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Original Research Article

Evaluation of Bone Healing in Open vs. Closed Fractures

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Abstract:

Background: Fracture healing is a complex physiological process significantly influenced by the integrity of the surrounding soft tissue envelope. While closed fractures generally proceed through predictable healing stages, open fractures present unique challenges due to periosteal stripping, contamination, and vascular compromise.

Objective: To evaluate and compare the radiological and clinical outcomes of bone healing in open versus closed fractures of long bones.

Methods: A prospective observational study was conducted at the Department of Orthopaedics, Jawaharlal Nehru Medical College and Hospital (JLNMCH), Bhagalpur, Bihar, from January 29, 2025, to the present. The study enrolled 50 adult patients (aged 18–60 years) presenting with fresh diaphyseal fractures of the tibia or femur within 24 hours of injury. Participants were stratified into two cohorts: Group A (Closed Fractures, n=25) comprising Tscherne Grades 0–2 managed via Closed Reduction and Internal Fixation (CRIF), and Group B (Open Fractures, n=25) comprising Gustilo-Anderson Types I, II, and IIIA managed via emergency debridement followed by external fixation or primary nailing depending on contamination levels. Post-operative assessment was conducted at 2, 6, 12, 18, and 24 weeks. The primary outcome measure was radiological union, quantified using the Radiographic Union Scale for Tibial fractures (RUST), alongside clinical indicators of painless full weight-bearing.

Results: The mean time to radiographic union was significantly shorter in Group A (14.2 $\pm$ 2.1 weeks) compared to Group B (22.4 $\pm$ 4.5 weeks). Deep infection rates were markedly higher in Group B (20%) compared to Group A (0%). The RUST score progression at 6, 12, and 18 weeks showed faster cortical bridging in closed fractures.

Conclusion: Open fractures are associated with delayed union and higher complication rates compared to closed fractures. Aggressive soft tissue management and early stabilization are critical for optimizing outcomes in the open fracture cohort.

Introduction

Fracture healing is a distinct and intricate biological phenomenon wherein tissues are restored to their original physical and mechanical properties without the formation of scar tissue. This regenerative capacity is heavily dependent on the local biological environment, specifically the adequacy of the blood supply and the condition of the surrounding soft tissues [1]. The distinction between open and closed fractures extends far beyond the dermatological presentation; it represents a fundamental divergence in the biological potential for healing and the associated risks of complications. The integrity of the soft tissue envelope is paramount, as it serves as the conduit for vascularity and the source of mesenchymal stem cells necessary for repair.

Pathophysiology of Fracture Healing: Bone healing generally occurs via two main pathways: primary (direct) healing and secondary (indirect) healing. Secondary healing is the most common mode in treated fractures and proceeds through distinct phases: inflammation, soft callus formation, hard callus mineralization, and remodeling [2]. This process is governed by the "Diamond Concept," which postulates that successful union requires osteogenic cells, an osteoconductive scaffold, growth factors, and mechanical stability [1]. In closed fractures, the periosteal hinge often remains partially intact, and the fracture hematoma is contained. This hematoma is a rich reservoir of inflammatory cytokines like Interleukin-1 and Interleukin-6, as well as growth factors such as Bone Morphogenetic Proteins (BMPs) and Vascular Endothelial Growth Factor (VEGF), which are critical for initiating the reparative response [3].

Impact of Open Injuries: In contrast, open fractures involve a breach in the skin and underlying soft tissues, leading to the immediate evacuation of the beneficial fracture hematoma and the exposure of the bone to the external environment. This exposure results in varying degrees of contamination and periosteal stripping, as systematically classified by Gustilo and Anderson [4]. The severity of the soft tissue injury is a critical prognostic factor because high-energy trauma disrupts the extra-osseous blood supply. This disruption creates a zone of ischemia that impedes the early phases of callus formation and increases the susceptibility to infection. Furthermore, the presence of bacteria can lead to the formation of biofilms on the bone or implant surface, further antagonizing the healing process [5].

