Predicting the Outcome of Open Type IIIC Tibial Fractures Regarding Union, Osteomyelitis, and Amputation

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Research Article

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Abstract

Backgrounds: This study aimed to assess factors that affect union time and complications in Gustilo IIIC tibial fractures.

Methods: Patients who presented to our center with IIIC open tibial fractures from January 2000 to October 2020 were eligible for this retrospective analysis. Patient demographics, fracture characteristics, timing, numbers, and type of surgical intervention were documented. Outcomes of interest included union time, occurrence of osteomyelitis, and amputation.

Results: Fifty-eight patients were enrolled and grouped by fracture type; eight union on time (13.8%); 27 late union (46.6%); eight delayed union (13.8%); three nonunion (5.2%); and 12 amputation (20.7%). Nine fractures (15.5%) were complicated by osteomyelitis. Union time was prolonged in cases of triple arterial injury, distal third fractures, multiple trauma with Injury Severity Score (ISS) ≥ 16 points, and increased length of bone defect. Additionally, a bone gap > 50 mm, diabetes mellitus, low body mass index, and triple arterial injury in the lower leg were significant risk factors for amputation. A time from injury to definitive soft tissue coverage of more than 22 days was the major risk factor for osteomyelitis. A scoring system to predict union time was devised and the predicted probability of union within two years was stratified based on this score.

Conclusions: IIIC tibial fractures involving the distal third of the tibia, fractures with bone defects, triple arterial injury, and multiple trauma with ISS ≥ 16 points demonstrated delayed union, and an effective prediction system for union time was introduced in this study. Early soft tissue coverage can reduce the risk of osteomyelitis. Finally, diabetes and severe bone and soft tissue defects pose a higher risk of amputation.

Background

Tibial fractures are the most common long bone fractures, and approximately 24% are open type fractures [1]. Nearly 60% of open tibial fractures are Gustilo-Anderson type III fractures, indicating a high-energy breakage that often results from motor vehicle collisions or falls [2]. Gustilo type III fractures are generally subdivided into IIIA, with adequate soft-tissue coverage of the bone, IIIB with bone exposure, and IIIC with compromised arterial circulation [3]. Soft tissue severance, contamination, and vascular compromise in IIIC fractures increase the risk of subsequent infection, nonunion, and amputation and may lead to psychological stress and economic difficulties [4].

Adequate blood supply is a crucial factor in fracture union [5]. The anterior surface of the tibial shaft is covered with thin subcutaneous tissue, and blood supply is easily compromised after trauma; therefore, the tibia is at a higher risk of nonunion than other long bones, which have abundant blood vessels and soft tissue [6]. In type IIIC tibial fractures, the anterior tibial artery (ATA), posterior tibial artery (PTA), and peroneal artery are often damaged and require timely revascularization after initial cleansing, debridement, external fixation, and sometimes fasciotomy, to avoid reperfusion injury [7, 8]. After initial management with restoration of circulation, conversion to definitive internal fixation is often best deferred until adequate soft tissue coverage of the tibia and neurovascular structures has occurred and infection has been ruled out.

Being able to identify if a severe fracture will heal successfully or is likely to result in nonunion would improve clinical practice. An effective tool to predict the likelihood of serious complications would enable clinicians to apply advanced interventions earlier when required. Studies have revealed that poor outcomes are associated with fracture characteristics and the timing of intervention [9-12]. Despite the consensus that more complicated fractures and delayed soft tissue coverage might delay union [9-13], few studies have identified a cut-off value to predict the outcomes of type IIIC open tibial fractures.

This study aimed to determine the prognostic factors for outcomes in open IIIC tibial fractures regarding union time, osteomyelitis, and amputation by reviewing two decades of cases from a single tertiary trauma center. A scoring system was created based on the analytical results to predict probable union time of these types of fractures.

Methods

Inclusion criteria

Patients with open tibial fractures treated in a single tertiary trauma center between January 2000 and October 2020 were eligible for inclusion.

