

Attempting primary closure for all open fractures: the effectiveness of an institutional protocol

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Background: Immediate primary closure of open fractures has been historically believed to increase the risk of wound infection and fracture nonunion. Recent literature has challenged this belief, but uncertainty remains as to whether primary closure can be used as routine practice. This study evaluates the impact of an institutional protocol mandating primary closure for all open fractures.

Methods: We retrospectively reviewed all open fractures treated in a single level 1 trauma centre in a 5-year period. Prior to the study, a protocol was adopted standardizing management of open fractures and advocating primary closure of all wounds as a necessary goal of operative treatment. Patient and fracture characteristics, type of wound closure and development of infectious and bone healing complications were evaluated from time of injury to completion of outpatient follow-up.

Results: A total of 297 open fractures were treated, 255 (85.8%) of them with immediate primary closure. Type III open injuries accounted for 24% of all injuries. Wounds that were immediately closed had a superficial infection rate of 11% and a deep infection rate of 4.7%. Both proportions are equivalent to or lower than historical controls for delayed closure. Fracture classification, velocity of trauma and time to wound closure did not correlate significantly with infection, delayed union or nonunion.

Conclusion: Attempting primary closure for all open fractures is a safe and efficient practice that does not increase the postoperative risk of infection and delayed union or nonunion.

Contexte : On a de tout temps cru que la fermeture primaire immédiate des fractures ouvertes accroissait le risque d'infection de la plaie et de non soudure osseuse. La littérature récente remet cette position en question, mais on ignore encore si la fermeture primaire peut être utilisée de routine. Cette étude évalue l'impact d'un protocole d'établissement imposant la fermeture primaire de toutes les fractures ouvertes.

Méthodes : Nous avons passé en revue de manière rétrospective toutes les fractures ouvertes traitées dans un seul centre de traumatologie de Niveau 1 au cours d'une période de 5 ans. Avant l'étude, un protocole a été adopté pour standardiser la prise en charge des fractures ouvertes et promouvoir la fermeture primaire de toutes les plaies comme objectif imposé du traitement opératoire. Les caractéristiques des patients et des fractures, les types de fermeture de plaie et les complications infectieuses ou liées à la guérison osseuse ont été évalués à partir du moment de la blessure et jusqu'à la fin du suivi en clinique externe.

Résultats : En tout, 297 fractures ouvertes ont été traitées, 255 d'entre elles (85,8 %), au moyen d'une fermeture primaire immédiate. Les traumatismes ouverts de Type III comptaient pour 24 % de toutes les blessures. Les plaies qui ont été refermées immédiatement ont présenté un taux d'infection superficielle de 11 % et un taux d'infection profonde de 4,7 %. Ces 2 proportions sont équivalentes ou inférieures à ce qui a été observé chez les témoins historiques chez qui la fermeture de plaie a été reportée. La classification des fractures, la vitesse de l'impact à l'origine des traumatismes et le temps écoulé avant la fermeture des plaies n'ont pas été en corrélation significative avec l'infection et le retard de soudure osseuse ou la non soudure osseuse.

Conclusion : Tenter d'appliquer une fermeture primaire à toutes les fractures ouvertes est une pratique sécuritaire et efficace qui n'accroît pas le risque d'infection postopératoire, de retard de soudure osseuse ou de non soudure osseuse.

The timing of wound closure in the management of open fractures remains somewhat controversial in the orthopedic traumatology literature. Although there is universal agreement regarding early administration of antibiotic therapy, performing a meticulous surgical débridement and stabilizing the associated fracture(s),¹ the precise role for early versus delayed wound closure in the context of high-energy open injuries remains unclear.

Advocacy for delayed wound closure on a regular basis is largely historical²⁻⁶ and was established before the advent of modern débridement methods, current antibiotics and modern fracture stabilization techniques.⁷ Nevertheless, delayed closure may be necessary when a tension-free closure is not possible or when the wound is heavily contaminated with anaerobic or gram-negative bacteria.⁸ In such cases, serial débridements every 48 to 72 hours followed by definitive closure within 7 days of injury have been shown to produce the lowest infection rates.^{6,9} Apart from these circumstances, immediate primary wound closure is currently the popular choice among surgeons for most open wounds.¹⁰ This practice is empirically supported by work, such as that of DeLong and colleagues,¹¹ who found that in 119 patients with open fracture, those who underwent immediate closure had shorter hospital stays, decreased health care costs and, most importantly, equivocal infection and fracture union rates compared with patients who underwent delayed closure. Such findings have been reproduced by others, with the general consensus that primary closure is safe in the context of adequate débridement.⁹ An additional argument favouring early closure is the finding that only 18% of infections following open fractures arise from the same organism isolated perioperatively, suggesting that most infections are acquired in hospital and are more likely to affect wounds that are left open.¹²

