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ORIGINAL STUDY

The treatment of infected tibial nonunion by bone transport using the Ilizarov external fixator and a systematic review of infected tibial nonunion treated by Ilizarov methods

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This study was designed to evaluate the effectiveness of the treatment of infected tibial nonunion by bone transport using the Ilizarov external fixator.
We retrospectively reviewed 66 patients with infected tibial nonunion treated by bone transport using the Ilizarov external fixator. Our study included 62 males and 4 females with a mean of age 37.06 years. The average length of the bone defects after radical debridement was 6.27 cm (range 3-13 cm).
The mean follow-up after removal of the apparatus was 25.91 months (18-46 months). 6 patients were lost to follow-up. All the patients achieved bone union and no recurrence of infection was observed. The mean external fixation index was 1.38 months/cm (range 1.15-1.58 months/cm). According to Association for the Study and Application of the Method of Ilizarov (ASAMI) classification, bone results were excellent in 44, good in 15, fair in 5 and poor in 2 ; functional results were excellent in 24, good in 26, fair in 10 and no poor.
***Conclusions :* Our study and the current evidence suggested that Ilizarov methods in the treatment of infected tibial nonunion acquired satisfied effects in bone results and functional results. Radical debridement is the key step to control bone infection.**

Keywords : bone transport ; infected nonunion ; bone defects ; Ilizarov methods ; systematic review.

INTRODUCTION

Infected tibial nonunion is common in clinical practice (*27*), and there are usually some coexisting problems of bone and soft tissue loss, deformities, limb-length inequalities and polybacterial infection (*12*). Up to now, the treatment of infected tibial nonunion has still been a challenge for orthopedic surgeons (*25*). Some different treatment options have been reported, including bone grafting, free tissue transfer, antibiotic cement and Ilizarov methods. Bone grafting has some limitations such as size of graft for large bone defects and donor site morbidity. Free tissue transfer is technically demanding

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treatment, and usually associated with some problems of stress fractures and nonunions (20). Antibiotic cement is only suitable for the treatment of infected tibial nonunion with small bone defects or none, and bone grafting is usually indispensible. Besides, these three methods may not be capable of treating infection and bone nonunion simultaneously. The ability is possible with application of the methods of Ilizarov, and recurrence of infection was seldom observed (5,21,26). Bone transport is a type of Ilizarov methods, and it is suitable for the treatment of infected nonunion with bone defects of any length. Hence, bone transport has gradually been a major treatment for infected tibial nonunion.

In the following report, we describe our successful experience in the treatment of infected tibial nonunion by bone transport using Ilizarov external fixator. To our knowledge, our study represents the largest retrospective series on the number of patients with infected tibial nonunion and the species of infectious bacteria, and we conducted a first systematic review of infected tibial nounion treated by Ilizarov methods. Two hypotheses are proposed : (1) Ilizarov methods in the treatment of infected tibial nonunion can acquire satisfied effects in bone results and functional results. (2) Radical debridement is the key step to control bone infection.

PATIENTS AND METHODS

Between January 2004 and January 2011, 72 patients with infected tibial nonunion were treated by bone transport using Ilizarov external fixator in our institution. The eligible criteria were : (1) patients of age of 18 years or more ; (2) patients without an associated neurological impairment of the ipsilateral lower extremity ; (3) no amputation. 66 patients were included in our study.

There were 62 males and 4 females with a mean of age 37.06 years (18 to 62) in our study. The mechanisms of initial injury were recorded in Table I. The mean interval from the initial treatment to administration to our hospital was 22.80 months (range 4-110 months). The initial treatments of the fracture included open reduction and internal fixation in 32 patients, unilateral external fixation in 32 patients and hybrid external fixation in 2 patients. Infected tibial nonunion existed at the time of surgery in our hospital and the mean number of previous surgical procedures was 2.4 (range 1-8 procedures).The sites of tibia nonunion were proximal in 12 cases, middle in 20 cases and middle-distal in 34 cases. The average length of the bone defects after radical debridement was 6.27 cm (range 3-13 cm), which was measured in the operation. The infection was active with purulent drainage in 42 patients and the rest was quiescent without drainage. The samples that were obtained from purulent drainage or deep bone at the site of infected nonunion were cultured and the outcomes were complete for 91% and the rest was incomplete, and bacterial species grown in culture were shown in Table II, 51 patients had bone infection with one bacterium and 9 patients had more than one.

