Use of Vacuum-Assisted Closure and a Dermal Regeneration Template as an Alternative to Flap Reconstruction in Pediatric Grade IIIB Open Lower-Extremity Injuries

Ted M. Barnett, MD, and Jeffrey S. Shilt, MD

Abstract

Severe degloving injuries to the pediatric lower extremity are difficult to treat, traditionally requiring local or free flaps for coverage. Combining vacuum-assisted closure techniques with a dermal regeneration template is proposed as a means for covering these difficult wounds.

We retrospectively reviewed the charts of 7 consecutive patients (age range, 2-12 years) who underwent this treatment. All extremities healed without flap reconstruction or amputation. Mean follow-up was 24.4 months, and mean wound size was 196 cm^2. There were 2 superficial graft complications, 1 nonunion successfully treated with bone grafting, 2 patients with subsequent bony deformity, and 1 patient who underwent subsequent soft-tissue procedures for equinus contracture.

Use of vacuum-assisted closure and a dermal regeneration template has shown good results as a means of successfully managing grade IIIB injuries without performing complicated flap reconstructions.

Dr. Barnett is Resident, and Dr. Shilt is Associate Professor, Department of Orthopaedic Surgery, Wake Forest University School of Medicine, Winston-Salem, North Carolina.

Address correspondence to: Ted M. Barnett, MD, Department of Orthopaedic Surgery, Wake Forest University School of Medicine, PO Box 1070, Winston-Salem, NC 27157-1070 (tel, 336-716-3946; fax, 336-716-3861; e-mail, tbarnett@wfubmc.edu).

Am J Orthop. 2009;38(6):301-305.

Open injuries in pediatric lower extremities remain difficult to manage and are associated with high complication rates and multiple surgical procedures.[1-8] The most difficult of these injuries include type IIIB open tibia fractures and degloving injuries of the foot and ankle.

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The Gustilo–Anderson system is the most commonly used system for classifying open fractures.[9,10] Type I, II, and IIIA injuries are commonly treated with local skin management and have reasonably good outcomes. Type IIIB injuries, however, require more extensive soft-tissue management. These injuries have soft-tissue defects, extending more than 10 cm, that historically require local or free flaps for coverage of the exposed fracture. Similar treatment has been advocated for degloving injuries of the foot and ankle.

The reported success of limb salvage surgery for type IIIB injuries has been variable.[11,12] Early wound coverage (0-7 days) has been shown to decrease complication rates, shorten healing time, promote fracture union, and reduce costs of hospitalization and rehabilitation when compared with late coverage (after 7 days).[13,14] In areas such as the distal tibia and foot, where tissue for local transfer is limited, early wound coverage is a significant challenge; with advances in microsurgical techniques, however, it has been possible to provide free-tissue transfer for these challenging injuries.[15] Although there has been reasonable success with microsurgical free-tissue transfer in pediatric patients,[16,17] the procedures are technically demanding, require intensive monitoring of flap viability, and are more costly than local tissue transfers.[2,3,5,16-18] They are also associated with high rates of complication, flap loss, and donor site morbidity, leaving a need for better wound coverage options for these injuries.

With the advent of new biomaterials, such as the Integra® dermal regeneration template (Integra LifeSciences Corporation, Plainsboro, NJ), and the vacuum-assisted closure (V.A.C.®) device (Kinetic Concepts, Inc., San Antonio, Tex), wound closure has become a possibility without use of free-tissue transfer. The Integra dermal matrix is a bilayered biosynthetic material that consists of collagen and

Figure 1. (A,B) Two views of same leg at 57-month follow-up in patient who had sustained tibia fracture with near circumferential degloving.

silicone and acts as a scaffold for dermal regeneration, providing an adequate bed for application of split-thickness skin grafts.[19] The V.A.C system has been successfully used in the treatment of both adult and pediatric patients with open traumatic wounds, including wounds with exposed tendon, bone, and orthopedic hardware.[20-23] Soft-tissue incorporation of Integra has been shown to be accelerated with V.A.C use, allowing for earlier definitive coverage.[19]

Previous reports of defects treated with V.A.C and/or dermal matrix involved small wounds only. The modest success of this treatment prompted its use as a possible alternative for larger defects, such as those associated with type IIIB open fractures of the distal tibia or foot. The morbidity associated with free-tissue transfer certainly makes this an attractive alternative.[24]

Here we report the results from our study of pediatric Gustilo grade IIIB lower-extremity injuries treated with wound débridement, V.A.C with Integra, and split-thickness skin grafting. We hypothesized that this treatment protocol would be an acceptable alternative to flap reconstruction and would be associated with less donor site morbidity, less need for complicated microvascular reconstructions, and possibly improved cosmetic and functional outcomes.