Despite the accumulation of literature evaluating the benefits of different treatment strategies, very little information exists regarding effective protocols involving primary closure for open fractures. Although evaluation of immediate skin closure has been previously reported,¹³ this study was limited to Gustillo–Anderson¹⁴ type III injuries and used a complex list of inclusion criteria. The present study evaluates the effectiveness of a simplified treatment protocol advocating the immediate closure of all types of open fractures when possible. Our primary outcome measures were the incidence of superficial and deep wound infection as well as delayed union and nonunion. We hypothesized that the use of this evidence-based protocol would result in the majority (> 50%) of open fracture wounds being primarily closed and that both infection and bone healing complication rates would be at least equivalent to historical controls treated with primary or delayed closure.

METHODS

Establishment of institution protocol

Following a comprehensive analysis of the orthopedic literature, the Orthopaedic Division in our level 1 trauma centre instituted a treatment protocol for all patients admitted to hospital with open fractures. The protocol is subsequently presented (Fig. 1), with the empirical evidence for each step presented as per the level of evidence (in parenthesis) currently used in the orthopedic literature.¹⁵ After trauma team consultation in the emergency department (ED), all patients were assessed by the orthopedic resident on call. Intravenous antibiotic prophylaxis was administered for all open injuries, consisting of a first-generation cephalosporin (cefazolin) for Gustillo–Anderson type I injuries, the addition of an aminoglycoside (gentamicin) for type II and III injuries, and the addition of penicillin G for grossly contaminated or farmyard injuries (Level 1).^{12,16} In the event of a penicillin allergy, cefazolin was substituted for vancomycin. All open wounds were irrigated in the ED with 3 L of sterile saline to remove obvious foreign bodies (Level 5). The wound was not probed or explored and was covered with a saline-soaked dressing. Displaced fractures were reduced under conscious sedation when necessary and were immobilized in a plaster-of-paris splint. When medically fit, patients were taken to the operating room (OR). Open wounds were thoroughly irrigated with sterile saline, all necrotic or questionable soft tissue was systematically débrided, and fracture stabilization was performed. Initial irrigation, if done in the first 6 hours after injury, was accomplished by gravity inflow and brush (Level 2).¹⁷ After 6 hours, pulsatile lavage was used (Level 5). No antibiotics or soap were added to the irrigation solution (Level 1).¹⁸ Wound closure was attempted following fracture stabilization regardless of Gustillo–Anderson classification (Level 3).⁹ Closure consisted of a primary side-to-side repair using nonabsorbable 2–0 nylon suture. Wounds that were definitively repaired in the first surgical setting were defined as being immediately closed. Furthermore, wounds that were initially closed and later reopened for fracture fixation or second-look débridement and then closed again were also defined as being immediately closed. Wounds that were left open for any reason after the first surgery and were later treated by definitive closure or the use of skin grafts were categorized as delayed closure. Postoperatively, antibiotic coverage was continued for 24 hours after definitive wound closure (Level 2).¹⁹ Wounds undergoing delayed closure received continued antibiotic treatment until definitive closure was achieved. Definitively closed wounds were inspected on a daily basis by the treating orthopedic team until the patient was discharged from hospital.

Patient selection and study design

We retrospectively reviewed all open fractures treated at a level 1 trauma centre over a 5-year study period (July 2000 to June 2005). Owing to cross-coverage with plastic surgery, all finger fractures were excluded from our

analysis. Institutional board review was attained before study commencement. We retrieved the following information from the patients' charts: sex, age, mechanism of injury, fracture location, Gustillo–Anderson classification, time to antibiotic administration, time to surgical débridement, timing of wound closure, method of wound

