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Research Article

Comparative Evaluation of Linear Rail System and Ilizarov Ring Fixator in the Management of Infected Tibial Nonunion: A Prospective Comparative Study

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ABSTRACT

Background: One of the most challenging conditions seen in orthopedics is infected nonunion of the tibia due to its complexities associated with persistent infection, poor vascularity, bone loss, deformity, limb-length discrepancy and compromised soft-tissue coverage. In such cases, a successful treatment requires eradication of infection, radical removal of nonviable bone, restoration of mechanical stability and, when required, reconstruction of the resultant bone defect. Ilizarov circular external fixation has been widely used for the management of infected tibial nonunion. It permits compression, distraction, deformity correction and bone lengthening. An alternative method for managing such cases is Linear Rail systems, that provides external fixation and may offer advantages in terms of application, postoperative management and patient comfort.

Aim: To compare the clinical and radiological outcomes of linear rail system (LRS) fixation and Ilizarov ring fixation in the treatment of infected tibial nonunion.

Materials and Methods: This prospective comparative study included 34 patients with infected nonunion of the tibia involving the proximal, middle or distal third. Fourteen patients were treated with a linear rail system, 15 patients were treated with an Ilizarov ring fixator and 5 patients dropped out of study. Patients with infected nonunion with an implant in situ, infected nonunion of less than 9 months duration and patients with atrophic nonunion of another long bone, such as the femur, in the same limb were excluded. In the LRS group, radical debridement of the infected nonunion was performed, including excision of the infected bone segment and fibular osteotomy where required. The medullary canal was opened and acute docking of the healthy bone ends was achieved using the LRS. A proximal or distal corticotomy was subsequently performed depending upon the location of the docking site. Distraction at the corticotomy site was initiated after a latency period of 7 days, while compression was continued at the docking site. Patients treated with Ilizarov fixation underwent radical debridement followed by application of a standard Ilizarov frame, with compression, acute docking and/or distraction osteogenesis according to the bone defect and operative findings. Outcomes were assessed using union rate, time to union, ASAMI bone and functional scores, pin-tract infection and limb-length discrepancy.

Results: Fourteen of 14 patients in the LRS group achieved union, giving an observed union rate of 100%, whereas 12 of 15 patients in the Ilizarov group achieved union, giving an observed union rate of 80%. The mean time to union was approximately 6 months in the LRS group compared with 8 months in the Ilizarov group; giving an inference of overall ASAMI bone outcome be excellent in the LRS group and good in the Ilizarov group. The overall ASAMI functional outcome was predominantly good in the LRS group and fair in the Ilizarov group. Pin-tract infection occurred in one patient in the LRS group and three patients in the Ilizarov group. Limb-length discrepancy occurred in one patient in the LRS group and three patients in the Ilizarov group.

Conclusion: Both linear rail and Ilizarov external fixation are an effective management approach for infected tibial nonunion. In the present study, LRS fixation was associated with a higher observed union rate, shorter mean time to union, better overall ASAMI bone and functional outcomes and fewer reported complications. Therefore, LRS may represent a useful alternative to circular fixation in appropriately selected patients with infected tibial nonunion.

Keywords: Infected Tibial Nonunion, Linear Rail System, LRS, Ilizarov Fixator, External Fixation, Bone Transport, Acute Docking, Corticotomy, Distraction Osteogenesis, ASAMI Score.

INTRODUCTION

Infected nonunion of the tibia represents one of the most demanding problems in reconstructive orthopaedic surgery. The tibia is particularly vulnerable to infection because of its relatively poor soft-tissue coverage and its frequent involvement in high-energy injuries, open fractures and multiple surgical procedures. Once infection develops in a nonunion, treatment becomes more complex because infection is often accompanied by impaired vascularity, compromised biological activity, mechanical instability, bone loss, deformity and soft-tissue deficiency.

