CHAPTER **28**

INCISIONAL NEGATIVE-PRESSURE WOUND THERAPY IN FOOT AND ANKLE TRAUMA

Kwasi Y. Kwaadu, DPM
Justin J. Fleming, DPM
David G. Blancho, DPM
Derek Florek, DPM

INTRODUCTION

High-energy lower extremity trauma can be a significant life-altering event with considerable functional loss. The most considerable of these injuries in the foot and ankle are fractures of the tibial plafond, talus, calcaneus, and Lisfranc joint. Positive outcomes are dependent on fracture restoration and minimizing soft tissue complications. These injuries are typically associated with high-velocity mechanisms and significant soft tissue compromise. Compounded with potential complications following surgical intervention, realistic expectations must be made transparent for the patient and those complications that can directly be attributed to the surgeon's skill must be minimized. Unfortunately, there are many other factors beyond the surgeon's control.

Beyond the injury themselves, techniques and incision placement for surgical management can be associated with significant morbidity when they manifest. The vascular supply of the lateral calcaneal subperiosteal flap has been described in detail to help facilitate the understanding of proper incision placement in order to help avoid wound complications (1) (Figure 1). Pilon fracture management through the anterior ankle incision must similarly be approached with the utmost care because depending on the visualization required, the incision may lie directly within the anterior tibial angiosome, an undesirable location with respect to perfusion (Figure 2) (2). Complication rates following open reduction and internal fixation of calcaneal and pilon fractures have been reported as high as 20% and 54%, respectively (3, 4). Awareness of these complications has led to standardized protocols of delayed fracture management, staged repair with external fixation, and percutaneous repair techniques with specialized implants.

Argenta and Morykwas are credited for the development of negative-pressure wound therapy. This modality has demonstrated significant utility in the management of chronic wounds. The accelerated healing has been described as a result of improved perfusion through the reduction of interstitial edema and increased rate of granulation tissue formation as a result of mechanical stress (5, 6). Although the negative-pressure wound therapy system was designed for the accelerated healing of chronic wounds, the use of this device has been advocated in

Figure 1. Subperiosteal calcaneal flap for surgical repair of calcaneal fractures.

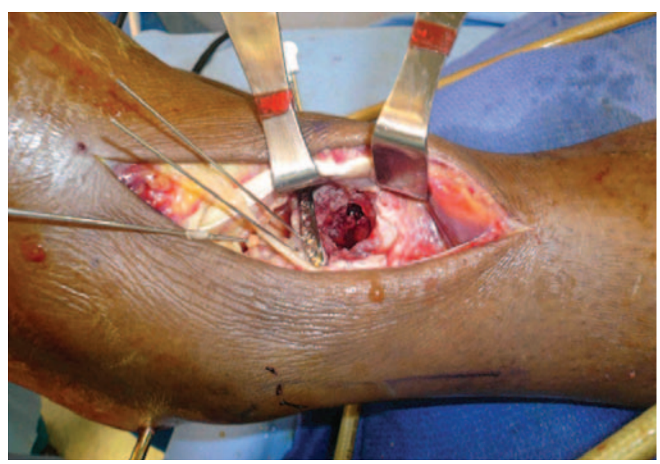

Figure 2. Anterior ankle exposure for distal tibial articular reconstruction within the anterior tibial artery angiosome. The foot is oriented at the 9 o'clock position and the leg at the 3 o'clock.

reducing soft tissue complications following acute skeletal trauma. Negative-pressure wound therapy in traumatic wounds is a new concept, and even newer, the utilization over closed incisions (7-10).

We sought to investigate the utility of incisional negative-pressure wound therapy in high-risk incisions in foot and ankle trauma settings at our institution. It was our belief that the prophylactic use would reduce the incidence of soft tissue complications. We also sought to describe specific techniques in its application and the settings of the negative-pressure wound therapy unit.