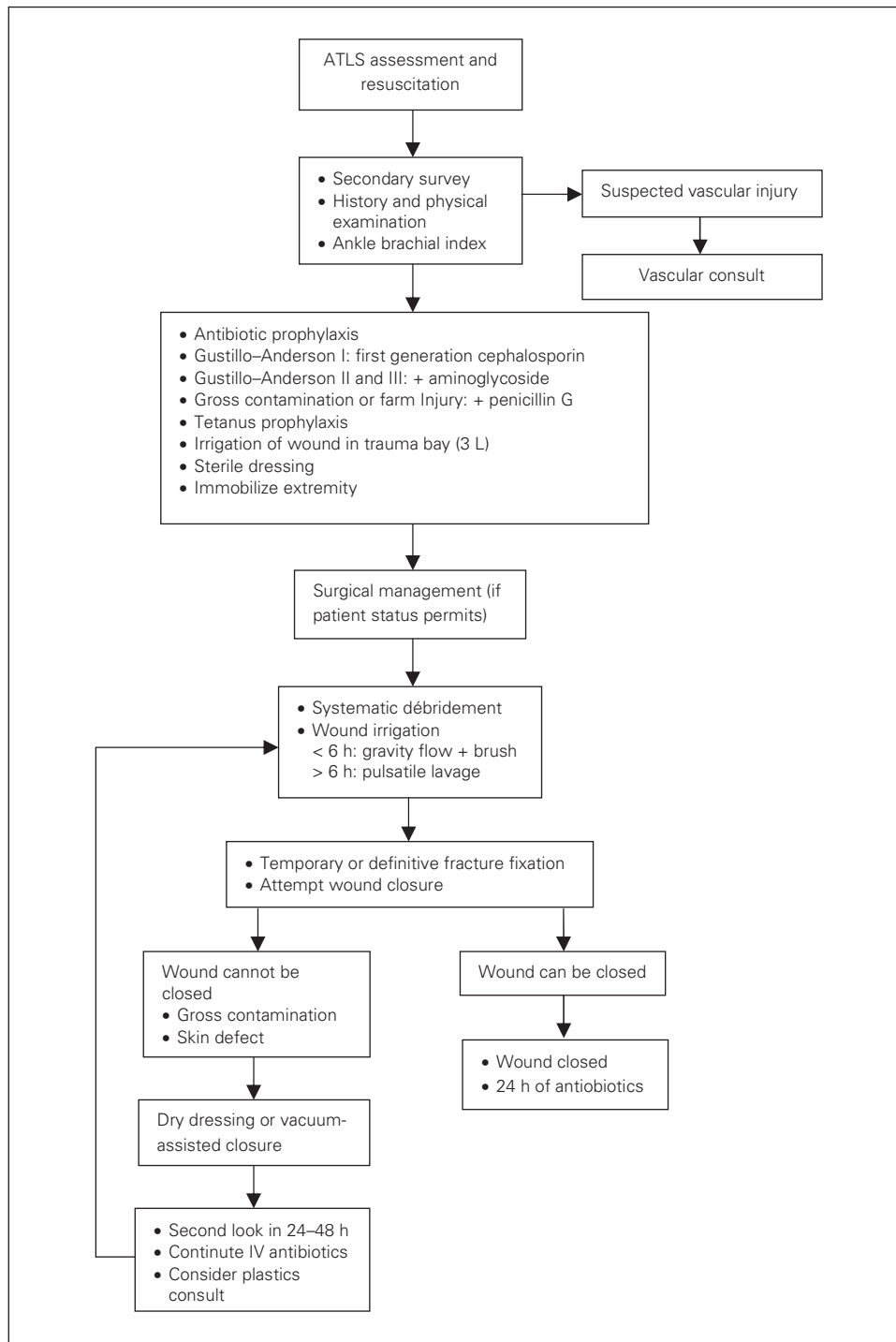


Fig. 1. Treatment algorithm for open fractures. The Gustillo–Anderson classification is used only to determine prophylactic antibiotic selection. Wound closure is attempted regardless of open fracture grade. ATLS = Advanced Trauma Life Support; IV = intravenous.

closure, occurrence of infection, delayed union or non-union within the first 5 years of postoperative follow-up. Exclusion criteria were death from associated injuries, incomplete preoperative or intraoperative information and lack of complete outpatient follow-up.

The diagnosis of postoperative wound infection was confirmed using clinical signs and symptoms (erythema, swelling, warmth, constitutional symptoms), documented presence of a draining sinus and elevated serum markers (C-reactive protein, erythrocyte sedimentation rate). Superficial infections were those limited to the skin and subcutaneous tissues. Deep infections were those extending to the fracture site, causing abscess formation and/or osteomyelitis. With regard to fracture healing, fractures were classified as union, delayed union or nonunion. Owing to disagreement in the literature regarding the accuracy of radiographs in diagnosing fracture union,²⁰ we used a combination of clinical and radiological criteria. To be classified as union, fractures had to meet 2 criteria: 1) radiographic evidence of callus cortical bridging and 2) clinical evidence of being able to tolerate functional axial and torsional load at 16 weeks or less postoperatively. Delayed union was defined as fractures that did not meet both of the previously mentioned criteria at 16 weeks post-surgery. Delayed fractures were treated either with a prolonged period of immobilization or with operative débridement and stabilization. Delayed unions that did not meet the criteria for union following treatment were defined as nonunions.

