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Primary reattachment of avulsed skin flaps with negative pressure wound therapy in degloving injuries of the lower extremity

G. Sakai[a,b], T. Suzuki[a,*], T. Hishikawa[a], Y. Shirai[a], T. Kurozumi[a], M. Shindo[a]

[a] Department of Trauma and Reconstruction Center, Teikyo University School of Medicine, Tokyo, Japan
[b] Department of Orthopedic Surgery, Nagoya City University Graduate School of Medical Sciences, Nagoya, Japan

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ABSTRACT

Large avulsed skin flaps of the lower extremity caused by degloving injuries eventually develop skin necrosis in most cases. The current treatment option involves excision of the degloved skin and reapplication as a full- or split-thickness skin graft. We considered that reattachment of avulsed skin flaps without excision would be theoretically beneficial, since some circulation may remain around the connected pedicle and thus facilitate graft take. Furthermore, securing the skin to the original anatomic position is much easier using retained landmarks. We treated a total of 12 patients (13 cases) with degloving injuries of the lower extremity. In all cases, the avulsed skin flap was defatted and sewn back to the original position, then negative-pressure wound therapy was applied over those grafts as a bolster for approximately 7 days. Most of the avulsed skin flap took excellently, particularly close to the connected pedicle. Nine cases did not need any additional surgical procedures. Four cases required secondary skin graft for a small area of open wound due to partial necrosis of the defatted skin, as well as the raw surface left by the primary skin defect in the initial operation. Primary reattachment of the avulsed skin flaps without excision is convenient and efficient to cover the open wound over the exposed fascia and periosteum in degloving injuries. This would potentially offer a better alternative to definitive wound closure.

Introduction

Degloving injuries are caused by shearing force and result in avulsion of the cutaneous and subcutaneous skin tissue from the underlying fascia and periosteum. Most of the perforators of the skin are disrupted [1–3], and re-suturing of the avulsed skin flap frequently results in disseminated tissue necrosis [4,5]. In particular, primary wound closure is considered to be contra-indicated for large, circumferential degloving injuries [6]. Therefore, in the acute management of large degloving injuries, the excision of the degloved skin, primary defatting, and immediate securing as skin graft is generally recommended [7]. However, in terms of the area of excision, drawing the line between vital skin and skin that will eventually fall into necrosis is difficult at the initial operation. Theoretically, the circulation may remain intact around the connected pedicle of the avulsed skin flap, and the blood supply gradually decreases with proximity to the edge of the injured skin. We hypothesized that conversion of the avulsed skin flaps into skin graft without excision is much more advantageous and effective in closing the wound compared with the conventional method.

The primary purpose of this study was to evaluate the efficacy of our strategy for reattaching the defatted and fenestrated skin graft without excision for lower extremity degloving injuries using negative-pressure wound therapy (NPWT). We measured the taken area of skin graft and recorded the additional surgical procedures required. This paper offers a preliminary report of our initial cases.

Surgical techniques

After the initial resuscitation and stabilization according to the Advanced Trauma Life Support guidelines, the patient was transferred to the operation room. First, apparently non-viable tissues were debrided and the contaminated wound was irrigated with a large amount of normal saline. Open reduction and internal fixation of the fracture were performed if indicated. Subsequently, the avulsed skin flap was flipped over from the opposite side of the

* Corresponding author at: Department of Trauma and Reconstruction Center, Teikyo University School of Medicine, 2–11–1 Kaga, Itabashiku, Tokyo 173–8606, Japan.
E-mail address: takashisuzuki911@yahoo.co.jp (T. Suzuki).

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connected pedicle and gradually defatted from the edge of the degloved skin towards the connected side using a scalpel and/or scissors (Fig. 1). Complete defatting of the base of the connected pedicle was never possible under this condition of simply flipping the avulsed skin flap. However, we intentionally left defatting imperfect around the connected pedicle, since some perforators in the proximity may have been left intact and some circulation retained. After such defatting, multiple stab wounds were made to drain seroma and hematoma from the recipient bed. This procedure making an avulsed skin flap into a meshed skin graft facilitated expansion of the graft and was very helpful to cover a wide area. This meshed skin graft was sutured to the original anatomic position as a full-thickness skin graft (FTSG). The skin graft was then secured using NPWT. The NPWT entailed an ActiV.A.C. system (KCI, San Antonio, TX) or RENASYS GO system (Smith & Nephew, London, UK) and black polyurethane foam, which was applied directly over the skin graft without a non-adherent contact layer. In cases where some primary skin defect was present, the remaining raw surface was also covered with NPWT. The amount of negative pressure was at the discretion of the attending surgeon, and actually ranged between 50 and 100 mmHg. The initial foam was left in place for 6–7 days before discontinuation or change. If open wounds remained at the first dressing change, the foam was exchanged and reapplied for more several days. Finally, remaining small open wounds (approximately $<10\,cm^2$) were treated with spontaneous epithelialization by creating a moist wound environment. Wider area wounds required split-thickness skin graft (STSG) 3–4 weeks after injury.

