Research Square

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Clinical Experience with the Ilizarov Technique for Limb Reconstruction after Severe Trauma

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Research Article

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Abstract

Objective

To evaluate the clinical efficacy and operative strategy of the Ilizarov technique in limb reconstruction for bone defects, malalignment, and soft-tissue defects following severe trauma.

Methods

We retrospectively reviewed 36 patients (21 men, 15 women; mean age 34.2 years, range 17–58) treated for post-traumatic limb dysfunction between January 2019 and June 2024. All patients had nonunion, bone defects (5–16.5 cm), or persistent dysfunction after standardized debridement. Treatment followed a stepwise pathway: debridement, rigid external fixation, bone transport, and rehabilitation. A circular or monolateral frame was applied according to the defect characteristics. Transport began on postoperative day 7 at 0.75–1mm/day, delivered in four daily increments, with concurrent alignment correction and soft-tissue management. Follow-up included Paley scoring and complication recording.

Results

All 36 patients completed follow-up (mean 27 months, range 18–42 months). Bony union was achieved in all cases. Paley functional scores were excellent in 11 patients, good in 19, and fair in 6, giving an excellent/good rate of 83.3%. Pin-site infection occurred in 11 patients (30.6%) and resolved with local care and antibiotics. Docking-site delayed union occurred in 3 patients (8.3%) and healed after secondary bone grafting. No major vascular or nerve injury occurred.

Conclusion

The Ilizarov technique integrates the mechanical stability of external fixation with distraction osteogenesis, enabling single-stage management of bone defects, malalignment, and soft-tissue defects after severe trauma. Thorough debridement, individualized uniform transport, proactive docking-site management, and dryness-centered pin-site care are key to reliable outcomes. The technique is a safe and reliable core procedure for limb reconstruction after severe trauma.

1 Introduction

After severe limb trauma, large bone defects, nonunion, and osteomyelitis frequently coexist. Loss of bony support and destruction of soft-tissue coverage occur simultaneously, while alignment maintenance and infection control impose competing constraints. Large bone defects are generally defined as defects ≥2cm or exceeding 50% of the bone circumference. When the defect exceeds 5cm, traditional autologous bone grafting faces multiple limitations, including limited donor supply,

insufficient graft vascularity, and a superimposed risk of infection recurrence, making reconstruction considerably more difficult [13].

The Ilizarov technique is based on the biological principle of tension–stress and induces bone and soft-tissue regeneration through continuous, slow, and stable distraction. It offers a solution distinct from traditional bone grafting for these dilemmas [3]. Since Paley et al. systematically reported its use for tibial nonunion with bone loss in 1989 [1], the clinical indications have gradually expanded from nonunion and bone defects to infected bone defects, composite soft-tissue defects, and deformity correction. Paley subsequently proposed a three-tier framework of “problems, obstacles, and complications” for limb lengthening, which remains a fundamental reference for evaluating the safety of the Ilizarov technique [2]. Compared with the Masquelet induced-membrane technique, bone transport has shown certain advantages in bony outcomes and residual deformity control for large defects. A systematic review and meta-analysis reported an excellent/good rate of 82.8% for ASAMI bone results in the bone transport group versus 64% in the Masquelet group, with residual deformity rates of 1.9% and 9.7%, respectively [9]. In severe trauma, however, soft-tissue conditions are poor, the number of previous operations is high, and the infection burden is heavy. The high incidence of pin-site infection during transport, uncertainty regarding docking-site healing, and the risk of axial deviation remain practical bottlenecks that prolong treatment and compromise final efficacy. This study retrospectively summarizes a single-center experience with 36 patients who underwent Ilizarov reconstruction for limb dysfunction after severe trauma. We focus on the execution details of the stepwise pathway, bone healing, and functional outcomes, and discuss the logic of complication prevention and control as well as the applicable boundaries of the technique in light of recent large-sample evidence.

2 Materials and methods

2.1 Patient characteristics

A total of 36 patients with limb dysfunction after severe trauma, admitted to the Department of Traumatic Orthopedics, a tertiary hospital, between January 2019 and June 2024, were retrospectively included. There were 21 men and 15 women, with a mean age of 34.2 years (range, 17–58 years). Inclusion criteria were nonunion, bone defect, or limb dysfunction remaining after initial debridement, with a bone defect of 5–16.5cm. Exclusion criteria were uncontrolled systemic infection, severe medical comorbidities precluding external fixation, or incomplete follow-up data.

