International Journal of Health Sciences and Research
[Indexed, Peer-Reviewed Journal]
Volume 16; Issue: 7; July 2026
Website: www.ijhsr.org
Original Research Article *ISSN: 2249-9571*

Clinical, Radiological, and Functional Outcomes of Open Long Bone Fractures Treated Primarily with the Limb Reconstruction System: A Prospective Observational Study

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DOI: https://doi.org/10.52403/ijhsr.20260711

ABSTRACT

Background: Open long bone fractures are associated with significant soft tissue injury, infection, delayed union, and functional impairment. The Limb Reconstruction System (LRS) provides stable external fixation while facilitating soft tissue management and early rehabilitation. However, prospective evidence regarding its clinical and functional outcomes remains limited.

Objective: To evaluate the clinical, radiological, and functional outcomes of open long bone fractures treated primarily with the Limb Reconstruction System (LRS).

Materials and Methods: This prospective observational study was conducted at the Department of Orthopaedics, SRMS Institute of Medical Sciences, Bareilly, India, between April 2024 and September 2025. Of the 24 patients assessed for eligibility, 19 completed the 24-week follow-up and were included in the final analysis. Clinical and radiological outcomes were assessed using the Modified Johner and Wruhs criteria, Association for the Study and Application of Methods of Ilizarov (ASAMI) bone and functional criteria, radiological union, weight-bearing status, and postoperative complications. Fisher's exact test was used to evaluate the association between Gustilo–Anderson fracture grade and treatment outcomes.

Results: The mean age of the participants was 36.4 ± 10.7 years, and 78.9% were males. Tibial fractures accounted for 78.9% of injuries. The mean time to definitive fixation was 7.4 ± 2.8 hours, while radiological union was achieved in 18 (94.7%) patients at a mean of 18.3 ± 4.1 weeks. Excellent outcomes were observed in 52.6% of patients according to the Modified Johner and Wruhs criteria, 73.7% according to the ASAMI bone criteria, and 63.2% according to the ASAMI functional criteria. Superficial pin tract infection was the most common complication (36.8%). Although patients with Gustilo type IIIB fractures showed comparatively poorer outcomes, the association was not statistically significant ($p>0.05$).

Conclusion: Primary LRS fixation achieved satisfactory fracture union, favorable functional recovery, and an acceptable complication profile, supporting its use as an effective treatment option for selected open long bone fractures.

Keywords: *Open fracture; Limb Reconstruction System; External fixation; Functional outcome; Radiological union; ASAMI; Gustilo–Anderson classification.*

INTRODUCTION

Open fractures of long bones represent one of the most challenging injuries in orthopaedic trauma because of the combined disruption of bone, soft tissues, and surrounding neurovascular structures. These injuries are predominantly caused by high-energy trauma, particularly road traffic accidents, and are associated with increased risks of infection, delayed union, non-union, prolonged hospitalization, and long-term functional impairment. The primary goals of treatment are to prevent infection, achieve fracture union, restore limb function, and minimize complications through timely debridement, antibiotic administration, fracture stabilization, and soft tissue management.[1–3]

The Gustilo–Anderson classification remains the most widely accepted system for classifying open fractures and guiding treatment strategies. Higher-grade injuries, particularly Gustilo type III fractures, are associated with extensive soft tissue damage, contamination, delayed healing, and inferior functional outcomes compared with lower-grade injuries.[2,4] Therefore, stable fracture fixation that preserves the biological environment while allowing adequate soft tissue care remains a major challenge in the management of these injuries.

Several fixation methods have been described for the management of open long bone fractures, including external fixation, intramedullary nailing, and plate osteosynthesis. Although intramedullary nailing is considered the standard treatment for many diaphyseal fractures, its use in severely contaminated open fractures remains controversial because of concerns regarding infection and additional disruption of the endosteal blood supply. Conventional external fixation provides rapid stabilization and facilitates wound care but is often associated with complications such as pin tract infection, pin loosening, malalignment, and patient discomfort.[5,6]

The Limb Reconstruction System (LRS) is a monolateral external fixation device based on the principles of distraction osteogenesis. It provides rigid fixation, allows controlled compression and distraction, facilitates early mobilization, and permits repeated wound inspection without disturbing fracture stability. Compared with circular external fixators, LRS is technically less demanding, more patient-friendly, and generally better tolerated while providing satisfactory biomechanical stability.[7–9]

