Epidemiological analysis of outcomes in 323 open tibial diaphyseal fractures: a nine-year experience

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INTRODUCTION Open fractures of the tibia pose a challenge to orthopaedic and plastic surgeons. A retrospective observational review was conducted to evaluate the epidemiological factors and fracture outcomes in the Singapore context.

METHODS A nine-year period of open tibial shaft fractures presenting to our institution was reviewed. Demographic and management data were recorded. Statistical analysis was performed on the outcomes of length of hospital stay, number of operations, time to union and infection rates.

RESULTS 323 fractures met our inclusion criteria (Gustilo [G] 1 = 53, G2 = 100, G3 = 170). Mean age of patients was 36.5 years, 91.3% were male and 40.9% were non-Singaporeans. 69.3% of fractures occurred from road traffic accidents and 21.7% from industrial accidents. Mean length of hospital stay was 28.7 days and number of operations was 4.29. Time to union was 10.7 months and overall infection rate was 20.7%. Infection rates were significantly higher in G3b/G3c compared to G3a (45.7% vs. 21.1%) patients. There was no significant reduction in infection rates when open tibial fractures were operated on within six hours of admission. Multiple injured patients required a longer time to union and hospital stay. There was an exponential cost increase with greater severity of fracture.

CONCLUSION High Gustilo and AO classification injuries positively correlate with high non-union and infection rates, requiring multiple operations and long hospital stay. There is no benefit in performing surgery on open tibial fractures within six hours of presentation. A significant proportion of these patients would be polytraumatised, indirectly affecting fracture union.

Keywords: amputation, economics, epidemiology, open tibia fractures, salvage
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INTRODUCTION

The tibia is the most commonly fractured long bone.[1] Management of open tibial fractures remains a challenge for orthopaedic, plastic and vascular surgeons. These fractures occur as a result of high-velocity injuries, such as a fall from height or crush injury. A small but significant proportion of fracture will occur in patients with multiple injuries. High-grade open tibial injuries often require complex reconstruction with advanced soft tissue coverage techniques to achieve wound and fracture healing.[2] These fractures are associated with high infection[3] and non-union rates, and may result in limb loss in an otherwise fit and healthy adult.[4] An understanding of its epidemiology and pathogenesis allows the surgical team to better plan and allocate resources for fixation and soft tissue coverage so as to ensure the best outcome for the patient.

The purpose of this retrospective study was to determine how factors, such as patient demographics, mechanism of injury, AO classification,[5] Gustilo-Anderson classification[6] of open fractures and multiple injuries, correlate with length of hospital stay, number of operations, infection rates and time to union. This study examines how these factors affected our study endpoints in the Singaporean context, and adds to the information from smaller studies in the literature.[6-8]

METHODS

The National University Hospital (NUH), Singapore serves the western central part of Singapore, and is the primary receiving centre for road traffic accidents occurring on three major expressways. It is also a tertiary referral centre for complex trauma referred from other hospitals. Western Singapore is mostly industrialised, with a major container port and an oil refinery. The 2009 statistics from the Ministry of Manpower, Singapore indicate that 2,853 workplace injuries occurred in the construction industry (eight injuries a day), with 31 fatalities and 44 injuries resulting in permanent disability. An analysis was performed on all patients with open tibial fractures who presented to NUH over a nine-year period from April 2000 to April 2009. The demographic and clinical details of all the patients were recorded, along with information on the type of fracture and accompanying soft tissue injuries. All relevant data on surgical procedures and postoperative management were also recorded. Local ethical approval for our research study was obtained through our institutional review board.

The minimum follow-up period was six months, and follow-up was continued till radiographic evidence of union (maximum 72 months). Information was available through clinical notes and digitally stored radiographs. Data on Gustilo-

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Table I. Demographic data according to the Gustilo-Anderson classification.