Statistical analysis

Statistical analyses were performed using SPSS software version 19.0 (IBM). To compare continuous variables, we used tests of normalcy (Kolmogorov–Smirnov and Shapiro–Wilk tests). We performed a χ^2 test to compare differences in fracture characteristics and time to treatment according to patient demographic characteristics. Continuous variables were evaluated as prognosticators of postoperative infection or delayed union and nonunion using the Pearson correlation coefficient, while ordinal variables were evaluated using a stepwise analysis of variance (ANOVA) regression. We calculated 95% confidence intervals (CIs), and we considered results to be significant at $p < 0.05$.

RESULTS

Patient demographic and clinical characteristics

During the study period, 324 patients with open fractures were treated at our level 1 centre. Of these, 276 patients with 297 open fractures met our inclusion criteria. We excluded 48 patients from our analysis: 12 died from associated injuries, 13 completed postoperative follow-up at an outside institution, 16 were lost to follow-up and 7 lacked

complete pre- and postoperative data. Of the 276 included patients, 187 (68%) were men and 89 (32%) were women. The average age of patients was 42 (range 16–94) years. Injury from high-velocity trauma accounted for 229 (77.1%) injuries, with most (24.5%) due to motor vehicle crashes, followed by pedestrian–motor vehicle collisions (21.4%). Sixty-eight open fractures (22.9%) resulted from low-velocity accidents, with the most common mechanism being a fall from the patient's own height (73.5%).

With regard to anatomic location of open injuries: 29% involved the upper extremity, 14% the femur, 37% the tibia and 20% the foot and ankle. No hand or finger fractures were included. Analysis of open fracture classification of included patients yielded 152 type I (51.2%), 73 type II (24.6%), 46 type IIIa (15.5%), 13 type IIIb (4.4%) and 13 type IIIc (4.4%) injuries. Types I, II and IIIa accounted for 91.3% of all open fractures, while types IIIb and IIIc accounted for only 8.7%. Average time from injury to the first antibiotic administration was 4 hours 37 minutes (range 45 min to 80 h). Average time to surgical débridement was 8 hours 10 minutes (range 1 h 15 min to 120 h). The most common causes of delay to surgical débridement were transfer of patients from remote areas and unfitness of polytraumatized patients for the OR.

We found no significant difference in time to antibiotic treatment or time to débridement between men and women ($p = 0.80$). Men had a significantly higher rate of high-velocity injuries than women ($p = 0.001$). Demographic characteristics and their relation to intraoperative treatment and postoperative complications are detailed in Table 1.

Wound closure

A total of 255 (85.8%) patients with open fractures underwent definitive immediate closure following irrigation and débridement in the OR. Forty-two patients required serial débridements, and their wounds were not closed primarily at the discretion of the treating physician. Of these patients, 14 underwent primary closure in a subsequent surgery, 16 required split thickness skin grafting and 12 required coverage using regional flaps. The complication rates of those fractures treated with delayed closure are summarized in Table 2. When stratified by fracture classification, Gustillo–Anderson type I ($n = 141$, 92.8%) and type II fractures ($n = 69$, 94.5%) had the highest rates of definitive immediate closure; only 45 (62.5%) patients with type III fractures underwent primary closure (type IIIa, 73.9%; type IIIb, 15.4%; type IIIc, 69.2%). With regard to fracture location, immediate closure was performed for most open fractures involving the upper extremity (90.8%), femur (95%) and foot and ankle (88.5%). Open fractures of the tibia were associated with the lowest rate of immediate closure (77.1%) and with the highest rate of type III fractures (33%).

Development of postoperative infection

We found no significant correlation between patient age ($p = 0.38$), sex ($p = 0.41$) or location of fracture ($p = 0.21$) and the development of superficial or deep infection.

