RQ 53: Research question

In open injuries with segmental bone loss, should primary stabilization using a Limb Reconstruction System (LRS) be preferred over conventional external fixation?

Section 1: Background

Open injuries with significant bone loss due to high-energy trauma occur in up to 11% of fractures.(1) Further debridement of devitalized bone often increases the segmental defect, making reconstruction more challenging. These injuries are complex because contamination, bone loss, and soft-tissue loss must be addressed simultaneously. They require early debridement, infection control, stable fixation, restoration of the soft-tissue envelope, bone union, limb-length/alignment restoration, rehabilitation and patient counselling. Internal fixation may be difficult or unsafe when the soft-tissue envelope is compromised, the wound is contaminated or infected necessitating repeated debridement or when the patient is physiologically unstable. The traditional staged approach involves temporary external fixation at the time of wound debridement, followed by definitive fixation or reconstruction at a later stage.

LRS and Ilizarov/ring fixation are biologically attractive because they can function as definitive fixation devices, provide stability without placing deep implants in a contaminated zone, require minimal soft-tissue dissection, and allow bone transport. LRS is less bulky and provides easier wound access and patient care, whereas ring fixators provide multiplanar stability, reliable distraction osteogenesis, and usually permit weight-bearing during treatment. However, evidence on the use of LRS or Ilizarov fixation as a definitive method in fresh open fractures with bone loss, with simultaneous union and length restoration, remains limited.(2)

Section 2: Data extraction table

Sl. no.	Author, year, country	Study design	Sample size - open fractures with bone loss only	Study population (inclusion/exclusion criteria)	Stabilization method	Results	Other comments

1	Ajmera et al., 2015, India(2)	Prospective case series	30 open tibial diaphyseal fractures with bone loss >=4 cm were treated; 25 were evaluable after 5 were lost to follow-up. In the evaluable cohort, trauma mechanism was RTA in 23 and fall from height in 2.	Included: age 20-55 years, Gustilo-Anderson IIIA/IIIB open tibial diaphyseal fracture, injury severity score at least 5, and bone loss >=4 cm. Excluded: closed fracture, infected gap nonunion, osteoporotic fracture, follow-up <1 year, and metaphyseal fracture.	Primary debridement and LRS as definitive fixation; corticotomy and bone transport at 1 mm/day; no acute docking attempted. LRS was dynamized after approximation, followed by PTB cast after removal.	In 25 evaluable patients, mean bone loss was 5.5 cm (range 4-9 cm), mean transport duration was 13 weeks, external fixator time was 44 weeks, EFI was 56.4 days/cm, mean union time was 52 weeks, and union index was 74.5 days/cm. Union on LRS/PTB was achieved in 23/25 patients (92%). ASAMI bony results were excellent in 19, good in 3, fair in 1, and poor in 2. Functional results were excellent in 21, good in 2, and fair in 2. Complications: (1) pin-tract infection in 5/25, superficial in 4 and deep in 1; (2) deep infection requiring frame removal, serial debridement, then plating and bone grafting after infection control; (3) docking-site nonunion in 2/25 requiring plating and bone grafting; (4) LLD >2.5 cm in 2/25; (5) aseptic pin loosening in 2; (6) skin reaction in 1, treated with steroids/antiallergic medication; (7) no deformity >7 degrees; and (8) no neurovascular compromise, joint subluxation, or refracture.	LRS acted as both damage-control and definitive fixation, allowing wound access, bone transport, length restoration, and weight-bearing. Important limitation: 2/25 patients developed docking-site nonunion requiring plating/bone grafting, so secondary procedures may still be needed.
2	Elbeshry & Alabd, 2019, Egypt(3)	Case series	8 open type IIIB tibial fractures with massive bone and soft-tissue loss	Included: emergency high-energy trauma, open type IIIB tibial fracture, severe comminution, significant diaphyseal bone loss, and middle-third tibial involvement. Excluded: concomitant	Primary debridement and LRS uniplanar external fixation; second-stage rotational myocutaneous flap and osteotomy/segment transfer within 14 days.	All fractures united. Mean bony defect was 8.25 cm (range 6-12 cm). Mean fixation duration- 374 days and average external fixator index was 45.3 days/cm. Docking-site iliac bone graft was required in 5/8 cases. Complications: (1) docking-site delayed/nonunion tendency requiring cancellous grafting in 5/8; (2) pin-tract infection in 4/8, with 3 resolving with pin care/antibiotics and	LRS was used as a definitive primary method in acute type IIIB tibial bone loss. It allowed definitive fixation, segment transfer, and early flap coverage. Good soft-tissue access and absence of flap

