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Original Article

Negative pressure wound therapy in the management of mine blast injuries of lower limbs: Lessons learnt at a tertiary care center

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ARTICLE INFO

Article history:

Received 2 March 2016

Accepted 13 June 2016

Available online 26 July 2016

Keywords:

Mine blast injuries

Foot defects

Negative pressure wound therapy

Delayed reconstruction

Prosthetic rehabilitation

ABSTRACT

Background: Mine blast injuries of foot are devastating injuries that result in composite tissue loss or amputations. Negative pressure wound therapy has helped in the management of such combat-related wounds. The aim of this study was to report experiences gained in managing such injuries at a tertiary care center.

Methods: 17 combatants who sustained mine blast injuries were included in this study. Severity of foot injury was assessed as per Foot and Ankle Severity Score. After wound debridement, negative pressure wound therapy was started and foot defect was appropriately reconstructed. Following wound healing, the foot was assessed for Foot and Ankle Severity Score in terms of impairment. The patients were then suitably rehabilitated by shoe modifications, orthosis, or custom-made prosthesis.

Results: Mean age of soldiers who sustained mine blast injuries was 30.2 years. The mean Foot and Ankle Severity Score was 3.76. Temporary wound closure was achieved using negative pressure wound therapy and it prevented local and systemic infection. The defect could be reconstructed appropriately using split skin graft, regional fasciocutaneous flap, or microvascular free flap. Mean time to definitive reconstructive procedure was 16.5 days. Mean Foot and Ankle Severity Score in terms of impairment was 4.11. All soldiers could be rehabilitated and were returned to their respective units and were able to perform sedentary duties assigned to them.

Conclusion: The negative pressure wound therapy was helpful in preventing proximal amputations due to mine blast injury and was helpful in satisfactory reconstruction of foot defects.

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<http://dx.doi.org/10.1016/j.mjafi.2016.06.002>

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Introduction

Mine blast injuries are devastating injuries that can result in loss of life and limb. The victims who survive these injuries are often incapacitated for life. The massive contamination and a composite tissue loss in the limb require an urgent attention. The reconstruction is aimed at achieving a pain free and functional limb. In the absence of satisfactory wound management and reconstruction, the rates of below-knee amputation are significantly high.¹ Negative pressure wound therapy (NPWT) has become an accepted modality in the management of such combat-related wounds and its benefits are well reported in literature.^{2–4} This study was conducted at a tertiary care center, which receives casualties from forward areas. Aim of this study was to report the experiences gained while managing such injuries.

Materials and methods

A prospective, longitudinal study was conducted at a tertiary care center between April 2014 and November 2015. 17 combatants who sustained mine blast injury to the foot and lower limbs were included in this study. They were evaluated for hemodynamic stability, local tissue damage, and for injuries in other body parts. The anatomical site of injury was categorized as forefoot, midfoot, and hindfoot, severity of injury was assessed as per Foot and Ankle Severity Score (FASS) as described by trauma committee of American Orthopedic Foot and Ankle Society.⁵ All patients were subjected to routine hematological and biochemical tests. Radiographs of the affected foot and other injured areas were obtained to ascertain the nature and extent of skeletal injury.

Once hemodynamic stability was established, injured limb was examined under combined spinal and epidural anesthesia. Wounds were irrigated with copious saline and surgically debrided under loupe magnification and tourniquet control. Skeletal stabilization was achieved using K wires. Wound was covered with antibiotic impregnated gauze pieces. Compression bandages were applied to ensure hemostasis. After 48 h, wounds were reexamined and debrided further in the presence of necrotic tissue. Foot defects were assessed based on classification by Hidalgo et al.⁶ Once devoid of nonviable tissue, NPWT was applied to prepare the wound for skin/soft tissue cover. Under sterile conditions, the wound covered with reticulated open cell foam (ROCF) dressings was secured with adhesive waterproof dressing. This was connected to NPWT device, which maintained a subatmospheric pressure of 100–125 mmHg. The dressing changes were made after 72 h, and during each dressing change, the wound was inspected and evaluated for reduction in its size, the amount and quality of granulation tissue, and its microbiology.

When the wound was found healthy, appropriate skin/soft tissue cover was provided keeping in view the reconstructive requirements. After wound healing, patients were evaluated by FAASS in terms of impairment (FASS-I).⁵ The patients were then suitably rehabilitated at the artificial limb centre (ALC), Pune by shoe modifications, orthosis, and custom-made prosthesis. At final follow-up, functional outcome was

Fig. 1 – Foot defects.

assessed in terms of their fitness to return to active military duty.