Successful management requires a combination of principles, including thorough eradication of infection, excision of all nonviable tissue, restoration of mechanical stability, management of dead space and reconstruction of the resulting osseous defect. External fixation is particularly useful in this setting because it can provide stable mechanical support while avoiding the placement of permanent internal implants within an infected field.

The Ilizarov method has been extensively used in the management of infected tibial nonunions. Its versatility permits compression, distraction, deformity correction, bone transport and restoration of limb length while maintaining stable fixation [1–3]. Radical excision of the infected segment followed by acute compression or docking and subsequent lengthening through a separate corticotomy is an established strategy for managing large osseous defects [10].

Despite these advantages, circular external fixation has several limitations. Application of a ring fixator is technically demanding and frequently requires multiple transosseous wires and/or half-pins. The frame can be bulky, pin-site problems are common, and prolonged frame use may affect patient comfort, mobility and acceptance [6,11,12].

The linear rail system (LRS) provides an alternative form of external fixation. It uses Schanz pins attached to a unilateral rail and permits controlled compression and distraction across the involved segment. In appropriately selected cases of infected nonunion, radical excision of infected bone followed by acute docking and subsequent distraction osteogenesis can address infection, bone loss and limb shortening within the same treatment strategy.

The present prospective comparative study was undertaken to evaluate the clinical and radiological outcomes of LRS and Ilizarov ring fixation in patients with infected tibial nonunion.

Aim

To compare the clinical and radiological outcomes of the linear rail system and Ilizarov ring fixator in the treatment of infected tibial nonunion.

Objectives

1. To compare the union rates between patients treated with LRS and those treated with Ilizarov fixation.
2. To compare the mean time to union between the two treatment groups.
3. To compare ASAMI bone outcomes between the LRS and Ilizarov groups.
4. To compare ASAMI functional outcomes between the two groups.
5. To compare complications, particularly pin-tract infection and residual limb-length discrepancy, between the two techniques.

MATERIALS AND METHODS

Study Design and Patient Population

This was a prospective comparative clinical study conducted at a tertiary care institution, involving patients with established infected nonunion of the tibia. Non-unions involving the proximal, middle and distal thirds of the tibia were included after their informed written consent.

A total of 34 patients were initially enrolled. Five patients were subsequently lost to follow-up. Therefore, 29 patients were available for the final analysis. Of these, 14 patients were treated using an LRS and 15 patients were treated using an Ilizarov ring fixator.

Inclusion Criteria

Patients were considered eligible when they fulfilled the following criteria:

1. Established infected nonunion of the tibia.
2. Nonunion involving the proximal, middle or distal third of the tibia.
3. Clinical and radiological evidence of infected nonunion.
4. Willingness to undergo external fixation and comply with the scheduled follow-up protocol.

Exclusion Criteria

Patients were excluded when they had:

1. Atrophic infected tibial nonunion with an implant in situ.
2. Infected tibial nonunion of less than 9 months' duration.
3. Atrophic nonunion involving another long bone, such as the femur, in the same limb.
4. Inability or unwillingness to participate in postoperative follow-up.

Preoperative Evaluation

All patients underwent a detailed clinical assessment. The evaluation included the duration of nonunion, previous operative procedures, presence of a discharging sinus or other clinical manifestations of infection, quality of the surrounding soft-tissue envelope, limb-length discrepancy, deformity, range of motion of the adjacent knee and ankle joints, and distal neurovascular status.

Baseline laboratory investigations included complete blood count and inflammatory markers such as erythrocyte sedimentation rate and C-reactive protein when clinically indicated.

Anteroposterior and lateral radiographs of the affected tibia were obtained to determine the level of nonunion, alignment, extent of bone loss, deformity, appearance of the proximal and distal bone ends and status of the fibula. Additional investigations were performed when clinically indicated to determine the extent of infection.

Antibiotic treatment was selected according to the clinical condition of the patient. Where microbiological specimens were available, antibiotic therapy was subsequently modified according to culture and sensitivity results.

Surgical Technique

LRS Group

All procedures were performed under appropriate anaesthesia using standard aseptic precautions (Figure no. 1).