Methods

After obtaining institutional review board approval and parental consent, we retrospectively reviewed the cases of all the pediatric patients with grade IIIB lower-extremity injuries treated with V.A.C and Integra at our university-based orthopedic practice between November 2001 and May 2006. All patients 18 years old or older were excluded from the study.

The injuries were treated similarly. In each patient's case, the protocol included early irrigation and débridement of wounds, bony stabilization, and use of negative-pressure dressing with continuous suction (V.A.C). After initial management, the patient was transferred to the pediatric orthopedic service for definitive wound and fracture management. Wound care consisted of formal irrigation and débridement performed in the operating room with V.A.C dressing changes every 2 to 4 days until the wound was considered appropriate for coverage with the dermal regeneration template.

After suitable serial débridements and absence of nonviable tissue and debris, the dermal matrix graft was cut to fit the full extent of the wound and was sutured in place with absorbable monofilament suture. The graft was "piecrusted" by making multiple slits in the graft with a scalpel. A negative-pressure dressing was applied over the graft and left in place for 5 to 6 days. The patient then returned to the operating room for removal of the dressing, including the silicone layer of the dermal matrix, and placement of a meshed split-thickness skin graft. Again, a negative-pressure dressing was applied over the skin graft with nonadherent gauze between the graft and the sponge. This dressing was left undisturbed for 4 days. Then, depending on the patient's ability to tolerate the procedure, the dressing was removed either at the patient's bedside or with the patient under anesthesia. Skin grafts were dressed with petroleum jelly gauze dressings daily until healed.

The patient's medical record was reviewed to determine wound size, number of débridements before coverage with Integra, length of hospital stay, presence or absence of infection or nonunion, need for subsequent bony or soft-tissue procedures, and need for subsequent flap reconstruction or amputation. Postoperative activity was determined by fracture pattern and fixation stability.

Results

Seven patients (5 boys, 2 girls) were identified as having been treated with this protocol, and all are included in this report (Table). There were 3 open tibia fractures, 3 foot and ankle degloving injuries, and 1 open ankle fracture-dislocation. All injuries included exposed bone and were not amenable to primary or secondary wound closure. Mean patient age was 7.4 years (range, 2-12 years), mean follow-up was 24.4 months (range, 10-57 months), mean wound size was 196 cm^2 (range, 60-324 cm^2), mean number of formal débridements before dermal matrix placement was 4.6 (range, 2-9), and mean hospital stay associated with the initial injury was 21 days (range, 7-42 days).

Figure 2. (A,B) Two views of same foot at 10-month follow-up in patient who had sustained degloving injury of foot with exposed tendon and bone.

Table. Data on 7 Patients Who Underwent Treatment

Injury	Age (y)	Wound Size (cm^2)	No. of Débridements Before Integra	Initial Hospital Stay (d)	Complication(s)
Pedestrian vs car/foot degloving	2	96	2	12	None
Bush hog/foot degloving	7	225	7	29	Equinus contracture, physeal bar, skin graft ulceration
Bicycle vs car/tibia fracture and degloving	9	324	9	34	None
Motorcycle vs car/grade IIIB tibia fracture	11	204	7	42	Tibia nonunion
Lawnmower injury/foot degloving	5	204	2	7	None
All-terrain vehicle/open ankle dislocation with skin loss	12	60	2	7	Delayed graft healing
Dirt bike/grade IIIB tibia fracture	6	192	3	16	External fixator pin infection

All the wounds and fractures healed without flap reconstruction or amputation (Figures 1, 2). One acute infection developed from the initial injury and treatment. A deep infection of an external fixator pin site occurred and was successfully treated with external fixator removal.

Two patients developed complications of the Integra and split-thickness skin graft site. In one of these patients, delayed healing of a 1-cm area at the graft site responded to dressing changes. In the other patient, who also underwent gastrocnemius recession for equinus contracture, an ulcer over the lateral malleolus was treated with débridement and secondary closure at 3 months.

