

Review Article

Reconstructive challenges in war wounds

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ABSTRACT

War wounds are devastating with extensive soft tissue and osseous destruction and heavy contamination. War casualties generally reach the reconstructive surgery centre after a delayed period due to additional injuries to the vital organs. This delay in their transfer to a tertiary care centre is responsible for progressive deterioration in wound conditions. In the prevailing circumstances, a majority of war wounds undergo delayed reconstruction, after a series of debridements. In the recent military conflicts, hydrosurgery jet debridement and negative pressure wound therapy have been successfully used in the preparation of war wounds. In war injuries, due to a heavy casualty load, a faster and reliable method of reconstruction is aimed at. Pedicle flaps in extremities provide rapid and reliable cover in extremity wounds. Large complex defects can be reconstructed using microvascular free flaps in a single stage. This article highlights the peculiarities and the challenges encountered in the reconstruction of these ghastly wounds.

KEY WORDS

Delayed reconstruction, reconstructive challenges, war wound, wound debridement

INTRODUCTION

Wounds inflicted in war are devastating and more complex than those encountered in civilian practice. High velocity missiles not only produce extensive soft tissue and osseous destruction, but also lead to heavy contamination of the wounds with possible vascular and neural damage.^[1,2] The introduction of gun powder in the 14th century dramatically changed the nature of battlefield injuries. Conventionally, war wounds have been managed by an early debridement and delayed primary closure.^[3,4] Current concepts in

the management of war wounds have evolved over experiences gained during numerous wars fought all over the world. In the pre antibiotic era, Ambrose Pare in 1536 used makeshift dressings made of egg yolk, oils and turpentine in the treatment of war wounds. Introduction of an effective debridement in World War I reduced the amputation rate by preventing the wound infection and gangrene. Continued advances in weapon technology have resulted in wounds with more extensive composite tissue losses, where reconstruction is challenging and often a multistage procedure. An understanding of the pathophysiology of war wounds is important towards achieving an optimal reconstruction.

HOW ARE WAR WOUNDS DIFFERENT?

Military medicine in combat zone differs from civil medicine practice in number of respects. The war wounds are heavily contaminated with dust, soil, clothing and other foreign

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bodies. Blast wounds are characterised by extensive composite tissue damage with large areas of devitalised tissue and significant foreign body loading.^[5] Due to combat situations, the casualties reach late beyond the golden period to the surgical team. The combat hospitals are overwhelmed by the number of casualties during the lull period of war and therefore the triage becomes a necessity. The aim of triage is to provide optimum care to maximum number of casualties. War wounds are often associated with concomitant injuries to other organs and management of life threatening injuries to the vital organs takes priority over the management of soft tissue losses. Also, evacuation of casualties to a tertiary care centre may be delayed by several days to weeks. These factors are responsible for deterioration in wound conditions. Reconstruction of these wounds therefore becomes a challenging problem.

WAR WOUNDS BALLISTICS AND EPIDEMIOLOGY

War wounds result due to the absorption of kinetic energy of the projectiles transferred to the tissues. The amount of damage to the tissues depends on the mass of projectile, its velocity, shape and the characteristics of penetrated tissues.^[6] The energy transfer to high density structure like bone is much more and hence it suffers the maximal damage. Modern weapons with high velocity projectiles (above 750 m/s) produce extensive tissue destruction during their course through the tissues. Explosive weapons (bombs, grenades, mines and improvised explosive devices) produce extensive composite tissue damage due to blast effect, which are shown in Table 1.

Extremity wounds are most common, accounting for 70 to 75% of war wounds.^[7] Other regions commonly involved are head and neck, chest and abdomen.^[8] Weapons which commonly cause such injuries are shown in Table 2.