Several studies have demonstrated favorable fracture union and functional outcomes following LRS fixation in open tibial fractures and infected non-unions. Ajmera et al. reported excellent bone and functional outcomes in the majority of patients treated with LRS for open tibial fractures with bone loss.[10] Similarly, Singh et al. observed satisfactory fracture union with early weight bearing and good functional recovery following primary LRS fixation.[11] However, most available studies have focused primarily on tibial fractures, while evidence regarding both tibial and femoral open long bone fractures remains limited. Furthermore, prospective data evaluating clinical outcomes, radiological union, postoperative complications, and the influence of fracture severity on functional recovery are still scarce.

Therefore, the present study was undertaken to evaluate the clinical, radiological, and functional outcomes of open long bone fractures managed primarily using the Limb Reconstruction System and to determine the relationship between Gustilo–Anderson fracture severity and final treatment outcomes.

Objective

To evaluate the clinical, radiological, and functional outcomes of open long bone

fractures treated primarily with the Limb Reconstruction System (LRS).

MATERIALS & METHODS

Study Design and Setting

This prospective observational study was conducted in the Department of Orthopaedics at Shri Ram Murti Smarak Institute of Medical Sciences, Bareilly, Uttar Pradesh, India, between April 2024 and September 2025. The study aimed to evaluate the clinical, functional, and radiological outcomes of open long bone fractures managed primarily with the Limb Reconstruction System (LRS).

Study Population/Sample size

A total of 24 consecutive patients presenting with open long bone fractures were assessed for eligibility. Two patients were excluded because they did not meet the inclusion criteria, and three patients were lost to follow-up. Consequently, 19 patients who completed the scheduled 24-week follow-up were included in the final analysis.

Since this was a prospective observational study conducted over the study period, all eligible consecutive patients fulfilling the inclusion criteria were included. No formal sample size calculation was performed.

Inclusion Criteria

i. Patients aged ≥18 years.
ii. Open diaphyseal fractures of the tibia or femur classified as Gustilo–Anderson type II, IIIA, or IIIB.
iii. Patients managed primarily with the Limb Reconstruction System.
iv. Patients who provided written informed consent.

Exclusion Criteria

i. Gustilo–Anderson type I and type IIIC fractures.
ii. Fractures older than two weeks.
iii. Closed fractures.
iv. Pathological fractures.
v. Established non-union.
vi. Patients unwilling to participate or unable to complete follow-up.

Surgical Procedure

Following initial resuscitation and administration of intravenous antibiotics, all patients underwent thorough wound irrigation and surgical debridement under aseptic conditions. Fracture stabilization was performed using the Limb Reconstruction System (LRS) according to standard operative techniques. The choice of Schanz pin placement and frame configuration depended on the fracture location and morphology. Soft tissue management was performed simultaneously or in a staged manner whenever required.

Postoperative Management

All patients received intravenous first-generation cephalosporin antibiotics for 5–7 days, followed by appropriate oral antibiotics when indicated. Passive range-of-motion exercises were initiated on the first postoperative day. Protected weight bearing was encouraged according to fracture stability and radiological progress. Patients were reviewed regularly in the outpatient department for clinical and radiological assessment.

Outcome Measures

Patients were followed for 24 weeks after surgery.

The primary outcome was functional recovery assessed using the Modified Johner and Wruhs criteria.

Secondary outcomes included:

Radiological outcome assessed using the Association for the Study and Application of Methods of Ilizarov (ASAMI) Bone Criteria.

Functional outcome assessed using the ASAMI Functional Criteria.

Time to radiological union.

Time to definitive fixation.

Achievement of full weight bearing.

Postoperative complications, including superficial pin tract infection, pin loosening, delayed union, malunion, deep infection, non-union, and the requirement for secondary surgical procedures.

Radiological union was defined as bridging callus across at least three cortices on anteroposterior and lateral radiographs together with painless full weight bearing.

Data Collection

Demographic characteristics, injury profile, operative details, postoperative progress, functional scores, radiological findings, and complications were prospectively recorded using a standardized case record form.