Rationale for the Study: While global literature extensively covers fracture management, regional data concerning fracture healing patterns in Tier-2 cities in India remains limited. The patient demographic at JLNMCH Bhagalpur often presents with specific challenges, including high-velocity road traffic accidents, delayed presentation to the hospital, and variable nutritional status, all of which may influence clinical outcomes. Furthermore, the socio-economic impact of delayed union in this predominantly working-class population is substantial. This study aims to provide a comparative analysis of healing trajectories in this specific demographic to better inform local treatment protocols and patient prognostication.

Methodology

Study Design and Setting: This prospective observational study was conducted at the Department of Orthopaedics, Jawaharlal Nehru Medical College and Hospital (JLNMCH), Bhagalpur. As a tertiary care center serving a large catchment area in Eastern Bihar, the institution handles a high volume of trauma cases. The study period spanned from January 29, 2025, to the present date, allowing for a longitudinal assessment of fracture healing over several months.

Sample Size and Population: The study population consisted of 50 patients who presented to the emergency or outpatient department with long bone fractures. The sample size was calculated based on previous comparative studies estimating a significant difference in union rates between open and closed injuries, suggesting that a cohort of 50 would be sufficient for preliminary statistical validity. The participants were stratified into two distinct groups based on the nature of their injury: Group A consisted of 25 patients with closed fractures, while Group B comprised 25 patients with open fractures.

Inclusion and Exclusion Criteria: To ensure the validity of the data and minimize confounding variables, strict eligibility criteria were applied. The inclusion criteria selected for patients aged between 18 and 60 years who presented with diaphyseal fractures of the tibia or femur. It was mandatory that these patients presented to the hospital within 24 hours of the injury to standardize the initial management timeline. Regarding injury severity, the study included Gustilo-Anderson Types I, II, and IIIA for open fractures, and Tscherne Grades 0-2 for closed fractures.

Conversely, several exclusion criteria were established to remove factors that predominantly alter bone metabolism independent of the fracture type. Patients with pathological fractures, which imply underlying bone disease, were excluded. Similarly, severe open injuries classified as Gustilo-Anderson Type IIIB and IIIC were excluded because they require complex flap reconstruction or vascular repair, which would introduce significant variability in treatment protocols. Furthermore, patients with uncontrolled diabetes mellitus, metabolic bone disorders, or poly-trauma patients with severe head or chest injuries were not included in the final analysis to ensure that systemic factors did not skew the healing data.

Management Protocol: Upon arrival at the hospital, all patients were resuscitated and assessed according to standard Advanced Trauma Life Support (ATLS) protocols. For patients in Group A (Closed Fractures), the standard of care involved closed reduction and internal fixation (CRIF). This was typically achieved using reamed intramedullary interlocking nails or plating, depending on the specific geometry of the fracture line.

The management for Group B (Open Fractures) was more aggressive, necessitating emergency intervention. These patients underwent thorough debridement and irrigation in the operating theater to reduce bacterial load. Fixation strategies varied based on the contamination level; external fixators were utilized initially for cases with severe contamination or soft tissue compromise, whereas primary intramedullary nailing was performed for Grade I and select Grade II injuries. Broad-spectrum antibiotic prophylaxis, typically a combination of a Cephalosporin and an Aminoglycoside, was instituted immediately upon admission and continued based on culture sensitivity reports [6].

Outcome Assessment: A structured follow-up protocol was implemented to monitor healing progress. Patients were reviewed at intervals of 2 weeks, 6 weeks, 12 weeks, 18 weeks, and 24 weeks. The primary outcome measure was radiological union, assessed using the Radiographic Union Scale for Tibial fractures (RUST). This validated scoring system assigns a value from 1 to 3 for each of the four cortices (anterior, posterior, medial, lateral) on AP and Lateral X-rays, where a total score of $\ge

10$ is considered definitive union [7]. In parallel, clinical assessment focused on the functional recovery of the limb, specifically looking for the absence of pain at the fracture site during full weight-bearing and the absence of abnormal mobility or tenderness upon palpation.

