Therapeutics and Clinical Risk Management

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Clinical Outcomes of Ilizarov Bone Transport for Distal Tibial Defects in Refractory Osteomyelitis: A Retrospective Study

Abudusalamu Alimujiang[1,*], Qiyu Jia[1,*], Jian Guo[1], Jun Zhang[1], Xi Wang[1], Meng Zhao[1], Meidege Ouzhabayier[2], Yingbo Wang[3], Chuang Ma[1]

[1]Department of Trauma Orthopedics, the First Affiliated Hospital of Xinjiang Medical University, Urumqi, Xinjiang, People's Republic of China; [2]Department of Rehabilitation Medicine, the First Affiliated Hospital of Xinjiang Medical University, Urumqi, Xinjiang, People's Republic of China; [3]College of Chemical Engineering, Xinjiang Normal University, Urumqi, Xinjiang, People's Republic of China

*These authors contributed equally to this study

Correspondence: Chuang Ma; Yingbo Wang, Email 1516175919@qq.com; ybwang20002575@163.com

Background: Distal tibial defects following refractory osteomyelitis pose a significant orthopedic challenge, necessitating effective reconstruction. The Ilizarov bone transport technique is a potential treatment option, but its clinical outcomes specifically for distal tibial infectious defects need further evaluation.

Methods: In this retrospective observational single-arm study, we analyzed the clinical data of 22 patients who had undergone multiple debridements for refractory distal tibial osteomyelitis (DTO) and had associated bone defects, and were subsequently treated with the Ilizarov bone transport technique. Following debridement surgery, bone transport treatment was administered. Regular X-ray examinations, rehabilitation guidance, and follow-up were conducted to assess infection control, bone healing, limb function recovery, and complications. Therapeutic effects were evaluated using the Association for the Study and Application of Methods of Ilizarov (ASAMI), Visual Analog Scale (VAS) score, Activities of Daily Living (ADL) score, and American Orthopaedic Foot & Ankle Society (AOFAS) score improvement.

Results: The mean follow-up was 29.32±20.92 months, with an average of 3.77±1.83 debridements. All bone defects healed, though 5 patients later required ankle arthrodesis. Complications included pin tract infection (n=10), axial deviation (n=3), ankle joint stiffness (n=2), non-union at the docking site (n=2), and delayed consolidation (n=2). At the last follow-up, ASAMI bone results: 15 excellent, 5 good, 2 poor (90.9% superiority rate). ASAMI functional results: 6 excellent, 14 good, 1 fair, 1 poor (90.9% superiority rate). VAS decreased from 4.86±0.83 to 0.5±0.66 ($p<0.001$). ADL improved from 80 (78.75–85) to 92.5 (90–95) ($p<0.001$). AOFAS score increased from 32 (25–38.25) to 82 (77–87.5) ($p<0.001$), with an 86.4% overall superiority rate.

Conclusion: Bone transport post - debridement is a valuable salvage for reconstructing distal tibial defects post-refractory osteomyelitis, with high safety, healing rate, and good efficacy. However, further comparative studies are warranted to confirm its advantages over other treatments.

Keywords: Ilizarov technique, tibia, bone defect, osteomyelitis

Background

Osteomyelitis remains a significant challenge in orthopedic practice, with an annual incidence ranging from 16.7 to 21.8 cases per 100,000 population.[1] Causes include trauma, postoperative contamination, and secondary complications arising from vascular insufficiency or soft tissue infection.[2] This pathological process initiates a sequence of progressive events, including inflammatory bone destruction mediated by a complex interplay of cytokines, chemokines, and immune cells. Bone necrosis and subsequent new bone formation occur as a result of this inflammatory response.[3] In the context of refractory osteomyelitis, particularly affecting the distal tibia (DTO), the persistent infection despite repeated debridement interventions underscores the need for radical and

Received: 12 March 2025
Accepted: 26 August 2025
Published: 17 September 2025

exhaustive debridement procedures, often leading to segmental bone deficiencies.[4] The management of DTO presents a formidable task due to several factors, including the severity of trauma, anatomical features such as the relative lack of soft tissue protection and poor blood supply at the site, soft tissue defects, and proximity to the ankle joint.[5]

Addressing DTO requires not only infection control but also reliable and safe reconstruction strategies to restore normal function and improve quality of life. Various treatment options for infectious bone defects have been reported, including autologous bone grafting, the Masquelet technique, Ilizarov bone transport technique, and free vascularized or non-vascularized fibular grafting.[6–9] However, the comparative effectiveness of these techniques remains a topic of debate, yet no consensus on a "gold standard" has been reached. While the Ilizarov technique has been widely advocated as a promising option for its ability to gradually transport bone segments and fill defects,[10–12] recent meta-analyses and RCTs have highlighted the need for a more nuanced understanding of its comparative effectiveness with other techniques, such as the Masquelet technique or vascularized fibular grafting, especially in complex infected cases.[13–15] Furthermore, the sample size and variability in outcomes in previous studies necessitate a more detailed examination.

The objective of this study is to explore the clinical efficacy and related complications of the Ilizarov bone transport technique as a salvage procedure for reconstructing bone defects caused by DTO. We hypothesize that the Ilizarov technique, due to its unique ability to provide mechanical stability, gradual bone transport, and soft tissue coverage, offers distinct advantages in managing DTO, particularly in cases where other methods have failed. By summarizing our long-term clinical application experience, we aim to contribute to the understanding of the optimal treatment strategies for this challenging condition.

Materials And Methods

Patients

This single-arm retrospective observational study included 22 patients with distal tibial osteomyelitis treated at the First Affiliated Hospital of Xinjiang Medical University from January 2015 to December 2022. A patient selection flowchart is presented to clearly show the screening process (Figure 1). Inclusion criteria encompassed patients with an age range of 18 to 65 years diagnosed with DTO (with the infection focus above the ankle point within 6–7cm) presenting bone defects of ≥4 cm post-debridement, and those who underwent the Ilizarov technique for DTO-related bone defects. Informed consent was obtained from each patient upon admission, and the study was approved by the ethics committee of the First Affiliated Hospital of Xinjiang Medical University (Approval No. K202308-11), this study complies with the Declaration of Helsinki. Exclusion criteria included patients with acute osteomyelitis accompanied by systemic symptoms, severe underlying diseases (such as malignant tumors or immune deficiency) affecting surgical tolerance, individuals with poor compliance or an inability to cooperate with treatment, and those with incomplete data or lost follow-up.

Preoperative Preparation

Laboratory assessments included white blood cell count, neutrophil count, C-reactive protein, erythrocyte sedimentation rate, and serum procalcitonin to determine infection presence and control status. Preoperatively, we conducted nutritional status assessments and psychological counseling on the patients to help them prepare mentally and improve treatment compliance. Before surgery, all antibiotics were stopped if the patients were already on. For the patients who had discharging sinus at the time of presentation, we obtained samples for bacterial culture and sensitivity tests. After cleaning the local area thoroughly with saline, sample was obtained with swab from deeper parts of the sinus. Apart from thorough clinical assessment, biplanar radiographs were obtained in all cases. Selected cases (especially the ones without metallic implants) had CT or MRI to assess bone defect length or lower limb shortening post-necrotic bone tissue removal and assist surgical planning. The healthy limb's length served as a reference for designing postoperative osteotomy transport length.