Statistical Analysis: Data were analyzed using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were summarized as frequencies and percentages. The association between Gustilo–Anderson fracture grade and ASAMI bone and functional outcomes was assessed using Fisher's exact test because of the small sample size and sparse contingency tables. A two-sided p-value <0.05 was considered statistically significant.

Ethical Considerations

The study was approved by the Institutional Ethics Committee of Shri Ram Murti Smarak Institute of Medical Sciences, Bareilly (Approval No. SRMSIMS/ECC/ 2024/101). Written informed consent was obtained from all participants before enrolment.

RESULT

Figure 1 depicts the participant flow during the study. Of the 24 patients assessed for eligibility, 2 were excluded based on the predefined eligibility criteria. The remaining 22 patients underwent LRS fixation, of whom 3 were lost to follow-up. Consequently, 19 patients completed the 24-week follow-up and were included in the final analysis.

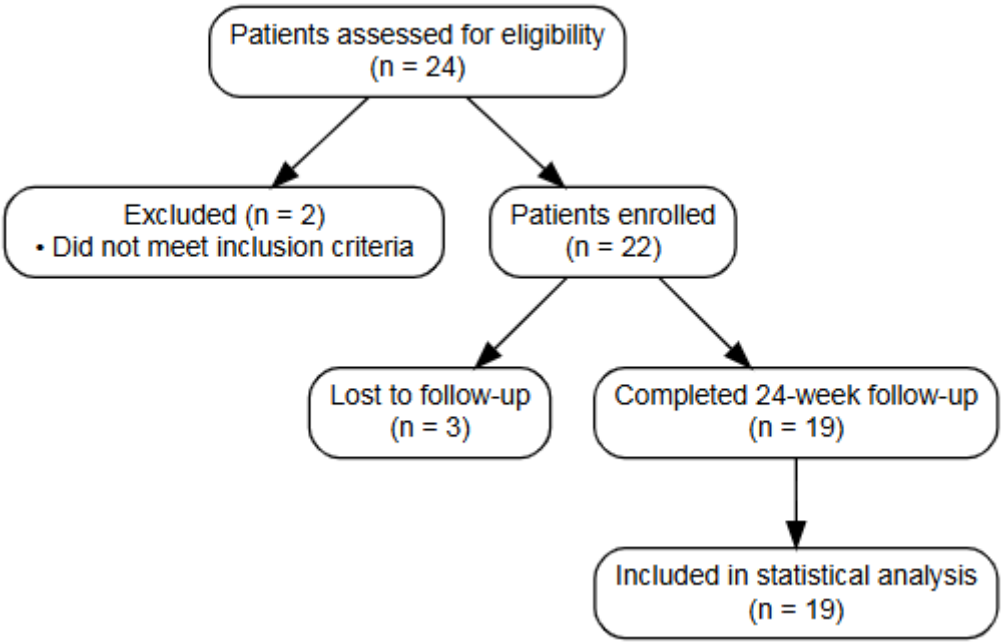

Figure 1: Study Flow Diagram of Patient Recruitment and Follow-up

Table 1 show that the 19 patients completed the study. The mean age was 36.4 ± 10.7 years, with most patients belonging to the 36–45-year age group (36.8%). Males constituted 78.9% of the study population. Tibial fractures accounted for 78.9% of injuries, while femoral fractures represented 21.1%. Road traffic accidents were the predominant mechanism of injury (89.5%). Nearly half of the fractures (47.4%) were classified as Gustilo–Anderson type IIIB, indicating a high proportion of severe open injuries.

Table 1: Baseline Demographic and Injury Characteristics of Study Participants (N=19)

Variable	Category	n (%) / Mean ± SD
Age (years)	Mean ± SD	**36.4 ± 10.7**
	18–25	3 (15.8)
	26–35	5 (26.3)
	36–45	7 (36.8)
	46–55	3 (15.8)
	56–65	1 (5.3)
Sex	Male	15 (78.9)
	Female	4 (21.1)
Bone involved	Tibia	15 (78.9)
	Femur	4 (21.1)
Mechanism of injury	Road traffic accident	17 (89.5)
	Industrial accident	2 (10.5)
Gustilo–Anderson grade	Type II	5 (26.3)
	Type IIIA	5 (26.3)
	Type IIIB	9 (47.4)

Table 2 shows that the mean interval between injury and definitive LRS fixation was **7**.4 ± 2.8 hours**.** Radiological union was achieved at a mean duration of 18.3 ± 4.1 weeks**.** By the final follow-up at 24 weeks**,** 94.7% of patients had achieved full weight bearing. Secondary surgical procedures were required in 31.6% of patients during follow-up.