The inclusion criteria were as follows:

1. Gustilo type IIIC tibial fractures caused by trauma
2. Arterial injuries requiring revascularization for limb salvage, including occlusion or rupture involving the anterior tibial artery, posterior tibial artery, peroneal artery, or popliteal artery, identified by conventional angiography, computed tomographic angiography, or intraoperative findings.
3. Fracture location involving tibial plateau, proximal and distal metaphyses, and diaphysis

The exclusion criteria were:

1. Open fractures other than type IIIC
2. Type IIIC ankle malleolar fractures
3. Patients referred for management of complications from other hospitals
4. Re-fracture due to falls or motor vehicle accidents during recovery
5. Insufficient clinical or radiographical data

Data collection

Patient characteristics such as age, sex, body mass index (BMI), comorbidities, fracture location, associated fracture, injured vascular structure, mangled extremity severity score (MESS), length of bone defect, soft tissue defect area, surgical site infection, and osteomyelitis were recorded. The characteristics of internal and external fixation, the artery that was primarily anastomosed or revascularized, time from injury to definitive soft tissue coverage, and number and type of flap surgeries were recorded. Lastly, additional interventions such as vascularized bone graft (VBG), non-vascularized bone graft (NVBG), or Masquelet technique were also recorded. Proximal fractures included fractures involving the tibial plateau and the proximal metaphysis of the tibia, diaphysis fractures involved the middle third of the tibia, and distal fractures involved the distal metaphysis of the tibia with the exclusion of malleolar fractures. Segmental fractures were recorded when a fracture involved more than one fracture location. Bone defect length was measured after surgical removal of devitalized bones and defined as the length between the proximal and distal ends of the fracture. Multiple trauma was defined as an Injury Severity Score (ISS) of more than 16 points with internal organ laceration, intracranial hemorrhage, or hypovolemic shock caused by internal bleeding or fracture wound bleeding. Soft tissue defect area was defined as the area of bone exposure requiring flap coverage. Patients were divided into groups based on fracture healing time after trauma; on time, union less than 1 year; late, union between 1 and 2 years; delayed, union > 2 years; nonunion, no union or limited progress on X-ray before a patient discontinued care at our hospital; or amputation. Radiographic union score for tibial fractures [14] $\geq$ 10 (measured by three board-certified orthopedic surgeons) and allowance of partial weight-bearing were regarded as union.

Ethics Approval

This retrospective study involving human participants was conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The study protocol was approved by the relevant Institutional Review Board.

Statistical analysis

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Univariate analysis of categorical variables was conducted using the chi-squared test or Fisher's exact test. The means and medians of continuous variables were compared using ANOVA or Kruskal-Wallis tests. For multivariate analysis, a Cox proportional hazards model with a follow-up duration of 2 years, logistic regression, and stepwise modelling were conducted to identify the predictive factors of the union time and complications such as osteomyelitis and amputation. Nonunion and amputation were regarded as adverse outcomes and grouped for stepwise modelling.

Results

Of 483 patients eligible for inclusion in this study, 70 patients with type IIIC open tibial fractures were reviewed. Fifty-eight patients who met the study criteria (45 men, 12 women) were included in the retrospective analysis. The demographic data and injury characteristics of the enrolled patients are shown in Tables 1 and 2.

Table 1. Patient Demographics

Characteristics	No. (%)
Mean age ± SD, yr	35.8 ± 16.6
Sex	
Male	45 (77.6)
Female	13 (22.4)
BMI ± SD	23.9 ± 4.6
Diabetes mellitus	5 (8.6)
Other chronic diseases	4 (6.9)
Smoking	19 (32.8)
Other substance abuse	3 (5.2)

There were 11 cases of popliteal artery injury: four were tibial plateau fractures, three were proximal tibial shaft fractures, two involved the tibial plateau and proximal metaphysis, and two were tibial diaphysis fractures with extensive avulsion injury. The mean length of bone defect, area of bone exposure requiring flap coverage, and tissue coverage details are documented in Table 2. Of note, two fractures initially treated with free flap coverage resulted in amputation and ten cases where soft tissue reconstruction was not performed as progressive soft tissue necrosis after revascularization led to amputation.

