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The use of negative pressure wound therapy in severe open lower extremity fractures: identifying the association between length of therapy and surgical outcomes

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ABSTRACT

Background: Negative pressure wound therapy (NPWT) is a widely accepted method of temporary coverage for complex lower extremity wounds before definitive reconstruction. However, the precise role of NPWT in the perioperative management of patients with complicated lower extremity injuries remains unclear. In this study, we examine the effect of NPWT on flap complications and overall outcomes based on timing of soft-tissue reconstruction relative to initial injury and implementation of NPWT.

Methods: We retrospectively reviewed the medical records of 32 consecutive patients presenting to a single institution receiving lower extremity reconstruction after Gustilo class IIIB or IIIC open tibial fractures over a 5-y period. Length of hospitalization, number of surgical procedures, flap failure, infection, and nonunion were parameters of interest in this study.

Results: The incidence of complications in patients treated with NPWT was lower compared with patients who underwent wet-to-dry dressing changes, regardless of when surgery was performed. The highest rate of complications was observed in patients operated on >6 wk after injury and who received wet-to-dry dressing changes wound care. By comparison, those who underwent surgery within 1 wk of injury and who were bridged with NPWT had the lowest rate of complications.

Conclusions: The use of NPWT therapy in the perioperative management of patients with open lower extremity fractures reduces complication rates associated with limb salvage surgery. Our results suggest that NPWT can be used as a temporizing measure to optimize patients before flap surgery, effectively lengthening the window of opportunity for definitive reconstruction.

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1. Introduction

Open tibial fractures can be extremely debilitating injuries that are associated with a risk for limb loss. Optimal surgical management and strategies for managing open wounds between the time of surgery and surgical repair remain matters of some debate. Complication rates are high regardless of the specific type of fracture sustained or treatment strategy used [1–3]. Rates of infection for severe open tibial fractures have been reported to be as high as 66% in some studies [2,3]. The combination of injured soft tissue and avascular bone fragments provides an optimal environment for the proliferation of pathogenic organisms [4]. Despite improved methods of surgical management and wound care for open tibial fractures, functional outcomes remain suboptimal, with return-to-work rates found to be as low as 64% at 34 mo after injury [5,6].

The Gustilo classification system for open fractures defines three grades of injury; it has proven to be very useful in the assessment and management of open tibial fractures [7,8]. Fractures associated with extensive soft-tissue damage (>10 cm) are classified as grade III. Grade III fractures are further divided into A, B, and C subtypes. Gustilo IIIA fractures are those that have sufficient soft tissue for coverage, whereas grade IIIB and C wounds have extensive soft-tissue damage with periosteal stripping, precluding effective soft-tissue coverage using surrounding tissues. Additionally, Gustilo IIIC fractures are associated with vascular injury [8]. These injuries represent a subset of complex, high-energy orthopedic injuries that require a multidisciplinary approach to care and, often, multiple operations for adequate reconstruction of bone and soft tissue to successfully salvage affected limbs and avoid amputation [9].

Under ideal circumstances, wound debridement and coverage should occur immediately after injury. From a practical standpoint, however, this is not always possible. Delays in coverage of the lower extremity may be necessary because of the management of other life-threatening injuries sustained during the initial traumatic event or until a multidisciplinary team can address any scheduling conflicts that may arise in coordinating a surgical time and date that is suitable to all surgeons involved in the patient's care. Given these realities, the use of a bridging mechanism capable of providing effective wound care of the involved extremity until surgery is feasible and necessary in almost all Gustilo IIIB fractures. Ideally, such temporary wound coverage would be associated with minimal morbidity and support successful long-term surgical outcomes.

Landmark studies by Byrd *et al.* in 1985 and Godina *et al.* in 1986 effected a paradigm shift in the management of lower extremity wounds [10–12]. These authors propagated the notion that the incidence of flap-related complications in lower extremity reconstruction correlated with the duration of time between injury and definitive wound coverage. Optimal results were associated with early soft-tissue reconstruction, whereas surgery during the subacute phase was shown to be associated with the highest rates of flap-related complications. These studies, therefore, emphasized the importance of early surgical intervention.