Exposure and Sampling

The nonunion site was exposed through an incision planned according to the previous surgical scars, sinus tract and condition of the soft tissues. Viable soft tissue was preserved whenever possible. Deep tissue and pus specimens were obtained for microbiological examination before initiation or alteration of antibiotic therapy, where clinically appropriate.

Fibular Osteotomy

The fibula was exposed at an appropriate level and osteotomised when required to release the lateral tether and facilitate approximation of the tibial segments. This permitted controlled acute docking following excision of the infected segment.

Radical Debridement

Extensive debridement was performed to remove all grossly infected, necrotic and nonviable tissue. The infected segment of tibia was resected using an oscillating saw until healthy, viable and bleeding bone was encountered. The extent of resection was determined intraoperatively by the presence of viable bone rather than by a predetermined length of resection.

Preparation of the Medullary Canals and Bone Ends

After removal of the infected segment, the medullary canals of both tibial fragments were opened and cleared of fibrous, necrotic or obstructing tissue. The bone ends were prepared until healthy viable surfaces suitable for docking were obtained.

Application of the LRS

The LRS was applied using appropriately positioned Schanz pins inserted into the proximal and distal tibial segments. Pin placement was planned to provide adequate mechanical stability while avoiding major neurovascular structures, joint penetration and areas of compromised soft tissue.

Acute Docking

Following radical debridement and preparation of the bone ends, the proximal and distal tibial segments were gradually approximated using controlled compression through the LRS. Acute docking was performed whenever the soft-tissue condition permitted direct contact of the healthy bone ends.

The degree of acute shortening depended on the amount of bone removed and the ability of the surrounding soft tissues to accommodate the shortening.

Corticotomy

A corticotomy was subsequently performed in a healthy metaphyseal region. The site of corticotomy, whether proximal or distal, was selected according to the level of the docking site, availability of healthy metaphyseal bone, soft-tissue condition, amount of shortening and overall limb alignment.

The principle was to maintain compression at the docking site while restoring limb length through distraction osteogenesis at a separate healthy segment, as described in established Ilizarov-based reconstruction protocols [2,3,10,13].

Latency and Distraction

A latency period of approximately seven days was allowed following corticotomy. Distraction was then initiated gradually according to established principles of distraction osteogenesis [3,13]. The rate of distraction was modified when necessary based on the radiological appearance of the regenerate, clinical findings and patient tolerance.

Compression was maintained across the docking site during distraction in order to encourage union while simultaneous length restoration was achieved at the corticotomy site.

Postoperative Care

Postoperative antibiotic therapy was continued and modified according to culture and sensitivity results when available. Regular pin-site care was instituted. Early mobilisation and physiotherapy were encouraged, with particular emphasis on maintaining knee and ankle range of motion.

Weight-bearing was progressively increased according to the clinical and radiological status of the patient.

Figure no.1: Sequential response on radio-imaging with LRSmanagement:

a)

b)

c)

d)

e)

Ilizarov Group

Patients allocated to the Ilizarov group were managed according to established principles of circular external fixation for infected tibial nonunion [1,4,5,7,8,11,12], (Figure no. 2).

Frame Planning

The circular frame was planned according to the location of the nonunion, tibial dimensions, extent of bone loss, deformity, required compression or distraction and the anticipated need for acute docking or bone transport.

Debridement and Bone Preparation

The infected nonunion was exposed through an appropriate incision, and deep tissue specimens were obtained for microbiological analysis. All infected and nonviable soft tissue and bone were excised until healthy bleeding bone was encountered. The medullary canals were opened and the tibial bone ends were prepared in a manner similar to that used in the LRS group.

Fibular Osteotomy

Fibular osteotomy was performed when necessary to facilitate correction of deformity, compression or acute docking.

