Research Article

Functional Outcome of Open Tibial Fractures with Delayed Wound Debridement Beyond 6 Hours: A Prospective Observational Study from a Tertiary Care Hospital in India

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Abstract

Background: Early wound debridement, traditionally within 6 hours, is a cornerstone of open fracture care, but in many resource-limited settings it is rarely achievable. We assessed wound healing and functional outcome in adults with open tibial fractures debrided more than 6 hours after injury and compared those debrided within 24 hours with those debrided later.

Methods: This prospective observational study at a tertiary care hospital (November 2022 to November 2024) included adults with open tibial fractures who presented and underwent debridement more than 6 hours after injury. Patients were grouped as debrided ≤24 h or >24 h from injury. Outcomes were wound culture, infection, wound healing, radiographic union (RUST score), complications, number of procedures, and Johner–Wruhs functional grade. Groups were compared with Fisher's exact, Welch's t and Mann–Whitney U tests.

Results: Forty-two patients were enrolled (92.9% male; 83.3% road traffic accidents; Gustilo–Anderson type II most common, 42.9%). Mean injury-to-debridement time was 86.1 hours; 11 patients (26.2%) were debrided within 24 hours and 31 (73.8%) later. Wound cultures were positive in 19 patients (45.2%, 95% CI 31.2–60.0); MRSA was the most frequent isolate (7.1%). Infection occurred in 45.5% of the ≤24 h group and 45.2% of the >24 h group (p = 1.00). Of 33 patients with a Johner–Wruhs grade, 66.7% were excellent or good, 30.3% fair and 3.0% poor; the grade distribution did not differ significantly between groups (p = 0.09). Union was achieved in 15 of 17 patients with at least 6 months of follow-up. Split-skin grafting was more frequent in the ≤24 h group (36.4% vs 6.5%, p = 0.03). Eight patients (19.0%) were lost to follow-up or died.

Conclusion: Infection was common in late-presenting open tibial fractures, but no significant difference in infection, union or functional grade was detected between debridement within and after 24 hours. The small sample, attrition and short follow-up limit inference; larger multicentre studies that adjust for injury severity are needed.

Keywords: open fracture; tibia; wound debridement; delayed debridement; surgical site infection; Gustilo–Anderson; Johner–Wruhs

1. Introduction

Open fractures of the tibia are among the commonest and most difficult open long-bone injuries because the subcutaneous tibia has little soft-tissue cover and a vulnerable blood supply. They are classified by the Gustilo–Anderson system[1,2] and carry a substantial risk of infection, non-union and long-term disability.[3] Thorough wound

debridement, together with antibiotics, skeletal stabilisation and soft-tissue cover, is regarded as the most important step in management, and prompt treatment within 6 hours of injury has long been advocated to reduce the risk of infection.

The evidence behind the 6-hour threshold is inconsistent. Earlier cohorts linked late debridement of grade II and III tibial fractures with osteomyelitis and infection,[4,5] and delayed debridement of severe open fractures was later associated with a higher rate of deep infection.[6] In contrast, a systematic review and a large prospective cohort found no clear association between time to debridement and infectious complications,[7,8] and a study in children found no excess of acute infection with surgical delay.[9] A review of open tibial shaft fractures likewise concluded that the effect of surgical timing on outcome remains uncertain.[10] Studies also differ on the threshold itself, with cut-offs of 6, 8, 12 and 24 hours used.

In India and other low- and middle-income settings, many patients cannot meet a 6-hour target. Delays arise from late presentation, travel from remote areas, financial constraints and limited availability of operating theatres and specialist teams, so that debridement is often performed days after injury. At our institution, most patients with open tibial fractures present late and are debrided well beyond 6 hours. Severe injuries also need combined orthopaedic and plastic surgical care,[11,12] which is not always immediately available. Data on the outcomes of such delayed management in the Indian setting are limited. We therefore studied wound healing and functional outcome in patients with open tibial fractures debrided more than 6 hours after injury, and compared outcomes between those debrided within 24 hours and those debrided after 24 hours.

2. Materials And Methods

2.1 Study design and setting

This was a prospective observational study conducted in the Department of Orthopaedics of a tertiary care teaching hospital in Salem, India, from November 2022 to November 2024. The study is reported in line with the STROBE guidelines for observational studies.

2.2 Participants

All patients aged over 18 years with an open fracture of the tibia who presented more than 6 hours after injury and were taken to the operating theatre after 6 hours were eligible. Patients with polytrauma (multiple long-bone fractures), a wound that was already infected with open discharge, surgery performed elsewhere, vascular injury requiring vascular repair,[13] or compartment syndrome at presentation were excluded.