Demographic	No (%)			
	Gustilo 1	Gustilo 2	Gustilo 3a, 3b, 3c	Total
No. of patients	53 (16.4)	100 (31.0)	170 (52.6)	323 (100)
Mean age; range (yrs)	37.7; 17–67	33.9; 16–74	37.6; 18–83	36.5; 16–83
Gender				
Male	45 (84.9)	90 (90.0)	160 (94.1)	295 (91.3)
Female	8 (15.1)	10 (10.0)	10 (5.9)	28 (8.7)
Nationality				
Singaporeans	36 (67.9)	51 (51.0)	104 (61.2)	191 (59.1)
Non-Singaporeans	17 (32.1)	49 (49.0)	66 (38.8)	132 (40.9)
Race				
Chinese	31 (58.5)	51 (51.0)	96 (56.5)	178 (55.1)
Indian	13 (24.5)	30 (30.0)	38 (22.4)	81 (25.1)
Malay	8 (15.1)	18 (18.0)	32 (18.8)	58 (18.0)
Others	1 (1.9)	1 (1.0)	4 (2.3)	6 (1.8)
Side injured				
Right	29 (54.7)	52 (52.0)	80 (47.1)	161 (49.8)
Left	24 (45.3)	48 (48.0)	90 (52.9)	162 (50.2)

Anderson classification was obtained from the postoperative notes, and AO classification was done retrospectively if the information was not found in the notes. Outcomes of length of hospital stay, number of operations, time to union, infection rate and cost were recorded. Calculation of the total length of hospital stay included repeat admissions for treatment or complications of open fracture. Cost of treatment data was available from the period 2005 to 2009. Inclusion criteria were all adults (age ≥ 16 years) with open diaphyseal tibial fractures who presented during the study period. Patients were identified through operative records as well as in-house electronic discharge coding. Paediatric patients (age < 16 years) and those with delayed presentations (i.e. referrals from other local and overseas centres) were excluded from our study.

Time to fracture union was based on radiological evidence of callus bridging at least three cortices. Assessment of radiographic union was independently performed by two of the authors. Information on infection rates and type of microbes was obtained from clinical notes that documented infection as well as bacteriological cultures from operative samples. Deep infection was defined as infection requiring surgical debridement with positive deep tissue or bone cultures.

Statistical analysis was performed using the Statistical Package for the Social Sciences version 16.0 (SPSS Inc, Chicago, IL, USA). For comparison of means, the *t*-test or analysis of variance was used for parametric vs. continuous variables. For parametric data comparisons, the chi-square test was used. Where the data was not normally distributed, analysis was performed on the $\log_{10}$ value.

RESULTS

A total of 364 open fractures of the tibia were identified during the study period. 323 fractures, including 11 patients with bilateral open tibial shaft fractures, met the inclusion criteria. There were two mortalities – one at postoperative Day 1 and another at postoperative Day 4 due to other injuries. Demographic data of 42 patients who were lost to follow-up before union were included for demographic analysis but excluded for outcomes analysis. All patients received intravenous antibiotics and were operatively managed, undergoing at least a thorough wound debridement and temporary fracture stabilisation at the initial operation.

Table II. Mechanisms of injury.

Mechanism of injury	No. (%)
Road traffic accident	224 (69.3)
Motorcyclist	135 (41.8)
Pedestrian	35 (10.8)
Driver	30 (9.3)
Passenger	13 (4.0)
Cyclist	11 (3.4)
Industrial accident	70 (21.7)
Direct trauma	64 (19.8)
Fall from a height	5 (1.5)
Blast injury	1 (0.3)
Others	20 (5.2)
Fall from a height	11 (3.4)
Trip and fall	4 (1.2)
Assault	4 (1.2)
Sports	1 (0.3)
Unknown	9 (3.3)

The mean age of the cohort was 36.5 (range 16.4–83.4) years, and 91.3% (n = 295) were male. The demographic data is summarised in Table I. There was no statistically significant difference in the study endpoints (i.e. length of hospital stay, number of operations, time to union and infection rates) according to age, race or gender. 69.3% (n = 224) of fractures occurred as a result of road traffic accidents, while 21.7% (n = 70) occurred due to industrial accidents (Table II). There was no significant endpoint difference in outcomes for fractures due to road traffic accidents compared to other modalities of injury.

Table III. Gustilo grade and AO type vs. outcomes (n = 281).