MATERIALS AND METHODS

Following institutional board review, consent was obtained from all patients. The inclusion criteria included all patients who sustained high-energy foot and ankle fractures and underwent open reduction and internal fixation with high-risk incisions managed with negative pressure wound therapy and were able to provide consent. Exclusion criteria included incisional negative pressure therapy utilized outside the scope of acute trauma, subjects under the age of 18 years, and refusal of consent. High-energy fractures were injuries with associated soft tissue trauma as defined by any of the following criteria: all OTA 43 fractures excluding A1 and B1 fractures, all Sanders grade III or greater fractures, all open fractures, all Tscherne grade C2 or greater, all falls from greater than 9 feet, and all vehicular modulated injuries (11). High-risk incisions were defined as any incision under the following circumstance: incisions in any patient with poorly controlled diabetes mellitus, smokers with an active ≥5 pack year history, any lateral extensile L-shaped calcaneal fracture incision, and any anterior ankle incision within the anterior tibial artery angiosome. Twenty-three patients managed by a single surgeon (JJF) in a single level-II trauma system within 11 months were selected. Of our initial 23 subjects, one was a minor, and one patient refused to consent for the study. A total of 21 patients met our inclusion criteria. There were 16 men and 5 women with an average age of 45.5 years, range 23-65. There were 7 calcaneal fractures in 7 patients, of which one of these subjects sustained concurrent ipsilateral talar neck and navicular body fractures. There were also 8 OTA 43 type fractures in 8 patients, two Lisfranc fractures in 2 patients, and 3 ankle fractures in 3 patients, with only one being classifiable by Lauge-Hansen. One additional patient sustained an open medial subtalar joint dislocation. There were a total of five open injuries: three pilon fractures, one subtalar joint dislocation, and a severe supination-adduction ankle dislocation. The time from injury to definitive surgery was 8.7 days, with a range of 0-18 days. The patient demographics are shown in Table 1.

Dislocated ankle fractures were managed upon presentation with closed-reduction and placed in a Jones splint. Calcaneal and Lisfranc fractures with no structures at risk were similarly managed initially with a Jones splint to control edema. Pilon fractures were initially managed with open reduction and internal fixation of the fibular fracture, if present, and closed-reduction and external fixation of the tibial fracture, then placed in a Jones compression dressing without a splint.

Open fractures were managed with immediate debridement and gravity non-pulsatile irrigation with 9 liters of normal sterile saline with placement of nonabsorbable antibiotic beads. The patient returned to the operating room on the second postoperative day for removal of the antibiotic beads, repeat debridement and irrigation.

All closed fractures received 2 grams of intravenous (IV) cefazolin or 1g of vancomycin, in the presence of a penicillin allergy, preoperatively within an hour of incision. Postoperatively, they received 24 hours of the same preoperative IV antibiotic dosed as directed. For all open fractures, tetanus prophylaxis was employed when indicated by the history. In addition, all open fractures received a loading dose of 2 grams of IV cefazolin or 1g of vancomycin, in the presence of a penicillin allergy, immediately, and 80 mg of gentamycin. These antibiotics were continued for 48 hours following incisional closure, administered at pharmacologically acceptable doses.

Layered and anatomic closure was employed with a monofilamentous absorbable suture for deep closure. The skin was approximated with a monofilamentous nonabsorbable suture with interrupted Donati pattern. A percutaneous drain was employed for all calcaneal fracture incisions, as has been our protocol prior to the utilization of incisional negative-pressure wound therapy.

The peri-incisional area was protected with the adhesive dressings, with the incision and 0.25 to 0.5 cm of the peri-incisional area exposed on each side. A thin single-layered strip of nonadhesive petrolatum gauze dressing was cut the length of the incision and placed on the incision. The black polyurethane foam sponge was then placed on top of the petrolatum gauze with an adjacent incisional overlap of approximately 2 cm on each side of the incision then covered with additional adhesive dressing. It is more desirable to utilize more adhesive to obtain coverage of the sponge rather than stretching the adhesive to obtain coverage. The former technique prevents adjacent soft-tissue strain, irritation, and bullae formation once therapy is initiated. A dime-sized aperture is created in the adhesive to expose the underlying sponge. The tubed adhesive is then applied over this aperture. This tube is then connected to the canister tube (Figure 3).