2.3 Management protocol

Patients were assessed in the casualty department and fractures were classified by the Gustilo–Anderson system.[1,2] Wound debridement was followed by skeletal stabilisation, using external fixation, intramedullary interlocking (IMIL) nailing, TENS nailing or plating according to fracture pattern and wound condition. Staged conversion from external fixation to definitive fixation and soft-tissue procedures (re-debridement, secondary suturing, split-skin graft or flap cover) were performed as clinically required. Wound swabs were sent for culture and sensitivity.

2.4 Exposure groups

The interval from injury to debridement was recorded in hours. Because the 6-hour limit derives largely from studies in high-income countries and was exceeded in all of our patients, patients were divided into two groups using a 24-hour threshold: debridement within 24 hours of injury (≤24 h group) and debridement after 24 hours (>24 h group).

2.5 Outcome measures

Patients were followed at 1, 3, 6 and 12 months. Outcomes were wound culture result; infection; wound healing and time to healing; radiographic union assessed with the Radiographic Union Score for Tibial fractures (RUST);[14,15] non-union; malunion; limb-length discrepancy; range of knee and ankle motion; gait and pain; complications (compartment syndrome, foot drop, osteomyelitis, systemic complications); number and type of bony and soft-

tissue procedures; length of hospital stay; and overall functional outcome by the Johner–Wruhs criteria (excellent, good, fair, poor).[16] Wound infection was identified by a positive wound culture.

2.6 Statistical analysis

Data were analysed from the study records. Categorical variables are presented as counts and percentages and were compared with Fisher's exact test because of small expected cell counts. Continuous variables are presented as mean ± standard deviation and compared with Welch's t-test. The ordinal Johner–Wruhs grade was compared with the Mann–Whitney U test. Proportions are given with 95% Wilson confidence intervals where stated. A two-sided p value below 0.05 was considered significant. Because of the small sample and number of comparisons, all between-group analyses are exploratory and unadjusted. A sample-size calculation was not performed.

3. Results

3.1 Study population

Forty-two patients were enrolled (Figure 1). Participants ranged from the second to the eighth decade, with the largest groups aged 41–50 years (26.2%) and 21–30 years (23.8%). Most were men (92.9%) and road traffic accidents caused 83.3% of injuries (Table 1, Figure 3). The Gustilo–Anderson classification (Figure 2) was type I in 8, type II in 18, type IIIA in 6, type IIIB in 7 and type IIIC in 2 patients. Seven patients (16.7%) were diabetic and 2 (4.8%) were smokers. No patient had a nerve injury at presentation.

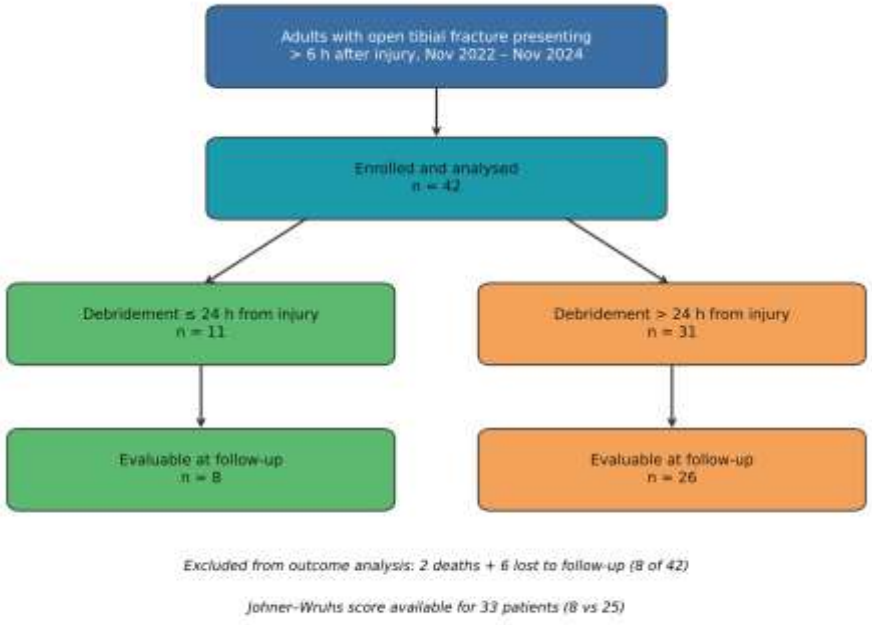


Figure 1. Flow of participants through the study. Of 42 enrolled patients, 11 were debrided within 24 h and 31 after 24 h of injury. Eight patients (2 deaths, 6 lost to follow-up) were excluded from outcome analysis.