Materials and methods

This was a retrospective study of 12 consecutive patients (13 cases) who were treated for degloving injuries of the lower extremity in our institution between April 2014 and December 2015. Injuries of Gustilo IIIB open fractures and degloving injuries of the calcaneal heel pad were excluded, since these injuries frequently require subsequent flap surgeries. Participants comprised 4 males and 8 females, with a mean age of 64.8 years (range, 18–91 years). Nine of the 12 patients had been involved in traffic accidents, comprising an auto-pedestrian accident in 6 patients, auto-bicycle accident in 2 patients, and auto-motorcycle accident in 1 patient. Three patients sustained crush injuries. The demographic characteristics of these 13 cases are shown in Table 1.

There were 9 foot and ankle legions, most of which were caused by run-over injury. Three cases showed lower leg lesions. One case had an extensive degloving injury from the thigh to lower leg (Case 8). Twelve cases had associated fractures, of which 10 were open. They comprised 8 Gustilo type IIIA fractures and 2 Gustilo type II fractures. Immediate internal fixation of the open fractures was performed in 6 cases. Four cases underwent delayed open reduction and internal fixation following completion of the wound closure. Two fractures were treated conservatively. The mean area of the degloving injury was $330\,cm^2$ (range, $60–1650\,cm^2$). The most frequently applied negative pressure was 75 mmHg (range, 50–90 mmHg). Five cases required circumferential application of the NPWT foam, where relatively low pressure (50 mmHg) was chosen. The mean total duration of NPWT was 8.3 days (range, 6–14 days).

Electronic medical records and X-rays from picture archiving and communication systems were reviewed. We evaluated the clinical courses, including rates of infection and bone healing. We also estimated the taken area of skin graft using digital photographs with measures recorded in electronic medical records.

Fig. 1. Defatting of the avulsed skin flap of the foot. A scalpel is used to make a full-thickness skin graft (Case 12).

Results

At the emergency operation, initial appraisal suggested considerable primary skin defects and an open wound much wider than the avulsed skin flap. However, at the end of the operation, the fenestrated, meshed skin graft was revealed to have successfully covered more than 80% of the degloving injury in 11 of 13 cases (Table 1).

After 1-week application of NPWT, mean initial take of the graft was 88% successful (range, 55–100%). In 9 cases, most of the area covered with meshed skin graft took excellently and no additional surgical procedures for wound closure were required. There were 4 cases that underwent a subsequent STSG procedure. In these cases, some part of the grafted area gradually fell into skin necrosis (Fig. 2). The site of necrosis was located relatively close to the edge of the degloved skin and no necrosis was evident around the connected pedicle of the avulsed skin flap. After demarcation, tangential excision of the necrotic tissues and simultaneous STSG was performed over the debrided area as well as the raw surface area that could have not be covered in the initial operation. One patient underwent STSG following necrosis and amputation of the big toe due to initial total degloving (Case 2). Another reason for failure of the meshed skin graft seemed to be insufficient initial debridement of the underlying wound bed in 2 cases (Cases 3 and 7). The remaining one patient who developed necrosis of the grafted skin and underwent subsequent STSG had been administered antiplatelet agents due to post-percutaneous coronary intervention (Case 8). In that patient, formation of massive hematoma was observed under the grafted skin at the initial dressing change during NPWT (Fig. 3).

No deep infections developed at any stage during the treatment course. Two patients were administered antibiotics due to superficial infection. All the associated fractures achieved bone union without additional osteosynthesis or bone grafting.