Table 2. Injury characteristics

Characteristics	No. (%)
Fracture Location	
Proximal	8 (13.8)
Middle	10 (17.2)
Lower	22 (37.9)
Upper and middle	4 (6.9)
Upper and lower	11 (19)
Middle and lower	3 (5.2)
Multiple trauma with ISS ≥ 16 points	9 (15.5)
MESS ± SD	5.6 ± 1.5
Osteomyelitis	9 (15.5)
Surgical site infection	35 (60.3)
Length of bone defect ± SD, mm	38.8 ± 37.6
Soft tissue defect area ± SD, cm^2	201.86 ± 148.5
Type of internal fixation	
Intramedullary nail	17 (29.3)
Plate	29 (50)
Did not receive internal fixation	12 (20.7)
Type of soft tissue coverage	
Free flap	37 (63.8)
Local flap	8 (13.8)
Primary closure	3 (5.2)
Did not receive soft tissue reconstruction	10 (17.2)
Injured arterial structure	
Anterior tibial artery (ATA)	13 (22.4)
Posterior tibial artery (PTA)	9 (15.5)
Peroneal artery (PEA)	1 (1.7)
Popliteal artery (POPA)	9 (15.5)

ATA and PTA	10 (17.2)
ATA and PEA	2 (3.4)
ATA and POPA	2 (3.4)
PTA and PEA	3 (5.2)
ATA and PTA and PEA	9 (15.5)

Union time and related influencing factors

The univariate analysis of union time is shown in Table 3. In addition to those fractures, 12 amputations (20.7%) were performed. The overall mean union time for patients with or without an ISS $\geq$ 16 points were 773.6 ± 348.4 days and 498.9 ± 237.9 days respectively ($p=0.025$). Among the nine patients with ISS $\geq$ 16 points, six (66.7%) had hypovolemic shock caused by internal organ laceration or massive bleeding, one (11.1%) had intracranial hemorrhage, one (11.1%) had rhabdomyolysis after trauma with resultant renal failure, and one (11.1%) had cervical spine injury.

Table 3. Union time in univariate analysis

Covariate		Union on time	Late union	Delayed union	Nonunion	P-value
		N=8	N=27	N=8	N=3	
Age mean (SD)		33 (16.72)	38 (15.72)	30.13 (12.61)	24 (2.65)	0.269
Sex (%)						0.677
	Female	1 (12.5)	4 (14.81)	2 (25)	1 (33.33)	
	Male	7 (87.5)	23 (85.19)	6 (75)	2 (66.67)	
BMI mean (SD)		25.43 (3.29)	24.2 (3.41)	26.03 (7.16)	22.47 (7.21)	0.661
DM (%)	With	1 (12.5)	1 (3.7)	0 (0)	0 (0)	0.661
Fracture location (%)						0.841
	Upper	2 (25)	5 (18.52)	1 (12.5)	0 (0)	
	Middle	2 (25)	3 (11.11)	1 (12.5)	1 (33.33)	
	Lower	3 (37.5)	10 (37.04)	3 (37.5)	1 (33.33)	
	Upper and middle	1 (12.5)	2 (7.41)	1 (12.5)	0 (0)	
	Upper and lower	0 (0)	6 (22.22)	2 (25)	0 (0)	
	Middle and lower	0 (0)	1 (3.7)	0 (0)	1 (33.33)	
Segmental fracture (%)	With	1 (12.5)	9 (33.33)	3 (37.5)	1 (33.33)	0.714
Other upper limb fracture (%)	With	0 (0)	0 (0)	0 (0)	1 (33.33)	0.065
Other lower limb fracture (%)	With	4 (50)	6 (22.22)	3 (37.5)	0 (0)	0.270
Axial skeleton fracture (%)	With	0 (0)	0 (0)	1 (12.5)	0 (0)	0.413
ATA injury (%)	With	5 (62.5)	14 (51.85)	5 (62.5)	3 (100)	0.506
PTA injury (%)	With	5 (62.5)	12	5 (62.5)	1 (33.33)	0.623