Table I. — The mechanisms of initial injury

Mechanisms of initial injury	Frequency	Percentage
Traffic accident	48	72.81%
Hitting by weight	8	12.62%
Low energy injury	6	8.73%
Hurting by machines	2	2.92%
High Falling injury	2	2.92%
Total	66	100%

SURGICAL TECHNIQUE

The patients were positioned supine on a radiolucent table. Ilizarov external fixator was assembled, according to the length of patient’s limb, the site of infected nonunion and the functional status of knee and ankle joint. Then the operative incision, the scope of the resection of infected bone and the site of pre-selected osteotomy were marked in order to make the full of preparation for the operation. The assembled Ilizarov external fixator was fixed to the tibia shaft as the way that Ilizarov rings were placed on the distal and proximal fragments parallelled to their respective joints and the fixed pins were inserted into the same plane and perpendicular to the mechanical axis of the tibia under the image intensifier control. The aforementioned step in entire operation is very important, if we don’t do this step before the resection of infected bone , the reduction will become very difficult because of loss of reference object. Then the operative incision was performed in accordance with beforehand marked incision. The infected scarred soft tissue and necrotic bone were debrided radically. Bones with bleeding margins were regarded as vital bones. A 1-2 cm

Table II. — Proportion of bacterial species growth in culture

Species	Percent of Culture
Staphylococcus aureus	47%
Pseudomonas aeruginosa	16%
Escherichia coli	13%
Klebsiella	9%
Enterococcus	6%
Acinetobacter	3%
Serratia	3%
Proteus	1%
Burkholderia cepacia	1%
Candida	1%

incision was made below 1cm to the tibial tuberosity through the marked pre-selected osteotomy site, and then a subperiosteal transverse osteotomy was performed. If limbs were complicated with deformity or shorting, the distal lateral fibula was performed with a subperiosteal transverse osteotomy. The periosteum was sutured and the incisions were closed with drainage tubes. If large soft tissue defects existed in the infected site, open dressing changing or vacuum sealing drainage (VSD) were made to close the wound. All patients received a course of sensitive antibiotics for 2 to 4 weeks in intravenous way and were encouraged to partial weight beat with crutches, isometric muscle and joint range-of-motion exercises on the second day after operation. The latency period before bone transport was 7-10 days and the rate of distraction was 0.25 mm per 6 hour. If regenerate quality is poor, the speed of distraction will slow down. When bone transport completed, the tibia docked ends were compressed by 0.25 mm per day in order to provide full contact until the patient felt pain at the docking site.

EVALUATION OF OUTCOMES

Bone transport time, external fixation time, external fixation index, complications were all recorded. Radiographs were reviewed every 2 weeks during the distraction period and monthly during the consolidation period. Ilizarov external fixator was removed when radiographs showed solid docking-site union and the regenerate area had a minimum of three complete cortices. Bone results and functional results were evaluated according to Association for the Study and Application of the Method of Ilizarov (ASAMI) classification (*6,9,21*).

RESULTS

The mean follow-up after removal of the apparatus was 25.91 months (18-46 months). 6 patients were lost to follow-up, because they moved and changed telephone number and could not be contacted. We were unable to evaluate the final