2.2 Treatment pathway

All cases followed a uniform stepwise framework.Stage 1 comprised infection control and wound preparation. Standardized graded debridement was performed, with thorough removal of devitalized bone and soft tissue. Establishment of a healthy soft-tissue bed and stabilization of infection markers were prerequisites for entering the reconstruction stage.Stage 2 comprised external fixation and mechanical stabilization. A circular external fixator or a monolateral bone transport frame was selected according to defect site, soft-tissue conditions, and expected transport distance. The circular frame

offers advantages in three-dimensional rigid control, whereas the monolateral frame is preferable in terms of patient tolerance and soft-tissue friendliness. The primary criterion for choosing between them was whether alignment could be maintained throughout transport.Stage 3 comprised bone transport and concurrent correction. Transport began on postoperative day 7 at 0.75–1mm/day, delivered in four equal daily increments, allowing time for soft-tissue tension and local blood supply to adapt.Stage 4 comprised docking-site management and functional rehabilitation.As transport approached the target position, the contact conditions and vascular status of the docking ends were evaluated, and secondary intervention was planned in advance for patients at risk of sclerosis, atrophy, or soft-tissue interposition. During follow-up, pin sites, alignment, and joint function were monitored simultaneously. This temporal sequence of “debridement first, reconstruction second” is consistent with the basic principles for treating infected bone defects and determines whether subsequent transport can proceed in a mechanical and biological environment with a relatively low infection burden [8].

2.3 Outcome measures

Bone healing was assessed according to the Paley bone result criteria, with comprehensive evaluation of bony union, infection control, deformity angle (< 7°), and limb length discrepancy (< 2.5 cm). Limb function was evaluated using the Paley functional result criteria, covering activities of daily living, pain, limping, joint contracture, and soft-tissue nutritional status, and graded as excellent, good, fair, or poor. The occurrence and management of complications—including pin-site infection, docking-site delayed union, axial deviation, and vascular or nerve injury—were also recorded.

3 Results

3.1 Bone healing and functional evaluation

Table 1
Paley functional grading (n = 36)

Grade	n	Proportion
Excellent	11	30.6%
Good	19	52.8%
Fair	6	16.7%
Total	36	100%

All 36 patients completed treatment and follow-up. Follow-up ranged from 18 to 42 months (mean, 27 months). Clinical bony union was achieved in all cases, and no patient underwent amputation because of reconstruction failure. Paley functional scores were excellent in 11 cases (30.6%), good in 19 (52.8%), and fair in 6 (16.7%), with an overall excellent/good rate of 83.3% (30/36). Large-sample data on Ilizarov bone transport for tibial defects have shown comparable healing trends; in a large Chinese series of 315 patients with infected tibial bone defects treated with the Ilizarov technique, infection was controlled in

one stage, all wounds healed, and all 63 patients with shortening who underwent lengthening achieved one-stage bony union [11], which is consistent with the healing trend observed in our cohort.

3.2 Complications and management

Pin-site infection was the most common complication, occurring in 11 patients (30.6%). All patients presented with redness, swelling, and discharge around the pin holes and recovered after local dressing changes, maintenance of pin-site dryness, and antibiotic treatment. No deep infection or recurrence of osteomyelitis occurred. Docking-site delayed union occurred in 3 patients (8.3%); all achieved bony union after freshening of the bone ends, removal of interposed soft tissue, and secondary autologous iliac bone grafting. No severe vascular or nerve injury occurred, and no refracture occurred after external fixator removal. Compared with the data of Feng et al. on 199 cases of tibial bone transport, in which the pin-site infection rate was 61.3% and the docking-site delayed union rate was 25.13% [5], both indicators were lower in our cohort. Given the limited sample size and single-center design, however, this difference should not be attributed directly to superiority of the technique itself; it is more likely related to differences in case composition, number of previous operations, and pin-site management strategy.

3.3 Illustrative case

A 56-year-old woman was admitted with a left tibial open fracture (Gustilo–Anderson IIIB). After debridement, a tibial bone defect of approximately 16 cm remained, accompanied by an anterior tibial soft-tissue defect. According to the stepwise pathway used in this study, thorough debridement, infection control, and wound preparation were performed first. An Ilizarov circular external fixator was then applied for bone transport. Transport began on postoperative day 7 at 0.75–1 mm/day in four equal daily increments. During transport, alignment was maintained and the soft-tissue defect was managed concurrently. Pin-site care centered on maintaining local dryness. As transport approached the docking site, the contact conditions and vascular status of the bone ends were evaluated, and secondary intervention was planned. Ultimately, bony union was achieved, infection was controlled, and alignment was maintained. After external fixator removal, the patient could walk independently, with good functional recovery and no severe vascular or nerve injury. Representative imaging and functional data are shown in Fig. 1. Written informed consent was obtained from the patient for publication of this case and the accompanying images.