			(44.44)			
Peroneal A injury (%)	**With**	1 (12.5)	5 (18.52)	1 (12.5)	0 (0)	1.000
Popliteal A injury (%)	**With**	1 (12.5)	8 (29.63)	1 (12.5)	0 (0)	0.659
Vascular injury (%)						0.885
	1 artery	5 (62.5)	16 (59.26)	5 (62.5)	2 (66.67)	
	2 arteries	2 (25)	10 (37.04)	2 (25)	1 (33.33)	
	3 arteries	1 (12.5)	1 (3.7)	1 (12.5)	0 (0)	
MESS score mean (SD)		5.38 (2)	5.78 (1.63)	4.88 (0.99)	4.33 (0.58)	0.222
Bone gap length mean (mm) (SD)		28.22 (24.63)	25.94 (18.43)	40.51 (24.1)	39.06 (28.83)	0.387
Soft tissue defect area mean (cm^2) (SD)		273.6 (176.89)	238 (120.55)	193.5 (117.52)	228.67 (36.68)	0.700
Deep wound infection before osteosynthesis (%)	**With**	4 (57.14)	12 (46.15)	4 (50)	0 (0)	0.465
Deep wound infection after osteosynthesis (%)	**With**	5 (71.43)	15 (55.56)	6 (75)	2 (66.67)	0.814
Osteomyelitis before osteosynthesis (%)	**With**	1 (14.29)	1 (3.7)	1 (12.5)	0 (0)	0.423
Osteomyelitis after osteosynthesis (%)	**With**	1 (14.29)	5 (18.52)	2 (25)	1 (33.33)	0.766
Duration of external fixation mean (days) (SD)		138.14 (67.19)	104.59 (70.4)	100.57 (57.08)	142.67 (120.83)	0.400
Time of injury to osteosynthesis mean (days) (SD)		110.43 (60.58)	67.92 (53.53)	92 (71.11)	98.33 (71.81)	0.377
Exchange of internal fixation (%)						0.437
	0	7 (100)	21 (77.78)	7 (87.5)	2 (66.67)	
	1	0 (0)	4 (14.81)	0 (0)	0 (0)	
	2	0 (0)	1 (3.7)	1 (12.5)	0 (0)	
	3	0 (0)	1 (3.7)	0 (0)	1 (33.33)	

Nonvascularized bone graft (%)	**With**	2 (25)	16 (59.26)	6 (75)	3 (100)	0.089
Nonvascularized bone graft numbers (%)						0.965
	1	2 (100)	11 (68.75)	4 (66.67)	2 (66.67)	
	2	0 (0)	2 (12.5)	0 (0)	0 (0)	
	3	0 (0)	3 (18.75)	2 (33.33)	1 (33.33)	
Time to definitive coverage mean (days) (SD)		16.63 (9.47)	14.85 (10.07)	20.63 (10.32)	10.67 (8.5)	0.450
Free flap (%)	**With**	7 (87.5)	18 (66.67)	7 (87.5)	3 (100)	0.454
Local flap (%)	**With**	5 (62.5)	15 (55.56)	5 (62.5)	2 (66.67)	1.000
Vascularized bone graft or Masquelet (%)						0.248
	neither	5 (62.5)	23 (85.19)	5 (62.5)	2 (66.67)	
	VBG	1 (12.5)	1 (3.7)	2 (25)	0 (0)	
	Masquelet	2 (25)	3 (11.11)	1 (12.5)	1 (33.33)	

The parametric p-value was calculated by ANOVA for numerical covariates and chi-squared test for categorical covariates. Non-parametric p-values were calculated by the Kruskal-Wallis test for numerical covariates and Fisher's exact test for categorical covariates.

Regarding cases with larger bone defects (mean = 57.12 ±17.76), four patients underwent VBG (mean defect length = 68.33 ±7.05), and seven underwent the Masquelet technique (mean defect length = 52.91 ±19.04). The union time for cases that underwent VBG and Masquelet procedures was 713.75 ± 449.29 and 539.57 ± 234.08 days respectively (p = 0.166). Comparing those who underwent either VBG or Masquelet versus those who did not, the union time were 602.91 ± 318.05 and 505.49 ± 242.23 days respectively (p = 0.190).