Discussion

Selection of the treatment modality is crucial in degloving injuries. If mismanaged, the avulsed skin flap will develop delayed necrosis and wound sepsis. The current study showed favorable results for a treatment method that includes no excision of the degloved skin, subsequent defatting and fenestration, and primary reattachment as a meshed skin graft with NPWT. Nine of the 13 cases healed without any additional surgical procedures for wound closure, even though complete take of the skin graft was not achieved. Four patients required a secondary STSG due to insufficient debridement of the underlying wound bed and

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Table 1
Patients' characteristics.

Case	Age/ Gender	Mechanisms of injury	Site	Gustilo type	NPWT pressure (mmHg)	NPWT duration (days)	Injured area (cm2)	Covered area (cm2)	% coverage	% graft take	Secondary procedures	Complications
1	85/F	auto-pedestrian	foot and ankle	IIIA	50	6	91	90	99	95	–	–
2	83/F	auto-pedestrian	foot and ankle	IIIA	70	12	60	44	73	55	STSG	big toe amputation
3	38/M	auto-pedestrian	foot and ankle	IIIA	50	13	750	661	88	89	STSG	–
4	74/F	auto-pedestrian	foot and ankle	–	70	7	98	98	100	94	–	–
5	18/M	motorcycle	foot and ankle	II	70	10	63	48	76	100	–	–
6	68/F	crush	foot and ankle	IIIA	75	7	120	120	100	100	–	superficial infection
7	55/M	crush	foot and ankle	IIIA	50	14	192	157	82	89	STSG	–
8	67/F	bicycle	thigh and lower leg	–	50	6	1650	1641	99	74	STSG	–
9	66/F	auto-pedestrian	foot and ankle	IIIA	50	6	81	81	100	85	–	–
10	91/F	auto-pedestrian	lower leg	IIIA	75	7	750	746	99	99	–	–
11			lower leg	–	75	7	240	240	100	98	–	–
12	85/F	bicycle	foot and ankle	II	75	7	136	136	100	93	–	superficial infection
13	47/M	crush	foot and ankle	IIIA	100	6	50	40	80	80	–	–

STSG: split-thickness skin graft.

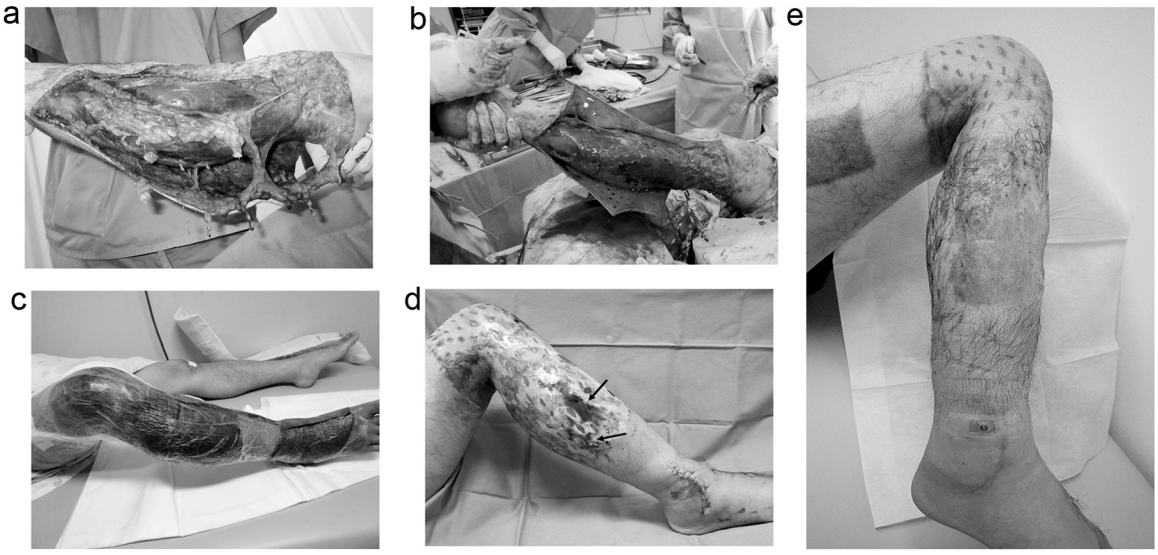

Fig. 2. A 38-year-old man with large degloving injury of the lower leg (Case 3). **A)** Subtotal circumferential degloving injury. **B)** Defatting and fenestration are performed without excision. **C)** Application of NPWT over the lower leg. **D)** Partial necrosis over the lateral side of the lower leg (arrows). **E)** At the 6-month follow-up, the patient continues to show excellent range of motion in the knee from 0 to 130°.

hematoma formation. No cases developed skin necrosis due to imperfect defatting around the base of the connected pedicle.