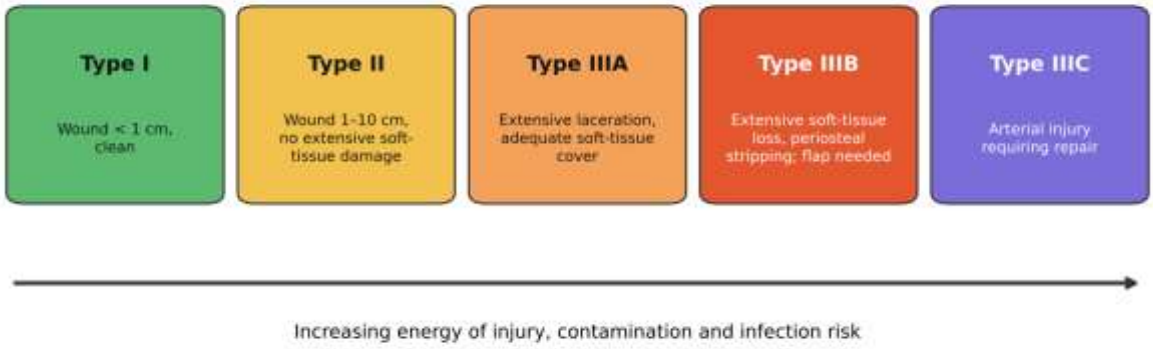


Figure 2. Gustilo–Anderson classification of open fractures.[1,2] Original schematic prepared by the authors.

Table 1. Baseline characteristics of 42 patients with open tibial fractures.

Characteristic	n	%
Age group (years)		
10–20	3	7.1
21–30	10	23.8
31–40	6	14.3
41–50	11	26.2
51–60	5	11.9
61–70	5	11.9
>70	1	2.4
Sex		
Male	39	92.9
Female	3	7.1
Mode of injury		
Road traffic accident	35	83.3
Fall from height	2	4.8
Mechanical injury	5	11.9
Gustilo–Anderson type		
I	8	19.0
II	18	42.9
IIIA	6	14.3
IIIB	7	16.7
IIIC	2	4.8

Comorbidity and habits		
Diabetes mellitus	7	16.7
Smoker	2	4.8
Associated injury		
Vascular injury	2	4.8
Nerve injury	0	0.0

Percentages are calculated on n = 42. Age-group and Gustilo–Anderson counts as recorded sum to 41.

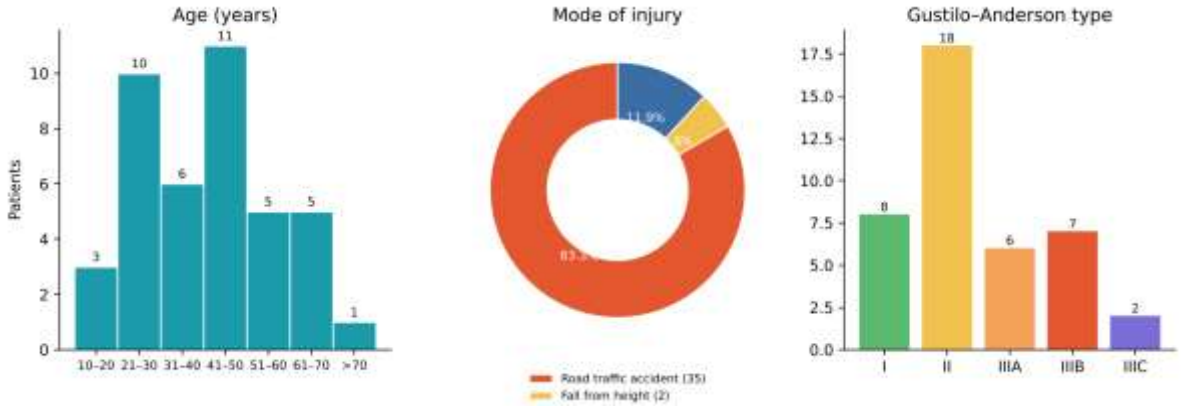


Figure 3. Baseline characteristics: age distribution (histogram), mode of injury and Gustilo–Anderson type of the 42 patients.