Results

The results have been summarized in Table 1. The anatomical location of foot injury is shown in Table 2 and the type of foot defects is depicted in Fig. 1. The NPWT helped in temporary wound closure and prevented local and systemic infection. It promoted robust granulation and wound could readily be covered with simple reconstructive procedures like split skin grafting (SSG). However, in weight-bearing regions of foot and stumps that required prosthesis, full-thickness cover in form of fasciocutaneous flap or muscle flaps was necessary (Figs. 2 and 3). SSG at the stump was found unstable despite adequate granulation requiring stump revision (Fig. 4). In all patients who presented to us with complex mine blast injuries, below-knee amputation could be avoided while adhering to the protocol of repeated wound debridement, NPWT, and delayed definitive reconstruction, thus enabling us to achieve limited plantigrade ambulation and normal ambulation after prosthetic rehabilitation (Fig. 5). Mean FAASS was 3.76 (range 3–5) and mean FAASS-I was 4.11 (range 3–6). Mean time to definitive reconstructive procedure was 16.5 days (range 10–21). Most common complication seen was breakdown of scar at the flap and SSG interface, which healed conservatively. All soldiers could be rehabilitated and were returned to their respective units and were able to perform sedentary duties assigned to them. However, none of them was found fit for active military duty in the follow-up period.

Discussion

Anti-personnel mines are small explosive devices that are laid under the ground and are activated either by pressure or by a trip wire. They are designed to inflict damage to the soldier ending his role as a combatant. Injuries resulting from mine blasts are due to pressure waves entering limb, penetrating injuries from splinters of mines, soil, stones, and foot wear. There is extensive osseous and soft tissue destruction at the

Table 1 – Result summary.

S. no	Age	Side	Defect	FASS-s	Debridements	NPWT changes	Microbiology of wound	Reconstruction undertaken	FASS-I	Additional injuries	Rehabilitation
1	24	Left	Posterior composite foot defect with heel pad loss	4	02	04	Nil	Extended RSA	4	Nil	Prosthesis
2	25	Right	Transtarsal amputation with preserved heel	4	03	05	Nil	Extended RSA	5	Nil	Prosthesis
3	34	Left	Lateral composite tissue loss with preserved heel and medial foot	3	03	06	Nil	SSG	3	Nil	Orthosis
4	30	Left	Medial composite foot defect	3	03	05	Nil	Extended RSA	3	Nil	Shoe modification
5	24	Left	Posterior composite foot defect with heel loss	4	02	05	Enterococcus	RSA	4	Nil	Prosthesis
6	29	Right	Posterior composite foot defect with heel loss	4	03	05	Nil	RSA	4	Nil	Prosthesis
7	34	Bilateral	Medial soft tissue foot loss (right) with below-knee amputation left	3 (R) 6 (L)	02	04	Nil	SSG	6	Splinter injury left gluteal region	Below-knee Prosthesis left
8	24	Left	Posterior composite foot defect with heel loss	4	02	05	Mixed growth	RSA	4	Nil	Prosthesis
9	37	Right	Amputation through metatarsophalangeal joint	4	03	04	Nil	SSG	5	Nil	Orthosis
10	32	Right	Transtarsal amputation with preserved heel	4	03	05	Nil	RSA	4	Nil	Prosthesis
11	26	Left	Transtarsal amputation with preserved heel	4	02	06	Nil	SSG	5	Nil	Revision Syme's amputation and Prosthesis
12	34	Right	Transtarsal amputation with preserved heel	4	03	05	Nil	Free gracilis flap cover	4	Nil	Prosthesis
13	35	Right	Medial composite foot defect	3	02	05	Nil	Free gracilis flap cover	3	Multiple splinter injuries in leg and thigh	Shoe modification
14	33	Left	Forefoot transtarsal amputation 1-3rd toes	3	03	05	Nil	SSG	3	Nil	Shoe modification
15	28	Right	Transtarsal amputation with preserved heel	5	03	03	Nil	Free gracilis flap cover	5	Eye injury not causing visual defect	Prosthesis
16	28	Right	Posterior composite defect with heel loss	4	03	05	Pseudomonas aeruginosa	RSA	4	Nil	Prosthesis
17	38	Left	Lateral composite foot defect with preserved heel	4	03	05	Nil	SSG	4	Nil	Orthosis

Fig. 2 – (a)–(e) Mine blast injury resulting in composite foot defect on medial aspect of foot. After wound debridement, negative pressure wound therapy, and reconstruction of defect with extended reverse sural artery flap.