One patient had a soft-tissue deformity that required additional surgery. An equinus contracture in a patient with a limb-length discrepancy secondary to a physeal bar was treated initially with botulinum toxin and casting. The deformity was not completely corrected, so the patient then required gastrocnemius recession. The patient had a persistent deformity at time of physeal bar resection and underwent Achilles tendon lengthening and posterior tibial tendon lengthening to correct it. A secondary, superficial wound infection of the surgical incision after gastrocnemius recession was successfully treated with oral antibiotics.

Two patients had bony complications that required additional surgery. One of these patients was the patient who developed a growth arrest secondary to a physeal bar that resulted in a leg-length discrepancy. Distal tibial physeal bar resection was performed along with contralateral epiphysiodesis. The other patient, who had segmental tibial bone loss, was treated with bone transport. This patient developed bone transport site nonunion, which was treated with iliac crest bone grafting, and then a valgus deformity of the tibia, which was successfully treated with an osteotomy.

Discussion

Grade IIIB open tibia fractures and degloving injuries of the foot and ankle are difficult injuries to treat in the pediatric and adult populations. These injuries have been associated with high rates of complications, including infection, delayed union, nonunion, compartment syndrome, and long-term functional disabilities.[1-6] In addition, these injuries are the subject of controversies regarding adequate wound débridement, timing of wound coverage, type of wound coverage, and need for involvement of additional specialties, such as plastic surgery.

It is accepted that initial management of severe open fractures requires formal surgical irrigation and débridement with removal of gross contamination and devitalized tissue.[2-4,8] There are reports that some devitalized bone in pediatric patients may be left in place and will reincorporate as autograft, but this remains controversial.[2] After initial débridement, repeat surgeries are often necessary for wound débridement before definitive wound coverage.

Several recent reports in the adult and pediatric populations have evaluated management of wounds between débridements with use of V.A.C.[1,20-23] Studies have suggested that V.A.C reduced bacterial loads within the wound,[25,26] improved the formation and amount of granulation tissue,[22] and decreased tissue edema.[1,22] One report determined that use of V.A.C and use of conventional open dressings are similar in cost but that V.A.C use is linked to improved patient comfort and less nursing staff time.[27] A randomized, controlled multicenter trial comparing V.A.C therapy with wet-to-dry dressing changes in diabetic partial foot amputations showed increased healing rates, decreased healing times, and increased granulation formation rates in the V.A.C group.[28] Frequency and severity of complications were the same for the 2 groups. Moues and colleagues[29] reported results from a prospective, randomized trial comparing V.A.C therapy with conventional gauze dressings in the treatment of a variety of wounds that could not be closed primarily. Their results showed no difference in quantitative bacterial loads, a trend toward shorter treatment in the V.A.C group, a significantly faster rate of wound surface area reduction in the V.A.C group, and significantly healthier appearing wounds (according to a visual grading scale) in the V.A.C group.

Early coverage of traumatic wounds has been shown to decrease complication rates and improve out-

comes.[3,13,14,17] In 1983, Cierny and colleagues[14] reported on the importance of early wound coverage in the treatment of severe open tibia fractures. They defined early wound coverage as occurring between 0 and 7 days and late coverage as between 8 and 30 days. Their results showed significantly lower rates of wound complications (20.8% vs 83.3%) and shorter time to fracture union (4.0 vs 6.4 months) in the early coverage group. In the pediatric population, data are more limited, but flap reconstruction within 7 days of injury for lower-extremity trauma has been shown to decrease complication rates compared with reconstructions performed more than 7 days after injury.[3,17] A more radical approach was described by Gopal and colleagues.[13] In their series, 84 consecutive patients were treated for a severe open tibia fracture with radical débridement and coverage with muscle flap. Sixty-three of the fractures underwent muscle flap coverage within 72 hours. The authors, who reported higher complication rates in the patients treated with coverage after 72 hours, recommended early aggressive muscle flap reconstructions with combined plastic surgery and orthopedic surgery services at a tertiary-care center. This method of early flap coverage has been dubbed the *fix-and-flap method*.