Multivariate analysis demonstrated that triple arterial injury, distal third fracture, bone defect, and multiple trauma with ISS≥ 16 points were significant adverse factors for the fracture to unite within 2 years. A forest plot of the multivariate model is shown in Figure 1a. Based on the Cox PH model, we proposed a scoring system to predict the probability of union within 2 years (Tables 4 and 5). Furthermore, our cohort was divided equally into three groups and labelled low, moderate, and high based on the estimated probability of union by the Cox PH model. The scoring system was validated using a Kaplan-Meier plot. The mean score of each group from low to high probability of union was 15.7, 8.7, and 4.0, and the mean probability of union within 2 years was 19%, 79%, and 85%, respectively. The higher score implies a higher probability of nonunion after two years. There was a significant difference in union time between the high versus moderate and high versus low groups (p<0.0001) (Figure 1b).

Table 4. Tibial Open IIIC Fractures: Prediction for Union within 2 years

	Yes	No
Multiple trauma with ISS ≥ 16 points	+9 to score	0 points
Triple arterial injury	+7 to score	0 points
Distal third fracture	+4 to score	0 points
Bone defect	(+ different points according to defect size)	0 points

* Bone defect length (mm) was stratified as follows: 0 points: < 6 mm; 1 point: 6-10 mm; 2 points: 10-16 mm; 3 points: 16-23 mm; 4 points: 23-30 mm; 5 points: 30-39 mm; 6 points: 39-41 mm; 7 points: 41-60 mm; 8 points: 60-72 mm; 9 points: >72 mm.

Table 5. Prediction result in our cohort

Score	**Probability of union within 2 years (stratified in every 10% probability)**
0 to 1	85-95%
2	75-85%
3 to 4	65-75%
5	55-65%
6	45-55%
7 to 8	35-45%
9 to 10	25-35%
11 to 12	15-25%
13 to 18	5-15%
19 to 29	<5%

Osteomyelitis and related predicting factors

Stepwise modelling of multivariate logistic regression of nine cases of osteomyelitis revealed that a time of injury to definitive coverage of greater than 22 days, the third interquartile in our data, significantly increased the risk of osteomyelitis (Figure 2).

Amputation and related predicting factors

There were five cases of early amputation (amputated within 1 d) and seven delayed amputations (amputated after 1 d). Among the 12 amputations, nine were amputated despite initial revascularization attempts, and three did not receive revascularization due to extensive soft tissue loss or avulsion injury. Multivariate logistic regression showed that diabetes, bone gap > 50 mm, lower BMI, and triple arterial injury increased the risk of amputation in IIIC tibial fractures, despite attempts at revascularization (Figure 3).

Discussion

Union time

Gustilo type IIIC fracture of the tibia might result in various sequelae such as nonunion, surgical site infection, osteomyelitis, and amputation [4]. Various factors which may influence the union of open tibial fractures have been proposed in the literature [10, 13]. However, this is the first retrospective study dedicated to the prognosis of type IIIC tibial fractures regarding union time, osteomyelitis, and amputation.

We found a 5.2% rate of nonunion after a two-year follow-up. This is comparable with findings of 7.4% and 6.8% nonunion in all tibial fractures reported previously [15, 16].

In our cohort, a significantly lower number of cases with multiple trauma or triple arterial injury achieved union within 2 years compared to those without either condition. Although, it is worth mentioning that one patient had multiple trauma and triple arterial injury simultaneously. Although the result was not statistically significant, a slightly longer mean union time was noted in distal third tibial fractures compared to fractures not involving the distal tibia. The length of the bone defect significantly affected union time in univariate analysis and the multivariate model and the probability of union within 2 years decreased with an increase in the bone defect length.

The commonly injured arteries in our study were consistent with previous literature with middle third tibial fractures and concomitant ATA injury as the most common injury [17, 18]. Distal third tibial fractures have been proposed as an adverse factor in the healing of open tibial fractures [18-20]. Stranix et al. [18] proposed that these fractures are commonly complicated by damage to the PTA and peroneal artery, which usually implies a more serious impact during trauma than injuries to the ATA at the middle third tibia. A study of 18 patients with type IIIC fractures found that PTA injury posed an increased rate of nonunion [19]. The PTA supplies blood to the inner two-thirds of the diaphyseal cortex of the tibia, while the outer third of the diaphyseal cortex is supplied by the periosteum. Therefore, PTA injury, with severance of the posterior envelope in distal fractures, may compromise tibial union [20, 21]. Although the analyses did not reach significance, in our cohort fractures with PTA injury were more inclined to unite after 2 years or require amputation compared to those without PTA injury.