Table 2 – Anatomical location of defect.

Anatomical location	Number
Forefoot	1
Midfoot	5
Hindfoot	5
Combined	6

contact point, which may result in traumatic amputation at variable level.⁷

The anatomical damage to the foot depends upon its contact with the land mine and may affect any region of the

foot. Hindfoot and heel may be affected in majority of such injuries leading to complex defects. These are associated with high degree of contamination with foreign bodies including soil, clothing, and microorganism.⁸ The blast effect causes severe periosteal stripping from bones and opening of fascial planes proximal to the site of injury. Fractures of long bones may occur occasionally and injuries to other anatomical sites are also a possibility.

Management of mine blast injuries remains a challenge and there is no documentation of standard guidelines. However, an aggressive approach in their management

Fig. 3 – (a)–(e) Mine blast injury resulting in transtarsal foot amputation with preserved heel. After wound debridement, negative pressure wound therapy, and reconstruction of stump with free gracilis flap, and soldier with limited plantigrade ambulation without prosthesis.

Fig. 4 – (a)–(f) Mine blast injury resulting in transtarsal amputation. After wound debridement, negative pressure wound therapy, and wound cover with split skin grafting.

Fig. 5 – (a)–(f) Mine blast injury with posterior heel defect. After debridement, negative pressure wound therapy, reconstruction with reverse sural artery flap, and ambulation with custom-made prosthesis.

improves the functional outcomes. Basic principles of combat wound management applies to these injuries as well.

Wound debridement is the key for a successful outcome in such injuries. Early removal of nonviable tissue, foreign body, soil, and splinters with wound irrigation prevents local and systemic infection. It may be necessary to do repeat wound debridements until wound is found to be devoid of devitalized tissue.⁹ Mean number of debridements in our patients was 2.64 before application of NPWT. Celikoz et al. in their study of 215 patients with high-energy wounds, which included gunshots, landmines, and missile injuries, have reported the mean number of debridements as 1.9.¹⁰ Our figure of mean debridement was higher, as the cases that we managed were only due to landmine explosion.

Traditionally, post-wound debridement, the wound was managed with daily wound dressing followed by definitive wound closure.¹¹ The disadvantages of this form of therapy are

well recognized. The usefulness of NPWT was clearly seen in civilian traumatic and nontraumatic wounds.^{12,13} The use of NPWT in war wounds was first described by Burris et al. in 2004, which was found to be helpful in healing of war wounds of varied etiology.¹⁴ NPWT was widely used in the management of combat wounds during Operation Iraqi Freedom and Operation Endurance Freedom in 2003, with more than 90% of casualties requiring this form of therapy by September 2003.^{3,15} There are several advantages of NPWT, which include reduced frequency of wound dressings as compared to conventional dressings, faster wound closure rates, and reduced local and systemic infection rates.^{16,17} Leininger et al. reported 0% infection rate in their study of 88 high-energy soft tissue wounds, as compared to 80% infection rate before the introduction of NPWT in their protocol.¹⁵ Similar reduction in the infection rates was noted by Helgeson et al. in which the delayed reconstruction of combat wounds was

undertaken after an average duration of 46 days, which they attributed to NPWT.¹⁸ We did not find the mention of infection rates in mine blast injuries treated with NPWT in literature and we assume that there will be similar rates in combat wounds as well. In this study, surface microbiology was positive in 3 patients, which was not significant clinically, and none of our patients showed features of local or systemic infection. Therefore, antibiotics were discontinued after 5 days, which was an added advantage.

All these advantages can be attributed to the mechanism of action of NPWT. The NPWT system consists of 4 components: (i) sponge or foam commonly called as ROCF, which is placed directly over the wound forming a foam–wound interface; (ii) opsite airtight dressing; (iii) a negative pressure-generating device, which can generate a variable subatmospheric pressure and (iv) tubing to connect device with foam. The wound healing achieved with NPWT is multifactorial, which includes wound contraction due to macrodeformation leading to reduction in the wound size mainly due to centripetal forces exerted on the wound.¹⁹ Mechanical forces generated due to negative pressure cause microdeformation at the cytoskeleton level. This promotes cellular proliferation leading to increased fibroblasts and epithelial and endothelial migration.^{20,21} This is responsible for the formation of healthy granulation tissue on the wound. Therefore, NPWT creates an atmosphere in the wound that becomes conducive for early definitive reconstruction.