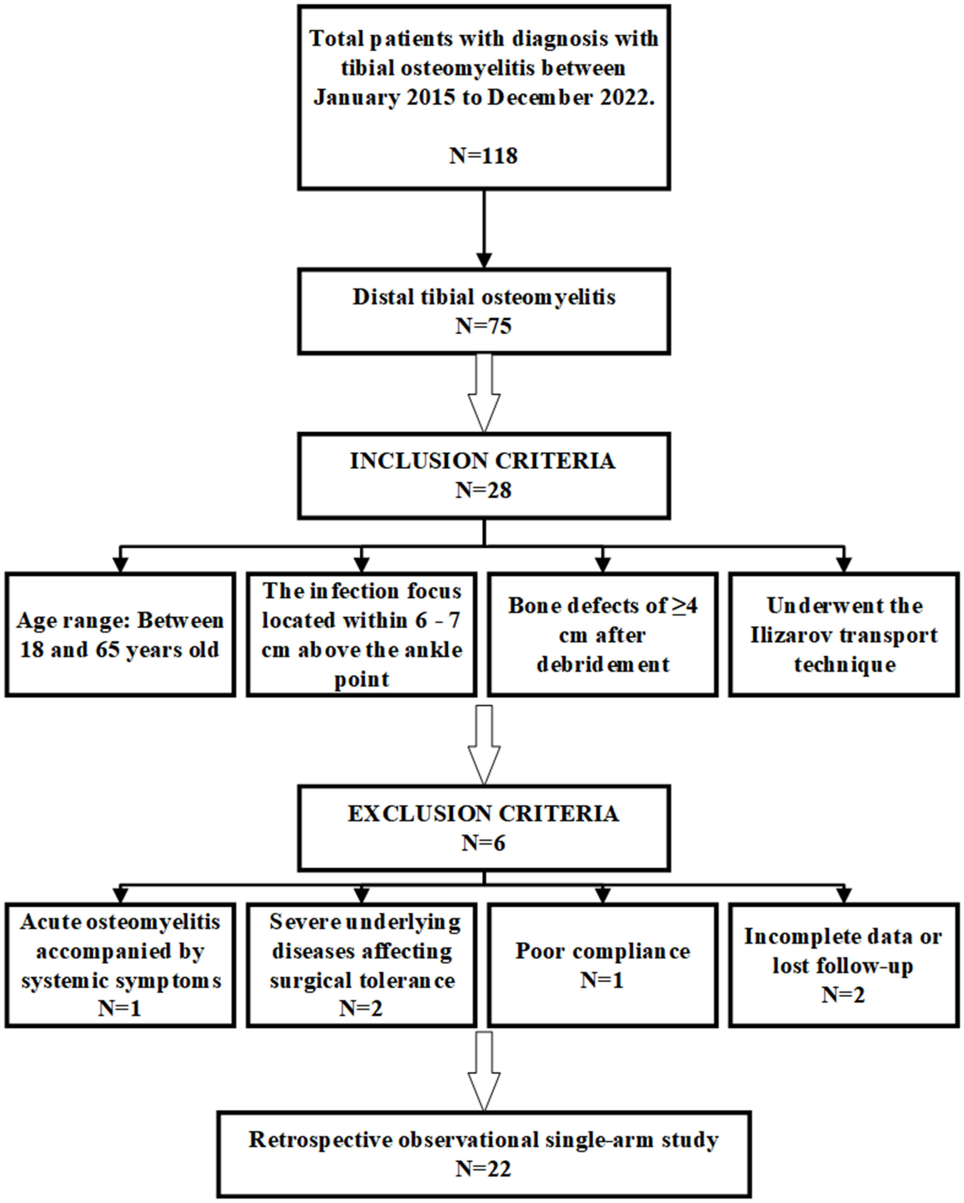

Figure 1 STROBE flowchart.

Surgical Technique

To address bone defect lesions caused by distal tibia osteomyelitis, we employed combined spinal-epidural anesthesia or general anesthesia for thorough debridement. The debridement timing was standardized as soon as the patient's condition allowed after admission and necessary preoperative evaluations were completed. Excision of infected and inactivated tissues, shaped spindly along the sinus orifice, involved the complete removal of pus, inflammatory granulation, and scar tissue. The bone marrow cavity of the distal tibia was chiseled, and the necrotic bone tissue was removed using a bone rongeur until fresh blood oozed (the chili powder sign).[16] The operative area underwent repeated irrigation with hydrogen peroxide, iodophor, and normal saline.

In the first stage, the two sides of the bone defect were trimmed, an external fixation device was installed for the stabilization of the defect area. The choice of the external fixation device was based on the patient's bone condition, defect size, and overall physical status to ensure optimal stability and facilitate subsequent bone transport. Antibiotic bone cement filled the defect. In the second stage, antibiotic bone cement was removed after confirmation of the induced

 https://doi.org/10.2147/TCRM.S525768

membrane formation (approximately 4–6 weeks), the biological membrane was carefully closed, followed by Ilizarov bone transport technique. Osteotomy at the proximal tibial metaphyseal, stretching of the osteotomy surface, and confirmation of integrity under fluoroscopy were performed. The process of transporting individual bone segments was initiated following a latency period ranging from 7 to 10 days. Pressurization was applied when the transport segment docked the distal side of the bone defect to promote healing at the docking site. Ankle arthrodesis was performed in the late stage when the bone defect directly involved the ankle joint.

Postoperative Management

Postoperatively, all patients received care involving intravenous and oral antibiotics, enhanced nutrition, improved immunity, wound secretion drainage, and routine dressing changes. To prevent pin - tract infections, we regularly cleaned and disinfected the pin tracts and maintained dryness of the surrounding skin. The classic Ilizarov method guided bone transport, initiated at 0.5–1 mm/day from 7–10 days post-surgery, 2–4 times daily. Pain, nerve, and vascular symptoms were closely monitored during bone segment transport. Adjustments were made if there was evidence of poor bone consolidation or excessive pain. Based on postoperative conditions, we established a unified rehabilitation standard for early functional exercises. Patients were encouraged to walk with crutches, gradually transitioning to walking without crutches.

Following the surgical procedure, X-ray examinations were conducted regularly, relevant bone transport indicators were diligently recorded, and common complications such as axial deviation should be monitored and corrected. Parameters such as bone callus, infection recurrence, pain levels, and complications were meticulously observed. External fixators were loosened when a solid callus formed, and removal occurred after 4 to 8 weeks, based on the patient's condition. Post-bone transport and healing, the ASAMI score was employed to assess bone transport effectiveness, the AOFAS score evaluated ankle function, while the VAS (0=no pain, 10=most severe pain) and ADL scores assessed pain intensity and overall quality of life. When evaluating the above-mentioned scores, observer bias was minimized through training the assessors and adopting a double-blind assessment method.

Statistical Analysis

For statistical analysis, SPSS 26.0 (IBM Corp., Armonk, NY, USA) software was utilized. Normally distributed continuous variables were expressed as mean ± standard deviation and analyzed using t-tests; non-normally distributed variables were reported as median (interquartile range), ie M (Q_1, Q_3) and compared via Mann-Whitney U tests. Continuous variables are also represented by (range: minimum value, maximum value) to indicate their range. Categorical variables were presented as absolute and relative frequencies (percentages), and evaluated using chi-square or Fisher's exact tests. $P<0.05$ was statistically significant.

Results

Demographic and infection-related data were collected at admission, revealing male predominance (n=17/22, 77.3%) with a mean age of 40.68 ± 16.02 years (range:18–65). 11 cases involved the right lower limb, and 11 involved the left. Most cases were associated with trauma (n=20), including traffic accidents (n=11), falling injuries (n=6), falls from height (n=2), and heavy object injuries (n=1). Some patients presented with a history of smoking (n=6), diabetes (n=3), and hypertension (n=2).