Six patients with multiple trauma with ISS ≥ 16 points, which was a risk factor for nonunion in this study, had hypovolemic shock caused by either organ laceration or massive bleeding, and the fracture reconstructions were deferred until the patient's vital signs had stabilized. Bundkirchen et al. [22] evaluated the fracture healing process after trauma hemorrhaged in a mouse model. Their findings revealed reduced bone and callus density and they concluded that fracture healing is impeded when severe hemorrhagic shock occurs.

A bone gap >40 mm was associated with delayed union or nonunion/amputation in the multivariate model, while fractures with a bone gap of less than 30 mm healed within 2 years. A randomized controlled trial of tibial fractures proposed 1 cm, or 50% of the circumference of tibial diaphyseal defect, as a critical cut-off for bone defect size [23]. However, a systematic review by Azi et el. [24] found no direct relationship between the size of the bone defect and union rate when NVBG was applied in open fractures of long bones. In our cohort, four patients underwent VBG and eight underwent the Masquelet technique for the management of bone defects. Although these cases had a longer bone gap than the rest of the patients, the difference in union time did not reach statistical significance, which supports our theory that the bone gap might not be the most important factor affecting union time.

Osteomyelitis

Despite agreement that soft tissue coverage within 1 week benefits the outcome of severe tibial fractures [9, 25], soft tissue coverage might be delayed for many reasons [26]. In our cohort, a 22-day cut-off represented the third interquartile range of time to definitive soft-tissue coverage. Of the fractures with osteomyelitis, 44.4% received definitive soft tissue coverage more than 22 days after the initial trauma; these fractures were complicated by multiple traumas which delayed the timing of soft tissue coverage. Our results were consistent with a previous study, which proposed that severely traumatized tissue commonly requires more debridement to obtain a clear margin for better wound healing potential which often delays the definitive coverage to >2 weeks, and a longer time to wound coverage independently predicts infection [27]. In contrast, Stranix et al. found that the timing from injury to flap coverage was not associated with increased major complications in their study; however, their study focused more on flap failure rate, rather than infection [18].

Amputation

There was a 20.7% amputation rate in our cohort, which was similar to findings of 19.4% and 21% in previous studies [20, 28]. Although the injured arterial structures were not predictive of the union time, triple arterial injury was a risk factor for amputation in multivariate analysis and was often associated with large bone and soft tissue necrosis. Three of six triple arterial injury cases received immediate amputation in our cohort.

A lower BMI was noted as a significant risk factor for amputation in our multivariate analysis. Literature regarding multiple trauma has shown an “obesity paradox”, in which the overall survival seemed to be higher in obese patients than in underweight patients [29, 30]. One study found that a BMI <18.4 kg/m^2 was associated with an increased risk of mortality after multiple trauma [30]. We surmised that a lower BMI indicated less subcutaneous fat coverage to cushion or protect neurovascular and bony structures. Soni et al. [19] and Lin et al. [28] regarded an MESS score ≥ 9 as a valid predictor for amputation. Although MESS did not reach statistical significance in the present study, the amputation group tended to have a higher mean MESS score than the limb salvage group.

Diabetes mellitus (DM) has been proposed to impair healing and result in chronic wounds [31]. A significantly higher amputation rate was noted for patients with DM compared to those without DM (4.3%). Piwnica-Worms et al. [32] found a significant relationship between DM and the amputation rate in 129 patients with lower extremity trauma who required free flap reconstruction, which is compatible with our findings.

The limitations of our study stem from its retrospective nature. We were limited to existing medical records, and cases with missing information were excluded. Although more patients were enrolled than in previous studies of type IIIC tibial fractures, the principles of management might differ between surgeons, which could not be controlled for. Ambulation status in daily living and other outcomes regarding quality of life should also be evaluated and analyzed in future prospective studies.