Application of the Ilizarov Frame

A circular Ilizarov frame was constructed using appropriately sized rings positioned proximal and distal to the nonunion. Tensioned wires and/or half-pins were inserted through safe anatomical corridors and connected to the rings. The frame was assembled to provide stable fixation while allowing subsequent compression, distraction and correction of limb-length discrepancy.

Acute Compression or Docking

Following radical resection, the healthy tibial segments were brought into contact whenever acute docking was feasible. Compression was applied across the docking site to promote mechanical stability and union.

Corticotomy and Distraction

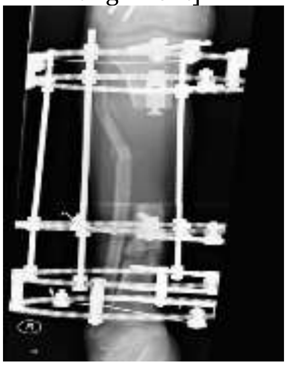
When bone shortening or a segmental defect required restoration of limb length, a proximal or distal metaphyseal corticotomy was performed. The site was selected according to the location of the docking site, availability of healthy metaphyseal bone and the overall reconstruction plan.

A latency period of approximately 5–7 days was observed before distraction was initiated. Gradual distraction was subsequently performed according to the quality of the regenerate and clinical and radiological response [3,13].

Postoperative Management

Patients underwent regular pin-site care, physiotherapy and progressive weight-bearing. Serial radiographs were obtained to assess docking-site union, regenerate formation, alignment, limb length and correction of deformity. Frame modifications were performed whenever clinically required.

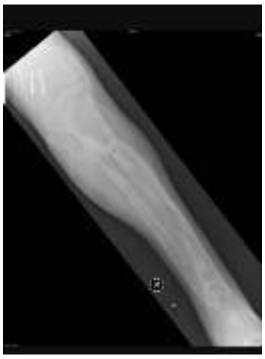
Figure no.2: Sequential response on radio-imaging with Ilizarov management[(d) showing non-alignment]:



a)

b)

c)



d)

Follow-up and Outcome Assessment

Patients were reviewed at regular postoperative intervals. Clinical assessment included pain, limb function, range of motion of the knee and ankle, evidence of persistent infection, pin-site condition, limb-length discrepancy, residual deformity and weight-bearing ability.

Radiographic evaluation included assessment of union at the docking site, regenerate formation, alignment, consolidation and restoration of limb length.

The external fixator was removed only after satisfactory clinical and radiological evidence of union at the docking site and adequate consolidation of the regenerate had been obtained.

Outcome Measures

The primary outcome measures were:

- Achievement of union.
- Time required to achieve union.

Secondary outcome measures included:

- ASAMI bone score.
- ASAMI functional score.
- Pin-tract infection.
- Limb-length discrepancy.
- Other treatment-related complications.

The Association for the Study and Application of the Methods of Ilizarov (ASAMI) scoring system was used to assess bone and functional outcomes, as it is widely applied in the evaluation of reconstructive procedures for infected tibial nonunion.

RESULTS

Thirty-four patients were initially enrolled in the study. Five patients were lost to follow-up, leaving 29 patients for final analysis. Fourteen patients were treated with an LRS and 15 with an Ilizarov ring fixator.

Table 1. Distribution of patients in LRS &Ilizarov group:

Parameter	LRS group	Ilizarov group
Number of patients	14	15
Mean age	24 years	22 years
Site	Tibia	Tibia
Type	Infected nonunion	Infected nonunion

All 14 patients in the LRS group achieved union, giving an observed union rate of 100%. In the Ilizarov group, 12 of 15 patients achieved union, corresponding to an observed union rate of 80%.

The mean time to union was approximately six months in the LRS group compared with eight months in the Ilizarov group.

According to the ASAMI bone outcome criteria, the majority of patients in the LRS group had an excellent bone outcome, whereas the predominant outcome in the Ilizarov group was good. Functional assessment similarly demonstrated predominantly good outcomes in the LRS group, while the Ilizarov group showed predominantly fair functional outcomes.