Recent advances in microsurgical techniques have made use of free-tissue transfer possible in pediatric patients.[16,17] However, flap reconstructions are fraught with complications. In their 10 years of using microvascular free flaps in pediatric lower-extremity trauma, Rinker and colleagues[17] found a postoperative complication rate of 62%. Three of 28 flaps were lost, 5 patients required reexploration for venous thrombosis, and 9 patients developed a serious infection. In their series of 22 pediatric patients who underwent flap reconstruction of upper and lower-extremity traumatic wounds, Duteille and colleagues[16] reported partial flap loss in 1 patient and reexploration for venous thrombosis in 3 patients. Of note, after surgery, all these patients were admitted to an intensive care unit for 24 hours for hourly flap monitoring. In the adult literature, Khouri and Shaw[15] reported on 304 cases of free-flap reconstruction in the lower extremity and found an 8% rate of flap failure, a 15% rate of anastamotic thrombosis, a 6% rate of amputation within 3 months, and a 20% rate of donor site morbidity. The cost of free-tissue transfer has also been called into question. In 2005, Thornton and colleagues[18] conducted a cost-and-outcome study comparing free-tissue transfer and local muscle flaps in the reconstruction of lower-extremity traumatic wounds. They found equivocal outcomes, but local muscle flap cost nearly half as much as free-tissue transfer ($11,729 vs $19,989).

"This method may be particularly useful in treating wounds with exposed tendons, as it allows better excursion of the tendons."

Because of the complications and expense of free-tissue transfer in treating traumatic wounds, and the microsurgical expertise required, interest in identifying alternative treatment strategies has increased. In a 2006 study, Dedmond and colleagues[1] determined that use of V.A.C therapy was safe and effective in treating high-energy open tibial shaft fractures in children. Three of 6 grade IIIB fractures ultimately required flap reconstruction for coverage. The authors concluded that use of V.A.C therapy may reduce need for major soft-tissue reconstructions in pediatric open tibia fractures. Another study examined V.A.C use in 27 patients with complex wounds that required coverage.[23] V.A.C produced granulation tissue over exposed bone, tendon, joint, and hardware. Fifteen of 27 patients required only a split-thickness skin graft over granulation tissue after V.A.C treatment. No patients required free-tissue transfer, but 2 pedicle flaps and 1 "cross-leg" flap were used. A 2006 study of trends in managing severe open tibia wounds between 1992 and 2003 showed a significant decrease in free-tissue transfers and more split-thickness skin grafts and delayed closures with use of V.A.C therapy.[11] Integra was developed as a dermal regeneration template and has been used extensively in treating burns and in other soft-tissue reconstructions.[19,24,30] It has been used to successfully cover wounds with exposed bone, tendon, and joint surfaces.[19,24] Time to vascularization and the ultimate success rate of split-thickness skin grafting have improved with V.A.C use, making use of Integra more reasonable in traumatic wounds.[19]

In the present study, we successfully managed 7 pediatric patients with severe lower-extremity wounds that historically have required amputation or flap reconstruction. In using a dermal regeneration template with V.A.C therapy, we generated a healthy bed of granulation tissue over exposed bone and tendons that was acceptable for split-thickness skin graft. Presence of dermal matrix separated the skin graft from underlying tissue and could potentially allow more motility of the overlying skin graft. This method may be particularly useful in treating wounds with exposed tendons, as it allows better excursion of the tendons. We believe the added tissue under the skin graft also gives a more natural appearance to the graft and may improve most cosmetic results. We successfully used Integra over areas of exposed bone and tendon. In this consecutive series, no local or free-muscle flaps were required for wound coverage. The skill needed for dermal matrix placement and use is quickly learned. This treatment protocol has the potential to reduce the overall costs of limb salvage when compared with free-flap reconstructions.

This study had several limitations. It was a retrospective review of a small number of patients. However, all patients who had the described diagnoses and presented after this treatment algorithm was initiated were treated in this manner. Continued enrollment of patients thus treated will yield more information and possibly provide instances in which this treatment is not indicated. At our institution, V.A.C is used extensively, and our surgeons are aggressive and comfortable with it. In centers where it is not used routinely, there may be a learning curve. Successful use of this treatment protocol is likely not applicable to patients outside the pediatric age range. Several authors have reported that age is an important influence on outcomes in pediatric open tibia fractures. Younger patients have had faster healing rates, less infection, and fewer complications.[6-8]

Conclusions

In this article, we report on 7 pediatric patients who underwent successful treatment with Integra dermal regeneration template and V.A.C for severe lower-extremity injuries that historically have required free flap or amputation. Complicated flap reconstruction and amputations were not needed. All grafts healed with acceptable cosmetic results and were durable without the need for long-term soft-tissue treatment. Intensive care unit monitoring of soft-tissue management was not required. This treatment may be used as an alternative to flap reconstruction or amputation in similar patients and further supports the current trend of reducing free flap coverage in severe lower-extremity injuries.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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