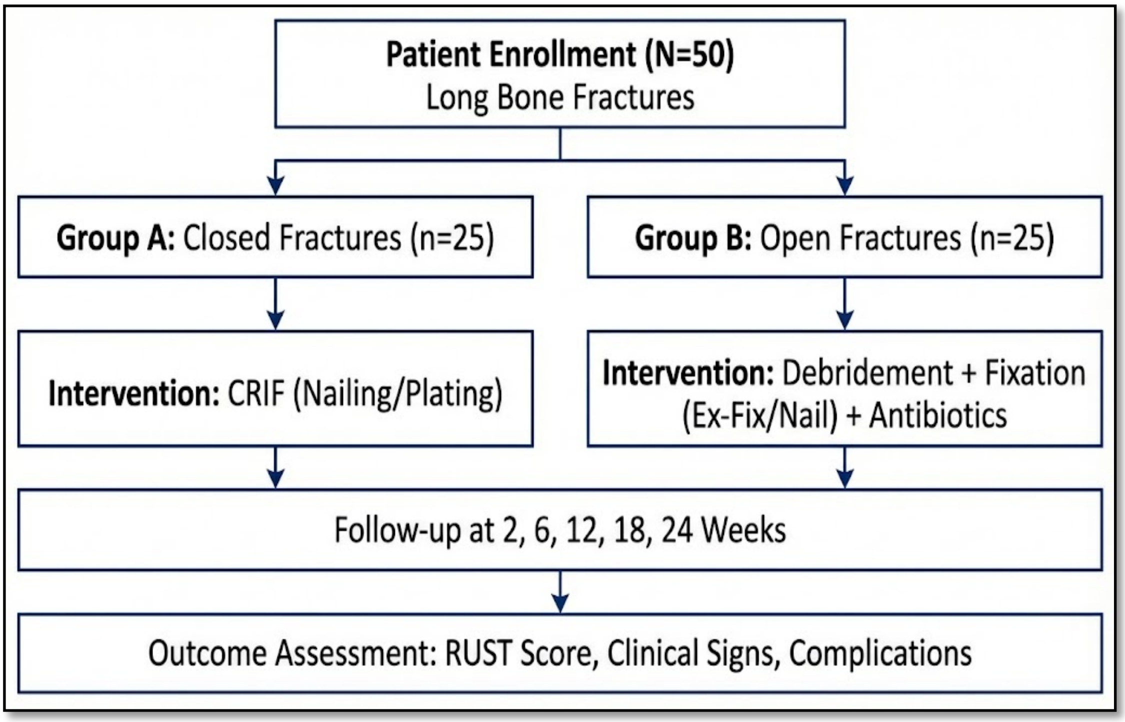

Figure 1: **Flowchart of study design and patient management protocol**

Results

Demographic Profile: The analysis of the demographic data revealed that the mean age of the participants was 34.5 years, indicating that the trauma burden primarily affects the young, working-age population. Gender distribution showed a clear preponderance of males, constituting 72% of the cohort. This statistic reflects the higher exposure of males to high-risk activities and road traffic accidents (RTAs) in this region. As detailed in Table 1, the mode of injury was predominantly RTA, particularly in the open fracture group, correlating with higher energy transfer during trauma.