3.2 Microbiology

Wound cultures were positive in 19 of 42 patients (45.2%; 95% CI 31.2–60.0) and showed no growth in 23 (54.8%) (Table 2, Figure 4). Of the 19 positive cultures, 10 grew Gram-negative organisms (Aeromonas, Pseudomonas, Klebsiella, Acinetobacter and Achromobacter species), 8 grew Gram-positive organisms and 1 was reported as a contaminant. Methicillin-resistant *Staphylococcus aureus* (MRSA) was the most frequent single isolate (3 patients, 7.1%).

Table 2. Wound culture results (n = 42).

Organism	Gram stain	n	%
No growth	—	23	54.8
Gram-positive organisms			
MRSA	Gram +	3	7.1
Enterococcus species	Gram +	2	4.8
Coagulase-negative staphylococcus	Gram +	1	2.4
Staphylococcus epidermidis	Gram +	1	2.4
Staphylococcus arlettae	Gram +	1	2.4
Gram-negative organisms			
Aeromonas species	Gram −	2	4.8
Pseudomonas putida	Gram −	2	4.8

Klebsiella species	Gram −	2	4.8
Pseudomonas aeruginosa	Gram −	1	2.4
Acinetobacter lwoffii	Gram −	1	2.4
Acinetobacter baumannii complex	Gram −	1	2.4
Achromobacter species	Gram −	1	2.4
Other			
Contaminant	—	1	2.4

Positive cultures: 19 of 42 (45.2%).

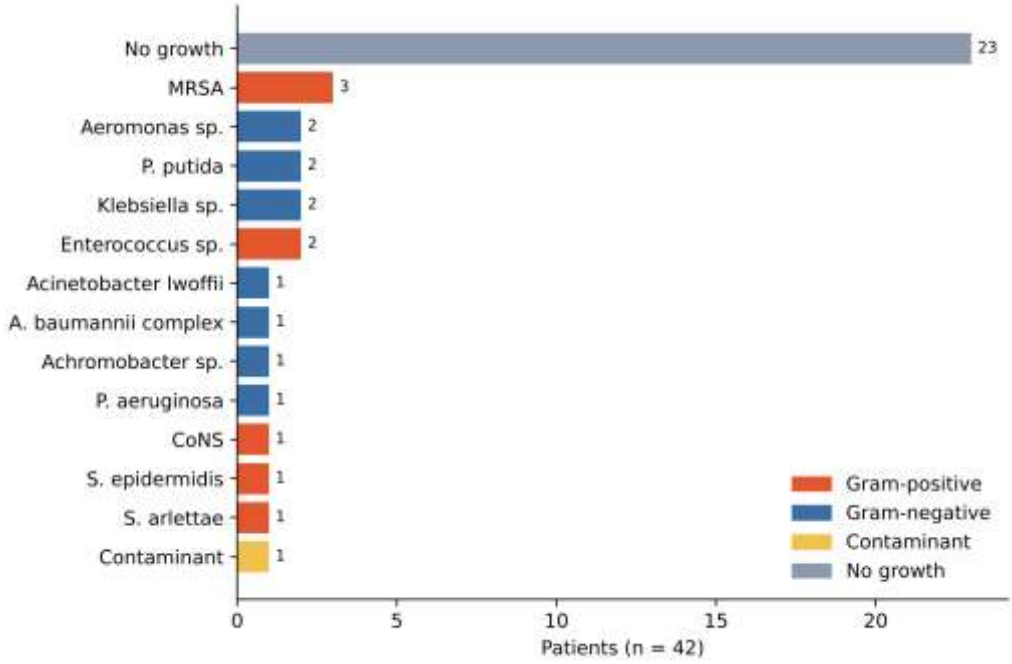


Figure 4. Wound culture results by organism, coloured by Gram stain. MRSA, methicillin-resistant Staphylococcus aureus; CoNS, coagulase-negative staphylococci.

3.3 Surgical procedures and perioperative data

External fixation was the primary bony procedure in 27 patients (64.3%), followed by IMIL nailing in 9 (21.4%), plating in 4 (9.5%) and TENS nailing in 2 (4.8%) (Table 3, Figure 5). Of the 27 patients treated initially with an external fixator, 18 were converted to IMIL nailing and 9 to plating. One patient with non-union 10 months after nailing underwent nail dynamization. The mean injury-to-debridement time was 86.1 hours, the mean admission-to-debridement time 75.6 hours and the mean duration of debridement 56.2 minutes. Patients had a mean of 1.83 bony or soft-tissue procedures, including 0.43 soft-tissue procedures, and stayed in hospital for a mean of 21.3 days (Table 4).