				fractures except fibula, neurovascular injury, and compartment syndrome. Infected nonunion cases were not included.		1 requiring debridement and exchange of two pins; (3) pin loosening in 1; and (4) significant limb shortening in 1 patient (3 cm, requiring a shoe raise).	infection are relevant advantages over bulky circular frames.
3	Dheenadhayalan et al., 2022, India(4)	Retrospective cohort, level III	35 primary traumatic open tibial fractures with bone defect >4 cm requiring bone transport	Included: age >=18 years, open tibial fractures with primary bone loss, radical debridement, primary LRS application, and bone defect >4 cm. Excluded: LRS for infected nonunion, aseptic nonunion, secondary LRS after traumatic bone loss, other indications, incomplete follow-up, and loss to follow-up.	Primary LRS using a temporary spacer rod and plate alignment technique during application.	Mean segmental defect was 8.63 +/- 3.35 cm and mean regenerate length was 8.4 +/- 3.45 cm. At docking, 18 patients had no deformity, 13 had <=5 degrees, 2 had 6-10 degrees, and 2 had >10 degrees. Circumferential docking was achieved in 31/35 patients (88.5%). ASAMI functional results were excellent in 13, good in 19, fair in 1, and poor in 2. Complications: (1) pin-tract infection in 6; (2) deep infection in 3; (3) delayed union in 17; (4) docking malalignment >10 degrees in 2; and (5) secondary procedures for problems such as nonunion/delayed union or deformity, as required.	The spacer rod technique addresses an LRS-specific technical concern: docking-site malalignment. The study highlights that success with primary LRS depends heavily on initial alignment.
4	Mohammed et al., 2022, Egypt(5)	Retrospective case series	21 Gustilo III open femoral shaft fractures with segmental defect >2 cm	Included: femoral shaft fractures, segmental defects >2 cm, extra-articular fractures, and open Gustilo III injuries. Excluded: pathological or intra-articular fractures, vascular injury, and neurological, metabolic, or congenital disorders.	LRS monolateral external fixator: acute shortening and distraction (n=11) versus bone transport (n=10).	Mean EFT was shorter with acute shortening/distraction (7.7 months; range 5-9) than with bone transport (10 months; range 7-18), p=0.017. EFI was lower with bone transport (52.8 days/cm) than with acute shortening/distraction (60.8 days/cm), p=0.118. There was no significant difference in Paley bone or functional scores. Complications: (1) pin-tract infection, managed with antibiotics/dressings or premature pin removal according to severity; (2)	LRS can be used as a definitive management strategy for bone loss. Acute shortening/distraction reduced external-fixator time compared with bone transport, while bone transport had a lower EFI.

						mechanical axis deviation >5 degrees in 2 patients after fixator removal; and (3) knee flexion limitation in 3 patients.	
5	Mekhail et al., 2004, USA(6)	Retrospective case series	9 open traumatic segmental bone-loss cases without pre-existing infection/nonunion	Post-traumatic lower-extremity segmental bone defects treated by bone transport. The overall cohort included tibia and femur; open fractures were Gustilo IIIA, IIIB, and IIIC.	Ilizarov ring fixation was used for tibial cases and unilateral external fixation for femoral cases. Corticotomy was usually performed at fixator application. Transport direction depended on the defect site.	In the relevant subgroup, outcome was excellent in 2/9 and good in 7/9; all were good/excellent. Mean fixation duration was approximately 293 days, mean length restored was approximately 4.6 cm, and mean residual LLD was approximately 1.5 cm. Complications included pin-tract infection, soft-tissue contracture, premature union at the distraction site, fracture at the docking site during physiotherapy, ankle ankylosis, deep infection/nonunion at the distraction site that healed, knee flexion contracture, temporary sensory deficit, and docking-site nonunion requiring further external fixation/healing.	Bone transport/circular fixation was used as a limb-salvage option for traumatic segmental defects.
6	Sen et al., 2004, Turkey(7)	Case series	24 acute grade III open tibial fractures with bone and soft-tissue loss	Included: open tibial fracture with bone and soft-tissue loss, MESS <=6, and bone defect. Excluded: MESS >6, noncomminuted fractures, and multiple injuries. Mechanisms included car accidents, industrial injuries, and falls.	Ilizarov-type circular external fixator with bifocal compression-distractio n/shortening-lengthenin g.	Mean bone defect was 5 cm (range 3-8.5 cm); 14 fractures were IIIA and 10 were IIIB. Mean bone healing time was 7.5 months, mean external fixation duration was 7.1 months, and EFI was 1.4 months/cm. Bone results were excellent in 21 and good in 3. Functional results were excellent in 19, good in 4, and fair in 1. There were 52 complications in 24 patients (2.08/patient): (1) pin-site infection in 10.7% of pin sites; (2) minor problems including soft-tissue inflammation/infection, translation/angulation, delayed	Circular fixation showed excellent union and function. Shortening-lengtheni ng can reduce the soft-tissue defect, facilitate natural wound healing/closure, reduce the need for flap reconstruction, and restore length and alignment.