However, Byrd and Godina made these recommendations in the era of open wound care: their patients were managed with open gauze dressing changes from the time of injury to the time of surgery. Their studies predated the introduction of negative pressure wound therapy (NPWT) as a reliable and efficacious treatment modality for complicated wounds. Since its introduction to the market nearly 20-y ago, NPWT has become widely adapted to the care of complex wounds throughout the body. Currently, nearly 75% of Gustilo grade III fractures are treated with NPWT for some period before flap coverage, yet formal evaluation of the efficacy of this treatment modality as it relates to surgical outcomes is lacking [8]. Specifically, there is limited data examining the association between the duration of use of NPWT before flap coverage of a mangled extremity and surgical outcome. Given this gap in our knowledge base, the aim of this study was to examine the efficacy of NPWT as a bridging mechanism between lower extremity injury and limb salvage surgery and to specifically determine if the duration of NPWT is related to the incidence of perioperative complications.

2. Materials and methods

2.1. Study design and population

We conducted an institutional review board–approved retrospective review of the medical records of all patients presenting to our level 1 trauma center over a 5-y period with Gustilo grade IIIB or IIIC open tibial fractures who received free-flap extremity reconstruction. The study period was chosen to include a time when our reconstructive surgeons began to replace open wound care with NPWT in the management in our treatment protocols. A total of 32 patients were identified who met these criteria. Medical records were complete for all and therefore all were included in this study. Patients were divided into three groups based on the amount of time-lapse between injury and definitive soft-tissue reconstruction. Patients stratified to the acute treatment subgroup were reconstructed within 6 d after injury. Patients operated on between 7 and 42 d after injury were included in the subacute treatment group. Finally, patients in the chronic subgroup underwent reconstruction at least 42 d after injury. Duration of follow-up was defined as the period between initial injury and the latest clinical encounter documented in the medical record.

2.2. Demographics and preoperative clinical data

Data were collected from patient medical records. Clinical characteristics of particular interest included age, gender, smoking status, mechanism of injury, and the presence of medical comorbidities.

2.3. Operative management

Only those patients receiving free-flap microsurgical reconstruction were included in this study. All patients received either open wound care with wet-to-dry dressing changes

(WDD) or NPWT between the time of initial presentation and reconstructive surgery. The duration of wound care, defined as the time of presentation to the time of surgery, was recorded. Based on these data, patients were stratified to either acute, subacute, or chronic treatment categories and further differentiated by type of wound care received within those categories.

2.4. Postoperative clinical data

Based on medical record documentation, we tabulated duration of hospitalization, number of procedures performed on each patient, flap-specific complications (e.g., flap failure and flap revision), and other postoperative complications (e.g., surgical site infection [SSI], osteomyelitis, hematoma, and bony nonunion). These data were then subject to statistical analysis.

2.5. Statistical analysis

We compared demographic data between acute, subacute, and chronic treatment subgroups. Proportions and frequencies were calculated for categorical data. Analyses of complication rates were performed for patients in each of the treatment groups, and the Z-test was used to compare differences in complication rates between WDD and NPWT patients within each treatment subgroup.

3. Results

3.1. Patient data

A total of 32 patients presenting with Gustilo grade IIIB or IIIC open tibial fractures with complete medical records met inclusion criteria for this study (Table 1). Patients had a mean follow-up time of 31 mo (range, 1 mo–13 y). Motor vehicle accidents represented the most common mechanism of injury ($n = 25$), followed by falls ($n = 4$) and industrial accidents ($n = 2$). Eight patients were reconstructed within the acute period (<7 d after injury), 16 were reconstructed within the subacute period (between 7 and 42 d after injury), and 8 patients were reconstructed in the chronic period (>42 d after injury). Within the acute treatment subgroup, two patients received NPWT and six received conventional WDD. Among the 16 patients who underwent reconstruction during the subacute period, eight patients received NPWT and eight received WDD. Of the eight patients in the chronic treatment subgroup, six received WDD and the remaining two received perioperative NPWT. There were no significant differences in the demographics of patients receiving WDD or NPWT.

3.2. Surgical management and complications

A summary of the surgical management of patients receiving limb salvage therapy in this study is presented in Table 2. Regardless of timing of reconstruction, the latissimus dorsi free flap was the most commonly implemented flap, used in 19 of 32 flap surgeries performed (59%). The rectus abdominis free flap was the next most often used, used in 10 of 32 cases (31%). Other free flaps used included the serratus anterior (1 of 32, 3%) and the parascapular flap (2 of 32, 6%). The mean number of procedures performed on each patient—including wound debridements, orthopedic surgeries, flaps surgeries, and flap revisions—was highest for patients undergoing surgery in the chronic subgroup. Patients who underwent flap surgery in the subacute period had the longest average hospital stays. Duration of hospitalization was lowest in patients who received NPWT and underwent surgery in the acute period.