Twenty patients were transferred from external hospitals, having undergone an average of 2.09±1.12 (range:0–6) debridement operations before admission. The mean time from injury or onset to referral was 16.48±21.61 months (range: 0–97). On admission, most cases presented with sinus tract formation (n=19), bone or plate exposure (n=12), and limb-length discrepancy (n=6). Stratification according to the infection source revealed cases of post-traumatic osteomyelitis (n=20), osteomyelitis caused by soft tissue infection (n=1), and hematogenous osteomyelitis (n=1). Ten patients had open fractures, classified as Gustilo II (n=2), Gustilo IIIA (n=3), and Gustilo IIIB cases (n=5).[17] According to the Cierny-Mader osteomyelitis classification, there were 12 cases of type IVA and 10 cases of type IVB.[18] After complete debridement, the average length of the complete bone defect was 6.09±1.50 cm (range: 4–9), with the distance from the

 https://doi.org/10.2147/TCRM.S525768

distal end of the defect to the ankle joint averaging 2.64±1.75 cm (range: 0–5), including 5 cases directly involving the ankle joint and 14 cases were accompanied by soft tissue defects. More details are shown in Table 1.

The outcomes of the Ilizarov bone transport technique were consistently favorable across all patients. Throughout the follow-up period, lasting a mean of 29.32±20.92 months (range: 10–79), the total debridement frequency averaged 3.77 ±1.83 times (range: 1–11). Among them, the debridement times before admission to our hospital was 2.09 ± 1.12 (range: 0–6), and the debridement times after admission to our hospital was 1.68 ± 0.82 (range: 1–5). One patient underwent a total of 11 debridement surgeries within 3 years due to difficult infection control and recurrent condition. Due to the patient's condition, there are some intended treatments here rather than surgical complications. Among the 14 patients with soft tissue defects, 5, 7, and 8 patients respectively underwent vacuum sealing drainage (VSD), skin grafting, and flap surgery, including patients receiving two or more combined procedures simultaneously. And among the 22 patients, 5 eventually underwent ankle arthrodesis surgery due to bone defects involving the ankle joint.

Clinical and imaging evidence indicated successful healing of the distracted callus and docking site in all 22 patients. Various aspects of the bone transport procedure, including external fixation types, bone transport levels, and relevant indicators, are summarized in Table 2. The mean bone transport length using Ilizarov technique was 6.09 ± 1.50 cm

Table 1 Detailed Baseline Characteristics of the Study Population (n=22)

Demographics	
Age (Years)	
Mean ± SD	40.68 ± 16.02
Range	18 - 65
Male/female n	17 / 5
Left/right n	11 / 11
Primary injury n (%)[a]	
Traffic accidents	11 (50.0%)
Falling injuries	6 (27.3%)
Falls from height	2 (9.1%)
Heavy object injuries	1 (4.5%)
Etiology n (%)	
Post-traumatic	20 (90.9%)
Open fracture	10 (45.5%)
Implant-related infection	10 (45.5%)
Soft tissue infection	1 (4.5%)
Hematogenous	1 (4.5%)
Gustilo classification n (%)[b]	
II	2 (9.1%)
IIIa	3 (13.6%)
IIIb	5 (22.7%)
Cierny-Mader classification n (%)	
IVA	12 (54.5%)
IVB	10 (45.5%)
Distance from bone defect to ankle joint (cm)	
Mean ± SD	2.64 ± 1.75
Range	0 - 5
Bone defect involving ankle joint n (%)	5 (22.7%)
Bone defect length (cm)	
Mean ± SD	6.09 ± 1.50
Range	4 - 9
Soft-tissue defect n (%)	14 (63.6%)

Notes: [a]Due to two patient lacking a history of trauma, the total count of Primary injury cases was recorded as 20. [b]Open traumatic injuries were documented in 10 patients.

 https://doi.org/10.2147/TCRM.S525768

Table 2 External Fixation and Ilizarov Bone Transport Related Indicators (n=22)

Related Indicators	
Type of external fixator n (%)	
Monolateral	16 (72.3%)
Ring	3 (13.6%)
Hybrid	3 (13.6%)
Level of bone transport n (%)	
Single	13 (59.1%)
Double	9 (40.9%)
Cross-ankle fixation	
Yes	7 (31.8%)
No	15 (68.2%)
Bone transport length (cm)	
Mean ± SD	5.86 ± 1.39
Range	4 - 9
Bone transport time (days)	
Mean ± SD	65.50 ± 17.24
Range	35 - 95
Bone transport index[a]	
Mean ± SD	11.43 ± 2.69
Range	6.5–14.5
Consolidation time (months)	
Mean ± SD	11.45 ± 3.45
Range	7 - 23
Consolidation index[b]	
Mean ± SD	1.98 ± 0.43
Range	1 - 3
External fixation time (months)	
Mean ± SD	15.32 ± 4.38
Range	9 - 26
External fixation index[c]	
Mean ± SD	2.68 ± 0.74
Range	1.25–4.5

Notes: [a]Bone transport index = Bone transport time (days) / Bone transport length (cm). It serves to quantitatively evaluate the velocity of bone segment transportation. [b]Consolidation index = Consolidation time (months) / Bone transport length (cm). It reflects the mineralization degree of the newly formed bone. [c]External fixation index = External fixation time (months) / Bone transport length (cm). It assesses the utilization efficiency of the external fixator.

(range: 4–9), with a transport duration of 65.50 ± 17.24 days (range: 35–95) and a transport index of 11.43 ± 2.69 days/cm (range: 6.5–14.5). Mineralization time averaged 11.45 ± 3.45 months (range: 7–23), with a mineralization index of 1.98 ± 0.43 months/cm (range: 1–3). External fixation persisted for an average of 15.32 ± 4.38 months (range: 9–26), yielding an external fixation index of 2.68 ± 0.74 months/cm (range: 1.25–4.5).

In accordance with Paley's classification of complications, a total of 34 complications (11 problems, 15 obstacles, 1 minor complication, and 7 major complications) were reported among the 22 patients.[19] These complications were diverse and managed with various interventions as outlined in the study (Table 3).

During the follow-up period, one case of pin loosening necessitated surgical pin replacement. Ten patients experienced pin tract infections, with two undergoing surgical debridement and replacement after conservative antibacterial treatment and dressing change nursing proved ineffective. Axial deviation occurred in three cases, all of which were

Table 3 Problems, Obstacles, and Complications During and After the Completion of Bone Transport Process, According to Paley's Criteria (n=22)

Complications	Problems, n	Obstacles, n	Complications - Minor, n	Complications - Major, n	Total
Pin loosening	-	1	-	-	1
Pin tract infection	8	2	-	-	10
Axial deviation	-	3	-	-	3
Soft issue incarceration	-	1	-	-	1
Non-union at docking site	-	2	-	-	2
Delayed consolidation	1	1	-	-	2
Ankle joint stiffness	1	1	-	-	2
Equinovarus foot	-	1	-	-	1
Fused ankle joints	-	-	-	5	5
Limb length discrepancy	-	-	-	2	2
Recurrence of infection	-	2	-	-	2
Refracture	-	1	-	-	1
Neurological injury	-	-	1	-	1
Skin pruritus	1	-	-	-	1
Total	11	15	1	7	34

corrected surgically, with two cases requiring adjustments or reinstallation of additional Schanz pins during the bone transport phase.

In one case, soft tissue incarceration manifested at the docking site, prompting surgical clearance and compressive fixation. Two cases presented non-union at the docking site, all of which underwent bone end trimming, iliac bone grafting, and compressive fixation surgery. Two cases exhibited delayed consolidation, with one undergoing partial weight-bearing exercise with crutch support and accordion technique application; however, delayed consolidation persisted, leading to iliac bone grafting and steel plate fixation surgery.