Table 2: Operative and Clinical Outcomes Following Limb Reconstruction System Fixation (N = 19)

Variable	Value
Time to definitive fixation (hours), Mean ± SD	7.4 ± 2.8
Radiological union (weeks), Mean ± SD	18.3 ± 4.1
Full weight bearing at 24 weeks	18 (94.7%)
Secondary procedures required	6 (31.6%)
Radiological union achieved	18 (94.7%)

Figure 2 shows functional assessment using the Modified Johner and Wruhs criteria demonstrated excellent outcomes in 52.6% of patients, whereas 15.8% achieved good results. According to the ASAMI bone criteria, 73.7% of patients had excellent radiological outcomes. Similarly, 63.2% achieved excellent functional outcomes based on the ASAMI functional criteria, indicating satisfactory clinical recovery in the majority of patients.

Figure 2 illustrates the distribution of postoperative complications among patients treated with the Limb Reconstruction System (LRS). Superficial pin tract infection was the most frequently encountered complication, affecting 7 patients (36.8%)**,** followed by delayed union in 4 patients (21.1%) and deep infection in 3 patients (15.8%)**.** Pin loosening and malunion were each observed in 2 patients (10.5%)**,** while non-union occurred in 1 patient (5.3%)**.** Overall, the majority of complications were minor and manageable, with superficial pin tract infection representing the predominant postoperative adverse event.

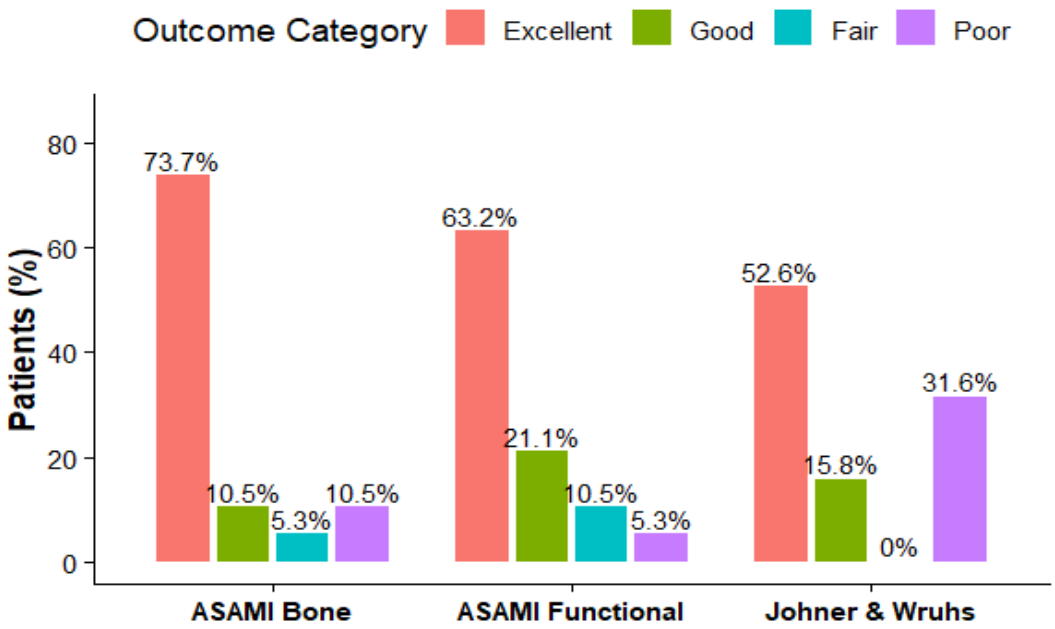

Figure 2: Functional and Radiological Outcomes at Final Follow-up (N = 19)