In general, patients who were treated with WDD had poorer flap outcomes compared with patients treated with NPWT (Table 3). There were no flap losses in the latter group, whereas WDD patients had a total of three flap failures (15%). Two of these occurred in patients treated in the subacute group ($P = 0.05$) and one in the chronic group. Seven patients treated with WDD (35%) required flap revision compared with four (33%) who were treated with NPWT. The difference in flap

Table 1 – Patient demographics, mechanisms of injury, and comorbidities.

Demographics, mechanism of injury, and comorbidities	Acute ($n = 8$)		Subacute ($n = 16$)		Chronic ($n = 8$)		Total ($n = 32$)
	WDD ($n = 6$)	NPWT ($n = 2$)	WDD ($n = 8$)	NPWT ($n = 8$)	WDD ($n = 6$)	NPWT ($n = 2$)	
Age	32.8	28.5	32	37	50.5	48	37.65
Gender, n (%)							
Male	5 (83.3)	2 (100)	8 (100)	7 (87.5)	5 (83.3)	2 (100)	29
Female	1 (16.7)	0 (0)	0 (0)	1 (12.5)	1 (16.7)	0 (0)	3
Smoking status, n (%)							
Smoker	1 (16.7)	1 (50)	4 (50)	1 (12.5)	3 (50)	0 (0)	10
Nonsmoker	5 (83.3)	1 (50)	4 (50)	7 (87.5)	3 (50)	2 (100)	22
Mechanism of injury, n (%)							
Motor vehicle accident	4 (66.7)	2 (100)	7 (87.5)	7 (87.5)	3 (50)	2 (100)	25
Fall	1 (16.7)	0 (0)	1 (12.5)	0 (0)	2 (33.3)	0 (0)	3
Industrial accident	1 (16.7)	0 (0)	0 (0)	0 (0)	1 (16.7)	0 (0)	2
Other	0 (0)	0 (0)	0 (0)	1 (12.5)	0 (0)	0 (0)	1
Medical comorbidities, n (%)	1 (16.7)	0 (0)	2 (25)	2 (25)	4 (66.7)	0 (0)	9

Table 2 – Reconstructive management of open distal lower extremity fractures.

Reconstructive management	Acute ($n = 8$)		Subacute ($n = 16$)		Chronic ($n = 8$)	
	WDD ($n = 6$)	NPWT ($n = 2$)	WDD ($n = 8$)	NPWT ($n = 8$)	WDD ($n = 6$)	NPWT ($n = 2$)
Flap choice, n (%)						
Latissimus dorsi	5 (83.3)	2 (100)	3 (37.5)	5 (62.5)	3 (50)	1 (50)
Rectus abdominis	0 (0)	0 (0)	4 (50)	2 (25)	3 (50)	1 (50)
Serratus anterior	0 (0)	0 (0)	0 (0)	1 (12.5)	0 (0)	0 (0)
Parascapular	1 (16.7)	0 (0)	1 (12.5)	0 (0)	0 (0)	0 (0)
Mean number of procedures	7	3	6.6	6.3	10.7	9.5
Mean duration of hospitalization (d)	31	13.5	47.1	52.6	18.7	32.5

revision rates was statistically significant only in the acute subgroup ($P = 0.04$). In general, the greatest number of flap-related complications was seen in the subacute group, in both WDD and NPWT patients.

Non–flap-related complications were most commonly observed in both WDD and NPWT patients in the subacute group as well, although statistical significance was only noted in the difference in rates of osteomyelitis ($P = 0.01$). SSI was significantly higher in patients receiving WDD in the acute subgroup, and both osteomyelitis and nonunion were significantly higher in WDD patients in the chronic subgroup. The incidence of complications as related to timing of flap coverage and type of interval wound care is summarized in the Figure.

4. Discussion

This study provides objective evidence for what has likely become accepted as a fact by many reconstructive surgeons based on their clinical experience; the use of NPWT serves as a safe and effective bridge to surgery from the time of injury in patients who have sustained limb-threatening lower extremity trauma. Specifically, we have shown that compared to conventional open wound care, the use of NPWT in the preoperative management of mangled lower extremities is associated with lower rates of flap failure, flap revision, SSI, osteomyelitis, hematoma, and fracture nonunion, regardless of when surgery is performed after the initial traumatic injury. To our knowledge, this is the most comprehensive analysis of the impact of NPWT on the surgical outcomes of Gustilo class IIIB or IIIC fractures. Prior work in this area has focused on patient populations with less severe open fractures or analysis of less comprehensive lists of perioperative complications [13,14].

