walking aid after removal of the external clamps to achieve dynamization to promote bone healing. Finally, bone union was obtained.

Some surgical methods [27, 28, 32–36], which can prevent its potential complications and bring about better clinical outcomes have been proposed to reduce the external fixation index. For example, bone transport using the unilateral fixator and locking plate/intramedullary nail to fix simultaneously to avoid prolonged wearing of external fixators. However, these methods require additional surgery, which is no doubt to leave a worse psychologic pressure and monetary burden for patients, given their multiple failed previous surgeries. Fortunately, it is universally accepted that the trifocal bone transport is born to shorten the external fixation index and reduce the complications during the implementation of distraction osteogenesis [12, 21, 37], which requires a less surgical procedure. Trifocal bone transport can partition the distraction gap and perform bone distraction in segments, which reduces the tensile stimulation to the middle of regenerated bone and avoid the occurrence of bone ischemia. In this study, satisfactory results of this technique were obtained in the treatment of lower limb infected bone defects. The patients in the femur group had shorter bone transport time (40.41 ± 8.67 vs 45.45 ± 5.75 days), shorter consolidation time (231.54 ± 3.31 vs 250.46 ± 2.99 days), shorter bone union time (323.72 ± 5.66 vs 344.25 ± 3.69 days), shorter external fixation time (334.49 ± 8.54 vs 344.64 ± 3.64 days), and smaller external fixation index (55.96 ± 2.96 vs 65.02 ± 1.29 days/cm). Trifocal bone transport in femurs was associated with significantly shortened external fixation time, and higher quality of bone healing (excellent/good/fair/poor, 3/11/3/1 vs 2/13/4/2), and recovery of limb function (excellent/good/fair/poor, 3/14/1/0 vs 4/13/3/1) than the tibia group, but this was accompanied by an increased complication rate (femur vs tibia, 94.4% vs 76.2%). According to our observation, more attention should be paid to the situation of the timely management of complications associated with abundant soft tissue during femoral bone transport. At the same time, alertness needs to be paid for the prompt response to the bone ischemia (hourglass-like or thin central cylinder showed by X-ray), which often occurred in the tibia during the process of bone transport and led to delayed union or nonunion. If nonunion occurred, the mechanic solutions published by Borzunov et al.[27] maybe a practical way to salvage the limb.

There are some limitations to this study. First of all, it was conducted retrospectively rather than as a randomized controlled trial, and the chart review process is possibly subject to assessor bias. Secondly, as our data represent the experience of one group of surgeons at a single institution, the potential for selection and information bias exists and our results are subject to the influence of surgeon experience, and patient selection preferences. Thirdly, long-term follow-up is required to assess the eventual efficacy of this strategy to enable better tailoring of the treatment strategy for individual patients.

Conclusion

In short, the trifocal bone transport, based on the Ilizarov technique, using the unilateral external fixator was able to reconstruct lower limb bone defects (> 6cm) successfully and simply, whilst accompanying soft tissue defects simultaneously. In the comparison of the tibia, the trifocal bone transport treatment period of the femur was shorter, the functional recovery was better and the risk of minor complications was higher.

Declarations

Acknowledgments

Not applicable.

Authors' contribution

KL, YSL, PR, and AY developed the research questions and scope of the study. KL and YSL conducted preoperative and postoperative data screening, and data charting. KL drafted the manuscript, prepare tables and figure with FYC's contribution. CCY developed the literature search strategies in collaboration with the other authors. KL, YSL, FYC, CCF, PR, and AY contributed to the organization, analysis, and interpretation of the results. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets generated and analyzed during the current study are not publicly available due to restrictions on ethical approvals involving patient data and anonymity but can be obtained from the appropriate authors as reasonably required.

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of The First Affiliated Hospital of Xinjiang Medical University and carried out in accordance with the ethical standards set out in the Helsinki Declaration. Informed consent was received from all participating.

Competing interests

The authors declare that they have no conflict of interest.

Consent for publication

Not applicable.

Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

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Figures

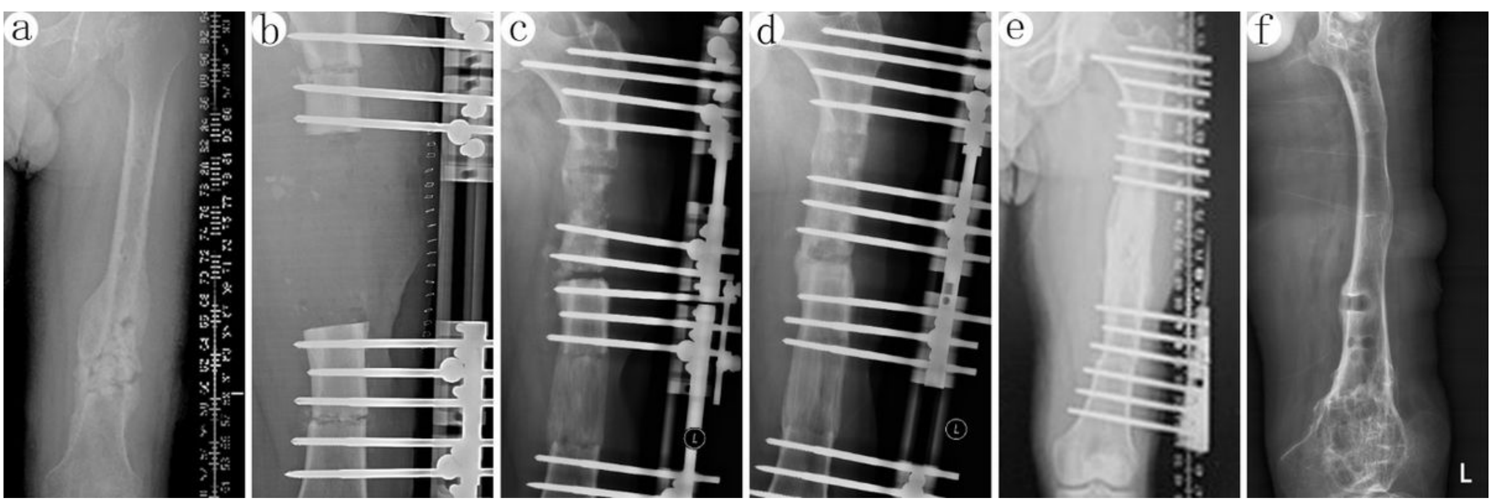

Figure 1

39-year-old male patient with posttraumatic osteomyelitis of the left femur was treated with trifocal bone transport from both side to docking site using Orthofix external fixator. a X-ray graph before treatment. Lesions on the sides of the middle and lower part of the femur. b After debridement, the bone defect reached almost 14 cm. The Orthofix external fixator was used to perform the distal and proximal biplane osteotomy. c The X-ray graphs at 40 days after surgery. The force line was available. d At 80 days, the butt joint healed. Regeneration zone growing well. e Bone healing of the osteotomy line was evident at eight months. f X-ray film after removing the external frame at last follow-up.

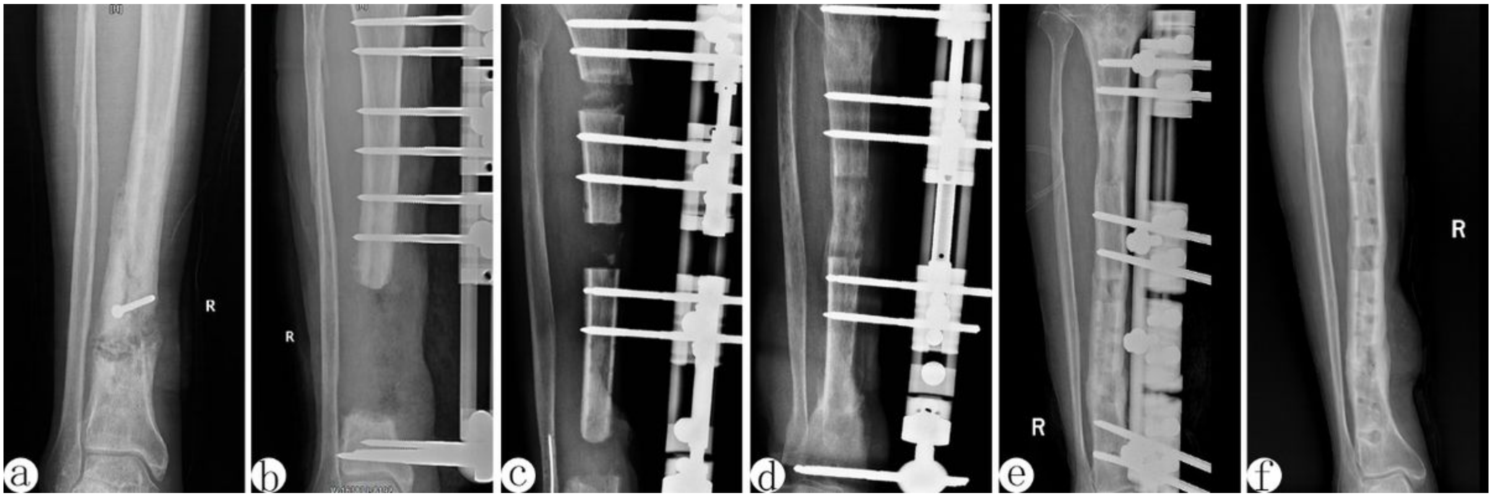

Figure 2

A 47-year-old female patient with posttraumatic osteomyelitis the right tibia and treated using Orthofix external fixator trifocal bone transport from proximal to distal. a X-ray graph before treatment. Lesions and internal fixator were on the sides of the middle and lower part of the tibia. b Segmental defect of the left tibia after debridement on X-ray graph. Excision of infection bone with 12 cm defect and application of Orthofix external fixation with trifocal bone transport. c The X-ray graphs at 40 days after surgery. The force line was available. d Bone healing of the osteotomy line was evident at four months. e Bone transport was completed with good regenerate consolidation and docking union was achieved and evaluated on the view of X-ray at six months. f Orthofix external fixator was removed with excellent bone union shown on the view of X-ray at eight months after operation.