Table 1: **Demographic and Injury Characteristics**

Parameter	Group A (Closed)	Group B (Open)	p-value
Mean Age (Years)	32.4 ± 8.1	36.1 ± 9.2	>0.05
Gender (M: F)	18:7	19:6	-
Mode of Injury (RTA)	60%	84%	<0.05
Bone Involved (Tibia)	18	20	-
Bone Involved (Femur)	7	5	-

Time to Union and Fixation Analysis: The healing trajectory showed a marked divergence between the two groups. Group A (Closed) achieved union significantly faster, with a mean time of 14.2 weeks, whereas Group B (Open) required an average of 22.4 weeks to reach the same endpoint. This statistical difference ($p < 0.01$) underscores the biological cost of open injuries. To further understand these results, the relationship between the specific fixation method and time to union was analyzed. As shown in Table 2, patients requiring conversion from external fixator to intramedullary nail had the longest healing times, often exceeding 24 weeks.

Table 2: Time to Union by Fixation Method

Fixation Method	Number of Patients (n)	Mean Time to Union (Weeks)	Range (Weeks)
Primary IM Nailing (Closed)	22	13.8	12 - 18
Plating (Closed)	3	16.5	14 - 20
Primary IM Nailing (Open)	12	19.2	16 - 26
Ex-Fix to IM Nail (Open)	8	25.4	20 - 32
Ex-Fix Definitive (Open)	5	23.1	18 - 30

Radiographic Progression (RUST Score)

The progression of callus formation was monitored objectively using the RUST score. Throughout the follow-up period, the closed fracture group consistently demonstrated higher scores, indicating earlier cortical bridging. At the critical 12-week interval, Group A had a mean score of 9.2, approaching clinical union, while Group B lagged with a mean score of 6.8, reflecting immature callus. Table 3 illustrates the comparative progression of these scores across all follow-up visits, highlighting the delayed osteogenesis in open fractures.

Table 3 Comparative Progression of Mean RUST Scores

Follow-up Interval	Group A (Closed) Mean Score	Group B (Open) Mean Score	Statistical Significance
2 Weeks	4.0	4.0	ns
6 Weeks	6.5	4.8	$p < 0.05$
12 Weeks	9.2	6.8	$p < 0.01$
18 Weeks	11.4	8.9	$p < 0.01$
24 Weeks	12.0	10.5	$p < 0.05$

Note: A RUST score of 4 indicates a fresh fracture; 12 indicates healed cortices on all views.