4 Discussion

The central challenge in limb reconstruction after severe trauma is the persistent tension between the mechanical demand created by structural defects and the poor local biological environment. Traditional staged strategies separate infection control, skeletal reconstruction, and soft-tissue coverage into sequential stages, but each additional operation may impose new disturbances on an already fragile local blood supply. The distinctive value of the Ilizarov technique lies in placing the mechanical stabilization function of external fixation and the regenerative induction capacity of distraction osteogenesis within the same treatment framework, allowing gradual filling of bone defects, dynamic

adjustment of alignment, and progressive soft-tissue adaptation to proceed in parallel on the same time axis.

The outcomes of the 36 cases in this cohort support this view. Despite a wide range of defect sizes (5–16.5cm) and generally poor soft-tissue conditions, all cases achieved bony union, and the Paley excellent/good rate reached 83.3%. Previous reports have suggested that earlier reconstruction in selected severe tibial defects may reduce the number of operations and shorten the treatment course [4]; however, this strategy places stricter demands on the thoroughness of debridement and infection control. The relatively conservative pathway used in our center—“stabilize infection first, then start transport”—has the cost of a longer treatment period, but the benefit is avoidance of catastrophic failure that may result from transport in an uncontrolled infection state.

The pin-site infection rate in this cohort was 30.6%, lower than the 61.3% reported by Feng et al. in 199 cases [5]. This difference should be interpreted within a risk-factor framework: an increased number of previous operations not only aggravates bone and soft-tissue damage but also increases the risk of pin-site infection by prolonging bed rest and suppressing immune status; defect length itself is also positively correlated with infection rate [12]. Previous studies have shown that pin-site infection is associated with pin position, external fixation pin type, and frame wearing time, with lower infection rates reported for distal rings than for proximal rings and for half-pins than for full-pins, and a marked increase after prolonged frame wear [6]. Another analysis of complications in bone transport for chronic osteomyelitis also identified pin-tract infection as a controllable but frequent primary problem, emphasizing that dressing changes and, when necessary, replacement of transosseous pins or wires are basic management measures [7]. Our center’s experience points to two actionable measures: first, the transport rate is strictly controlled at 0.75–1mm/day and delivered in equal daily increments; second, the focus of pin-site management is shifted from “cleaning frequency” to “maintaining dryness.” Recent clinical observations suggest that frequent cleaning of pin sites does not reduce the infection rate and may instead increase the risk of allergic reactions around the pin sites, whereas wrapping the pin holes with dry sterile gauze and keeping the local area dry can significantly reduce pin-site infection.

Docking-site delayed union occurred in 3 cases (8.3%), all resolved by secondary bone grafting, lower than the 25.13% reported by Feng et al. [5]. The mechanism of delayed union at the docking site involves multiple factors, including insufficient stress stimulation, insufficient contact area between bone ends, soft-tissue interposition within the gap, and poor local blood supply [10]. Feng et al.’s dedicated analysis of docking-site complications in bone transport showed that the incidence of delayed union or nonunion at the docking site can reach 18.8%–36.0% and that approximately 29% of patients require bone grafting intervention [5], suggesting that docking-site problems carry a considerable “pre-set probability.” Our center treats docking-site management as a “preplanned checkpoint” rather than an unexpected event: as transport approaches completion, the blood supply and contact quality of the bone ends are evaluated, and bone grafting is prepared in advance for patients at risk of sclerosis, atrophy, or soft-tissue interposition. This proactive strategy is consistent with the recommendation that early revision and bone grafting can reduce the incidence of docking-site nonunion [10].

Axial deviation is a mechanical complication that cannot be ignored in bone transport. Feng et al. reported an incidence of up to 43.2%, with middle-third tibial defects and longer external fixation time as independent risk factors [5]. Liu et al.'s 10-year retrospective analysis of 282 cases also listed axial deviation as one of the most common complication categories after bone transport (40.78%) [12]. Although axial deviation was not quantified as an independent outcome measure in our cohort, acceptable alignment was maintained through mechanical adjustment of the external fixation configuration, and no severe deviation requiring surgical revision occurred. This suggests that in composite defects after severe trauma, the mechanical redundancy of the external fixation configuration—rather than simple fixation stiffness—may be a more important variable for maintaining a stable transport trajectory. Recent studies have attempted to construct predictive nomograms to identify high-risk patients, suggesting that the predictability of this complication is improving and that configuration design and intraoperative adjustment still have room for optimization.

The limitations of this study should be clearly stated. This was a single-center retrospective study with a limited sample size, and the precision of the estimated Paley excellent/good rate and complication incidences is constrained by the number of events. The choice between circular and monolateral frames was based on clinical judgment rather than random allocation, and the independent effects of different fixation methods on transport accuracy, pin-site infection rate, and patient tolerance cannot be separated under this design. Although follow-up covered bone healing and early functional recovery, there was no systematic evaluation of the long-term remodeling quality of new bone, the process of joint degeneration, or the activity level of patients after social reintegration. Future studies should expand the sample size, perform stratified comparisons of fixation configuration, transport parameters, and pin-site management protocols, and extend functional follow-up until bone remodeling is complete. In addition, combination strategies such as bone transport combined with the accordion technique and sequential combination with flaps or induced-membrane techniques have shown potential to further improve healing rates and reduce infection rates in large bone defects and composite soft-tissue defects [14–15]. The complication spectrum of single-level transport for tibial defects caused by fracture-related infection has also been specifically reported [16]. These findings suggest that the experience of this cohort should be interpreted within a broader framework of technique combinations and indication stratification.