Classification	Infection rate	Mean ± SD		
		Mean time to union (mths)	Length of hospital stay (days)	No. of operations
Gustilo classification				
1	4/47 (8.5)*	7.98 ± 5.57	14.2 ± 15.73*	2.06 ± 1.39
2	8/85 (9.4)*	8.76 ± 4.56*	17.5 ± 22.02	2.39 ± 1.60*
3a	12/57 (21.1)*	13.35 ± 9.44*	33.8 ± 34.12*	4.32 ± 2.77*
3b & 3c	41/92 (44.6)*	12.75 ± 7.28	47.9 ± 41.36*	7.84 ± 4.92*
AO type				
A	27/106 (25.5)	9.18 ± 6.16†	27.1 ± 38.47†	3.83 ± 4.29†
B	12/96 (12.5)†	10.27 ± 4.50†	25.2 ± 24.79	4.16 ± 3.07
C	26/79 (32.9)†	13.70 ± 10.06†	36.3 ± 34.24†	5.85 ± 4.52†

Note: 42 patients who were lost to follow-up were not included in the outcomes analysis.
*$p < 0.005$, †$p < 0.05$
SD: standard deviation

The overall total length of hospital stay was 28.7 ± 33.3 (range 1–238) days. The mean number of operations to achieve union was 4.29 (range 1–23), and the mean time to radiographic union was 10.68 (range 3–72) months. The overall infection rate was 20.7% (n = 67). Subgroup analysis also revealed that Gustilo 3b and 3c fractures required more operations and a longer hospital stay than 3a fractures ($p < 0.005$), but there was no significant difference in time to union among the type of fractures (Table III). Infection rates were higher in Gustilo 3b/3c vs. Gustilo 3a fractures (45.7% vs. 21.1%, $p = 0.004$). Segmental fractures had a significantly longer time to union (18.5 vs. 10.2 months, $p < 0.000$) and required a longer hospital stay (46.0 vs. 29.0 days, $p = 0.03$) compared to fractures at a single level.

All 21 Gustilo 3c fractures (16 patients) occurred as a result of high-velocity injury. Two patients died during admission. 19 of these fractures were operated on within six hours of arrival at the hospital, one within 12 hours and the other within 24 hours. Five of the 16 patients had bilateral tibial shaft fractures. Of the 14 patients who did not have an immediate amputation, five developed infections requiring amputation at the same admission. The resulting nine out of the 21 Gustilo 3c fractures had their limbs salvaged. Compared to immediate amputation (n = 6), limb salvage (n = 9) required a longer hospital stay (31.8 vs. 61.0 days, $p = 0.239$) and more operations (1.8 vs. 10.8 operations, $p = 0.001$).

Until recently, it was our hospital policy to operate on all open fractures within six hours of arrival at the Emergency Department (ED). Most patients presented at the ED within an hour of their injury, and 203 (62.8%) of the fractures were operated on within six hours of arrival at the ED. A total of 303 (93.8%) fractures were operated on within 12 hours, and all operated on within 24 hours. Infection rates were significantly higher for operations performed within six hours vs. those performed within 6–24 hours (28.3% vs. 13.3%, p=0.04). This finding is confounded by the fact that the higher Gustilo grade fractures are more likely to be operated on earlier. An analysis of the infection rates in Gustilo 1, 2 and 3a fractures operated within six hours vs. those operated after six hours showed no statistical significance (17/112, 15.2% vs. 7/77, 9.1%; $p = 0.22$). Similarly, an analysis of Gustilo 3b and 3c fractures operated within six hours vs. those operated after six hours showed no difference in infection rates (35/71, 49.3% vs. 6/21, 28.6%, $p = 0.09$).

Compartment syndrome occurred in seven of the 323 (2.2%) fractures. A total of nine fasciotomies were performed – two were done prophylactically at the first operation to prevent development of compartment syndrome, five at the first operation for established compartment syndrome and another two for subsequent delayed development of compartment syndrome. 51 (15.8%) patients had additional fractures on the same limb, with five patients fracturing three sites or more on

Table IV. Multiple injured patients and length of hospital stay (n = 281).

	No. (%)	Mean length of hospital stay* (days)
No. of limbs injured		
1	229 (81.5)	27.7 ± 34.23; 2–238
2	43 (15.3)	42.3 ± 31.99; 5–166
3	7 (2.5)	39.7 ± 39.83; 14–123
4	2 (0.7)	19.0†
No. of body regions‡ injured		
1	241 (85.8)	28.0 ± 33.23; 2–238
2	28 (10.0)	39.1 ± 35.9; 5–156
3	8 (2.8)	51.3 ± 49.0; 15–166
4	3 (1.1)	63.3 ± 24.19; 36–82
5	1 (0.3)	46

Note: 42 patients who were lost to follow-up were not included in the outcomes analysis.
*Data is presented as mean ± standard deviation; range. † Data belongs to one patient with bilateral fracture. ‡ Body regions were divided into limbs, head and neck, spine, pelvis, chest and abdomen.