Table 3. Bony procedures.

Procedure	n	%
Primary procedure (n = 42)		

External fixator application	27	64.3
IMIL nailing	9	21.4
Plating	4	9.5
TENS nailing	2	4.8
Secondary procedure (n = 28)		
IMIL nailing	18	64.3
Plating	9	32.1
Nail dynamization	1	3.6

IMIL, intramedullary interlocking nail; TENS, titanium elastic nail.

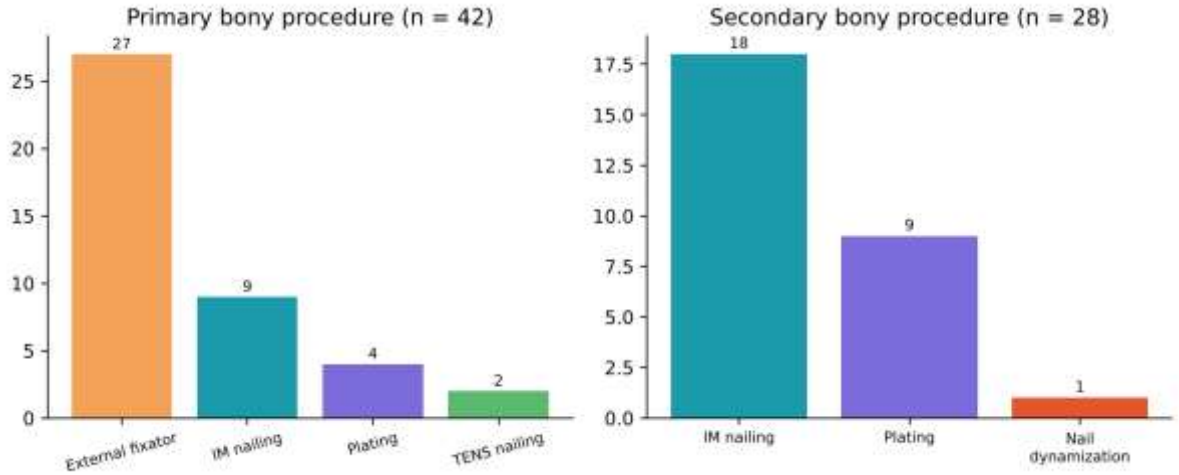


Figure 5. Primary (left) and secondary (right) bony procedures.

Table 4. Surgery-related data for all patients (n = 42).

Variable	**Mean (SD)**
Injury-to-debridement time (h)	86.1
Admission-to-debridement time (h)	75.6 (13.4)
Duration of debridement (min)	56.2 (17.0)
Hospital stay (days)	21.3
Total number of procedures	1.83 (0.93)
Number of soft-tissue procedures	0.43 (0.63)

Standard deviations for injury-to-debridement time and hospital stay are not reported.

3.4 Follow-up

Two patients died (from systemic complications) and six left hospital against medical advice and were lost to follow-up, leaving 34 patients with at least one follow-up visit. The last completed visit was at 1 month in 7 patients, 3 months in 10, 6 months in 11 and 12 months in 6 (Table 5). Seventeen patients had at least 6 months of follow-up. A Johner–Wruhs grade was available for 33 patients.

Table 5. Follow-up status (n = 42).

Status	n	%
Lost to follow-up (left against medical advice)	6	14.3
Died	2	4.8
Last visit at 1 month	7	16.7
Last visit at 3 months	10	23.8
Last visit at 6 months	11	26.2
Completed 12 months	6	14.3

3.5 Comparison of debridement within and after 24 hours

Eleven patients (26.2%) were debrided within 24 hours of injury and 31 (73.8%) later. Infection occurred in 5 of 11 (45.5%) and 14 of 31 (45.2%) respectively (p = 1.00; Table 6, Figure 6). Infection rates by Gustilo–Anderson type are shown in Table 7; none of the type-specific comparisons was significant, although each stratum contained very few patients. Infection tended to increase with fracture severity (infection in 3 of 8 type I, 7 of 19 type II, 3 of 6 type IIIA, 4 of 7 type IIIB and 2 of 2 type IIIC fractures).