Sex	Age	Injuries	Tscherne Grade	Mechanism	Associated Injuries	Duration in days from injury till surgery	Surgical Procedures	Duration in days till suture removal	Duration in weeks till WB	Soft tissue Complications	Additional Comorbidities
M	29	Right closed Sanders IV Right closed Hawkins II Right closed navicular fracture	N/A	Fall from height (21 feet)	Lumbar fracture	17	ORIF talus, calcaneus, navicular, STJ fusion.	15	11	None	IVDA, 15 pack years
M	38	Left closed Sanders IIIAC	N/A	Fall from height (18 feet)	None	16	ORIF calcaneus	15	12	None	20 pack years
F	43	Left closed OTA 43B2 Transverse fibular fracture	C1	Fall from height (10 feet)	None	0 13	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 15	8	None	IDDM II x 20 years HBA1c 11% AKD
M	47	Left closed Sanders IIIAC	N/A	Fall from height (10 feet)	None	17	ORIF calcaneus	16	10	None	10 pack years
M	61	Left closed Sanders IIIAC	N/A	Fall from height (10 feet)	None	9	ORIF calcaneus	13	12	None	HTN
M	39	Right closed dislocated OTA 43C2. Transverse fibular fracture	C2	Fall from vehicle	None	0 15	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 10	7	None	10 pack years EtOH
M	52	Left closed OTA 43C3 Comminuted fibular fracture	C2	Auto vs. Pedestrian	None	2 11	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 13	7	Small area of delayed healing distal anterolateral incision.	HIV CD 4 198 c/uL
M	50	Right closed partially incongruent lateral dislocation lisfranc fracture.	N/A	Fall from height (9 feet)	None	0	Subtotal arthrodesis and application of external fixator	10	9	None	10 pack years
M	60	Left closed Sanders IIB with tuberosity avulsion and skin at risk	N/A	Fall from height (10 feet)	Scrotal laceration	0	ORIF calcaneus	19	11	None	Bipolar, manic Depression, Marijuana
M	26	Right closed partially incongruent lateral dislocation lisfranc fracture	N/A	Fall from vehicle	None	5	Subtotal arthrodesis	11	7	None	Noncompliance
F	53	Right closed Sanders IIIAC	N/A	MVC	Tibial plateau fracture	5	ORIF calcaneus	24	10	None	None
F	42	Right closed OTA 43C1 Transverse fibular fracture	C1	Roller skating injury	None	0 4	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 16	12	Delayed healing anterolateral incision.	IDDM II x 15 years HBA1c 11.4% 5 pack years
F	51	Right open OTA 43A1 GA grade II Comminuted fibular fracture	N/A	Fall down stairs (12 steps)	Wrist fracture	0 7	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 13	10	None	5 pack year
M	23	Left open LH SAD I GA grade IIIB Syndesmotic rupture	N/A	Severe inversion	None	3	Closed reduction ankle external fixator Repair lateral ligaments Syndesmotic repair	N/A	8	Delayed healing	Prisoner
F	38	Left closed dislocated Trimalleolar fracture without syndesmotic rupture	N/A	Assaulted while intoxicated Fall from platform (9 feet)	None	2	ORIF ankle	22	6	None	EtOH Noncompliance 20 pack years
M	58	Right closed dislocated Trimalleolar fracture with syndesmotic rupture	N/A	Intoxicated fall from height (10 feet)	None	6	ORIF ankle	16	6	None	IDDM II x 15 years HBA1c 10% EtOH
M	45	Right closed OTA 43C3 Transverse fibular fracture	C2	MVC	None	0 18	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 16	10	None	Substance abuse Depression
M	29	Right open medial subtalar joint dislocation, GA grade IIB	N/A	MVC	Open patellar fracture	0 3	Closed reduction with application of external fixator ORIF talus and cuboid	 12	11	None	None
M	42	Right closed Sanders IIIAC	N/A	Fall from scaffold (21 feet)	None	8	ORIF calcaneus	13	10	None	None
M	65	Left open OTA 43C3 with comminuted distal fibular fracture GA grade IIIB	N/A	Fall from ladder (19 feet)	Pnuemothorax	0 15	Closed reduction tibia external fixator ORIF fibula ORIF tibia	 16	8 14	None	30 pack years
M	65	Left open OTA43C2 with severe multisegmental diaphyseal extension, GA grade IIIB severe soft tissue crushing with multiple separate areas with full-thickness soft tissue avusion, Comminuted distal fibular fracture Left Sanders IIB subtalar joint dislocation, Fracture metatarsals 2-5 Lisfranc instability Compartment syndrome	N/A	Fall off motorcyle	None	0 10 24 81 92	Closed reduction tibia with application of external fixator Open reduction TN dislocation with percutaneous pinning Fasciotomy ORIF tibia/fibula STSG Nonelective triple arthrodesis Revisional ORIF tibia/fibula STSG STSG	 14 12	 10	None	None