The first recorded successful replacement of an avulsed skin flap as FTSG was reported in 1939 by Farmer, who described a series of four cases [7]. This treatment method has gained general acceptance in recent years and has been reported to achieve a good rate of graft survival [8,9]. In practice, it is reasonable to debride thin, easily bruised or abraded skin, however, most of the area of degloved skin is potentially survivable as skin graft. The advantage of the immediate FTSG treatment is the lack of scarification at the donor site, coverage of open wounds in a first operation, and minimised contracture formation even if the skin graft surrounds a joint.

Radical and rigorous excision of degloved skin and complete defatting has been emphasized as essential for the success of FTSG take. However, differentiation between viable and non-viable tissue in the initial operation is usually difficult. This makes clinical decisions of what to excise and what to leave in situ quite difficult. Theoretically, the circulation remains intact around the bridge or base of the avulsed skin flap. Radical debridement potentially provides over-estimation of non-viable tissues and may remove viable skin that would survive. We defatted the avulsed skin flap while protecting the soft-tissue connection to the intact tissue. This imperfect defatting did not affect graft take, since the connected pedicle left attached maintains circulation from the perforators on the intact side and may provide better incorporation of grafts. Our techniques do not require unsparing assessment of the viability of borderline tissues. Over-excision of degloved skin is not imperative. Moreover, our techniques accurately facilitate reattachment of the skin graft to the original anatomic position.

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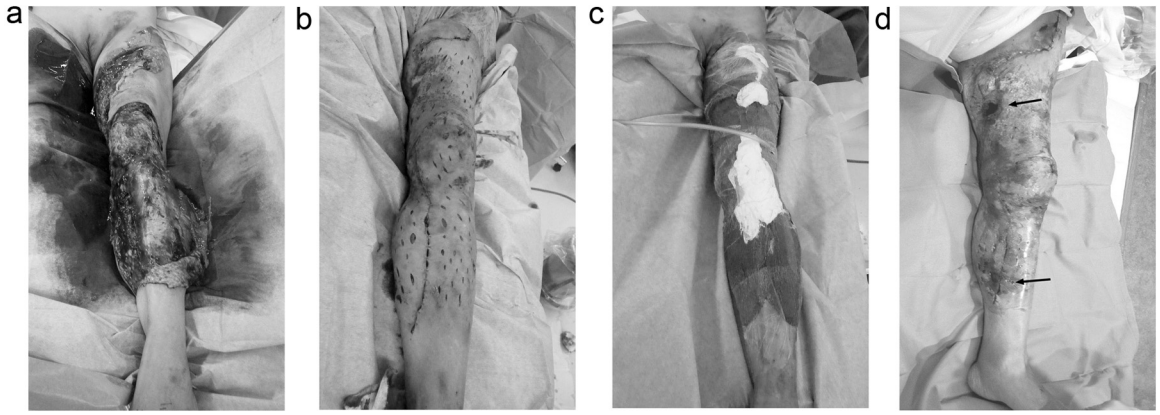

Fig. 3. A 67-year-old woman with massive degloving injury of the lower extremity (Case 8). **A)** The left lower extremity was involved in a bike-truck accident. **B)** The avulsed skin flap is reattached with multiple stab wounds. **C)** Application of the NPWT. Some gauze dressing is used due to the lack of foam. **D)** Development of necrosis on the medial side due to hematoma formation (arrows).

Cosmetic appearance can be improved because no additional incisions are made and scarring of the base of the pedicle is prevented [8].