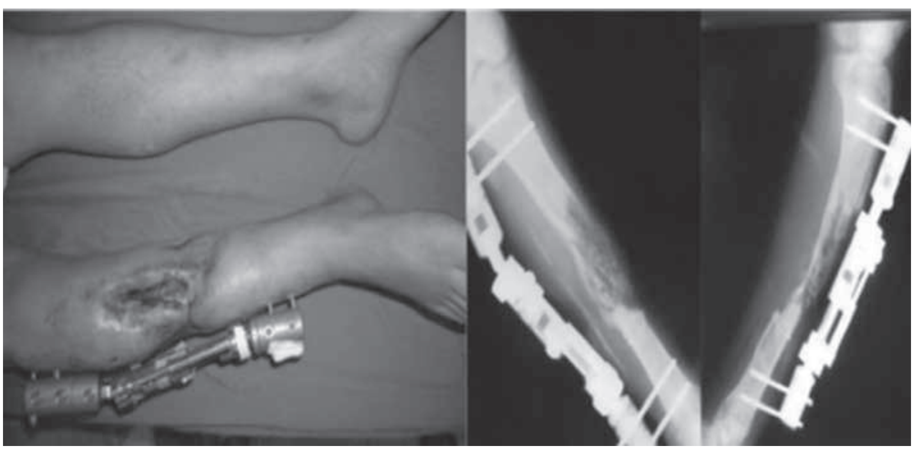

Fig. 1. — This is a 26 years old man who had an infected nonunion of the lower tibia and soft tissue defect. He had undergone 3 previous procedures before bone transport.

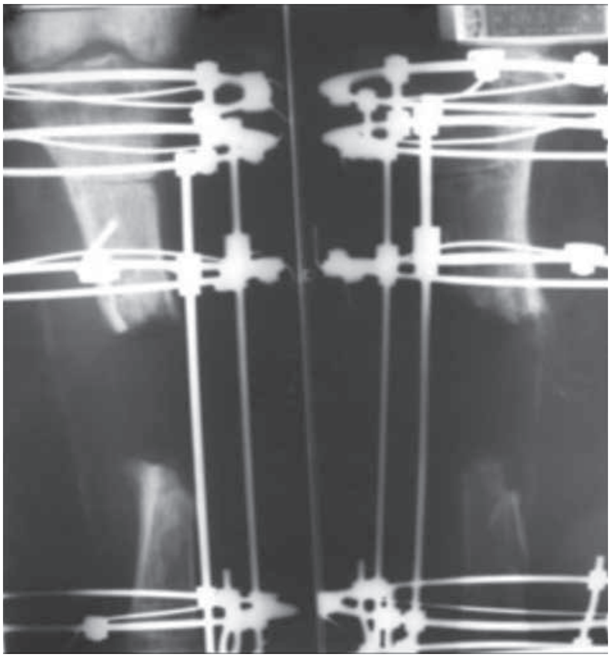

Fig. 2. — Debridement of the site of infected nonunion with a 10 cm bone defect and corticotomy of the upper tibia after application of the frame.

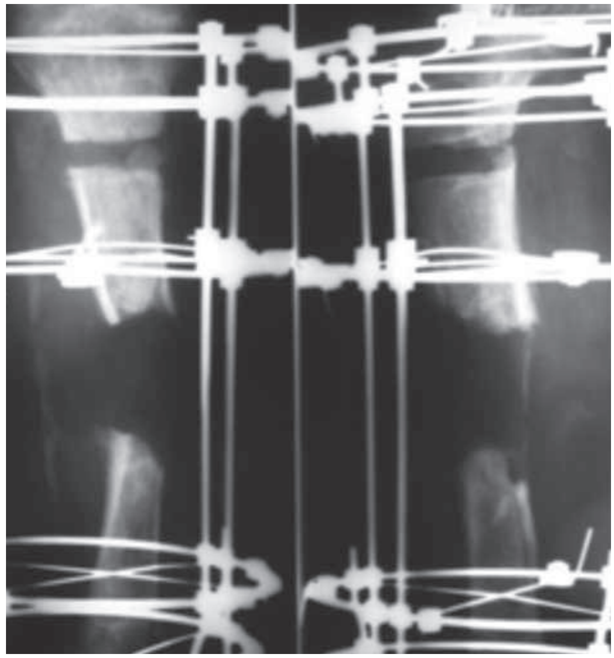

Fig. 4. — Four weeks after operation with bone transport

Fig. 3. — It showed open dressing changing after one weeks for surgery

functional outcomes in these 6 patients. All the patients achieved bone union. All soft tissue defects were healed by soft tissue transport or VSD technique, but there were some scars caused by the cutting of pins during the period of distraction. The time of bone transport took a mean of 68.74 days (range 33 to 137 days), and the mean external fixation time was 9.46 months (range 5.12-15.11 months), and the mean external fixation index was 1.38 months/cm (range 1.15-1.58 months/cm) (Figs. 1-9).