The defect before final reconstruction is defined and there are a number of classifications to define the foot defects. Pompeo et al. in their recently published article proposed a classification based on complex foot defects of traumatic and nontraumatic etiology.²² However, we classified foot defects based on classification by Hidalgo et al., which was based on traumatic etiology.⁶ Majority of our patients had type II defect (64.7%) indicating major soft tissue loss with amputation. Only one patient had type I defect, implying that limited soft tissue injury due to mine blast was uncommon. We did not find any classification of foot defects due to mine blast injury in literature. On analyzing the FASS score, the mean score in our patients was found to be 3.76, which was suggestive of moderate to severe injury. Ramaswamy et al. also reported the FASS score of 4 or more than 4 in 70% of patients with IED blast injuries indicating substantial injury.²³

Reconstruction of foot defects is challenging as the reconstructive surgeon has to decide if salvaging the foot will help the patient with a satisfactory weight-bearing ambulation or an amputation will be a better option. With NPWT, it was possible for us to preserve the remaining subunit of the foot allowing limited plantigrade ambulation without prosthesis. This was psychologically encouraging for the patient. Demiralp et al. have compared amputation versus functional reconstruction of foot injuries due to land mine explosions. The reconstruction group had significantly higher Body Image Quality of Life Inventory as compared to the amputation group.⁸ They also reported that in the reconstruction group, with proper orthosis and shoe modification, none of the group members required late amputation on long-term follow-up. We, therefore, believe that if foot salvage is feasible, the foot should be preserved and defect be reconstructed appropriately.

Functional reconstruction is important in foot defects and whenever possible simpler reconstruction option should be chosen. Major determinants are the size and anatomical site of defect along with or without bony loss and sensibility. Nonweight-bearing region of foot can be reconstructed with SSG after NPWT. The granulation tissue and the reduction in the size of the defect due to NPWT are helpful in achieving satisfactory outcomes. The other reconstructive options for foot defects due to mine blast include regional fasciocutaneous flaps and microvascular free flaps. In our series, extended reverse sural artery flap for reconstruction was used in 8 patients and microvascular free gracilis flap was used in 3 patients. Ozturk et al. reported satisfactory long-term results with heel defects caused due to landmine explosions, which were reconstructed with free muscle flaps. They preferred shoe modifications and orthosis to correct load distribution in the reconstructed foot.²⁴ Similar outcomes were reported by Selmanpakoglu et al. in which the foot defects were reconstructed with free microvascular muscle flaps.²⁵ Our approach was similar and we used either regional fasciocutaneous flap or microvascular free muscle flap to reconstruct the foot defects and rehabilitate these soldiers with shoe modification and orthosis to correct load distribution. However, in patients with loss of midfoot and forefoot, the remaining stump was reconstructed appropriately with a flap after NPWT and was fitted with custom-made prosthesis for their normal ambulation. Such patients were able to use the remaining foot for limited ambulation while staying indoors.

Complications due to NPWT are uncommon in combat-related wounds, and most complications in form of bleeding and infection have been reported in nontraumatic wounds treated by NPWT.²⁶ We did not find any complications related to NPWT. However, the most common complication related to reconstruction was breakdown of scar at the interface of flap and SSG, which healed with conservative measures. This may not be true in long term, as our maximum follow-up period was 19 months only.

Overall functional results for foot injuries can be evaluated using FASS-I, which is related to the degree of impairment. In our series, the mean FASS-I was 4.11, indicating severe impairment in foot functions, and with the limited follow-up period of 19 months, none of the patients were fit for active military duties. Ramaswamy et al., when analyzing the functional outcomes after a mean period of 33.3 months in soldiers with IED foot and ankle blast injuries, reported that only 14% were able to return to preinjury level and 65% were fit for only sedentary duties.²³

Conclusion

Mine blast injuries often result in complex foot defects and amputations. There are no standard protocols in their management and each case has to be assessed and planned specifically. The key to successful outcome is repeated wound debridements and prevention of infection. The NPWT was helpful in reconstruction of foot defects and in achieving satisfactory functional outcomes. With good orthosis, shoe modifications, and prosthetic rehabilitation in these patients, early results are encouraging. We strongly recommend the use

of NPWT in the management of mine blast injuries and other combat-related wounds.

Conflicts of interest

The authors have none to declare.

Acknowledgment

We acknowledge the role of Artificial Limb Centre, Pune for Prosthetic Rehabilitation of these soldiers.

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