ABBREVIATIONS

ORIF	Open reduction and internal fixation	Abx	Antibiotics	LH	Lauge-Hansen Classification
Sanders	Sanders Classification	HTN	Hypertension	Berndt Hardy	Berndt Hardy Classification
Sneppen	Sneppen Classification	OTA	Orthopaedic Trauma Association Classification	Eckert-Davis	Eckert-Davis Classification
STJ	Subtalar joint	EtOH	Greater than 3 drinks per day	IDDM	Insulin Dependendent Diabetes Mellitus
AKD	Anemia of Kidney Disease	Lisfranc	Hardcastle Classification	GA	Gustilo and Anderson Classification
PO	Per Os (by mouth)	MVC	Motor Vehicle Collision	N/A	Not applicable

Figure 3A. Anterior ankle incision for pilon fracture articular reconstruction approximated with Donati suture technique.

Figure 3B. Application of adhesive.

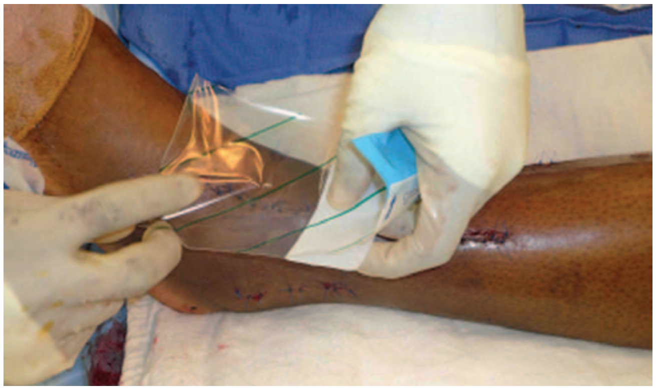

Figure 3C. Exposure of incision beneath adhesive.

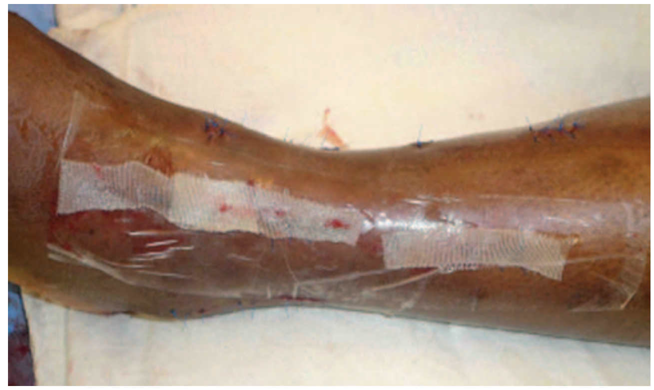

Figure 3D. Application of nonadhesive petrolatum gauze.

Figure 3E. Application of black polyurethane sponge over petrolatum gauze.

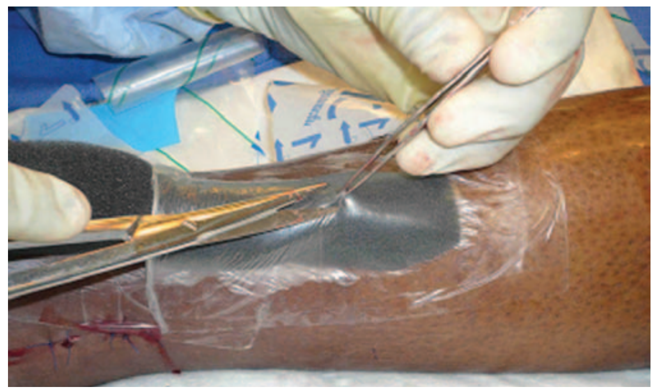

Figure 3F. Dime-sized hole in adhesive covering sponge.

Figure 3G. Application of adhesive suction tube.

Figure 3H. Negative pressure unit on at 75 mmHg.