According to Association for the Study and Application of the Method of Ilizarov (ASAMI) classification, bone results were excellent in 44,

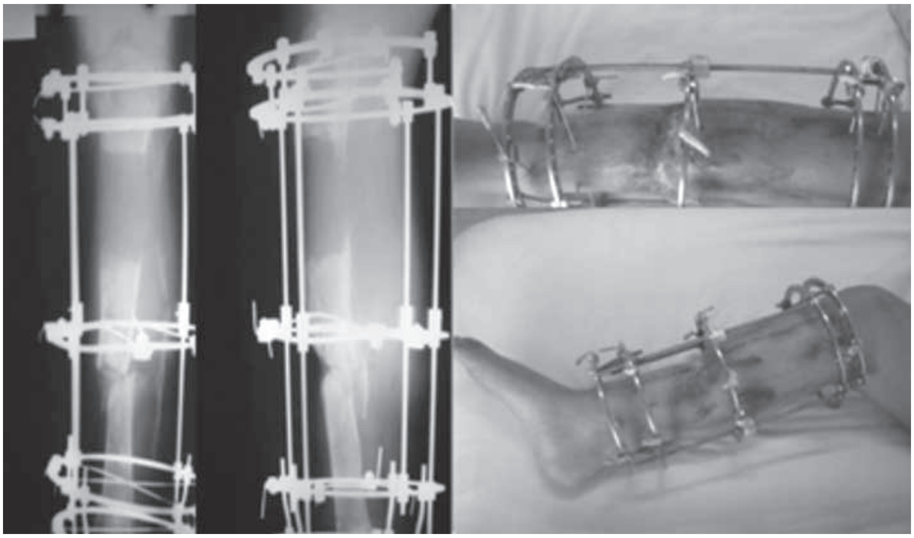

Fig. 5. — Four months after surgery with bone transport, bone ends contacted with each other at the docking site and the bone defect was filled with the regeneration and the soft tissue defect healed.

Fig. 6. — It showed eight months after operation with bone transport.

good in 15, fair in 5 and poor in 2 ; More details listed in Table III. Functional results were excellent in 24, good in 26, fair in 10 and no poor. More details listed in Table IV.

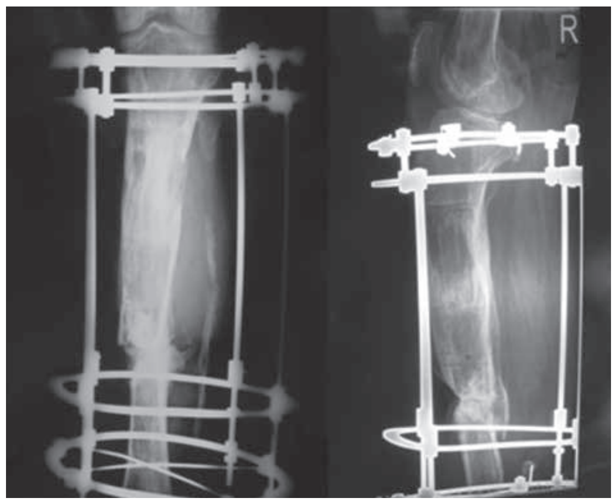

Fig. 7. — Ten months after operation with bone transport, good consolidation of the regenerate and bone union at the docking site were presented.

COMPLICATIONS

The most common complication was pin-track infection, which occurred in 40 patients. 38 patients had only local inflammation, which were treated by pin care and empirical broad spectrum antibiotics for oral administration. The 2 rest patients had a purulent drainage, and aspiration of pus for cultures were undertaken in the 2 patients in order to select