All 8 evaluable patients in the ≤24 h group and 23 of 26 in the >24 h group had healed wounds (p = 1.00). Mean RUST score at last follow-up was 8.25 ± 1.7 and 7.88 ± 1.6 (p = 0.60). Among the 17 patients with at least 6 months of follow-up, 15 had united; both non-unions were in the >24 h group (0 of 5 vs 2 of 12, p = 1.00). Complications were few and did not differ significantly between groups. Split-skin grafting was performed more often in the ≤24 h group (4 of 11 vs 2 of 31, p = 0.03), and the mean number of soft-tissue procedures was also higher in that group (0.78 vs 0.33, p = 0.04). Total procedures, re-debridement, flap cover and secondary suturing did not differ (Figure 7).

Table 6. Comparison of outcomes between patients debrided ≤24 h and >24 h after injury.

Variable	≤24 h (n = 11)	>24 h (n = 31)	p value
Infection and wound			
Infection, n/N (%)	5/11 (45.5)	14/31 (45.2)	1.00
Wound healed, n/N (%)	8/8 (100)	23/26 (88.5)	1.00
Mean time to wound healing (days)	25.0	28.4	—
Bone healing			
Mean RUST score ± SD	8.25 ± 1.7	7.88 ± 1.6	0.60
Non-union, n/N (%)	0/5 (0)	2/12 (16.7)	1.00
Soft-tissue and total procedures			
Re-debridement, n (%)	2 (18.2)	3 (9.7)	0.59
Split-skin graft, n (%)	4 (36.4)	2 (6.5)	0.03
Flap cover, n (%)	1 (9.1)	3 (9.7)	1.00
Secondary suturing, n (%)	1 (9.1)	2 (6.5)	1.00
Soft-tissue procedures per patient, mean ± SD	0.78 ± 0.6	0.33 ± 0.5	0.04

Total procedures per patient, mean ± SD	1.8 ± 1.4	2.1 ± 1.3	0.54
Mean hospital stay (days)	24.6	20.4	—
Complications, n (%)			
Compartment syndrome	1 (9.1)	1 (3.2)	0.46
Foot drop	1 (9.1)	0 (0)	0.26
Osteomyelitis	0 (0)	1 (3.2)	1.00
Fatal systemic complication	2 (18.2)	0 (0)	0.06

Denominators differ where outcomes were available only for patients with follow-up (wound healing 8 vs 26; RUST 8 vs 25; non-union 5 vs 12). Fisher's exact test for categorical and Welch's t-test for continuous variables; — = p value not calculable from the summary data available. Exploratory, unadjusted analyses.

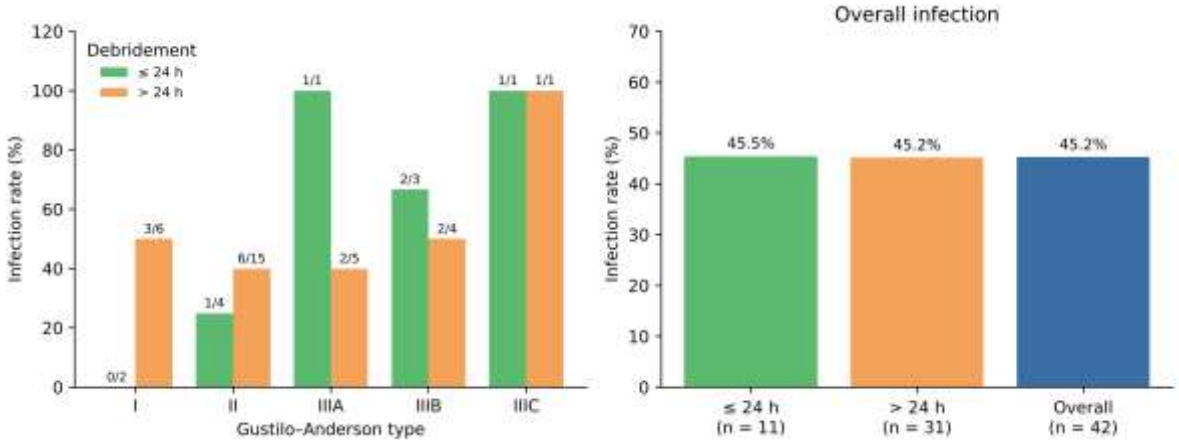


Figure 6. Infection rate by Gustilo–Anderson type and debridement group (left; labels show infected/total) and overall (right).

Table 7. Infection by Gustilo–Anderson type and debridement group.