Of the patients treated with immediate primary closure, 28 (10.9%) had superficial wound infections during the postoperative period. Patients treated with delayed closure has a similar proportion of superficial infections ($n = 6$, 11.9%). All superficial infections were treated with oral antibiotics (cefazolin or clindamycin) for at least 6 weeks with no residual complications. For immediate primary closure, deep wound infections occurred in 12 (4.7%) patients, with 6 (2.3%) infections progressing to osteomyelitis. For patients who underwent delayed closure, a higher proportion of deep infections ($n = 5$, 11.9%) and osteomyelitis ($n = 6$, 14.3%) were found. Regression analysis indicated that location of injury, fracture classification, velocity of trauma and patient demographics were not significantly

associated with the development of infectious complications. The duration of time to closure was not significantly associated with the postoperative development of superficial or deep infection ($p = 0.57$).

Delayed union and nonunion

With regard to all open fractures, an ANOVA regression model adjusted for repeated measurements revealed significant β values for location ($\beta = 0.027$) and infectious complication ($\beta = 0.001$) in relation to fracture union. Subsequent comparisons indicated that open femur fractures ($p = 0.023$) and fractures with postoperative deep wound infections ($p = 0.001$) were at increased risk of nonunion. Our χ^2 analysis demonstrated that type IIIb and IIIc injuries had a significantly higher risk of nonunion than less severe open injuries ($p = 0.029$).

For fractures treated with immediate primary closure, 255 (85.5%) met the criteria for fracture union at 16 weeks

Table 1. Association between fracture classification, anatomic region, injury characteristics and time to closure and postoperative complications in patients who underwent primary closure

Factor	No. open fractures	No. primary closures	Primary closure group; no. (%)			
			Superficial infection	Deep infection/osteomyelitis	Delayed union	Nonunion
Total	297	255	28 (10.9)	12 (4.7)	14 (5.5)	23 (9)
Gustillo–Anderson classification						
I	152	141	11 (7.8)	2 (1.4)	3 (2.1)	11 (7.8)
II	73	69	13 (18.8)	6 (8.7)	6 (8.7)	8 (11.6)
IIIa	46	34	4 (11.8)	4 (11.8)	4 (11.8)	4 (11.8)
IIIb	13	2	0	0	1 (50)	0
IIIc	13	9	0	0	0	0
Region						
Upper extremity	87	79	3 (3.7)	1 (1.2)	0	7 (8.8)
Femur	40	38	4 (10.5)	2 (5.3)	0	7 (18.5)
Tibia	109	84	12 (14.2)	5 (5.9)	10 (11.9)	8 (9.5)
Foot and ankle	61	54	9 (16.7)	4 (7.4)	4 (7.4)	1 (1.9)
Velocity						
High	229	192	19 (9.9)	10 (5.2)	10 (5.2)	16 (8.3)
Low	68	63	9 (14.3)	2 (3.2)	4 (6.3)	7 (11.1)
Time to closure						
< 8 h	165	162	19 (11.7)	9 (5.5)	12 (7.4)	11 (6.8)
≥ 8 h	132	93	9 (9.6)	3 (3.2)	2 (2.2)	12 (12.9)

Table 2. Complication rates of fractures treated with delayed closure

Type of wound closure	No. patients	Group; no.				
		Superficial infections	Deep infections	Osteomyelitis	Delayed union	Nonunion
Delayed closure	14	1	0	2	0	2
Flap	12	3	2	3	2	2
Split thickness skin graft	15	1	3	3	1	3

postsurgery, while 14 (5.5%) were classified as delayed unions and 23 (9%) as nonunions. The combined rate of delayed union and nonunion in the immediate primary closure group (14.5%) was lower than that of the delayed closure group (19.6%). The rate of union was not significantly associated with patient sex ($p = 0.43$) or age ($p = 0.36$). The highest rate of nonunion occurred in the femur (18.5%). The time to closure was not significantly associated with delayed union or nonunion ($p = 0.07$).

DISCUSSION

A growing body of literature supports attempting primary closure for all types of open fracture wounds.^{7,11,21-25} In a review of 119 open fractures, DeLong and colleagues¹¹ were able to perform primary closure 73% of the time, and primary closure was associated with a substantially lower rate (11%) of delayed union and nonunion than delayed closure. The incidence of deep infection was also markedly decreased with primary closure (3%) than with delayed closure (16%). Hohmann and colleagues⁹ performed a similar analysis of 95 open tibia fractures, finding that primary closure did not increase the risk of infection or nonunion and that it was a safe and potentially cost-effective way of treating open fractures. Furthermore, Benson and colleagues²¹ prospectively followed 82 patients with open fractures randomly assigned either to clindamycin or cephalosporin. Time to closure was not found to be a significant determinant of deep infection postoperatively; however, all deep infections that occurred in the study were in the delayed closure group. Collectively these studies suggest that performing immediate primary closure for open fractures is a safe and potentially cost-effective treatment, yet provide little insight into a specific treatment protocol that could maximize healing rates and minimize complications.