Two patients experienced varying degrees of ankle stiffness, with one undergoing arthrolysis surgery after unsuccessful rehabilitation exercise and physical therapy. One case of neurogenic Equinovarus foot underwent ankle arthrodesis surgery at a later stage. At the conclusion of treatment, five patients underwent ankle arthrodesis, with the primary complication being the inability of the ankle joint to move freely, though this did not affect their ability to bear weight. Two cases presented limb length discrepancies exceeding 2.5cm, with one being 3.5cm shorter and the other 4.0cm shorter. These two patients decided not to undergo any additional treatment based on their personal preferences.

There were two cases of infection recurrence, primarily in deep bone tissue. One case underwent fibula grafting and external fixation for a recurring bone defect after debridement at the docking site, while the other, facing extensive bone infection at the transport segment, underwent tibialization of fibula after segmental bone resection. In one case, refracture of the docking site occurred after the removal of external fixation, prompting iliac bone grafting and external fixation. Mild nerve injury persisted in one case, characterized by mild numbness in the tibial innervation area, with continued observation recommended. One case was diagnosed with skin pruritus during the consolidation period, which improved after hospitalization in the dermatology department and treatment with anti-allergic drugs.

At the last follow-up, based on the criteria of the Association for the Study and Application of the Ilizarov Method (ASAMI), bone results were evaluated as excellent, good, and poor in 15, 5, and 2 cases, respectively, yielding a superiority rate of 90.9%. Even with 5 patients undergoing ankle arthrodesis surgery included, functional results were assessed as excellent, good, fair, and poor in 6, 14, 1, and 1 cases, respectively, achieving a superiority rate of 90.9% (Table 4).[20]

Pain (VAS), ankle function (AOFAS), and quality of life (ADL) scores showed significant improvement, with statistically significant differences ($P < 0.001$) (Table 5). The VAS score decreased from 4.86±0.83 (range:3–6) before treatment to 0.5 ±0.66 (range:0–2), and the ADL score increased from 80 (78.75,85) (range:75–90) before treatment to 92.5 (90,95) (range:-80–100). The AOFAS score representing ankle joint function increased from 32 (25,38.25) (range:20–42) before treatment to

 https://doi.org/10.2147/TCRM.S525768

Table 4 ASAMI Criteria and Results of ASAMI Scores in This Study (n=22)

	Patient	Criteria
Bone results		
Excellent:	15 (68.2%)	Union, no infection, deformity < 7°, LLD < 2.5cm.
Good:	5 (22.7%)	Union plus any two of the following: absence of infection, deformity < 7°, LLD < 2.5 cm.
Fair:	0	Union plus any one of the following: absence of infection, deformity < 7°, LLD < 2.5 cm.
Poor:	2 (9.1%)	Nonunion/refracture/union plus infection plus deformity > 7°plus LLD > 2.5cm.
Functional results		
Excellent:	6 (27.3%)	Active, no limp, minimum stiffness (loss of < 15°knee extension/< 15°ankle dorsiflexion) no RSD, insignificant pain.
Good:	14 (63.6%)	Active, with one or two of the following: limb, stiffness, RSD, significant pain.
Fair:	1 (4.5%)	Active, with three or all of the following: limb, stiffness, RSD, significant pain.
Poor:	1 (4.5%)	Inactive (unemployment or inability to return to daily activities because of injury).
Failure:	0	Amputation.

Notes: LLD was evaluated via standing full-length lower extremity radiographs. Bilateral femoral lengths (proximal: femoral head apex to lateral condyle distal endpoint) and tibial lengths (proximal: plateau midpoint to distal: plafond midpoint) were summated, and the absolute inter-limb difference was computed; Superiority rate = (excellent + good) / total cases×100%; Deformity: Postoperative angular deformity was quantified utilizing weight-bearing anteroposterior and lateral radiographs.
Abbreviations: ASAMI, association for the study and application of methods of Ilizarov; LLD, limb length discrepancy; RSD, reflex sympathetic dystrophy.

Table 5 Improvement of Related Scores in This Study

Relevant Scores	Pre-Treatment	Post-Treatment	Statistic	P-value
VAS score	4.86±0.83 (range:3–6)	0.5±0.66 (range:0–2)	t=17.557	<0.001
ADL score	80 (78.75,85) (range:75–90)	92.5 (90,95) (range:80–100)	Z=−5.165	<0.001
AOFAS score	32 (25,38.25) (range:20–42) Poor 22	82 (77,87.5) (range:65–95) Excellent 4, good 15, fair 3	Z=−5.685	<0.001

Notes: concerning the AOFAS score: Excellent: 90–100; Good: 75–89; Fair: 50–74; Poor: less than 50. Superiority rate = (excellent + good) / total cases×100%.

82 (77,87.5) (range:65–95). After treatment, the AOFAS classification was excellent, good, and fair in 4, 15, and 3 cases, respectively, with an overall superiority rate reaching 86.4%. To assess the impact of clinical confounders, we performed subgroup analyses examining preoperative-postoperative score differences stratified by: (i) soft tissue defect presence (Tables S1 and S2) and (ii) concurrent ankle arthrodesis (Tables S3 and S4). Typical cases are shown in Figures 2 and 3.

Discussion

Ilizarov bone transport technique has emerged as a relatively safe and effective approach for addressing bone defects resulting from osteomyelitis in long bones.[21] This method operates on the tension-stress principle, leveraging the inherent regenerative capabilities of tissues. Through stable external fixation, anatomic adjustment, low-energy corticotomy, and controlled mechanical traction as needed, it facilitates the regeneration of soft tissues such as bone, blood vessels, muscles, and skin.[11,22,23] Although robust evidence supporting its therapeutic efficacy in distal tibial defects post-osteomyelitis is currently lacking, our current findings suggest positive therapeutic outcomes with the use of Ilizarov bone transport technique. Even in challenging scenarios involving complex infectious bone defects near the ankle with compromised soft tissue conditions or complications like scar degeneration, bone deformity, and shortening resulting from repeated surgical interventions after treatment failures, Ilizarov bone transport technique excels in achieving optimal bone reconstruction.[5] It effectively minimizes the risk of infections, enhances joint function, and ultimately preserves limb functionality.[21,24] Our study illustrates that