We observed the greatest number of overall complications in patients who underwent definitive wound coverage in the subacute period and the lowest complication rate in patients who received flap coverage within 7 d of injury. These findings are consistent with previously published studies that support early reconstruction in severe lower extremity trauma [10,11]. Godina [12] reviewed a series of 532 patients requiring free-flap transfer in extremity reconstruction. He noted a 0.75% flap failure rate for flaps performed in the immediate phase (<72 h) after injury, 12% failure rate of flaps performed within the delayed phase (3 d–3 mo), and 9.5% rate of failure in the group receiving flap coverage in the late phase (>3 mo) after injury. This pattern of a low rate of flap failure in the acute phase, highest rate in the subacute phase, and intermediate rate in the chronic phase is comparable with that observed in our series, although we have defined the length of time of these various phases differently. We observed higher overall rates of flap failure and flap revision in patients who received conventional dressing changes compared with patients who were treated with NPWT. We further identified significant decreases in the rates of soft tissue and bony infection and fracture nonunion in these patients.

Our results are also consistent with other studies examining the benefits of NPWT in mitigating infectious complications associated with open lower extremity fractures [2,5,15]. Stannard *et al.* [2] compared NPWT with

Table 3 – Postoperative complications and outcomes.

Complications and outcomes	Acute ($n = 8$)			Subacute ($n = 16$)			Chronic ($n = 8$)		
	WDD ($n = 6$)	NPWT ($n = 2$)	P	WDD ($n = 8$)	NPWT ($n = 8$)	P	WDD ($n = 6$)	NPWT ($n = 2$)	P
Flap-specific complications, n (%)									
Flap failure	0 (0)	0 (0)	0.05	2 (25)	0 (0)	0.05	1 (16.7)	0 (0)	0.14
Flap revision	2 (33.3)	0 (0)	0.05	3 (37.5)	3 (37.5)	0.5	2 (33.3)	1 (50)	0.66
Other postoperative complications, n (%)									
Surgical site infection	3 (50)	0 (0)	0.007	3 (37.5)	3 (37.5)	0.5	1 (16.7)	0 (0)	0.14
Osteomyelitis	1 (16.7)	0 (0)	0.14	3 (37.5)	0 (0)	0.02	2 (33.3)	0 (0)	0.04
Hematoma	1 (16.7)	0 (0)	0.14	3 (37.5)	1 (12.5)	0.12	0 (0)	0 (0)	0.05
Nonunion	1 (16.7)	0 (0)	0.14	3 (37.5)	1 (12.5)	0.12	4 (66.7)	0 (0)	0.002

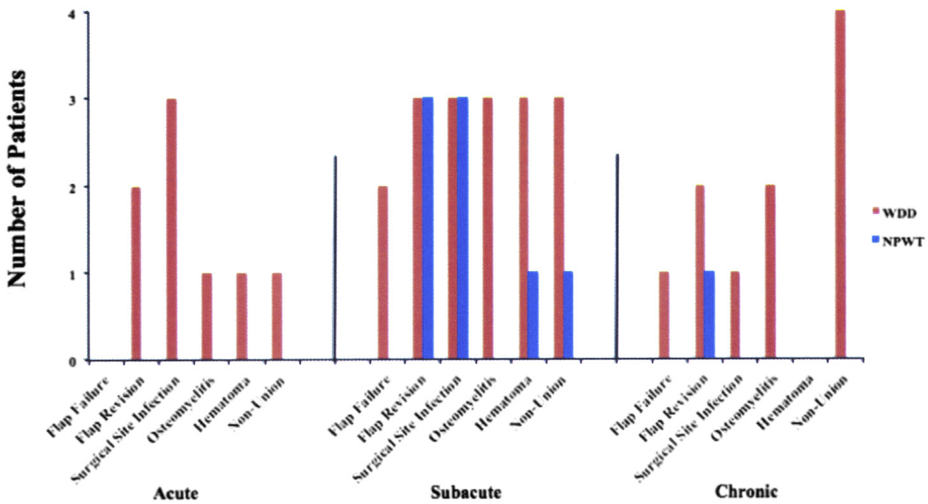

Figure – Postoperative complications by time of coverage and type of wound dressing. (Color version of figure is available online.)

conventional dressings in the management of open extremity fractures and found significantly lower deep infection rates when using NPWT as compared with conventional dressings. Similarly, Blum *et al.* [5] performed a retrospective study of open tibial fractures in which the authors determined that NPWT reduces the risk of deep infection by nearly 80%.