5 Conclusion

The Ilizarov technique integrates mechanical stability and biological regeneration within a single treatment framework and can provide single-stage management of the composite problems of bone defects, alignment deformity, and soft-tissue defects after severe trauma. In this cohort of 36 patients, all achieved clinical bony union, with a Paley excellent/good rate of 83.3%. Pin-site infection and docking-site delayed union were controlled after standardized management, and no major complications such as severe vascular or nerve injury occurred. The technique is a safe and reliable core procedure for limb functional reconstruction after severe trauma. Adherence to the timing of thorough debridement, individualized uniform transport, proactive intervention at the docking site, and pin-site management

centered on “maintaining dryness” together constitute the chain that translates the technique’s potential into clinical efficacy.

Declarations

Author Contribution

Qingping Pu: Conceptualization, Methodology, Surgery, Writing – review & editing, Supervision.Jin Tian: Data curation, Formal analysis, Investigation, Follow-up, Writing – original draft.Changhao Shi: Literature review, Data curation, Writing – review & editing.Xiangchun Shi: Surgery, Data curation, Imaging evaluation, Validation.All authors read and approved the final manuscript.

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Figures

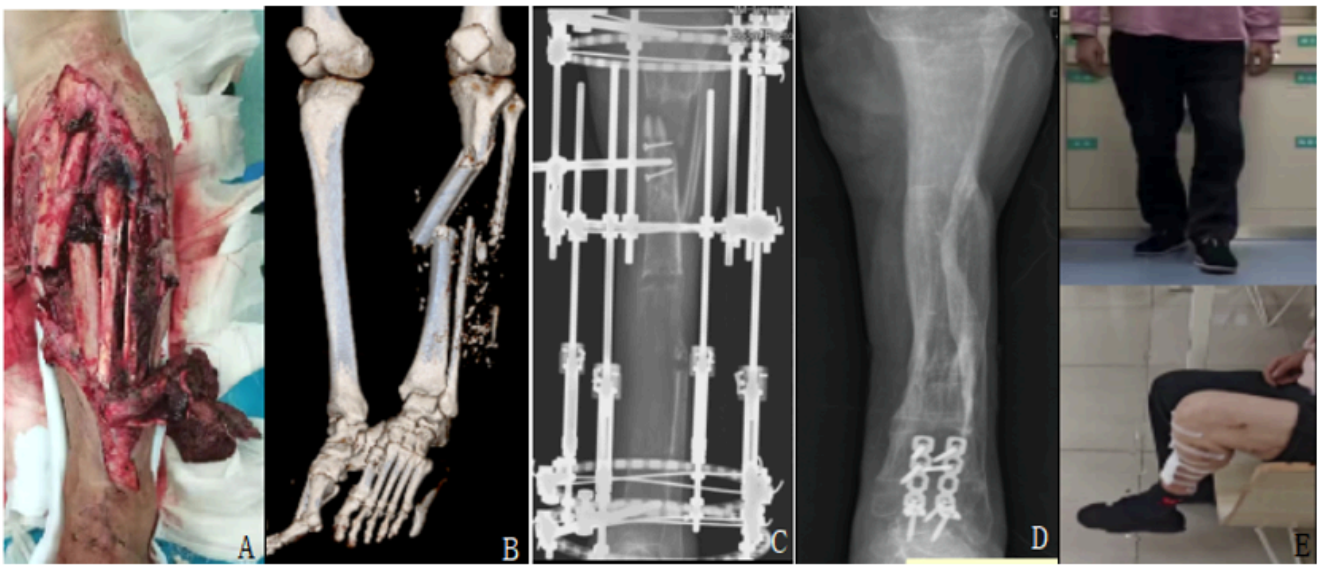


Figure 1

Illustrative case (female, 56 years old, left tibial open fracture, Gustilo–Anderson IIIB). A: Gross appearance of the wound after injury, showing a soft-tissue defect and bone exposure in the anterior tibia of the left lower leg. B: Post-injury three-dimensional CT reconstruction, showing a large tibial bone defect. C: X-ray during Ilizarov bone transport, showing the circular external fixator and the transported bone segment. D: X-ray after removal of the external fixator, showing bony union of the bone defect area

and maintained alignment. E: Functional photograph at the last follow-up, showing that the patient could walk independently.