Type	≤24 h, infected/n	>24 h, infected/n	Overall, infected/n (%)	p value
I	0/2	3/6	3/8 (37.5)	0.46
II	1/4	6/15	7/19 (36.8)	1.00
IIIA	1/1	2/5	3/6 (50.0)	1.00
IIIB	2/3	2/4	4/7 (57.1)	1.00
IIIC	1/1	1/1	2/2 (100)	1.00

Counts by type in this table sum to 42 (type II, n = 19) whereas Table 1 lists 18 type II fractures. Fisher's exact test.

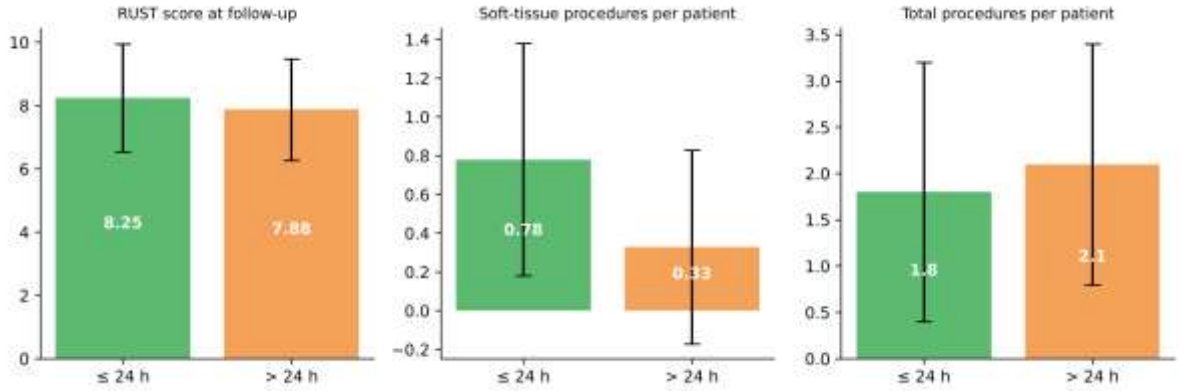


Figure 7. Mean ± SD RUST score, soft-tissue procedures and total procedures per patient by debridement group.

3.6 Functional outcome

Of 33 patients graded by the Johner–Wruhs criteria, 9 (27.3%) were excellent, 13 (39.4%) good, 10 (30.3%) fair and 1 (3.0%) poor, so 66.7% had an excellent or good result (Table 8, Figure 8). Fair results were more common in the ≤24 h group (5 of 8 vs 5 of 25), but the grade distribution did not differ significantly between groups (Mann–Whitney p = 0.09); the proportion with an excellent or good result was 37.5% vs 76.0% (p = 0.08).

Table 8. Johner–Wruhs functional outcome (n = 33).

Grade	All, n (%)	≤24 h, n = 8	>24 h, n = 25	p value
Excellent	9 (27.3)	1	8	0.09*
Good	13 (39.4)	2	11	0.09*
Fair	10 (30.3)	5	5	0.09*
Poor	1 (3.0)	0	1	0.09*

Mann–Whitney U test on the ordinal grade (single test across grades)

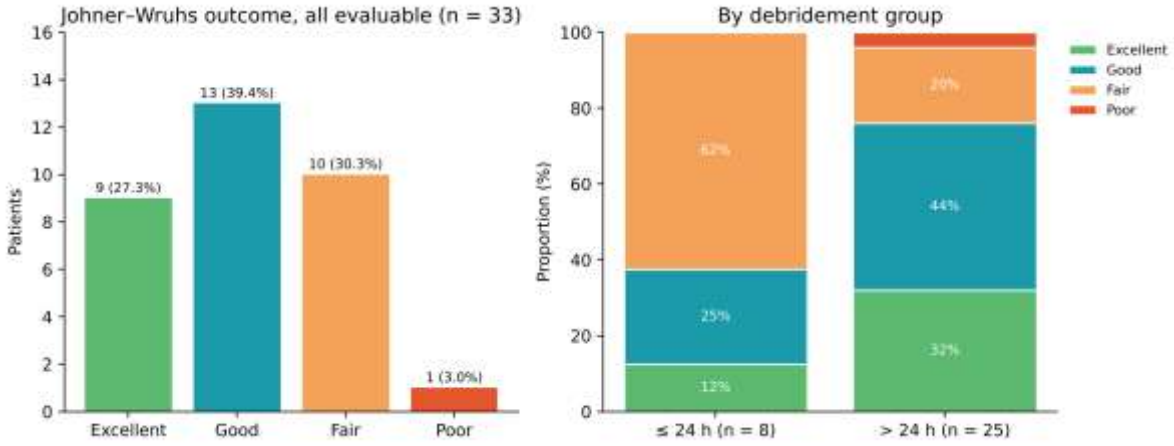


Figure 8. Johner–Wruhs functional outcome for all evaluable patients (left) and by debridement group (right).