Conclusion

In conclusion, IIIC tibial fractures with distal third tibial fractures, triple arterial injury, bone defect, or multiple trauma with ISS $\geq$ 16 points are likely to experience delayed union. Early soft tissue coverage should be the primary goal for reducing the risk of osteomyelitis. Lastly, severe bone and soft tissue defects, diabetes, and low BMI pose a higher risk of amputation.

Abbreviations

ATA, anterior tibial artery; PTA, posterior tibial artery; BMI, body mass index; MESS, mangled extremity severity score; VBG, vascularized bone graft; NVBG, non- vascularized bone graft; ISS, Injury Severity Score; DM, Diabetes mellitus

Declarations

Ethics Approval and Consent to Participate

This retrospective chart review study involving human participants was conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The study protocol was approved by the Institutional Review Board (IRB No.: 202000632B) of Chang Gung Memorial Hospital. The need for informed consent was waived due to the retropective nature

Consent for Publication

Not applicable

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Author’s Contributions

S-HC and P-HL conceptualized the study, wrote the first draft of the manuscript. C-CH conceptualized the study. Y-HY conceptualized the study, wrote the first draft of the manuscript, and reviewed and supervised the writing of the manuscript. S-HC, C-YL, and P-YC conducted the investigations. CHL reviewed and supervised the writing of the manuscript. All authors have read and approved the final manuscript.

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Figures

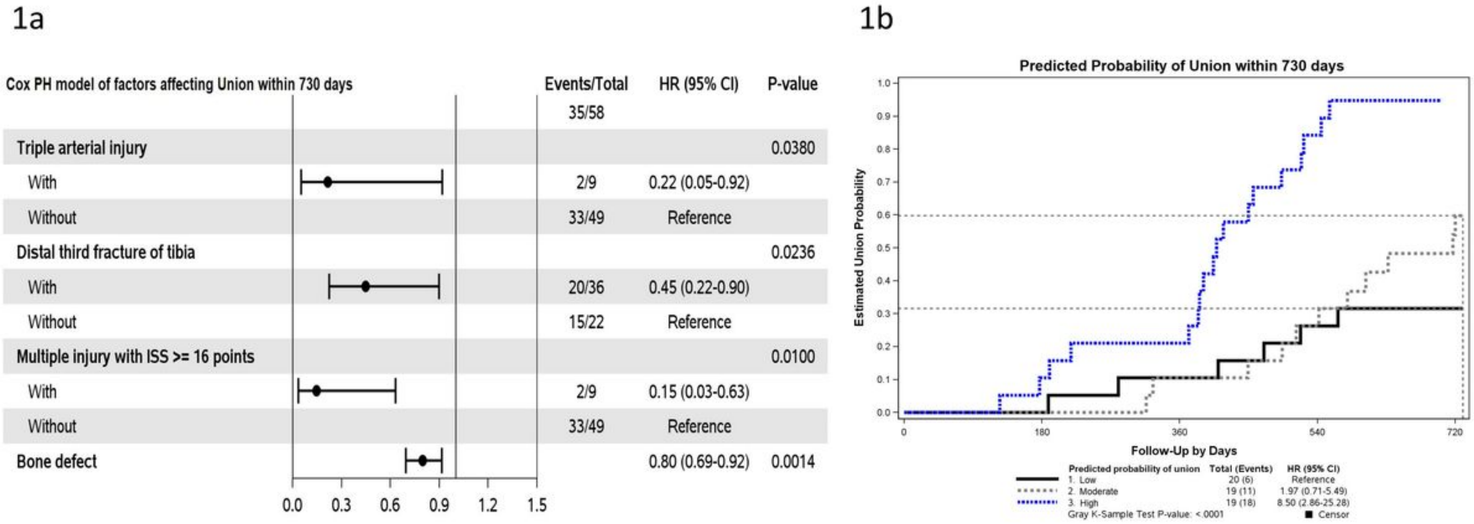

Figure 1

a. Cox PH model of union time Cox PH model comparing: fractures with and without triple arterial injury, fractures in the distal third against fractures in other locations, fractures with and without multiple trauma with ISS ≥ 16 points, and bone defect length. b. Patients grouping according to the probability estimated by the Cox PH model Using the present model, the cohort was divided into three groups according to the probability of union from low to high and presented in a Kaplan-Meier plot.