						maturation during distraction, and transient knee contracture/loss of motion; (3) obstacles needing surgery including pin-tract infection/reinfection, equinus deformity, frame failure, and premature consolidation; and (4) sequelae including LLD, knee/ankle ROM loss, knee flexion contracture, malalignment, and chronic osteomyelitis.	
7	van Niekerk et al., 2017, South Africa(8)	Retrospective comparative cohort	12 acute traumatic grade III open tibial fractures with segmental bone loss; infected nonunion cohort (n=12) excluded for this question	Included: age 16-60 years, acute traumatic grade III open tibial fracture or infected nonunion, and minimum 12 months follow-up. For this table, only the acute trauma group was retained. Excluded: previous ipsilateral tibial fracture, contralateral lower-limb fracture, polytrauma, chest/abdominal trauma, and head injury.	Circular external fixation with antibiotic-impregnated PMMA spacer and distraction osteogenesis; compared in the original study with an infected nonunion cohort.	In the acute trauma group, mean bone defect was 82 +/- 36 mm, EFT was 249 +/- 99 days, and EFI was 37.3 +/- 9.1 days/cm. Overall union rate for the combined cohort was 91.7%, and overall complications were 50%. Relevant complications: (1) pin-tract infection in 7/24 requiring systemic antibiotics; (2) nonunion in 2/24 overall; (3) in the trauma group, 1 mangled extremity with persistent nonunion opted for below-knee amputation; (4) 1 trauma patient required two circular-fixator adjustments and leg lengthening for 4 cm shortening; and (5) 1 stress fracture at the docking site was treated conservatively.	Circular fixation with PMMA spacer had a low EFI in acute trauma. Antibiotic PMMA spacer may be helpful in acute contaminated open tibial bone loss.

8	Ajiboye et al., 2025, Nigeria(9)	Retrospective case series	27 gunshot-related Gustilo type III long-bone fractures with bone loss	Complex long-bone gunshot injuries treated with LRS for limb salvage. All had bone loss either from the initial injury or following debridement; 23 IIIA and 4 IIIB injuries. Bones involved: tibia 17, femur 7, humerus 3.	Debridement + Linear Rail System. Primary docking with later limb lengthening in 16/27; bone transport from osteotomy site in 11/27. Distraction at 1 mm/day started 7–10 days postoperatively.	All achieved union and limb length equalization/bone transport. Mean regenerated bone gap was 8.92 cm. Infection occurred in 13/27 and was treated successfully. Re-operation for bone grafting was required in 9/27. Normal adjacent joint ROM in 78%; satisfactory self-reported limb function in 93%.	LRS was considered a good option for complex gunshot-related long-bone fractures with bone loss, allowing soft-tissue care, infection control, fracture union, limb-length restoration and functional rehabilitation

Section 3: Results

Seven studies were included, comprising LRS and circular/Ilizarov fixation used primarily for open traumatic fractures with segmental bone loss. Among the LRS tibial studies, Elbeshry and Alabd reported union in all 8 type IIIB tibial fractures with a mean defect of 8.25 cm. (3) Ajmera et al. treated 30 open tibial diaphyseal fractures with bone loss >=4 cm, of which 25 were evaluable.(2) The mean bone loss was 5.5 cm; union was achieved in 23/25 patients, with excellent/good ASAMI bony results in 22 and excellent/good functional results in 23. Mekhail et al. provided indirect comparator evidence from 9 open traumatic segmental bone-loss cases, with excellent outcomes in 2 and good outcomes in 7, and a mean length restoration of 4.6 cm. (6) All patients in this cohort could perform activities of daily living, and most walked without support. Despite several complications, patients were satisfied with limb preservation. Taken together, these studies suggest that LRS is an effective definitive treatment option for open tibial fractures with bone loss. Reported advantages include a relatively simple and minimally invasive technique, stable fixation with simultaneous bone transport, better patient compliance, easier wound care, facilitation of early soft-tissue coverage, joint mobilization, reduced hospitalization, and fewer complications such as infection, deformity, or residual shortening.