With respect to calcaneal fracture incision management, the technique of application is the same with the following exception. The sponge extends 2 cm posterior to the vertical arm and 2 cm inferior to the horizontal arm of the incision. However, on the flap itself, the sponge is generously applied. The sponge essentially is fashioned as a large square with its superior extent at the level of the lateral malleolus and its distal extent ending at the calcaneocuboid joint level (Figure 4).

The negative-pressure unit is turned on at a continuous setting at 75 mmHg subatmospherically and at moderate intensity. A Jones compression splint is then applied. This dressing is maintained undisturbed until the second postoperative day for incisional inspection. The incision is evaluated for hematoma or any clinical signs of infection then redressed with a sterile dressing and a Jones compression splint. The patient is then instructed to follow-up for postoperative care in the outpatient setting. Prior to the

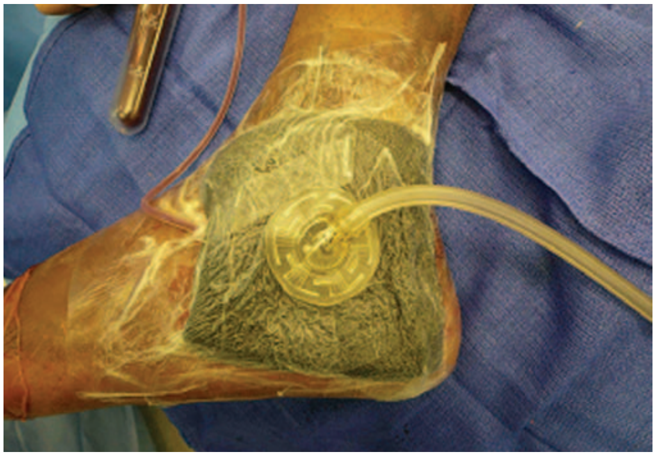

Figure 4A. Application following calcaneal fracture flap.

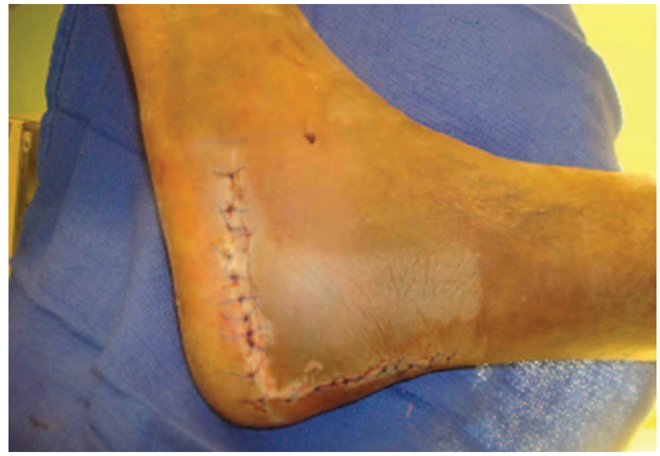

Figure 4B. Removal of VAC after 2 days of uninterrupted therapy. Note skin lines in flap consistent with reduction of interstitial edema.

initiation of the study, we utilized pressure settings of 125 mmHg, however we noted an increase in the incidence of incisional maceration. We have seen a reduction of this concern at a subatmospheric pressure of 75 mmHg. These findings and recommendations were shared by the study by Gomoll et al (7).

In a few instances, the unit was continued after the second postoperative day in the presence of recalcitrant edema, or incisional drainage. Maceration occurred episodically when the petrolatum gauze shifted away from the incision, resulting in direct contact of the incision with the black polyurethane sponge. In the presence of this maceration, the unit was discontinued after the second postoperative day. All outcomes were based on chart reviews, documenting the clinical appearance of the incision during the postoperative course through suture removal and until weightbearing was initiated.

RESULTS

Soft-tissue complications were defined as those requiring unplanned surgical intervention. Thus by definition, 20 patients (95%) underwent uneventful postoperative course. Eighteen of the 21 patients (85%) experienced no soft-tissue complications whatsoever. Of the remaining 3, 2 patients each experienced a 1 cm area of delayed wound healing that was managed uneventfully with daily dressing changes and local care. One patient, a 23 year-old prisoner underwent suture removal at the prison hospital ward by the prison physician at an unknown date. He, the only patient who required operative intervention of his incision, and 2 other patients experienced delayed incisional healing. The average duration to suture removal in 20 patients was 15 days, range 10-24 days.