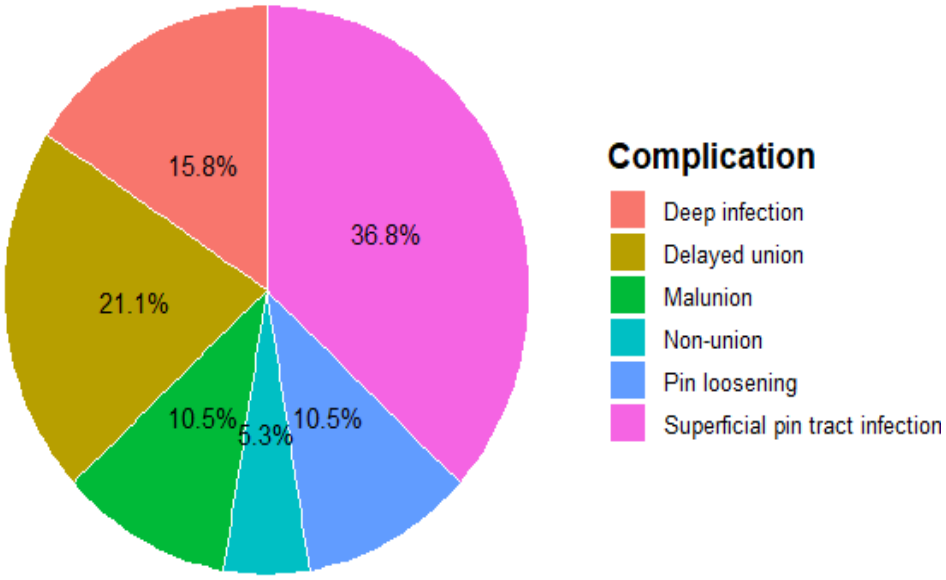

Figure 3: Distribution of Postoperative Complications Following LRS Fixation (N = 19)

Table 4 shows the association between Gustilo–Anderson fracture grade and both ASAMI bone and ASAMI functional outcomes. Excellent ASAMI bone outcomes were achieved in all patients with Gustilo type II fractures (100.0%), 80.0% of those with type IIIA fractures, and 55.6% of those with type IIIB fractures. Similarly, excellent ASAMI functional outcomes were observed in 80.0% of patients with type II fractures, 100.0% of patients with type IIIA fractures, and 33.3% of patients with type IIIB fractures. Fair and poor outcomes occurred exclusively among patients with type IIIB fractures. Although outcomes tended to worsen with increasing fracture severity, neither the ASAMI bone outcome ($p = 0.344$) nor the ASAMI functional outcome ($p = 0.501$) showed a statistically significant association with Gustilo–Anderson classification.

Table 4: Association of Gustilo–Anderson Classification with ASAMI Bone and Functional Outcomes (N = 19)

Outcome Measure	Outcome Category	Type II (n=5)	Type IIIA (n=5)	Type IIIB (n=9)	p-value*
ASAMI Bone Criteria	Excellent	5 (100.0)	4 (80.0)	5 (55.6)	**0.344**
	Good	0 (0.0)	1 (20.0)	1 (11.1)	
	Fair	0 (0.0)	0 (0.0)	1 (11.1)	
	Poor	0 (0.0)	0 (0.0)	2 (22.2)	
ASAMI Functional Criteria	Excellent	4 (80.0)	5 (100.0)	3 (33.3)	**0.501**
	Good	1 (20.0)	0 (0.0)	3 (33.3)	
	Fair	0 (0.0)	0 (0.0)	2 (22.2)	
	Poor	0 (0.0)	0 (0.0)	1 (11.1)	

***Fisher exact test**

DISCUSSION

The present prospective observational study evaluated the clinical, radiological, and functional outcomes of open long bone fractures managed primarily with the Limb Reconstruction System (LRS). The principal findings demonstrated that LRS provided satisfactory fracture stabilization, with a high rate of radiological union, favorable functional outcomes, and an acceptable complication profile. Radiological union was achieved in the majority of patients within a mean duration of 18.3 ± 4.1 weeks, while 94.7% of patients achieved full weight bearing by the final follow-up. According to the Modified Johner and Wruhs criteria, more than half of the patients (52.6%) achieved excellent functional outcomes, whereas the ASAMI bone and functional criteria demonstrated excellent outcomes in 73.7% and 63.2% of patients, respectively. Although patients with Gustilo–Anderson type IIIB fractures tended to have poorer outcomes than those with lower-grade injuries, the observed differences were not statistically significant. These findings suggest that primary LRS fixation is an effective treatment option for selected open long bone fractures, providing stable fixation while facilitating fracture healing and functional recovery.[9, 10]