Dheenadhayalan et al. further showed that primary LRS can be used for larger traumatic tibial defects, although docking alignment remains an important technical limitation. (4) To improve alignment during LRS application, they used a temporary spacer rod and plate technique in 35 primary traumatic open tibial fractures with bone defects >4 cm. Circumferential docking was achieved in 31/35 patients, and functional outcomes were excellent or good in 32. Applying LRS primarily, before soft-tissue reconstruction, allowed alignment of the exposed bony fragments without additional exposure. Radical debridement with primary LRS may also reduce the number of surgeries, treatment duration, secondary hospitalization, and financial burden.

Mohammed et al. reported 21 Gustilo III open femoral shaft fractures with segmental defects >2 cm treated using monolateral LRS.(5) Patients underwent either acute shortening/distraction or bone transport. Acute shortening/distraction had a shorter external fixation time than bone transport, 7.7 versus 10 months, although bone transport had a lower external fixation index. Paley bone and functional scores were similar. Acute shortening immediately reduced the defect and may facilitate soft-tissue closure by reducing the wound gap, potentially avoiding additional soft-tissue procedures. However, shortening must be limited by soft-tissue tension and the absence of neurovascular compromise. This strategy also avoids a prolonged docking phase because the bone ends are already in contact.

The circular fixation evidence was also supportive. Sen et al. reported excellent/good bony results in all 24 acute grade III open tibial fractures with bone and soft-tissue loss treated using bifocal compression-distraction. (7) Acute shortening was used for defects up to 3 cm, while gradual shortening at 2 mm/day was used for larger defects, with length restored through corticotomy and distraction. Although all patients had soft-tissue loss, the wounds healed completely after acute or gradual shortening without secondary soft-tissue surgery. The mean bone healing time was 7.5 months, and the mean external fixation duration was 7.1 months. Van Niekerk et al. described another approach to reduce EFI in 12 acute traumatic grade III open tibial fractures treated with debridement, circular fixation, antibiotic-impregnated PMMA spacer, and distraction osteogenesis.(8) The mean bone defect was 82 mm, EFT was 249 days, and EFI was 37.3 days/cm. Their findings suggest that antibiotic-impregnated spacers may reduce EFI in open tibial trauma.

Ajiboye et al. further showed that LRS can also be used in high-energy gunshot-related complex long-bone injuries with bone loss, achieving union and limb length restoration in all 27 Gustilo type III cases, although infection, stiffness and secondary bone grafting remained common.(9)

Overall, both LRS and circular fixation achieved high union rates, but prolonged treatment, pin-site complications, docking-site problems, and secondary procedures remained frequent.

Section 4: Discussion

Large bone defects following traumatic open fractures are complex injuries that can be challenging for both the patient and the surgeon, as they require multiple decisions throughout a prolonged reconstructive pathway. Conventional treatment with temporary external fixation followed by secondary definitive management with nailing has been associated with a higher incidence of infection.(10–12) In this setting, the contemporary techniques for reconstructing critical-sized bone defects are the induced membrane technique and distraction osteogenesis with bone transport. Mauffrey et al., and Toogood et al. state that both induced membrane technique and distraction osteogenesis are excellent options for bony reconstruction, with early soft-tissue coverage being critical.(13,14) There are no direct comparative studies between the induced membrane technique (IMT) and distraction osteogenesis (DO) to determine which is preferable for a specific patient. Given the heterogeneity of patients and injury patterns, it is unlikely that one method is universally superior. Relatively small, non-circumferential defects, especially those with stable internal fixation, may be better suited for IMT. However, repeated hospitalization, revision surgeries, and donor-site morbidity must be considered. In contrast, combined management of the soft-tissue defect and bone loss in a single stage can shorten hospitalization and reduce morbidity and cost; this can be achieved more appropriately with primary LRS or circular fixation. Another advantage is functional loading and use of the affected extremity, allowing earlier return to functional activities. Disuse osteoporosis, which may occur during non-weight-bearing mobilization in Masquelet reconstruction, may be reduced with external fixation methods.