The first of these patients, a 52-year-old with a long-standing history of HIV and a CD4 count of 198 cells/uL, sustained a closed OTA 43C3 fracture. Upon discharge, his incisions were well-coapted with no drainage. On his first postoperative visit 13 days following surgery, his incisions were healed with the exception of the most distal 1cm area of the incision at the anterior ankle. This area demonstrated delayed healing however healed by the second postoperative visit, 7 days following the first postoperative visit after it was reinforced with Steri-Strips (3M Nexacare) and treated with a 7-day supply of cephalexin. With his CD4 level in mind, the antibiotics were dispensed as an infection precaution however there was no additional concern of actual wound healing as a result of his disease considering all his remaining incisions healed predictably (12).

Figure 4C. Appearance at 6 months postoperative.

The second patient was a 42-year-old who sustained a closed OTA 43C1 fracture. This patient related a 15-year history of type II insulin-dependent diabetes mellitus with a HBA1c of 11.4% and an active 5 pack-year smoking history. Sixteen days following surgery, on the second postoperative visit, the patient presented for removal of all sutures with the exception of the most distal 1 cm area of the incision at the anterior ankle, which demonstrated, delayed healing. The patient was dispensed a 7-day supply of cephalexin, which she completed by the third postoperative visit. Healing progressed slowly through this third postoperative visit. On the fourth postoperative visit corresponding to 44 days following surgery, this site had evolved into a stable eschar. Nursing orders instructed daily local management with a topical enzymatic debrider with wet to dry dressings. On the fifth postoperative visit corresponding to 58 days following surgery, the site now presented as a 4 mm diameter superficial wound with no signs of infection. This completely healed on the sixth postoperative visit, 86 days following surgery with local care with weekly nonadherent dressing changes.

The third patient was a 23-year-old prisoner who sustained a severe inversion injury while playing basketball with the invagination of the distal skin soft tissues within the syndesmosis (Figure 5). His injuries involved ruptures of the anterior talofibular and calcaneofibular ligaments, the anterior ankle capsule, and paradoxically the syndesmosis with no surgical fractures. Following medical management according to protocol described earlier along with lateral ankle ligamentous repair, syndesmotic stabilization, and external fixation, he was discharged to the prison hospital ward. He was brought in for his first postoperative visit 41 days following surgery with a 1 cm mildly draining and dehisced incision with no other clinical signs of infection. He informed the examining physician (JJF) that the physician at the prison hospital ward removed them. He could not recall when this occurred. He was admitted on the same day but underwent wound debridement and removal of the external fixator the following day. The wound was managed with wet to dry dressings and went on to heal 13 days following this debridement.

Figure 5. Open inversion ankle dislocation.

DISCUSSION

Because this is a new concept, the mechanism of incisional negative-pressure wound therapy has yet to be entirely elucidated. Multiple previous case series have reported good outcomes with the utilization of this technique in the management of sternal incisions, acetabular fractures, femoral fractures, tibial fractures, and revisional hip arthroplasty (7). The results in our study similarly demonstrate that prophylactic use of negative-pressure wound therapy can be an important adjunct in optimizing soft-tissue outcomes for high-risk incisions following foot and ankle trauma, a trend consistent with these and the study by Stannard et al (9). The suspected mechanism involves the reduction of interstitial edema and volume resulting in increased cutaneous perfusion, the reduction of incisional shear between the interface of the incision and the dressing, improvement against dehiscence, and introduction of a shared tension across the entire length on the incision versus the pulley-type high tension architecture that occurs at each interrupted suture site (13, 14).

Chen et al evaluated iatrogenically created full-thickness wounds on the dorsal ears of 32 rabbits randomized into 2 groups of 16 with the contralateral ear as the control and compared blood flow velocity, capillary density, and structure with a microcirculatory microscope (15). Subatmospheric pressures at -5, -10, -15, -20 kPa were exerted each for 20 minutes with 10-minute intervals. The VAC group demonstrated statistically significant reduction of interstitial edema resulting in dilation of capillaries, increased blood velocity, and increased formation of granulation tissue. Microscopic cross-sectional imaging demonstrated capillaries with rounded and dilated lumen, changes in the basement membrane and endothelial cells consistent with an increased perfusion, and earlier capillary budding.