The demographic profile observed in the present study was consistent with the epidemiology of open long bone fractures reported in previous studies. The mean age of the study population was 36.4 ± 10.7 years, with the highest proportion of patients belonging to the economically productive age group of 36–45 years. Furthermore, 78.9% of the participants were male, and road traffic accidents accounted for 89.5% of all injuries. These findings reflect the increased exposure of young adult males to high-energy trauma and are comparable with previous reports that identified road traffic accidents as the leading cause of open fractures among the working-age population. [11, 13]

The predominance of tibial fractures (78.9%) observed in the present study is also in agreement with previous literature. Owing to its subcutaneous location and limited soft tissue coverage, the tibia is particularly vulnerable to open injuries following high-energy trauma. Nearly half of the fractures in the present study were classified as Gustilo–Anderson type IIIB, indicating that a substantial proportion of patients sustained severe soft tissue injuries. Despite this, satisfactory clinical and radiological outcomes were achieved following LRS fixation, highlighting the ability of this fixation system to provide adequate stability while allowing repeated wound inspection, soft tissue procedures, and early mobilization without compromising fracture alignment.[7,10]

One of the major findings of the present study was the favorable fracture healing observed following LRS fixation. Radiological union was achieved in almost all patients, with a mean union time of 18.3 weeks. This finding is comparable to previous studies evaluating LRS in open

tibial fractures, which have reported mean union times ranging from approximately 16 to 22 weeks, depending on fracture severity and associated soft tissue injury. The rigid unilateral frame design of the LRS permits controlled axial compression at the fracture site while preserving periosteal blood supply, thereby promoting biological fracture healing. In addition, the system facilitates early weight bearing, which may further stimulate callus formation and accelerate fracture union.[13,14]

The functional outcomes observed in the present study further support the effectiveness of LRS as a definitive fixation method for open long bone fractures. According to the Modified Johner and Wruhs criteria, 68.4% of patients achieved excellent or good functional outcomes, while the ASAMI functional criteria demonstrated excellent or good outcomes in 84.3% of patients. Similarly, excellent or good ASAMI bone outcomes were achieved in 84.2% of patients. These findings are consistent with previous prospective studies reporting favorable functional recovery following primary LRS fixation, which have attributed these outcomes to stable fracture fixation, preservation of the biological environment, and early rehabilitation protocols. [9,15]

Strength & Limitations:

This study has several limitations, including the relatively small sample size, single-center design, and short follow-up period of 24 weeks, which may limit the generalizability of the findings and the assessment of long-term outcomes. Additionally, the absence of a comparison group precluded direct evaluation of the effectiveness of the Limb Reconstruction System against other fixation methods. Strengths of the study include its prospective design, standardized surgical protocol, uniform follow-up schedule, and comprehensive evaluation using validated functional and radiological outcome measures.

CONCLUSION

The present prospective observational study demonstrated that the Limb Reconstruction System (LRS) is an effective treatment modality for selected open long bone fractures, providing stable fracture fixation with satisfactory clinical, radiological, and functional outcomes. Most patients achieved radiological union within an acceptable time frame, regained full weight-bearing capacity, and demonstrated excellent to good functional recovery according to the Modified Johner and Wruhs and ASAMI criteria. Although superficial pin tract infection was the most common postoperative complication, it was generally manageable with appropriate treatment. Patients with Gustilo–Anderson type IIIB fractures showed a trend toward poorer bone and functional outcomes; however, the association was not statistically significant. Overall, LRS represents a reliable option for the primary management of open long bone fractures, particularly in cases requiring stable fixation while preserving the soft tissue envelope. Nevertheless, larger multicenter studies with longer follow-up are warranted to validate these findings and further establish the long-term effectiveness of this technique.

Declaration by Authors

Ethical Approval: Approved
Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Devansh Agarwal, Suresh K. Kaushik, Sanjay Gupta, Anup Kumar, Aditya Sharma, Harshvardhan Buddhist. Clinical, radiological, and functional outcomes of open long bone fractures treated primarily with the limb reconstruction system: a prospective observational study. *Int J Health Sci Res.* 2026;16(7):104-112.
DOI: https://doi.org/10.52403/ijhsr.20260711

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