4. Discussion

In this prospective series of open tibial fractures that were all debrided well beyond the traditional 6-hour window, with a mean injury-to-debridement time of about 86 hours, wound culture positivity and infection were common (45.2%), but infection, union and overall functional grade did not differ significantly between patients debrided within 24 hours and those debrided later. Two thirds of the patients with a recorded functional grade had an excellent or good result.

The long delays in our patients reflect structural barriers rather than clinical choice: distance from a tertiary centre, late presentation, financial constraints and limited operating-theatre capacity, with additional delay in some patients from poor skin condition or complications. Similar constraints affect trauma care across low- and middle-income countries, and they explain why a 6-hour target derived from high-income settings is rarely attainable here. Reports linking delayed debridement to higher infection come mainly from settings in which delay is measured in hours[4–6] whereas our delays were measured in days.

The infection rate we observed is high. Interpretation of the timing effect is complicated by the literature, which is divided: some studies associate late debridement with deep infection,[4–6] whereas a systematic review and a large prospective cohort found no independent association once injury severity and contamination were considered.[7,8] Our finding of identical infection rates in the two groups (45.5% vs 45.2%) is compatible with the latter view, namely that wound contamination, soft-tissue damage and host factors may matter more than the exact hour of debridement when all patients present late. Infection rose with Gustilo–Anderson grade (type IIIB and IIIC fractures had the highest rates), consistent with the established link between injury severity and infection.[1,3] However, with only 11 patients in the ≤24 h group our study could detect only a very large difference, and the absence of a significant difference should not be read as evidence that timing is unimportant.

The microbiology of the infected wounds was notable for a high proportion of Gram-negative and environmental organisms (*Aeromonas*, *Pseudomonas*, *Acinetobacter*, *Klebsiella*), which may reflect gross contamination at the scene, unhygienic pre-hospital dressings and prolonged wound exposure in a tropical climate. MRSA was the most frequent single isolate (7.1%). These findings underline the importance of local antibiogram-guided antibiotic policies, early wound irrigation and clean dressing before transfer. The timing of culture collection relative to debridement was not analysed here, and positive cultures do not always indicate clinical infection.

Patients in the ≤24 h group underwent more split-skin grafts and had more soft-tissue procedures per patient. This is unlikely to be an effect of early debridement. The more probable explanation is that earlier surgery was more often performed in patients with more extensive soft-tissue injury, which we could not adjust for given the group size. Fair functional results were also more frequent in this group, again without statistical significance. These observations are hypothesis-generating only. Because many patients required staged care, with external fixation as the first procedure in 64.3% and conversion to definitive fixation later, combined orthopaedic and plastic surgical input remains important in severe injuries.[11,12]

Union was achieved in 15 of 17 patients with at least 6 months of follow-up; the two non-unions (11.8%) both occurred in the late group, and one was managed by nail dynamization. Non-union after open tibial fracture depends on fracture pattern, bone loss, infection and fixation method,[17,18] and our estimate is imprecise because of the small number of patients with adequate follow-up. Radiographic scoring with RUST at the last visit was similar in both groups.

4.1 Limitations

This study has several limitations. The sample was small and the groups unequal (11 vs 31), so power to detect clinically important differences was low and the analyses are exploratory and unadjusted for injury severity, contamination, diabetes or fixation method. Attrition was substantial: 8 patients (19.0%) died or were lost to follow-up, only 17 had at least 6 months of follow-up and only 6 completed 12 months, so functional outcomes were assessed at variable time points and may not represent final results. Subgroup analysis by Gustilo–Anderson type was not feasible. Infection was identified chiefly by wound culture, which does not distinguish colonisation from infection. The study was conducted at a single centre, and the 24-hour threshold was chosen pragmatically

rather than predefined from prior evidence. A sample-size calculation was not performed.

5. Conclusion

In adults with open tibial fractures debrided more than 6 hours after injury, infection was common (45.2%), but infection, union and functional outcome did not differ significantly between debridement within 24 hours and after 24 hours in this small series. Most patients with follow-up achieved an excellent or good functional result. Because of the sample size, attrition and lack of adjustment, these results should be interpreted cautiously. Larger multicentre prospective studies that adjust for injury severity, together with system-level measures to shorten the time to first debridement, are needed.

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