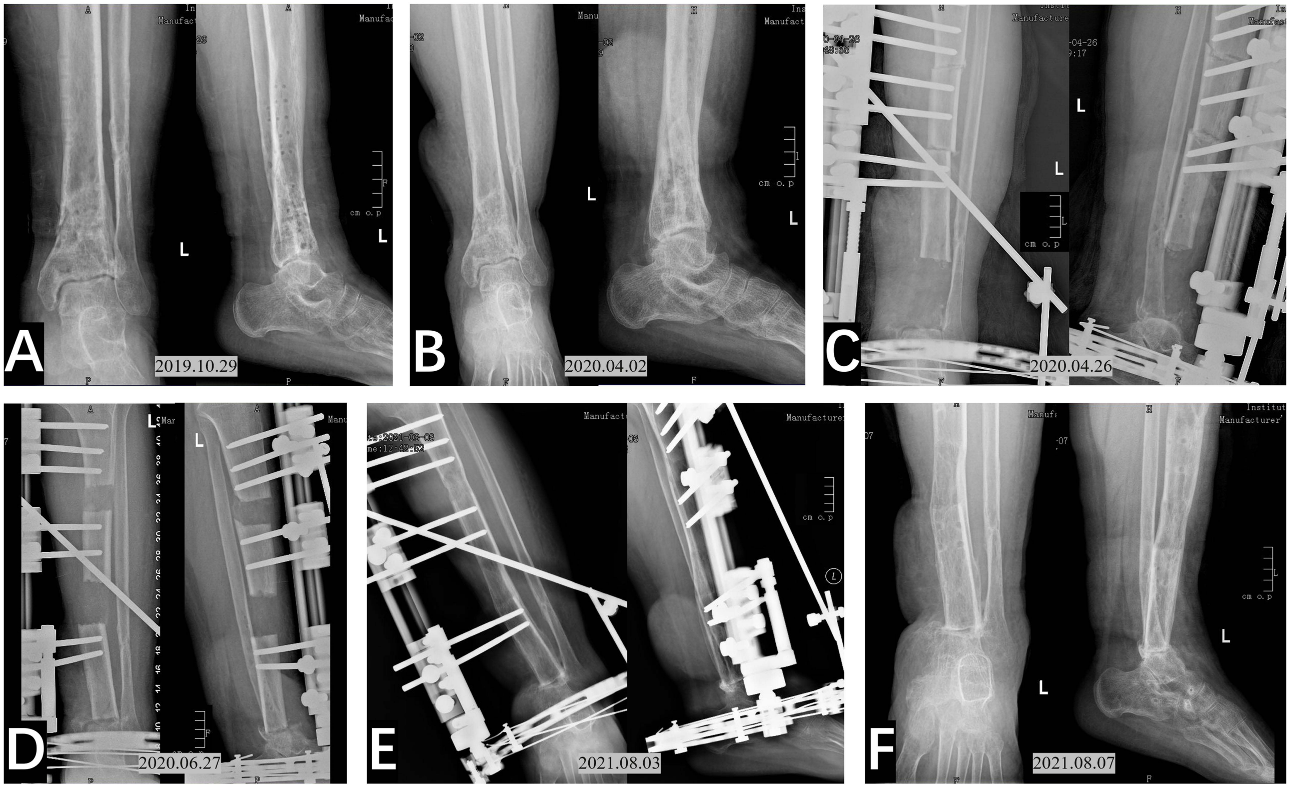

Figure 2 Illustrates a representative case involving a 30-year-old male diagnosed with a closed Pilon fracture and dislocation resulting from a car accident two years ago. Initial treatment at a local hospital involved open reduction and internal fixation surgery. Subsequent interventions included debridement, VSD drainage, and internal fixation removal due to pus discharge half a year ago. The patient was later transferred to our hospital due to persistent pus discharge from the sinus tract. (**A**) Pre-treatment X-ray in our department showcases the initial condition. (**B**) Post-debridement surgery, a posterior tibial artery perforator flap was performed on the 5cm by 8cm wound above the medial malleolus. After 5 months, aggravation of the distal tibia bone infection became evident. (**C**) Segmental resection of the infected bone (6cm) was undertaken, involving thorough debridement and installation of a combined external fixator, and, as advised by the doctor, a double-level bone transport procedure commenced one week later. (**D**) Ankle arthrodesis was performed after achieving the required transport to the level of the ankle joint. (**E**) The mineralization stage was completed, and the fusion of the ankle joint was successfully healed. (**F**) The external fixtures were subsequently removed.

Ilizarov bone transport technique yields satisfactory bone and functional outcomes in the treatment of refractory osteomyelitis-induced distal tibial bone defects (≥4cm). The final ASAMI scores for both bone and functional outcomes in the 22 patients included in this study who underwent Ilizarov bone transport demonstrated a superiority rate of 90.9%. Related scores also exhibited significant improvements, notably the AOFAS ankle function score averaging a median of 82, with a superiority rate of 86.4%. Although five out of 22 cases underwent ankle arthrodesis later on, these instances were closely tied to bone defects directly impacting the ankle joint in some patients. Compared with previous similar studies, our research indicates that the improvement in the AOFAS ankle function score is consistent with some reported results, and even better, though variations exist due to differences in patient populations and study designs.[25,26]

The anatomical complexity around the distal tibia, coupled with its proximity to the joint area, heightens the challenges of treating infections around the ankle joint.[27] Soft tissue deficiencies and the lack of protection increase the risk of bone exposure and infection exacerbation.[28] Trauma and surgical exposure may compromise nutrient and periosteal vessels, leading to suboptimal blood supply, hindering bone healing and infection control.[29] To address patients with soft tissue defects or vascular injuries, efforts were made during surgery to repair blood supply, and skin flap was applied to enhance soft tissue coverage, mitigating anatomical complexities to some extent.

Various methods have been developed for reconstructing bone defects after refractory osteomyelitis debridement, including autologous bone transplantation, allogeneic bone transplantation, antibiotic cement filling, Masquelet membrane induction, Ilizarov bone transport, and fibula transplantation.[30,31] Among these, the Ilizarov bone transport technique stands out as a commonly used and effective method.[2,32] Notably, in the unique context of the distal tibia, where reported surgical treatment options are limited or safety concerns arise, the Ilizarov bone transport technique

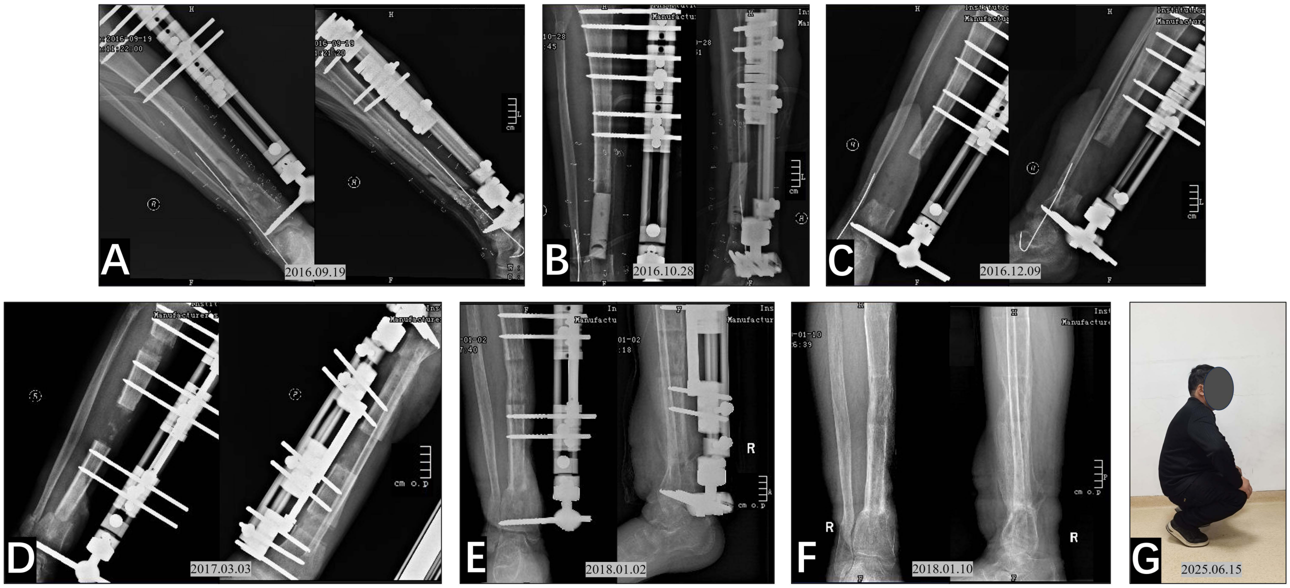

Figure 3 Presents a typical case involving a 51-year-old male, with hypertension and diabetes, suffered from closed fracture of lower tibia and fibula caused by car accident two weeks ago, and underwent open reduction and plate internal fixation in the local hospital. He was transferred to our hospital due to swelling, pain and pus discharge after surgery. (**A**) After being admitted to our department, the patient was considered as DTO. We removed the internal fixation plate, replaced it with external fixation for him. There was a 10cm by 15cm wound formed with bone exposure after debridement, and it was covered with VSD. (**B**) Due to the aggravation of infection, segmental resection of necrotic bone (8cm) was performed, and antibiotic bone cement was used to fill the bone defect. (**C**) The bone cement was taken out, and the wound was thoroughly debrided again, and the anterolateral thigh free flap and skin grafting were performed, and the Double-segmental Ilizarov bone transport was planned. (**D**) The transport period ended, and the ends of defect bone were docked. (**E**) The consolidation period ended, and the docking site was healed. (**F**) Radiographs after removal of external fixation. (**G**) Assessment of ankle joint function after removal of external fixation.