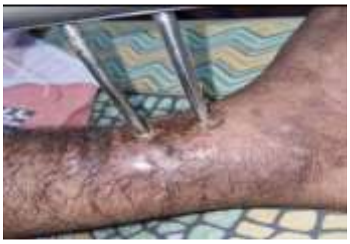
Table no. 2: Comparison of outcome of LRS & Ilizarov group:

Outcome	LRS (n=14)	Ilizarov (n=15)
Union	14/14 (100%)	12/15 (80%)
Mean time to union	6 months	8 months
Pin-tract infection	1/14 (7.1%)	3/15 (20.0%)
Limb-length discrepancy	1/14 (7.1%)	3/15 (20.0%)
Predominant ASAMI bone outcome	Excellent	Good
Predominant ASAMI functional outcome	Good	Fair
Pin-tract infection	1 (7.1%)	3 (20%)
Limb-length discrepancy	1 (7.1%)	3 (20%)

Pin-tract infection was observed in one patient in the LRS group (7.1%) and three patients in the Ilizarov group (20.0%) (Figure no. 3).Limb-length discrepancy was recorded in one patient in the LRS group (7.1%) compared with three patients in the Ilizarov group (20.0%).Because of the small sample size and absence of complete patient-level data for all outcome categories, no definitive claim of statistical superiority of one fixation method over the other can be made from the available aggregate data.

Figure no. 3: Pin side infection seen with Iliarov (a) as compared to LRS (b):

a)



b)

DISCUSSION

Infected tibial nonunion presents a complex combination of biological and mechanical problems. Successful reconstruction requires eradication of infection while simultaneously establishing mechanical stability and restoring bone continuity and, where necessary, limb length. External fixation is particularly useful in this situation because it provides stability without introducing an internal implant into a previously infected environment.

The Ilizarov method has a well-established role in the treatment of infected non-unions. Its fundamental principles are based on stable fixation, preservation of vascularity and the biological response to controlled mechanical tension. These principles allow compression at a nonunion site and distraction osteogenesis at a separate corticotomy site [1–3]. Numerous clinical studies have demonstrated the effectiveness of Ilizarov-based reconstruction in infected tibial nonunion [4,5,7,8,11,12].

In the present study, the observed union rate was higher in the LRS group than in the Ilizarov group. Union was achieved in all 14 patients treated with LRS, whereas 12 of 15 patients treated with Ilizarovfixation achieved union. The corresponding observed rates were 100% and 80%, respectively.

The mean time to union was also lower in the LRS group, approximately six months compared with eight months in the Ilizarov group. These findings may indicate a potential advantage of the acute docking and lengthening strategy when it is appropriately applied to selected patients. However, because of the limited number of patients, the difference should be interpreted cautiously and cannot be considered evidence of statistically proven superiority.

The reconstructive strategy used with the LRS was based on an important biological principle: the infected segment is radically removed until viable bone is reached, allowing the remaining healthy bone ends to be brought into contact. The shortening produced by resection is then corrected through distraction osteogenesis at a separate metaphyseal corticotomy. Similar concepts of acute compression followed by lengthening have been described using the Ilizarov technique for infected tibial defects [10].

Acute docking has several potential biological advantages. Removal of the infected segment directly addresses the principal focus of infection, while contact between viable bone ends provides a favourable environment for union. The resulting limb shortening can subsequently be corrected by distraction osteogenesis, thereby avoiding the need to retain an infected or poorly vascularised segment [2,3,10].

In the present study, fibular osteotomy was used when necessary to facilitate acute docking. The tibial infected segment was resected until healthy bleeding bone was identified, followed by preparation of the medullary canals and application of the external fixator. After docking, a proximal or distal metaphyseal corticotomy was performed according to the individual reconstruction requirements. Distraction was initiated following a latency period of approximately seven days, while compression was maintained across the docking site.