We consider that NPWT also contributed to graft success in our cases. Several factors have been reported to decrease graft take, including inadequate recipient bed preparation, hematoma collection, poor graft apposition to the bed, and local infection. NPWT is an effective option in terms of firmly securing and appropriately contouring the STSG, even above an irregular base. Constant drainage of discharge from the wound bed is also helpful in acute injury [10,11]. NPWT can also decrease times of dressing change and effectively separate the wound from the surrounding environment. These features theoretically minimise nosocomial contamination [12]. Additionally, NPWT coverage of the entire raw surface as well as reattached skin promotes hypervascular granulation tissue which is optimal for secondary STSG. In terms of the rate of STSG success, several comparative studies have demonstrated the benefits of NPWT compared to conventional tie-over bolster dressings [13–16]. A few studies showed conventional dressing for avulsed skin flaps was comparable with NPWT in degloving injuries, with graft incorporation rates of all around 80 to 90% [8,9]. However, employing negative pressure dressing is much easier to apply, and postoperative management is simpler, as mentioned above. It is considered that NPWT for open fractures is favorable to the total cost of treatment owing to shortened hospitalization and less infection rate [12]. To date, several studies have reported that NPWT was also effective for securing FTSGs following the excision of degloved skin [17–20]. FTSG is superior to STSG in terms of preventing contracture and reducing scar formation. We believe that the application of NPWT over FTSG utilizing degloved skin without excision is essential for successful graft take in the modern era [18].

The disadvantages of NPWT include monitoring and maintenance of the machine. Periodic evaluation of the apparatus is required to ensure a proper seal around the wound. In addition, because we cannot inspect the inside of the sealing apparatus, much attention must be paid to whether infection occurs. Circumferential application of NPWT remains controversial and some instruction manuals note that circumferential placement of NPWT foam is contraindicated due to the fear of elevated positive pressure that would disturb the circulation in underlying tissues and the development of compartment syndrome. However, clinically, large degloving injuries may require circumferential application of NPWT [21–23]. Suboptimal pressure settings have yet to be established, and further prospective studies are warranted to determine the amount of NPWT pressure suitable for circumferential foam application.

Our results showed that 4 cases suffered incomplete graft take and required secondary STSG. Appropriately judging wound bed preparation in the initial debridement is sometimes difficult. If debridement of the recipient site is insufficient and non-viable tissues remain, skin graft necrosis is likely. Our treatment strategy involved immediate coverage of the entire raw surface and routine second-look surgical debridement of degloving injury is not performed. In 3 of our 4 failed cases, graft loss was attributed to insufficient initial debridement of the wound bed. Further, complex soft-tissue injuries with long bone fractures such as Gustilo IIIB open fractures usually require subsequent flap surgery and are not amenable to skin graft [24]. Treatment of degloving injuries of the calcaneal heel pad is also problematic and FTSG application remains controversial [25]. We would like to emphasize that meticulous evaluation of the soft-tissue injury is essential and the current strategy is not always available for degloving injuries.

Some alternatives are available for the treatment of degloving injuries. Revascularization of the avulsed skin flap using microsurgical techniques might be potentially possible [26]. However, vascular anastomoses are rarely successful for damaged skin flaps and contraindicated in most degloving injuries. Application of free flaps might be another option for covering soft-tissue defects in degloving injuries. A “fix-and-flap” concept has been developed over the last two decades in the treatment of severe open fractures [27]. Free flap surgery is generally accepted as optimal for large defects of soft tissues and exposure of bone, joint, and neurovascular structures. However, flap surgery usually requires meticulous preoperative planning for both donor and recipient sites. Staged and complex procedures are usual and may extend the treatment period and sacrifice normal function for wound closure. We believe that when microsurgery is either unavailable or unnecessary, replacement of avulsed skin flaps as FTSG can consistently provide satisfactory results in the treatment of degloving injuries.

The current study had several limitations, primarily due to small size of the retrospective case series. Levels of negative pressure in NPWT were not identical, due to the discretion of the attending surgeon. Exact measurement of the area of degloving injury using digital software was not possible. Given the retrospective nature of this study, comparison of complication rates with other studies was not undertaken. Nonetheless, in our study, reattachment of the avulsed skin flaps after defatting and

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fenestration provided successful coverage of the open wounds even in extensive degloving injuries. Only a few studies have focused on the NPWT used for avulsed skin flaps in degloving injury, and no studies have described the potential advantages of not excising the avulsed skin flaps. The current preliminary report should help establish a standard strategy for degloving injuries in the contemporary world in the era of NPWT.

Conclusion

Reattachment of avulsed skin flaps without excision using NPWT offers a good alternative in the treatment of degloving injuries of the lower extremity. Several advantages have been identified in terms of success rate, recovery time, function, and cosmesis. Less-aggressive debridement is tolerable around the connected pedicle and offers a time-saving, efficient, safe, and simple procedure for both patients and physicians.

Conflict of interest

We declare that we have no conflict of interest in connection with this paper. All authors confirm that they have no financial and personal relationships with other people, or organizations, that could inappropriately influence (bias) this work.

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