proves instrumental.[5,33] It relatively effectively controls bone infections, consolidates bone, addresses defects, and significantly improves ankle joint function. Even in cases where ankle joint activity must be sacrificed due to infection, patients can retain crucial weight-bearing and other functions post-joint arthrodesis. At this point, the external fixation across the ankle joint may be less of a concern for patients and surgeons.

The success or failure of surgery often hinges on sound treatment decisions. Meanwhile, when considering healthcare resource allocation, it is essential to carefully evaluate the economic aspects and clinical benefits of each approach. While the long-term costs associated with using a large quantity of autologous bone grafts may be lower, inherent risks persist, including donor site complications and the potential for iliac bone fracture.[6,34] At the same time, while ensuring the complete elimination of the infection site, autologous bone grafting is a more suitable option only for patients with bone defects ≤ 3cm.[35] Allogeneic bone grafting may not be entirely suitable for large bone defects, and there is a risk of infection and immune rejection, which may increase overall expenses.[36,37] Antibiotic cement filling serves as a relatively cost-effective temporary solution and is not a long-term fix for infectious bone defects. The Masquelet membrane induction technique requires high soft tissue coverage and suffers from relatively limited bone mass.[8] Vascularized or non-vascularized fibula transplantation is recommended but poses technical challenges and substantial risks, and its cost-effectiveness needs to be further evaluated. At the same time, the diameter of the fibula is 12–15mm, which cannot effectively replace the load-bearing role of the tibia in a certain period of time.[9,20,38] Considering the limitations of these techniques, the Ilizarov bone transport technique may be considered a favorable option in certain indications, even if it requires long-term external fixation, proving effective in reconstructing bone defects caused by distal tibia refractory osteomyelitis while preserving limb function.

This study shows that half of post-traumatic osteomyelitis patients were affected by open high-energy trauma, and the remaining half were infected after internal fixation surgery for distal tibial fractures. Such cases were characterized by prolonged and refractory disease, often accompanied by challenging soft tissue and bone defects, making clinical treatment difficult.[5,39] It is well-established that the bone tissue and implants of patients with distal tibial fractures are infected by bacteria and form bacterial biofilms on the surface after surgery, which weakens the sterilization effect of antibiotics, and contributes to DTO.[40] Untimely diagnosis and removal of internal fixation, debridement, and other treatments can lead to severe complications, pus discharge, infection aggravation, and potential amputation.[31] Ultimately, efforts to eliminate infection and preserve limb function may not always succeed. Despite the potential drawbacks of causing significant bone defects and complicating treatment, early, frequent, and thorough debridement of osteomyelitis remains a crucial phase in early intervention.[4,27,28] This perspective aligns with the viewpoint presented by Li et al[41] In this study, each patient underwent an average of 3.7 debridement procedures, which is higher than the results of other similar studies.[21] This is largely attributed to these cases suffering from refractory osteomyelitis, the statistics include the total number of debridement surgeries performed in other hospitals and our hospital during the period from the onset to the end of treatment. Notably, a patient with a prolonged history of osteomyelitis and diabetes experienced persistent chronic infection due to poor self-conditions. However, after undergoing 11 debridement operations (including 5 at our hospital) within 3 years, successful outcomes were eventually achieved, including infection control, bone healing, and recovery of limb function.

Paley et al reported successful outcomes using the Ilizarov bone transport technique for chronic osteomyelitis and bone defects. They highlighted the technique's efficacy in eliminating deformities, infections, and defects, achieving healing.[20] The limitations of the Ilizarov technique were linked to pre-existing, irreversible neurovascular and joint injuries. This perspective is deemed applicable in DTO, emphasizing that while excellent bone results can be attained under adverse pathological conditions, functional outcomes are influenced by factors such as nerves, muscles, blood vessels, joints, and bones.[20] The present study showed a higher rate of excellence in bone results (68.18%) compared to functional outcomes (27.27%). In comparison with previous literature, our study's functional score improvement has its own characteristics. Some previous studies may have reported different improvement rates due to variations in patient populations, treatment protocols, and follow-up periods.[42,43] For example, Kemal Aktuglu et al reported that in a similar patient group, the excellent rate of functional outcomes was 45.05%, which is different from our finding.[11] This disparity is attributed to challenges in achieving high functional excellence rates and the pre-existing poor ankle joint function in many cases, leading to ankle arthrodesis later on, impacting joint function assessment.

No consensus has been reached on the optimal fixation methods employed during bone transportation and consolidation. Several studies advocate for internal fixation replacement approaches, such as intramedullary nails or locking plates, in the later stages of transport to mitigate adverse issues associated with external fixation. Intramedullary nailing offers advantages like reduced external fixation time, maintenance of alignment during transport, and the possibility of early weight-bearing exercise.[44] Similarly, the use of locking plates provides the advantage of early removal of the external fixator, lowering the incidence of complications.[45] In cases where complete infection control cannot be guaranteed, or confidence in preventing the recurrence of deep infections is lacking, opting for external temporary fixation is considered a more secure strategy. It is essential to consider defect characteristics, surrounding soft tissue quality, mechanical stability, and patient comfort when selecting an external fixation method.

Complications are inevitable throughout the entire bone transport process, underscoring the importance of timely measures to address patient complications, which significantly impact later disease outcomes. In our study, instances included cases of pin tract infection (n=10), axial deviation (n=3), ankle joint stiffness (n=2), non-union at the docking site (n=2), and delayed consolidation (n=2), among others. Despite sometimes efforts to enhance pin tract care and administer appropriate oral antibiotics, pin tract infections persisted. Notably, Iacobellis et al observed a similar prevalence of pin tract infections, ranking as the most common complication,[46] followed by axial deviation. Caution must be exercised in addressing axial deviation, given its association with increased risks of delayed union, non-union, and re-fracture at the docking site.[47] To mitigate axial deviation risks, we advocate for regular X-ray measurements of the lower limb's entire length during transportation, and for detecting any bending of the Schanz pins. Timely adjustments to the external fixation device can then be made, reducing the potential for axial deviation. In line with Liu's findings from a follow-up of 282 patients, we also noted a relatively higher likelihood of axial deviation during bone transport using monolateral external fixation.[48] The instability of monolateral external fixation can impact the overall force line, contributing to this risk. As observed in our study, most patients with axial deviation underwent monolateral external fixation (2 cases). Therefore, considering the potential benefits, the application of ring external fixation emerges as a viable option, especially when managing large bone defects. Lindsey et al revealed that patients with proximal tibial osteotomy experienced a lower prevalence of muscle and joint contractures, such as talipes equinovarus foot, compared to those with distal tibial osteotomy.[49] However, emphasis should be placed on changes in contraction tension and function of the calf muscle group during transport.