Timmers et al evaluated the effect on cutaneous blood flow with a noninvasive Doppler to varying pressures of negative-pressure wound therapy on intact skin on ten healthy volunteers utilizing both the black polyurethane (PU) and the white polyvinyl alcohol (PVA) foam (16). The experimental arm was treated with either the PU or the PVA foam for 2 uninterrupted days, then 2 additional days with the other foam. The control arm was similarly dressed but at a baseline subatmospheric value of 25 mmHg to facilitate the adherence of the dopplers imbedded within the foam onto the skin. The same foam was utilized on both the control and the experimental arms on the corresponding days. The experimental arm initially was evaluated at 100 mmHg subatmospherically for 20 minutes then at each 100 mmHg interval up to 500 mmHg. There was a 5-fold increase above baseline with the PU foam and a 3-fold increase with the PVA foam. With the bulk of the increase in perfusion units occurring from baseline to 200 mmHg, the increase of blood flow from 300 to 500 mmHg was not statistically significant, consistent with Morykwas and Argenta's studies, which demonstrated a peak in blood flow 4-fold above baseline at 125 mmHg subatmospheric (6).

Nonelective surgery offers little recourse for the treating physician to optimize the patient preoperatively prior to subjecting them to the soft-tissue insult associated with surgical management. These patients may present with comorbidities predisposing them to poor outcomes. Of these, factors shown to affect wound healing are smoking, diabetes mellitus, environmental factors, poor nutrition, depression, oxygenation, infection, age, stress, glucocorticoids, and alcohol consumption (17-22). Ultimately, the cost of this technique at our institution is no more substantial than the cost of most single cannulated screws, whereas conversely, the time and cost of the management of wound dehiscence and infection may prove much more substantial when they manifest.

Seventeen of the 21 patients had documented systemic and environmental risk factors predisposing to poor healing and infection. Of these 21 patients, 3 experienced soft tissue issues. In 2 cases, these presented as small areas of delayed healing, which subsequently healed with no surgical intervention. The only patient who required surgical intervention for a dehisced incision was the 23-year-old prisoner whose incision was debrided concurrently after removal of his external fixator, the primary procedure. In the absence of the external fixator, his wound would have been managed on an outpatient basis, effectively rendering our complication rate to 0 when defined as unplanned surgical intervention.

One patient who sustained a Gustilo and Anderson grade IIIB open OTA 43C2 type injury with multisegmental diaphyseal extension after he was thrown off a high-speed motorcycle also sustained the following ipsilateral injuries: joint depression calcaneal fracture extending into the calcaneocuboid joint, cuboid fracture, talonavicular and subtalar joint fracture dislocation, fractures of metarsals 2-5, and a hallux fracture. He presented with multiple large full-thickness soft tissue defects, the most impressive of which corresponded with the open fracture site (Figure 6). In addition to the definitive procedures, the patient underwent multiple wound debridements with soft-tissue coverage. However,

Figure 6A. 12 x 8 cm full open fracture site, exposing a significant portion of the anteromedial periosteal surface of the tibia.

Figure 6B. Posterolateral leg displaying a full-thickness 5 x 4 cm avulsion of soft tissue with exposed muscle.

Figure 6C. Anteroposterior radiograph of the pictured injury.

Figure 6D. Distal anteromedial tibial 5 days following application of a split-thickness skin graft.

Figure 6E. Incisions managed with negative pressure wound therapy. Two months postoperative.

all the incisions created for fracture management treated with incisional negative-pressure wound therapy healed predictably with no dehiscence or infection.

The weaknesses in this study are those inherent with any level IV study. There was no control to test our hypothesis. Preoperative serological markers were not routinely obtained for all the patients. It would be interesting to see if these would have reinforced or refuted our hypothesis in this setting. We have utilized this adjunct in high-risk diabetic patients with poor serologic markers undergoing extensive but elective reconstruction with promising outcomes. However, as we sought to evaluate soft tissue outcomes with incisional negative pressure wound therapy in the setting of foot and ankle trauma, we felt incorporating this patient population was beyond the scope of the study. Nonetheless, the trend is evident, supported by recent literature, and the clinical appearance of the incision has been impressive beyond what can be articulated. Experimental studies further describing and confirming the proposed mechanism of incisional negative-pressure wound therapy are warranted.