The Ilizarov method remains a valuable option because of its versatility. It permits simultaneous correction of deformity, management of bone defects, restoration of limb length and provision of stable fixation [1–3,7,8]. Bone transport using the Ilizarov apparatus has also demonstrated satisfactory results in infected tibial nonunion, particularly when substantial segmental bone loss is present [7,8].

One potential advantage of the LRS is its relatively straightforward unilateral configuration. Compared with a circular frame, a rail system may be easier to apply and may be more acceptable to some patients because of its lower profile. However, the unilateral system may be less versatile than a circular frame in cases involving severe multiplanar deformity, complex bone transport or compromised fixation corridors.

Pin-tract infection was observed in one patient in the LRS group and three patients in the Ilizarov group. Although the observed proportion was lower with LRS, the small number of patients does not permit a reliable statistical comparison. Pin-site complications remain an important consideration with any external fixation system, and meticulous pin insertion, appropriate postoperative care and regular monitoring are essential [6,11,12].

Limb-length discrepancy was also less frequently observed in the LRS group. This finding may reflect the planned use of distraction osteogenesis following acute docking. Nevertheless, limb-length restoration is influenced by the original defect size, amount of acute shortening, regenerate quality and patient compliance, and therefore cannot be attributed solely to the type of external fixator.

The ASAMI bone outcome was predominantly excellent in the LRS group and predominantly good in the Ilizarov group. Functional outcomes were predominantly good in the LRS group and fair in the Ilizarov group. These observations are encouraging, but interpretation is limited by the absence of detailed patient-level ASAMI scores and by the small sample size.

The findings suggest that LRS can be considered a useful alternative to circular fixation in appropriately selected infected tibial nonunions, particularly when radical resection, acute docking and subsequent lengthening are feasible. Nevertheless, the Ilizarov system remains an important reconstructive option and may be preferable when complex deformity correction, extensive bone transport or multiplanar adjustment is required [11,12,14].

The choice of fixation method should therefore be individualised. Important factors include the anatomical location of the nonunion, extent of infection and bone loss, quality of the soft-tissue envelope, residual deformity, anticipated limb shortening, available healthy bone for corticotomy, patient compliance and surgeon experience.

Table no. 3: Comparison of our study with Previous Studies:

Study	**Treatment method**	**No. of patients**	**Union rate**	**Mean time to union / frame duration**	**ASAMI bone outcome**	**ASAMI functional outcome**	**Major findings**
Present study – LRS group	LRS; radical debridement, acute docking and distraction osteogenesis	14	**100% (14/14)**	**6 months**	Predominantly excellent	Predominantly good	Lower observed pin-tract infection (7.1%) and limb-length discrepancy (7.1%)
Present study – Ilizarov group	Ilizarov; radical debridement, acute docking/compression and distraction osteogenesis	15	**80% (12/15)**	**8 months**	Predominantly good	Predominantly fair	Pin-tract infection 20.0%; limb-length discrepancy 20.0%

Maini et al., 2000 [4]	Ilizarov; bone transport and compression/ distraction	30 infected long-bone nonunions, including 23 tibial cases	**Not reported separately for tibia; 100% overall completion of defect reconstruction**	Median frame duration **150 days**	Excellent 70%; good 10%; fair 0%; poor 20%	Excellent 26.7%; good 40%; fair 10%; poor 23.3%	Radical resection with bone transport/compression-distraction addressed infection, bone loss, deformity and shortening simultaneously
McHale & Ross, 2004 [5]	Ilizarov with debridement and antibiotic beads; transport, shortening/lengthening, compression or bone grafting	10	**90% (9/10)** infection-free union reported in the published series	Not clearly reported in abstract	Not reported	Not reported	Two recurrences of infection; flap coverage required in 5 patients
Magadum et al., 2006 [10]	Ilizarov acute compression followed by distant-site lengthening	27	**100%**	**6.3 months** mean union time	19 excellent; 5 good; remaining 3 not excellent/good	Not reported as complete ASAMI distribution; functional results predominantly excellent/good	Mean bone resection 10 cm; mean lengthening 10 cm; acute compression and simultaneous lengthening avoided a second docking-site procedure
Yin et al., 2015 [8]	Ilizarov bone transport	65 tibial nonunions	**100% (65/65)**	External fixation duration reported in study; not directly comparable with present union-time measure	Excellent 25; good 27; fair 13; poor 0	Excellent 46; good 17; fair 7; poor 2	All cases achieved infection-free union; bone transport successfully reconstructed infected tibial defects
McNally et al., 2017 [11]	Ilizarov protocols: compression, distraction, compression/ distraction and bone transport	79	**86.1% (68/79)** after initial Ilizarov treatment	Mean frame time **7.5 months** overall; 5.0 months distraction, 6.2 months compression, 9.4 months compression/d	Excellent 74.7%; good 20.3%; fair 7.6%; poor 2.5%	Excellent 69.6%; good 20.3%; fair 7.6%; poor 2.5%*	Infection eradicated in 96.2%; distraction and bifocal compression/ distraction produced the highest primary union