Based on our experience, beyond the previously mentioned considerations, it is crucial to account for the following specific factors when employing the Ilizarov bone transport technique for reconstructing bone defects resulting from refractory DTO. Firstly, in cases where the infection directly involves the ankle joint, because of the obvious bone defect easily formed after debridement, a combination of tibia transport and ankle arthrodesis under external fixation is recommended. This approach may be beneficial in filling the defect and restoring weight-bearing walking ability. However, it should be noted that ankle arthrodesis is not the only option. Other techniques, such as joint - preserving procedures, have also been attempted in some cases, although their long - term effectiveness and applicability for different patient scenarios need further exploration. Secondly, when the bone defect does not directly affect the ankle joint and there is a considerable amount of intact bone (from the ankle joint to the bone defect area ≥ 3cm), it is a common practice to perform external fixation by crossing the ankle joint to prevents equinus and soft tissue problems. However, it should be noted that in order to reduce the risk of joint stiffness, it is necessary to take ankle extension off as early as possible at the end of the lengthening while ensuring stability.

It is important to acknowledge the limitations of our study. Firstly, it is a single-center, retrospective study, which may introduce potential biases. The absence of a control group (single-arm study) makes it difficult to directly compare the effectiveness of the Ilizarov bone transport technique with other methods. Secondly, the rarity of bone defects caused by refractory DTO resulted in a relatively small patient sample, which may limit the generalizability of our findings and hinder stratified analysis of some relevant indicators. Thirdly, we did not conduct a health economic analysis, despite the Ilizarov technique being associated with prolonged treatment durations and high resource utilization. Specifically, critical outcome measures such as cost-effectiveness and return-to-work rates were not systematically assessed.

Conclusion

The Ilizarov bone transport technique appears to offer satisfactory outcomes in selected cases of post-refractory osteomyelitis distal tibial defects, demonstrating potential advantages in terms of minimal invasiveness, effective infection control, and functional restoration. However, these preliminary findings should be interpreted with caution due to the study's design limitations. Future research should focus on large-scale prospective, multi-center studies incorporating control groups to enhance the robustness of our findings and further explore the technique's application.

Abbreviations

DTO, distal tibia osteomyelitis; VAS, the visual analogue scale; ADL, the activities of daily living; VSD, the vacuum sealing drainage; AOFAS, the American orthopedic foot and ankle society; ASAMI, the association for the study and application of the method of Ilizarov.

Data Sharing Statement

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

The study involving human participants was reviewed and approved by the Medical Ethics Committee of the First Affiliated Hospital of Xinjiang Medical University (Approval No. K202308-11). This study complies with the Declaration of Helsinki. Written informed consent to participate in this study was provided by the participants themselves or their legal guardians/next of kin. This study was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This study was funded by the Key Research and Development Projects of Xinjiang Uygur Autonomous Region (No. 2022B03013-6), the Graduate Student Innovation Projects of Xinjiang Uygur Autonomous Region (No. XJ2025G185), National Natural Science Foundation of China (No. 82260425) and the "Tianshan Talent" Youth Science and Technology Top Talent Program in the Xinjiang Uygur Autonomous Region (No. 2022TSYCCX0113).

Disclosure

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

References

1. Kremers H, Nwojo M, Ransom J, Wood-Wentz C, Melton L, Huddleston P. Trends in the epidemiology of osteomyelitis: a population-based study, 1969 to 2009. *J Bone Joint Surg Am Vol*. 2015;97(10):837–845. doi:10.2106/JBJS.N.01350
2. Ren Z, Cai W, Lu Y, et al. Debridement-reconstruction-docking management system versus ilizarov technique for lower-extremity Osteomyelitis. *J Bone Joint Surg Am Vol*. 2023;105(19):1527–1536. doi:10.2106/JBJS.23.00030
3. Flaviu M. Role of serum biomarkers in differentiating periprosthetic joint infections from aseptic failures after total hip arthroplasties. *J Clin Med*. 2024;13(19).
4. Marais L, Ferreira N. Bone transport through an induced membrane in the management of tibial bone defects resulting from chronic osteomyelitis. *Strate Trauma Limb Reconstruct*. 2015;10(1):27–33. doi:10.1007/s11751-015-0221-7
5. Shastov A, Mikhailov A, Kliushin N, Malkova T. Limb salvage and functional recovery in infected nonunion of the distal tibia treated with the Ilizarov techniques. *J Clinl Orthopaedics Trauma*. 2023;44:102255. doi:10.1016/j.jcot.2023.102255
6. Schmidt A. Autologous bone graft: is it still the gold standard?. *Injury*. 2021;52:S18–S22. doi:10.1016/j.injury.2021.01.043
7. Tetsworth K, Paley D, Sen C, et al. Bone transport versus acute shortening for the management of infected tibial non-unions with bone defects. *Injury*. 2017;48(10):2276–2284. doi:10.1016/j.injury.2017.07.018
8. Konda S, Gage M, Fisher N, Egol K. Segmental bone defect treated with the induced membrane technique. *J Orthop Trauma*. 2017;31:S21–2.
9. Ren G, Li R, Hu Y, Chen Y, Chen C, Yu B. Treatment options for infected bone defects in the lower extremities: free vascularized fibular graft or Ilizarov bone transport?. *J Orthopaedic Surg Res*. 2020;15(1):439. doi:10.1186/s13018-020-01907-z
10. Feng D, Zhang Y, Wu W, Jia H, Ma C. Docking site complications analysis of Ilizarov bone transport technique in the treatment of tibial bone defects. *J Orthop Surg Res*. 2023;18(1). doi:10.1186/s13018-023-04356-6
11. Aktuglu K, Erol K, Vahabi A. Ilizarov bone transport and treatment of critical-sized tibial bone defects: a narrative review. *J Orthopaed Traumatol*. 2019;20(1):22. doi:10.1186/s10195-019-0527-1
12. Hamiti Y, Yushan M, Lu C, Yusufu A. Reconstruction of massive tibial defect caused by osteomyelitis using induced membrane followed by trifocal bone transport technique: a retrospective study and our experience. *BMC Surg*. 2021;21(1):419. doi:10.1186/s12893-021-01421-x
13. Thakeb MF, Kozman MA, ElGebeily MA, Baraka MM, Al Kersh MA. Bone transport through induced membrane versus conventional bone transport in management of infected long-bone defects of lower limbs: a randomized controlled trial. *J Orthop Trauma*. 2023;37(9):462–468. doi:10.1097/BOT.0000000000002613
14. Yuanli S, Qihong Y, Hui C, Yitian F, Yuan L, Jun H. Evaluation of the comparative efficacy and safety of surgical strategies for long bone defects: a network meta-analysis. *Int J Surg*. 2025;111(4).
15. Vikas M, Balgovind SR, Bom B, Anil R, Mohit D, Aditya KSG. Outcome analysis of ilizarov and monorail fixators in the treatment of nonunion of long bones: a systematic review and proportion meta-analysis. *J Clin Orthop Trauma*. 2023;40.
16. Parsons B, Strauss E. Surgical management of chronic osteomyelitis. *Am J Surg*. 2004;188(1):57–66. doi:10.1016/S0002-9610(03)00292-7
17. Gustilo RB, Merkow RL, Templeman D. The management of open fractures. *J Bone Joint Surg Am*. 1990;72(2):299–304. doi:10.2106/00004623-199072020-00023
18. Cierny G 3rd, Mader JT, Penninck JJ. A clinical staging system for adult osteomyelitis. *Clin Orthop Relat Res*. 2003;414(414):7–24. doi:10.1097/01.blo.0000088564.81746.62
19. Paley D. Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. *Clin Orthopaedics Related Res*. 1990;250(250):81–104. doi:10.1097/00003086-199001000-00011
20. Paley D, Catagni M, Argnani F, Villa A, Benedetti G, Cattaneo R. Ilizarov treatment of tibial nonunions with bone loss. *Clin Orthopaedics Related Res*. 1989;241(241):146–165. doi:10.1097/00003086-198904000-00017
21. Xie J, Zhao G, Yasheng T, et al. Ilizarov bone transport to treat infected nonunion of long bones: a multicenter retrospective cohort study. *J Inter Med Res*. 2021;49(3):3000605211002701. doi:10.1177/03000605211002701
22. Barker K, Lamb S, Simpson A. Functional recovery in patients with nonunion treated with the Ilizarov technique. *J Bone Joint Surg Br Vol*. 2004;86(1):81–85.
23. Lin C, Chen C, Chiu F, Su Y, Liu C, Chen T. Staged protocol for the treatment of chronic tibial shaft osteomyelitis with Ilizarov's technique followed by the application of intramedullary locked nail. *Orthopedics*. 2012;35(12):e1769–1774. doi:10.3928/01477447-20121120-23
24. Wu C. Single-stage surgical treatment of infected nonunion of the distal tibia. *J of Orthop Trauma*. 2011;25(3):156–161. doi:10.1097/BOT.0b013e3181eaaa35
25. Muhammad YR. Ankle arthrodesis revisited: a systematic review of techniques, outcomes, and complications. *Cureus*. 2025;17(6).
26. Ashraf AK. Versatility of Ilizarov technique in difficult cases of ankle arthrodesis and review of literature. *Foot Ankle Surg*. 2013;19(1).