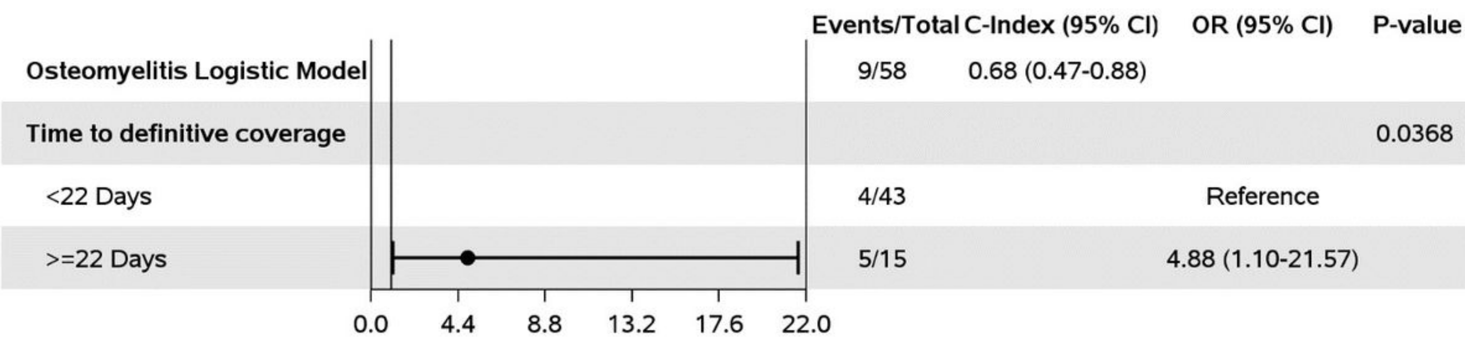

Figure 2

Logistic model predicting osteomyelitis occurrence The logistic model of osteomyelitis where definitive tissue coverage is achieved in more or less than 22 days.

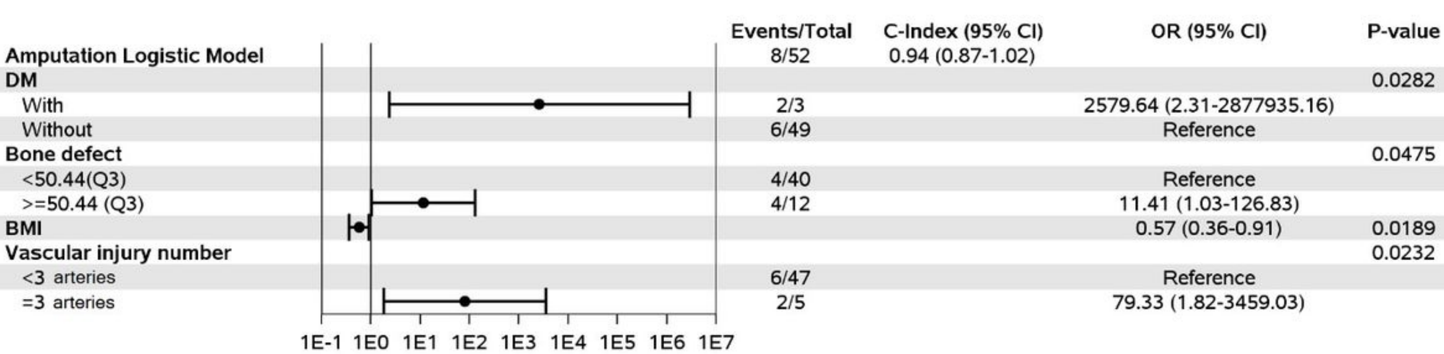

Figure 3

Logistic model predicting amputation The logistic model of amputation comparing: patients with and without diabetes, a bone gap length of less than or more than 50 mm, BMI, and triple arterial injury.