Table V. Cost of treatment at initial admission (year 2005–2009).

Gustilo classification	No. of cases	Average cost (range)*
1	23	$11,613 ($2,525–$41,252)
2	38	$17,849 ($5,545–$92,018)
3a	19	$34,499 ($7,535–$105,871)
3b	58	$46,666 ($6,673–$181,787)
3c	4	$102,499 ($63,678–$179,809)

Note: Data is available for 142 patients.
*Cost of treatment is in Singapore dollars.

the same limb. Two patients suffered traumatic amputations of their limb at the time of accident. 42 (13.0%) patients suffered fractures on the contralateral lower limb, of which five patients fractured three and more sites on the other leg and one suffered a traumatic amputation.

An analysis of polytraumatised patients is included in Table IV. Patients with more than one injured limb had a significantly longer time to union (12.0 vs. 10.4 months, $p = 0.043$) and longer length of hospital stay (41.0 vs. 27.7 days, $p = 0.01$). There was, however, no significant difference in infection rates between patients who injured more than one limb vs. those who had only one limb injury (25.0% vs. 22.7%, $p > 0.05$). Patients with significant injury in more than one body region had a longer time to union (12.1 vs. 10.4 months, $p = 0.025$) and hospital stay (43.5 vs. 28.0 days, $p = 0.008$), but there was no significant difference in infection rates (25.0% vs. 22.8%, $p = 0.84$). Financial data from 2005–2009 indicate that the mean cost for initial admission was S$33,222. A breakdown cost analysis showed an exponential cost increase as the severity of fracture increases (Table V).

DISCUSSION

This is the largest series of open tibial diaphyseal fractures reported to date. Smaller series on open tibial shaft fractures have been published by Gopal et al (84 fractures)[9], Reuss and Cole (81 fractures)[10] and Naique et al (73 fractures).[11] Since the year 2000, ED and operative notes, discharge summaries and radiographs have been computerised at our institution, which helped to ensure the accuracy of data collected. Moreover, the high volume of trauma cases handled at our hospital also enabled us to obtain clinically and statistically significant results for our study.

Gopal et al retrospectively reviewed 80 patients with 84 fractures (79 Gustillo 3b, five Gustillo 3c), of which 33 Gustillo 3b and two Gustillo 3c fractures underwent immediate 'fix and flap' and 75% had soft tissue coverage within 72 hours. The authors thus concluded that early internal fixation and soft tissue cover within 72 hours for high-grade injuries is safe.[9] Similarly, we recognise that fixation technique and soft tissue management are important for patient outcomes. Therefore, such relevant data was captured from our study population, including variables such as the type of fixation, soft tissue cover and definitive implant used for fixation, as well as the type of secondary procedures used to address delayed union or non-union. At the time of this writing, these parameters were undergoing further analysis.

The Gustilo-Anderson classification has been shown to have prognostic value when applied to open tibial fractures. Court Brown et al found that in open tibial shaft fractures ($n = 230$), 56.9% of fractures were Gustillo type 3 and 35.7% were AO type C. A higher Gustilo grade was found to positively correlate with a higher incidence of infection, longer hospital stay, more operations and a longer time to union.[1] These findings correspond to those from previous studies,[1,12] and further support the validity of our study. Segmental fractures in our study population required a significantly longer time to union (18.5 months) and inpatient stay (46 days), which is consistent with segmental fractures being upgraded to Gustilo 3 grading regardless of wound size, and thus, special consideration should be given when managing a patient with this injury.

Court-Brown et al performed an epidemiological analysis of 515 open long bone fractures, of which 230 were tibial diaphyseal injuries. The study population comprised 76.2% of male patients with an average age of 42.8 years. The causes of fracture were road traffic accidents (62.2%), falls (18.7%), sports (7.4%) and direct blows (8.3%).[1] In our study, a patient with open tibial fracture was typically male, in his thirties and had likely sustained the fracture from a road traffic accident, with motorcyclists accounting for a high proportion (41.8%) of patients.[13] In addition, there was also a high proportion (40.9%) of foreign industrial workers in our study population, which reflects the industrialisation of Western Singapore.