				istraction, 10.7 months bone transport			rates
Wang et al., 2015 [9]	Ilizarov-based methods; systematic review/meta-analysis	590 patients from 24 studies	**97.5% for infected tibial nonunion**	Mean external fixation time **9.41 months** for infected tibial nonunion	Low pooled poor-outcome rate	Low pooled poor-outcome	

Strengths & limitations of study:

The study was prospective in design and specifically evaluated patients with infected tibial nonunion, with representation of non-unions involving the proximal, middle, and distal thirds of the tibia. Both treatment groups were assessed using comparable clinical and radiological outcome parameters, and the ASAMI bone and functional scoring systems were used for outcome assessment. Furthermore, the study directly compared two established external fixation strategies, namely LRS and Ilizarov fixation, allowing their clinical and functional outcomes to be evaluated within the same study population.

Although the final sample consisted of only 29 patients& single-centric, which limited the statistical power of the study. Another limitation was that the microbiological findings and organism-specific outcomes could not be comparatively analyzed. In addition, potential confounding factors, including smoking status, diabetes, nutritional status, and the number of previous operations, were not available for analysis. Long-term patient-reported outcome measures were not incorporated, and the available data did not permit a robust statistical comparison of all outcome variables.

CONCLUSION

Both LRS and Ilizarov external fixation provided effective treatment for infected tibial nonunion in the present series. Among the patients available for final analysis, union was achieved in 100% of the LRS group compared with 80% of the Ilizarov group. The mean time to union was approximately six months with LRS and eight months with Ilizarov fixation.

The LRS group demonstrated predominantly excellent ASAMI bone outcomes and good functional outcomes, whereas the Ilizarov group demonstrated predominantly good bone outcomes and fair functional outcomes. Pin-tract infection and limb-length discrepancy were observed less frequently among patients treated with LRS.

The treatment strategy of radical excision of infected bone, acute docking of healthy tibial segments and subsequent restoration of limb length through distraction osteogenesis provides a logical approach to simultaneously addressing infection, nonunion and post-resection shortening. This principle is consistent with established distraction osteogenesis and Ilizarov-based reconstruction concepts [2,3,10,13].

Based on the present findings, LRS may represent an effective alternative to circular Ilizarov fixation in appropriately selected cases of infected tibial nonunion. However, the relatively small sample size and limited patient-level data prevent a definitive conclusion regarding superiority. Larger prospective comparative studies with standardized treatment protocols, detailed defect characteristics, microbiological analysis, validated functional outcomes and longer follow-up are required to determine the comparative effectiveness of the two techniques.

Declarations:

Ethical consideration&Informed Consent

The study follows the ethical principal of research. Written informed consent was obtained from all patients before enrollment and surgical treatment.

Conflict of Interest

The authors declare that they have no conflict of interest.

Funding

No external funding was received for this study.

Authors' Contributions

All authors contributed to the conception and design of the study, clinical management, data collection, analysis and preparation of the manuscript.

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