27. Chen CM, Su AW, Chiu FY, Chen TH. A surgical protocol of ankle arthrodesis with combined Ilizarov's distraction-compression osteogenesis and locked nailing for osteomyelitis around the ankle joint. *J Trauma*. 2010;69(3):660–665. doi:10.1097/TA.0b013e3181bc01e6
28. Hoang NT, Staudenmaier R, Feucht A, Hoehnke C. Effectiveness of free gracilis muscle flaps in the treatment of chronic osteomyelitis with purulent fistulas at the distal third of the tibia in children. *J Pediatr Orthop*. 2009;29(3):305–311. doi:10.1097/BPO.0b013e31819903e1
29. Kinik H, Kalem M. Ilizarov segmental bone transport of infected tibial nonunions requiring extensive debridement with an average distraction length of 9,5 centimetres. Is it safe?. *Injury*. 2021;52(8):2425–2433. doi:10.1016/j.injury.2019.12.025
30. Sambri A, Pignatti M, Tedeschi S, et al. Combined orthoplastic approach in fracture-related infections of the distal tibia. *Microorganisms*. 2022;10 (8):1640. doi:10.3390/microorganisms10081640
31. Thordarson DB, Patzakis MJ, Holtom P, Sherman R. Salvage of the septic ankle with concomitant tibial osteomyelitis. *Foot Ankle Int*. 1997;18 (3):151–156. doi:10.1177/107110079701800307
32. Loro A, Loro F, Franceschi F, Brown N. Bone transport in the management of post-osteomyelitis femoral defects in children: a case series with a minimum of 10-year follow-up in Uganda. *J Children's Orthopaed*. 2022;16(4):313–321. doi:10.1177/18632521221106389
33. Kliushin N, Burnashov S, Mekki W, Leonchuk D, Sudnitsyn A. Treatment of postoperative tibial chronic osteomyelitis using bone transport techniques; an observational study. *J Clinl Orthopaedics Trauma*. 2022;24:101652. doi:10.1016/j.jcot.2021.101652
34. Grechenig S, Worlicek M, Penzkofer R, et al. Bone block augmentation from the iliac crest for treatment of deep osteochondral defects of the knee resembles biomechanical properties of the subchondral bone. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(8):2488–2493. doi:10.1007/s00167-018-5242-6
35. Tiemann AH, Schmidt HGK, Braunschweig R, Hofmann GO. Strategies for the analysis of osteitic bone defects at the diaphysis of long bones. *Strategies Trauma Limb Reconstr*. 2009.
36. Stevenson S, Horowitz M. The response to bone allografts. *J Bone Joint Surg Am Vol*. 1992;74(6):939–950.
37. Centers for Disease Control (CDC). Transmission of HIV through bone transplantation: case report and public health recommendations. *MMWR Morb Mortal Wkly Rep*. 1988;37(39):597–599. PMID: 3138522.
38. Taylor G, Miller G, Ham F. The free vascularized bone graft. A clinical extension of microvascular techniques. *Plastic Reconstruct Surg*. 1975;55 (5):533–544. doi:10.1097/00006534-197505000-00002
39. Napora J, Weinberg D, Eagle B, Kaufman B, Sontich J. Hexapod stacked transport for tibial infected nonunions with bone loss: long-term functional outcomes. *J of Orthop Trauma*. 2018;32(1):e12–e18. doi:10.1097/BOT.0000000000001005
40. Cook G, Markel D, Ren W, Webb L, McKee M, Schemitsch E. Infection in orthopaedics. *J of Orthop Trauma*. 2015;29(Supplement 12):S19–23. doi:10.1097/BOT.0000000000000461
41. Li R, Zhu G, Chen C, Chen Y, Ren G, Deligianni D. Bone transport for treatment of traumatic composite tibial bone and soft tissue defects: any specific needs besides the ilizarov technique?. *Biomed Res Int*. 2020;2020(1):2716547. doi:10.1155/2020/2716547
42. Qun Z, Wei Z, Zhuo Z, Peifu T, Lihai Z. Accordion technique combined with minimally invasive percutaneous decortication for the treatment of bone non-union. *Injury*. 2017;48(10).
43. Zhiqiang R, Jinghong Y, Zi W, et al. Ilizarov method combined with accordion technique for treating long bone defects in the lower limbs: a systematic review. *J Orthop Surg Res*. 2024;19(1).
44. Emara K, Allam M. Ilizarov external fixation and then nailing in management of infected nonunions of the tibial shaft. *J Trauma*. 2008;65 (3):685–691. doi:10.1097/TA.0b013e3181569ecc
45. Oh C, Apivatthakakul T, Oh J, et al. Bone transport with an external fixator and a locking plate for segmental tibial defects. *Bone Joint J*. 2013;95-B (12):1667–1672. doi:10.1302/0301-620X.95B12.31507
46. Iacobellis C, Berizzi A, Aldegheri R. Bone transport using the Ilizarov method: a review of complications in 100 consecutive cases. *Strate Trauma Limb Reconstruct*. 2010;5(1):17–22. doi:10.1007/s11751-010-0085-9
47. Wang H, Wei X, Liu P, et al. Quality of life and complications at the different stages of bone transport for treatment infected nonunion of the tibia. *Medicine*. 2017;96(45):e8569. doi:10.1097/MD.0000000000008569
48. Liu Y, Yushan M, Liu Z, Liu J, Ma C, Yusufu A. Complications of bone transport technique using the Ilizarov method in the lower extremity: a retrospective analysis of 282 consecutive cases over 10 years. *BMC Musculoskelet Disord*. 2020;21(1):354. doi:10.1186/s12891-020-03335-w
49. Lindsey C, Makarov M, Shoemaker S, et al. The effect of the amount of limb lengthening on skeletal muscle. *Clin Orthopaedics Related Res*. 2002;402(402):278–287. doi:10.1097/00003086-200209000-00028