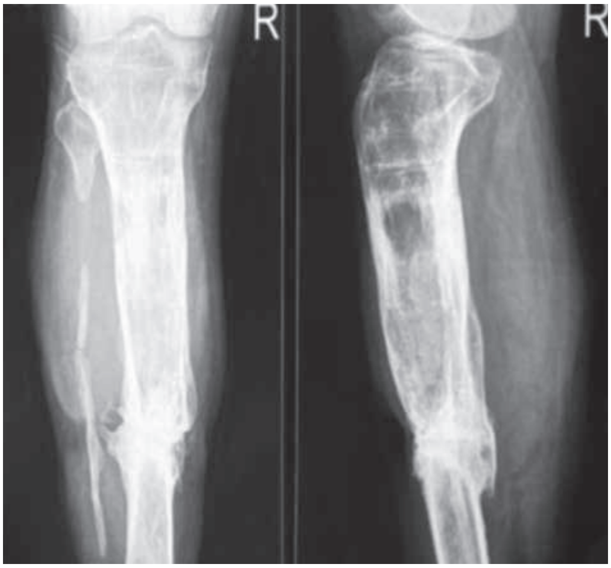

Fig. 8. — After 12 months of the surgery, it showed complete bone union and the external fixator was removed.

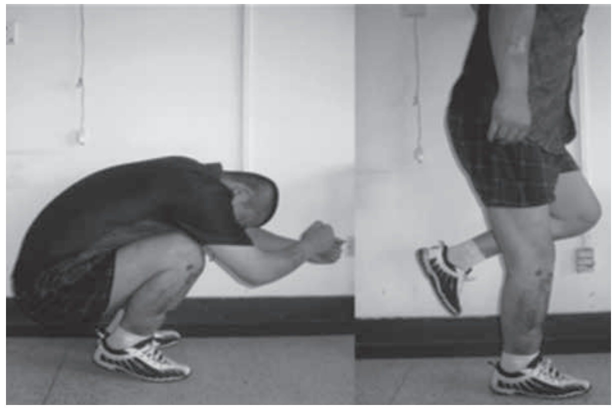

Fig. 9. — The patients had a excellent functional results

sensitive antibiotics, and finally they were treated by intravenous sensitive antibiotics. All the patients had a feeling of pain during the distraction period and required oral analgesics. The axial deviation during bone transport occurred in 19 patients and frame adjustments for modification were performed in these patients. Bone grafting was required at the docking site in 6 patients. 4 patients experienced loosening of wires which were removed and re-tension the loose wires. 2 patients suffered refracture at the docking site after removal of the external fixator, and then were re-applied the Ilizarov external fixators, and finally achieved bone union. There were no neurovascular complications or a compartment syndrome.

DISCUSSION

Ilizarov method has gained popularity for the treatment for infected nonunion. The technique bases on a biological principle which has been termed the tension stress effect by Ilizarov. It entails a segmental bone transport in which corticotomy is performed in the metaphysis and the bone is gradually distracted. Ilizarov methods mainly have three techniques, including bone transport, acute compression and lengthening, and compression osteosynthesis. Compression osteosynthesis is suitable for small defects or no defects (*4,8*). The application of the technique of acute compression and lengthening is also limited for the extent of bone defects. It was reported by a literature that a 4-5 cm acute shorting of the tibia was the limit for compression-distraction if adequate safety was to be guaranteed (*14*). Because acute compression beyond the limit could cause overmuch soft tissue stacking and arteriolar occlusion, which could affect new bone information and the healing of fracture ends. Another literature reported bone defects (< 6 cm) was suitable for adopting the technique of acute compression and lengthening (*24*). However, Magadum *et al* (*17*) treated successfully all large tibia defects (mean 10 cm, maximum 17 cm) by acute compression and distraction. They did not report any neurovascular complication and any additional surgery due to

Table III. — Evaluation of the bone results

Bone results	No. of patients	Criteria
Excellent	44	Union, no infection, deformity < 7°, limb length discrepancy (LLD) < 2.5 cm
Good	15	Union plus any two of the following : absence of infection, deformity < 7°, LLD < 2.5 cm.
Fair	5	Union plus any one of the following : absence of infection, deformity < 7°, LLD < 2.5 cm.
Poor	2	Nonunion/refracture/union plus infection plus deformity > 7° plus LLD > 2.5 cm

Table IV. — Evaluation of the functional results

Functional results	No. of patients	Criteria
Excellent	24	Active, no limp, minimum stiffness (loss of < 15° knee extension/< 15° ankle dorsiflexion), no reflex sympathetic dystrophy (RSD), insignificant pain.
Good	26	Active, with one or two of the following : limb, stiffness, RSD, significant pain
Fair	10	Active, with three or all of the following : limb, stiffness, RSD, significant pain
Poor	0	Inactive (unemployment or inability to return to daily activities because of injury)
Failure	0	Amputation

axial deviation or need for bone grafting. But then a letter questioned the research outcomes (*28*). Therefore, whether large tibia defects can be treated by acute compression and lengthening without neurovascular is still debatable. Bone transport could achieve good results in the treatment of both small and massive bone defects (*1,5, 15*), so bone transport have no limit for the extent of bone defects.