The incidence of compartment syndrome in our series was 2.2% (seven fractures), which is lower than the figure of 6.0%–9.1% previously cited in the literature.[14,15] Four of the seven cases occurred in Gustilo 3 fractures, correlating with the fact that fractures associated with severe soft tissue injury and fracture comminution are more likely to develop compartment syndrome. Blick et al reviewed 198 open fractures of the tibia and found 18 (9.1%) cases of compartment syndrome that were confirmed with compartmental pressure monitoring.[15] Of these, 15 cases occurred in Gustillo 3 fractures. Although the incidence is lower compared to severe closed tibial fractures, one should always maintain a high index of suspicion for diagnosing this highly disabling complication.

There have been many debates on limb salvage versus primary amputation for severe injuries in Gustilo 3c fractures.[16-18] In a systematic review of 28 observational studies on outcomes in Gustilo 3b and 3c fractures, Saddawi-Konefka et al found that limb salvage patients had a shorter inpatient stay (56.9 vs, 63.7 days) but had an extensive list of complications, i.e. secondary amputation (7.3%), osteomyelitis (17.9%), non-union (15.5%) and complete flap loss (5.8%). Additionally, the average time to union was 10.2 months. Therefore, no clear conclusion was reached on the superiority of limb salvage vs. amputation.[19] In our study, 16 out of 323 patients required amputations, of which 12 were Gustilo 3c fractures. Of these 16 amputations, ten were below-knee amputations and five patients had above-knee amputations at the initial admission. One patient with a Gustilo 3b fracture had a below-knee amputation two years later secondary to late infection.

Open tibial fractures usually result from high-velocity injuries, and such patients may have significant injuries in other limbs and body regions. Court-Brown et al found that 21% of patients who present with an open long bone fracture would have an Injury Severity Score (ISS) exceeding 15 and that 45% would have other significant musculoskeletal injuries.[1] Out of the 323 patients

in our study, 99 (30.7%) suffered injuries to two or more body regions and 57 (17.6%) suffered fractures to more than one limb. However, we found that it was not accurate to retrospectively apply the ISS to our study patients without taking into account spinal and pelvic injuries, which resulted in a high degree of morbidity within our study population. Patients with ipsilateral or multiple limb injuries are more likely to have a longer time to union due to difficulty in rehabilitation, and they are also more likely to require operative fixation for all fractures sustained in order to achieve fracture stability.

The oft-quoted six-hour rule for operating on open fractures is not evidence-based,[20,21] as the 2010 guidelines from the British Orthopaedic Association Standards for Trauma[22] have recommended that open lower limb fractures be managed in a tertiary referral centre with no mention of a specific time frame for most open fractures. Naique et al compared the management of open tibial fractures in local centres with specialist centres and found that local centres experienced a higher rate of revision surgery and complications.[11] Our institution, which possesses a full complement of general surgical trauma support with orthopaedic, vascular, plastic and microsurgical expertise, aims to operatively manage all open fractures as soon as possible (93.8% within 12 hours). Reuss and Cole, however, found that delayed operative management of up to 48 hours did not adversely affect non-union and infection rates in their study of 81 cases of open tibial shaft fractures.[10]

This study, however, is not without its limitations. Firstly, this was a retrospective single-institution review, where the patient population (from industrial area) that our hospital serves is unlike the rest of the country. Additionally, there was a relatively high number of patients lost to follow-up (n = 42) due to the significant proportion of injuries occurring in foreign industrial workers who returned to their country of origin once they were fit to travel. Further, costing information was only available for a five-year period and thus, the study only took into account the costs of initial admission.

In conclusion, our results confirm that severe open fractures of the tibia are associated with high infection and non-union rates, leading to multiple operations and a long inpatient stay. Accurate fracture classification should therefore be performed routinely, as it has been shown to have prognostic value. As most of these fractures occur in young men, the goal of management is to return them to their pre-morbid status expediently. Management of these fractures poses a high cost burden to both patients and the institutions providing treatment. Motorcyclists account for a large proportion of our study population, and thus, public awareness of safe riding and the use of appropriate safety equipment should be emphasised. Since operating on patients within six hours of arrival at the hospital has not been found to affect infection rates, we recommend that these fractures be managed within a tertiary trauma centre with multi-disciplinary input. We also propose that multiple injured patients be managed in the context of concurrent life-threatening injuries, as they are likely to suffer severe higher-grade open fractures.

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