The only published prospective study evaluating a wound closure protocol for open fractures is by Rajasekaran and colleagues,¹³ who used a combination of the injury severity score, Ganga Hospital total and several other specific criteria to determine whether to perform primary closure in 557 patients with Gustillo–Anderson type III open fractures. Additional criteria that ruled out primary closure included hand and foot injuries; hemodynamic compromise; sewage or farmyard contamination; and several pre-existing conditions, such as peripheral vascular disease, drug-dependent diabetes mellitus and connective tissue disorders. Although following this rigorous set of conditions produced a high proportion (86.7%) of patients who underwent primary closure and had excellent outcomes, a valid criticism is that such a substantial list of criteria is not only cumbersome to use clinically, but also unnecessarily limits the number of wounds eligible for primary closure. This limitation is observed within the study itself, as only 185 of 557 (33%) type III injuries were eligible for primary clo-

sure. Given that no study, including ours, has shown increased postoperative complication rates with immediate primary closure when modern antibiotic prophylaxis is used, efforts should be made to maximize the possibility of gaining definitive wound coverage through the use of a primary closure.

Results from our study illustrate that a treatment protocol aimed at performing an immediate primary closure of all open fracture wounds is a safe and effective practice. Immediate primary closure was not significantly correlated with the development of deep wound infection or complications of bony union. Instead, a lower rate of deep infection/osteomyelitis and delayed union or nonunion was found in the primary closure group. The complication rate in the primary versus delayed closure group was also lower in previously published studies. Henley and colleagues²⁶ reported a 30% wound infection rate when definitive soft tissue coverage was delayed more than 72 hours. Also, Dellinger and colleagues¹⁹ treated 248 open fractures with delayed wound closure and different antibiotic regimens, but still maintained a deep infection rate of 13%, which is 3 times the rate of the early closure group in our study. Furthermore, use of this simple protocol leads to a higher percentage of primary closures and equivalent postoperative complication rates for type III injuries compared with a more complex protocol previously suggested.¹³ In our series, only open femur fractures and deep infections were independently correlated with delayed union and nonunion. These findings are understandable given that open femur fractures are associated with high-energy mechanisms and soft tissue disruption, while deep infection compromises bone formation.

Limitations

Our study has some limitations. The retrospective cohort design does not allow an objective understanding of why some open wounds were not primarily closed by the treating physician at the time of surgery despite the presence of an accepted protocol. It was recognized that most of the patients in the delayed closure group were under the care of non-trauma trained surgeons. Despite this, the decreased postoperative complication rates may still be influenced by selection bias. A prospective study examining intraoperative decision-making for conducting a primary closure is necessary and is being planned in our institution. Furthermore, although included patients had documented follow-up in our institution, we cannot rule out the possibility that some may have been treated at an outside institution for complications later on in the postoperative period.

In the event that primary closure cannot be performed, surgeons should maintain an aggressive stance toward attaining wound coverage as soon as possible. In a study of 532 patients undergoing microsurgical reconstruction for

large traumatic defects, Godina²³ found that patients who underwent free flap transfers within the early (< 72 h) post-débridement period had a lower infection rate, shorter bone healing time and shorter hospital stay than patients who underwent delayed (3 d to 3 mo) and late (> 3 mo) free flap coverage. Similarly, Gopal and colleagues²⁷ reported a significantly reduced infection rate in patients with type III open tibial fractures who received early (< 72 h) versus late soft tissue flap coverage.

CONCLUSION

Our findings taken together with recently published literature demonstrate that achieving immediate primary closure should be a desired outcome when taking a patient with an open fracture to the OR. The combination of appropriate antibiotic prophylaxis, wound irrigation and systematic débridement make primary closure a safe treatment option that minimizes surgical morbidity, hospital stay and cost of treatment without increasing the risk of infection. Although delayed closure is still indicated in the context of large soft tissue defects, wound tension and gross contamination, it is not necessary for routine practice and should give way to definitive coverage with secondary closure or grafting procedures as soon as possible.

Competing interests: None declared.

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