We conducted a systematic review of tibia infected nonunion treated by Ilizarov methods. We searched literatures from the PubMed, Cochrane Library, EMBASE and other relevant English orthopaedic journals between January 1995 and April 2013. The initial literature search identified 225 relevant records, and finally 16 studies and a total of 303 patients were included in the systematic review (*1-3,5,7,9-11,13,15-19,22-23*). Mean age, mean bone defects, mean follow-up, bone union, bone results, functional results, complications per patient, external fixation time and external fixation index were recorded and statistically analyzed using weighted means based on the sample size in each study by SPSS 13.0. The following data were calculated : The mean age was 34.44 ± 5.05 years (range 25-44 years) ; The mean bone defects was 6.01 ± 1.99 cm (range 3.5-10.7 cm) ; The mean follow up was 44.37 ± 26.02 months (range 13-99 months) ; The bone union rate was 96.69% (range 87%-100%) ; The good and excellent rate in bone results was 87.52% (range 45%-100%) ; The good and excellent rate in functional results was 76.03% (range 23%-97%) ; The mean complications per patient was 1.47 ± 0.86 (range 0.12-3.35) ; The mean external fixation time was 9.19 ± 2.22 months (range 3.1-13.9 months) ; The mean external fixation index was 1.46 ± 0.42 months/cm (range 0.55-2.33 months/cm). More details listed in Table V.

In our study, the mean external fixation index was 1.38 months/cm , and the complications per patient was 1.08, these data were better than the average data that recorded in aforementioned systematic review. Good and excellent rate in bone results was 89.39%, and good and excellent rate in functional results was 83.33% in our study, these data was also better than the average data that recorded in aforementioned systematic review. However, The mean external fixation time was 9.46 months, which was longer than the average data that recorded in aforementioned systematic review. The reason might be our mean bone defects was larger. There is a controversial view on regular bone grafting at the docking site. Our study did not adopt regular bone grafting and bone grafting was required in only 6 patients. Pin-track infection and the axial deviation were common complications in the course of bone transport in previous reports and these complications also happened frequently in our study.

In our experience, some important aspects of bone transport should be paid attention. (1) Ilizarov external fixator should be assembled preoperatively under the image intensifier control. If we don't do this before the resection of infected bone , the reduction will become very difficult because of loss of reference object. (2) Debridement should be performed radically in order to avoid the recurrence of infection. This is the key step to control bone infection. (3) Distraction usually begins between 7 and 10 days after the operation at a rate of 0.25 mm per 6 hour. If regenerate quality is poor, the speed of distraction will slow down. (4) X-ray films should be reviewed every 2 weeks during the distraction