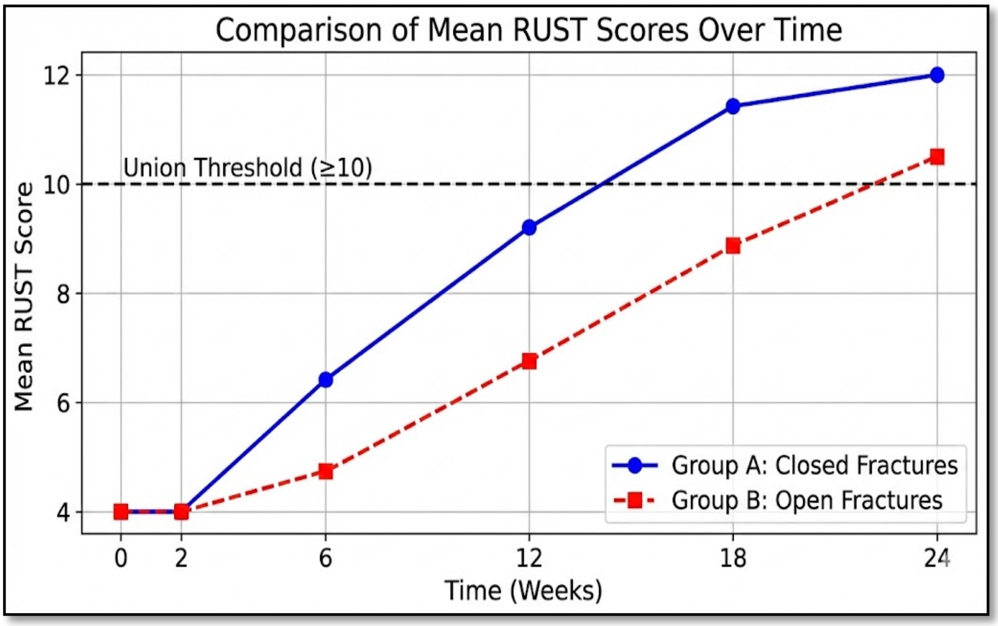

Figure 2: Comparative progression of mean RUST scores over 24 weeks

Complications: The complication profile provided significant insight into the morbidity associated with open injuries. While Group A remained largely free of severe sequelae, Group B experienced a substantial burden of infection. The deep infection rate in Group B was 20%, which was the primary driver for delayed healing and necessitated secondary interventions such as debridement and antibiotic bead impregnation. Table 4 summarizes the complication rates observed during the study period.

Table 4: Complication Rates

Complication	Group A (Closed)	Group B (Open)
Superficial Infection	1 (4%)	6 (24%)
Deep Infection	0 (0%)	5 (20%)
Delayed Union	1 (4%)	4 (16%)
Non-Union	0 (0%)	1 (4%)
Implant Failure	0 (0%)	1 (4%)

Discussion

The results gathered from this prospective study at JLNMCH corroborate established global evidence regarding the superior healing potential of closed fractures compared to open fractures, while also highlighting specific regional challenges. The demographic data confirms that high-energy trauma in young males is the predominant etiology, necessitating robust trauma systems in this geographical area.

Biological Environment and Healing: The significantly shorter time to union in Group A (14.2 weeks) compared to Group B (22.4 weeks) can be attributed directly to the preservation of the fracture hematoma. In open fractures, the loss of this hematoma removes the initial fibrin scaffold and the chemotactic gradient required for mesenchymal stem cell migration [8]. Furthermore, high-energy trauma, which was more prevalent in Group B (84%), causes extensive soft tissue crushing. This damage compromises the microscopic vascular network and perforators that supply the periosteum. Consequently, a zone of ischemia is created that impedes the early phases of callus formation [9]. Recent studies have further emphasized that the size of the interfragmentary gap and the quality of the soft tissue envelope are critical determinants of interfragmentary strain and subsequent ossification [10]. This aligns with the work of Perren, who highlighted the delicate balance between stability and biology in fracture fixation [11].

Infection as a Barrier to Union: Infection remains the most devastating complication in fracture care and was a major factor in the current study. The incidence of deep infection in the open group was 20%, which aligns with literature for Gustilo Type II and IIIA fractures in resource-constrained settings where environmental contamination levels are high [12]. The pathophysiology involves bacteria competing with host cells for metabolic resources and producing toxins that lyse the newly formed woven bone, a process known as bacteria-induced osteolysis. This creates a challenging clinical scenario often described as Fracture-Related Infection (FRI) by international consensus groups [13]. The data emphasizes the "Race for the Surface" concept, where host cells must cover the implant surface before bacteria can adhere and form a protective biofilm. Once a biofilm is established, systemic antibiotics are often ineffective, necessitating surgical removal of the implant.

Use of the RUST Score: The application of the RUST score provided an objective, quantifiable metric for assessment in this study. Previous reliance on "clinical judgment" or simple descriptions of callus often led to inter-observer variability, resulting in either premature weight-bearing or prolonged, unnecessary immobilization. The study demonstrated that radiological bridging, as evidenced by the rising RUST score, lagged behind clinical symptom relief by approximately 2 to 3 weeks. This finding is consistent with observations by Bhandari et al. in the SPRINT trial, highlighting the importance of radiological verification before allowing unprotected weight-bearing to prevent implant fatigue and failure [14].

Study Limitations: Despite the clear trends observed, the study has limitations that must be acknowledged. The sample size of 50, while sufficient for observing primary trends, is relatively small for detailed multivariate analysis. Additionally, the heterogeneity of fixation methods where some open fractures were managed with nails and others with fixators introduces a confounding variable, as the stability provided by these constructs differs. Furthermore, nutritional parameters such as serum albumin and Vitamin D levels were not standardized across all patients. Given the local demographics, subclinical malnutrition could be a latent variable impacting the healing rates in the open fracture cohort.