The lower rates of flap-related complications in patient subgroups treated with NPWT are attributable to the beneficial effects of NPWT on the wound bed [16–18]. The morphologic and biochemical changes that typically define a chronic wound environment—including fibrosis, edema, necrosis, and hypoxia—all likely contribute to the higher incidence of flap failure seen in the chronic and subacute conventional dressing treatment groups [18,19]. Open wound care, compared with NPWT, has a limited ability to modulate the numerous deleterious factors that define a hostile wound; its effects are primarily vested in the superficial debridement of contaminated tissues. NPWT, on the other hand, has been shown to expedite wound healing by a variety of mechanisms [19,20]. Negative pressure facilitates the continuous removal of fluid from the wound bed and decreases edema from surrounding tissues. This in turn can promote healing through improved peripheral circulation to the site of injury. NPWT also plays a role in immunomodulation of the wound [20–22]. Studies have shown that negative pressure applied to wounds increases the early accumulation of interleukin 1 and interleukin 8, inflammatory cytokines that ultimately affect accumulation of neutrophils at the wound site [20]. This augmented neutrophilic response is believed to facilitate clearance of bacteria from the wound and decrease the risk of developing a serious infection. NPWT has also been shown to specifically attenuate the concentration of tumor necrosis factor alpha in the wound bed, minimizing the deleterious effects it has on wound healing. Finally, the mechanical forces generated by negative pressure dressings promote tissue growth and elaboration of granulation tissue to a greater extent than traditional open wound care.

Patients who received NPWT and who were operated on within the acute period in this study underwent a lower mean number of reconstructive procedures and experienced shorter hospitalizations. (By extension, overall cost associated with their care was also decreased, although a formal analysis of the health care costs generated by this patient cohort was beyond the scope of this study and is the subject of a follow-up study i.e., currently underway). This observation is particularly relevant in today's health care delivery climate, where allocation of health care resources is increasingly being driven by financial considerations.

Our study was limited to patients who underwent free-flap extremity reconstruction. One of the potential benefits of NPWT, however, is its potential ability to "downstage" the complexity of a wound, allowing a less invasive reconstruction. Accelerated granulation tissue formation as a result of NPWT use may help to avoid free tissue transfer entirely [21,22]. Stannard *et al.* [15] concluded that NPWT, applied as a temporizing measure in the management of open lower extremity fractures, simplifies soft-tissue reconstruction and may ultimately downgrade how high surgeons must climb on the "reconstructive ladder" to achieve limb salvage. Similarly, Herscovici *et al.* [23] describe a series of 21 patients who presented with soft-tissue defects suitable for free tissue transfer coverage but in which only 12 patients ultimately required a free flap due to the ability of NPWT to improve the wound, allowing for a more simple reconstructive approach.

A significant weakness of the study lies in its small sample size, which limits our ability to draw sweeping conclusions or make definitive recommendations regarding patient care. However, the number of patients examined in this review is similar to other publications examining the effects of NPWT on lower extremity wounds [21,23]. In addition, our results are validated in part by their consistency with other studies of similar numbers of patients that have been published in the literature. Furthermore, despite the limited number of patients studied, our results comparing flap revision rates between the two treatment groups in the acute phase, flap failure rates in the subacute phase, infection rates (SSI and/or osteomyelitis) in all periods, and nonunion in the chronic phase all reached statistical significance. One reason we chose to limit our analysis to the 5-y period studied was that this period represented an era in which the practice of the surgeons included in this study began to shift from the use of conventional open wound care to the use of NPWT as a standard practice. We were therefore able to directly compare outcomes in patients with similar injury severity treated with two divergent treatment modalities by the same surgeons during the same period. Although choosing this specific time to investigate may have introduced some selection bias into our data analysis, our study design allowed for the most direct comparison of the two wound care strategies outside of the context of a randomized controlled protocol. Given the presence of a significant body of literature that now strongly supports the use of NPWT in the setting of acute complex extremity trauma, such a randomized trial comparing WDD and NPWT might be difficult to design and execute.

5. Conclusions

Compared with conventional open wound care, the use of NPWT in the preoperative management of patients with severe open tibial fractures reduces overall flap-associated and non–flap-associated complication rates associated with limb salvage surgery, regardless of the timing of surgery after injury. These improvements are most notable in the acute and chronic treatment periods. NPWT also diminished the number of procedures performed and length of hospital stay in patients undergoing surgery in the acute postinjury phase. NPWT is an effective temporizing measure to manage complex wounds while patients are optimized for surgery and can effectively lengthen the window of opportunity for reconstructive surgeons who manage these challenging patients.

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Authors' contributions: All authors were involved in the conception of study design and the writing of the article. K.S.R., M.N., and R.J. performed the data analysis and were involved in the study design.

Disclosure

The authors have no commercial or financial associations that might create a conflict of interest with the collection and presentation of the information contained in this article.

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