Table V. — The treatment of tibial infected nonunion by Ilizarov methods

Author	Technique	PN	MA (years)	MBD (cm)	MFU (months)	Bone union NO. %	Bone results (excellent/good/ fair/poor)	Functional results (excellent/good/ fair/poor)	Complications (per patient)	EFT (months)	EFI (M/cm)
Feng (15)	RD, AT, BT (IEF)	21	34.6	6.6	31	21/21 (100%)	19/2/0/0 (Paley)	___	0.4	9.8	1.48
Liu (21)	RD, AT, BT (MEF), 5flaps	35	37.3	3.5	72.5	35/35 (100%)	28/5/2/0 (Paley)	30/4/1/0 (Paley)	1.11	10.7	1.36
Sala (32)	RD, AT, BT (combined IEF and TSF)	12	44	8	24	12/12 (100%)	10/2/0/0 (ASAMI)	6/5/1/0 (ASAMI)	2.08	13.9	2.0
Megas (28)	RD, AT, CO or ACL (IEF)	9	39.7	5	26.6	9/9 (100%)	5/4/0//0 (Paley)	3/4/2/0 (Paley)	1.44	7.83	1.07
Bumbasirevic (7)	RD, AT, BT (IEF)	30	30.4	6.9	99	29/30 (97%)	19/10/0/1 (Paley)	13/14/2/1 (Paley)	1.4	9.7	1.48
Emara (14)	RD, AT, BT (IEF), BG RD, AT, BT (IEF and IMN), BG	16 17	29	6	36	16/16 (100%) 17/17 (100%)	15/1/0/0 (ASAMI) 17/0/0/0 (ASAMI)	12/1/3/0 (ASAMI) 13/2/2/0 (ASAMI)	0.4 0.12	8.5 3.1	1.5 0.55
Madhusudhan (24)	RD, AT, ACL (IEF) RD, AT, BT (IEF)	13 9	37.2	4	13	13/13 (100%) 9/9 (100%)	4/3/4/2 (ASAMI) 0/3/4/2 (ASAMI)	1/3/6/2 (ASAMI)[a] 0/1/3/2 (ASAMI)[b]	2.27	9.3 8.5	2.33 1.57
Magadum (25)	RD, ACL (IEF)	27	39	10	27	24/25 (96%)[c]	19/5/0/1 (ASAMI)	15/8/1/1 (ASAMI)	1.16	10.2	1.02
Abdel-Aal (1)	RD, BT (IEF)	9	30.66	10.7	___	9/9 (100%)	___	___	1.22	12.78	1.22
McHale (26)	RD, AT, BT or ACL or CO (IEF)	10	31	___	36	10/10 (100%)	___	___	___	9	___
Atesalp (3)	RD, AT, 3 flaps, BT (IEF)	14	25	4.4	33.2	13/14 (92.9%)	___	___	1.21	6.8	1.55
Barbarossa (5)	RD, AT, BT (IEF)	23	40.7	6.2	___	20/23 (87%)	8/8/2/4 (ASAMI) (1 amputation)	2/10/6/4 (ASAMI) (1 amputation)	3.35	___	___
Laursen (18)	RD, AT, CO or BT (IEF)	9	25.78	4.89	39.4	9/9 (100%)	___	___	1.56	6.7	___
Ring (31)	RD, 3 flaps, BT or ACL or CO (IEF)	10	34	4.3	72	9/10 (90%)	___	___	1.8	6.9	___
Hosny (16)	RD, 3 AT, BT or CO (IEF)	11	27	3.7	13	11/11 (100%)	___	5/3/2/1 (Cattaneo)	1.27	8.5	2.3
Dendrinos (11)	RD, BT (IEF)	28	37	6	39	25/28 (89%)	14/8/1/5 (ASAMI)	7/11/4/5 (ASAMI) (1 amputation)	2.5	10	1.67

[a] 1 patient lost for follow-up. [b] 3 patients were unable to evaluate. [c] 2 patients lost for follow-up.

ACL : acute compression and lengthing ; ASAMI : Association for the Study of the Method of Ilizarov ; AT : antibiotics treatment ; BG : bone graft ; BT : bone transport ; CO : compression osteosynthesis ; EFI : external fixation index ; EFT : external fixation time ; IEF : Ilizarov external fixator ; IMN : intramedullary nailing ; MA : mean age ; MBD : mean bone defects ; MFU : mean follow-up ; MEF : monolateral external fixator ; PN : patient number ; RD : radical debridement ; TSF : Taylor Spatial Frame.

period and monthly during the consolidation period in order to supervise the regenerate quality, the stability of external fixation, the axis of the traction on the segment, and the mineralization of the distracted area. Thus, we can correct these promptly with efficient measures. (5) Patients should be encouraged to conduct partial weight beat with crutches, isometric muscle and joint range-of-motion exercises on the second day after operation. When the callus mineralization completes, patients can gradually conduct full weight beat and remove the external fixator after 4-8 weeks.

In conclusion, Our study and the current evidence suggested that Ilizarov methods in the treatment of infected tibial nonunion acquired satisfied effects in bone results and functional results. Radical debridement is the key step to control bone infection. However, our study lack of direct comparison with any other treatment options, further randomized controlled trials are needed to draw more valuable conclusion.

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