Conclusion

The evaluation of bone healing at JLNMCH confirms that open fractures constitute a distinct pathological entity requiring a fundamentally different prognostic outlook than closed fractures. The study conclusively demonstrates that the disruption of the soft tissue envelope results in a healing delay of approximately 8 weeks compared to closed injuries. Furthermore, the risk of deep infection is negligible in closed fractures but remains a substantial threat (20%) in open fractures managed in this setting, serving as the primary cause for non-union and morbidity.

Based on these findings, it is recommended that the management of open fractures in this region involves not only aggressive early debridement but also a heightened vigilance for infection. The significant lag in RUST scores for open fractures suggests that rehabilitation protocols should be more conservative for these patients. Future protocols might benefit from a lower threshold for early secondary bone grafting in open fractures to mitigate the biological deficit caused by the loss of the fracture hematoma.

References

1. Giannoudis PV, Einhorn TA, Marsh D. Fracture healing: the diamond concept. injury. 2007 Sep 1;38: S3-6.
2. Marsell R, Einhorn TA. The biology of fracture healing. Injury. 2011 Jun 1;42(6):551-5.
3. Einhorn TA, Gerstenfeld LC. Fracture healing: mechanisms and interventions. Nature Reviews Rheumatology. 2015 Jan;11(1):45-54.
4. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. JBJS. 1976 Jun 1;58(4):453-8.
5. Gristina AG. Biomaterial-centered infection: microbial adhesion versus tissue integration. Science. 1987 Sep 25;237(4822):1588-95.
6. Chang Y, Bhandari M, Zhu KL, Mirza RD, Ren M, Kennedy SA, Negm A, Bhatnagar N, Naji FN, Milovanovic L, Fei Y. Antibiotic prophylaxis in the management of open fractures: a systematic survey of current practice and recommendations. JBJS reviews. 2019 Feb 1;7(2):e1.
7. Whelan DB, Bhandari M, Stephen D, Kreder H, McKee MD, Zdero R, Schemitsch EH. Development of the radiographic union score for tibial fractures for the assessment of tibial fracture healing after intramedullary fixation. Journal of Trauma and Acute Care Surgery. 2010 Mar 1;68(3):629-32.
8. McKibbin B. The biology of fracture healing in long bones. The Journal of Bone & Joint Surgery British Volume. 1978 May 1;60(2):150-62.
9. McBirnie J. The epidemiology of tibial fractures. The Journal of Bone & Joint Surgery British Volume. 1995 May 1;77(3):417-21.
10. Claes L, Eckert-Hübner K, Augat P. The effect of mechanical stability on local vascularization and tissue differentiation in callus healing. Journal of orthopaedic research. 2002 Sep;20(5):1099-105.
11. Perren SM. Evolution of the internal fixation of long bone fractures: the scientific basis of biological internal fixation: choosing a new balance between stability and biology. The Journal of Bone & Joint Surgery British Volume. 2002 Nov 1;84(8):1093-110.
12. Papakostidis C, Kanakaris NK, Pretel J, Faour O, Morell DJ, Giannoudis PV. Prevalence of complications of open tibial shaft fractures stratified as per the Gustilo–Anderson classification. Injury. 2011 Dec 1;42(12):1408-15.
13. Metsemakers WJ, Morgenstern M, McNally MA, Moriarty TF, McFadyen I, Scarborough M, Athanasou NA, Ochsner PE, Kuehl R, Raschke M, Borens O. Fracture-related infection: a consensus on definition from an international expert group. Injury. 2018 Mar 1;49(3):505-10.
14. Bhandari M, Tornetta P, Sprague S, Najibi S, Petrisor B, Griffith L, Guyatt GH. Predictors of reoperation following operative management of fractures of the tibial shaft. Journal of orthopaedic trauma. 2003 May 1;17(5):353-61.