REFERENCES

1. Borrelli Jr J, Lashgari J. Vascularity of the lateral calcaneal flap: a cadaveric injection study. J Orthop Trauma 1999;13:73-7.
2. Attinger CE, Evans KK, Bulan E, Blume P Cooper P. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incision, and reconstruction. Plastic Recon Surg 2006;117 (7 Suppl):263S-91.
3. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma 2004;18:1-6.
4. McFerran MA, Smith SW, Boulas HJ, Schwartz HS. Complications encountered in the treatment of pilon fractures. J Orthop Trauma 1992;6:195-200.
5. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg 1997;38:563-76.
6. Morykwas MJ, Argenta LC, Shelton-Brown EI, et al. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg 1997;38: 553-62.
7. Gomoll AH, Lin A, Harris MB. Incisional Vacuum-Assisted Closure Therapy. J Orthop Trauma 2006;20:705-9.
8. Stannard JP, Robinson, JT, Anderson ER, McGwin Jr G, Volgas DA, Alonso JE. Negative pressure wound therapy to treat hematomas and surgical incisions following high-energy trauma. J Trauma 2006;60:1301-6.
9. Stannard JP, Volgas DA, McGwin III G, Stewart RL, Obemskey W, Moore T, Anglen JO. Incisional negative pressure wound therapy after high-risk lower extremity fractures. J Orthop Trauma 2012;26:37-42.
10. DeCarbo WT, Hyer CF. Negative-pressure wound therapy applied to high-risk surgical incisions. J Foot Ankle Surg 2010;49:299-300.
11. Tull F, Borreli Jr J. Soft-tissue complications injuries associates with closed fractures: evaluation and management. J Am Acad Orthop Surg 2003:11:431-8.
12. Aird J, Noor S, Lavy C, Rollinson P. The effect of HIV on early wound healing in open fractures treated with internal and external fixation. J Bone Joint Surg Br 2011;93:678-83.
13. Kazala R. Test Report: Prevena Incionsal Therapy System sutured incins apposition force mearsurement. San Antonio, TX: Kinetic Concepts; Aug 2010.
14. Wilkes R. Prevena and SteriStrips 2D finite element models with sutures. San Antonio, TX: Kinetic Concepts; Oct 2009.
15. Chen SZ, Li J, Li XY, Xu LS. Effects of vacuum-assisted closure on wound microcirculation: an experimental study. Asian J Surg 2005; 28:211-7.
16. Timmers MS, Cessie SL, Banwell P, Jukema GN. The effects of varying degrees of pressure delivered by negative-pressure wound therapy on skin perfusion. Ann Plast Surg 2005;55:665-71.

17. Hoiness P, Engebretsen L, Stromsoe K. Soft tissue problems in ankle fractures treated surgically. a prospective study of 154 consecutive closed ankle fractures. Injury 2003;34:928-31.
18. Nasell H, Ottosson C, Tornqvist H, Linde J, Ponzer S. The impact of smoking on complications after operatively treated ankle fractures-a follow-up study of 906 patients. J Orthop Trauma 2011;25:748-55.
19. Nåsell H, Adami J, Samnegard E, Tonnesen H, Ponzer S. Effect of smoking cessation intervention on results of acute fracture surgery. J Bone Joint Surg Am 2010;92:1335-42.
20. Sorensen LT, Jorgensen S, Petersen LJ, Hemmingsen U, Bulow J, Loft S, Gottrup F. Acute effects of nicotine and smoking on blood flow, tissue oxygen, and aerobe metabolism of the skin and subcutis. J Surg Res 2009;152:224-30.
21. Fulcher MS, Koman LA, Smith BP, Holden M, Smith TL. The effect of transdermal nicotine on digital perfusion in reformed habitual smokers. J Hand Surg Am 1998;23:792-9.
22. Guo S, DiPietro LA. Factors affecting wound healing. J Dent Res 2010;89:219-29.