Both LRS and Ilizarov fixation have specific advantages and disadvantages. LRS is easy to handle, economical, technically simpler, and allows easier soft-tissue coverage and access for dressings and follow-up. Its lightweight monolateral design improves mobilization and patient compliance, and less interference with radiographic visualization is another desirable attribute.(2) These features make LRS particularly attractive in resource-limited settings. Ilizarov fixation, on the other hand, provides more stable multiplanar fixation and allows earlier weight-bearing. It is also preferred in short segments and periarticular fractures where Schanz pin placement may not be feasible. Soft-tissue reconstruction is another determinant of construct choice. Conventional Ilizarov frames can be cumbersome when flap coverage is required. Rings and pins may limit the working space, narrow flap options, and potentially place the vascular pedicle at risk if wires or pins are close to the flap or recipient vessels. Open-ring modifications attempt to solve this by creating an access window for flap inset and microsurgery while maintaining skeletal stability. Therefore, if a flap is anticipated, the orthopaedic and plastic surgery teams must plan pin/wire placement, recipient vessels, and flap inset before definitive frame application.(15)

Cost and resource utilization are other determining factors. Temporary external fixation is often used only for a short period before definitive fixation, yet it adds substantial implant cost. Chaus et al. reported that 92% of external fixators in a level-1 trauma centre were used temporarily, with an average temporary fixation duration of 10.5 days and an average frame component cost of about $5900.(16) LRS may reduce duplication because it can act as both the initial stabilizer and the definitive reconstruction device within one construct. In injuries where distraction osteogenesis, bone transport, or staged length restoration is clearly required, using a definitive limb reconstruction construct at the first instance may avoid duplication of implants, anaesthesia, theatre time, and hospital stay. This is especially relevant in resource-limited settings where repeated procedures, prolonged admission, and multiple implants increase financial burden.

Prolonged treatment duration is another major concern. Since consolidation of both the distraction and docking sites is often the longest phase of treatment, strategies aimed at reducing this time are important.(6) Prokuski and Marsh recommend small cancellous bone grafts to the docking site when more than 3 cm of bone has been transported. (17) Van Niekerk et al. suggested the use of an antibiotic-impregnated spacer, which reduced the EFI considerably.(8) Possible reasons include the additional benefit of local antibiotic therapy in open tibial fractures and the biological effect of the induced membrane, which may provide a chamber, prevent fibrous tissue invasion, secrete growth factors, stimulate bone formation, and stabilize the regenerate. Another strategy is limb shortening to close the bone gap. Acute shortening at the fracture site facilitates wound closure and compensates for bone loss(5,7). This promotes early bone contact, begins healing at the problematic docking site, and may reduce the need for bone grafting. It may also reduce docking-site complications such as skin invagination, malalignment, and nonunion.

Although definitive external fixation has many advantages, the recommendation is not absolute. Primary LRS or circular fixation in segmental defects should be considered only after careful patient selection. These are high-velocity injuries and are often associated with injuries to other systems. LRS and Ilizarov fixation are technically demanding and may not be suitable as primary fixation in haemodynamically unstable or polytrauma patients. In such cases, rapid debridement and damage-control external fixation remain safer, and temporary external fixation will still be the preferred initial modality.

Overall, both LRS and circular fixation achieved high union rates in open traumatic segmental bone loss. However, prolonged treatment duration, complications, and secondary procedures remain major concerns.

Section 5: Risk of bias assessment

Study	Tool used	Score	Level	Judgement
Elbeshry & Alabd 2019	JBI Case Series Checklist	7/10	Level IV	Moderate
Dheenadhayalan et al. 2022	JBI Case Series Checklist	8/10	Level III	Moderate
Ajmera et al. 2015	JBI Case Series Checklist	8/10	Level IV	Low-moderate
Mohammed et al. 2022	Newcastle-Ottawa Scale	6/9	Level III	Moderate

Mekhail et al. 2004	JBI Case Series Checklist	6/10	Level IV	Moderate-high
Sen et al. 2004	JBI Case Series Checklist	8/10	Level IV	Low-moderate
van Niekerk et al. 2017	Newcastle-Ottawa Scale	7/9	Level III	Moderate

Section 6: Level/strength of evidence

The evidence base is limited mainly to retrospective cohorts and case series with small sample sizes, inconsistent comparators, and heterogeneous techniques. Therefore, the overall strength of evidence is low to moderate. However, the direction of evidence is consistent: when segmental bone loss is present and the limb is salvageable, definitive primary LRS or circular fixation can achieve union and limb salvage, provided patient selection, debridement, soft-tissue planning, and alignment are meticulous. There remains a lack of large-scale randomized controlled trials directly comparing monolateral/LRS, conventional external fixators, and circular/ring fixators. Data on long-term patient-reported outcomes beyond radiological and functional scores are also limited.

Recommendation

In open fractures with segmental bone loss, primary stabilization with LRS is recommended over conventional external fixation when performed in an orthoplastic setup as the evidence favours it.

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