Table 1: Types of blast injuries

<i>Type of blast injury</i>	<i>Causative factor</i>
Primary blast injury	Direct effect of blast
Secondary blast injury	Flying objects due to blasts
Tertiary blast injury	Displacement of body as a whole
Quaternary blast injury	Other effects of blasts, burns, chemical contamination

Table 2: Nature of injuries due to war weapons

<i>Weapons</i>	<i>Nature of injury</i>
High velocity bullet missiles	Wound of entry is small, where as exit wound is large. Injuries to the bones, vessels and nerves may occur
Bombs, Grenades, Mortars	Primary blast wave may cause rupture of ear drums, visceral rupture or lung haemorrhage Secondary blast injuries- Penetrating injuries to soft tissue and bone
Anti-personnel mines	Traumatic amputations. Mangled extremities, extensive contamination of wounds

COMBAT CASUALTY CARE

In order to understand the reconstructive challenges, it is important to visualise the combat casualty care. The wounded combatant is evacuated from forward battle field areas to the rear echelons of medical care. The forward surgical team is located within the fighting formation to perform life and limb saving surgery. It is situated at a place where evacuation is possible and first surgical intervention can be undertaken within the golden period. The evacuation from these centres to tertiary care centre for definitive surgery is done if tactical situation permits and casualty is haemodynamically stable.

PRINCIPLES IN WAR WOUND MANAGEMENT

Since war wounds are different as compared to the injuries sustained in civilian trauma, it is pertinent to adhere to certain principles in the management of war wounds. The basic principles in war wound management are-

- Debridement
- Staged intervention
- Wound closure and reconstruction

Debridement

The term 'debridement' was used by French surgeons in late 18th century which consisted of incision of skin and deep fascia to release the swelling associated with missile injuries. At that time, extremity war wounds were managed non-operatively or by amputation.^[9] During World War I, the debridement was redefined and the term was used to denote excision of all nonviable tissue and foreign body. The debridement has been classified into incomplete, marginal, complete or radical.^[10] Both marginal and complete debridements are practiced in war wounds; however, as far as possible, complete debridement should be preferred to optimise the limited resources in the war time.^[11] Initial wound debridement should be done as early as possible. Jackson noted 10% rate of infection in wounds debrided within six hours of injury, which increased to 25% in those debrided beyond six hours.^[12] Meticulous technique of debridement is vital

for a successful outcome in war wounds. All dead and devitalised tissue should be excised and bleeding should be controlled by bipolar cautery. In extremities, pneumatic tourniquet improves visualisation of operative field and limits blood loss in a haemodynamically unstable patient. While debriding the muscles, colour, contractility, consistency and bleeding should be used together as guidelines to ascertain their viability. In landmine blast injuries of the limbs, each muscle with its epimysium should be exposed to remove the contamination from the deeper planes. All loose bone fragments without any tissue attachments should be excised. Wound should then be irrigated with warm saline. Recently, hydrosurgery jet system has been introduced in the removal of all particles and foreign bodies from the deep tissue planes.^[13] Once the end point of debridement has been reached, the wound should be covered with sterile dressings secured with sterile bandages. Heavily contaminated and infected wounds may need serial debridements before final closure is planned.

Staged intervention

The current literature in the management of civilian trauma indicates that early wound cover provides better outcome than delayed reconstruction. However, most of the extremity war wounds have been reconstructed after a delay of 4 to 5 days.^[14-15] This is due to a delay in evacuation to the tertiary care centre, associated multiple injuries, large zone of injuries requiring multiple debridements and evidence of wound infection at the time of presentation to reconstructive surgery centre. At each echelons of casualty care, staged intervention becomes necessary to prevent wound complications. Transportation and evacuation of casualties is performed by road or air depending upon the tactical situation. Faster evacuation and early definitive management have resulted in better functional outcomes.

Biomarkers in war wounds

There have been recent advances in objectively ascertaining the outcomes of war wounds. The use of biomarkers has been helpful in predicting the timing of wound closure. Forsberg *et al.*^[16] first reported that elevated serum and effluent procalcitonin (Pro CT) measured at the time of wound closure correlated later with wound dehiscence. No wound failed with an effluent ProCT concentration of greater than 220 micrograms/ml, IL-13 concentration of greater than 12 pg/ml or normal T expressed and secreted (RANTES) of > 1 000 pg/ml. They concluded that effluent ProCT, IL-13, RANTES

protein levels and serum ProCT levels correlated well with the wound dehiscence rate following closure of open extremity wounds. Similarly, Hawksworth *et al.*^[17] analysed serum and wound effluent cytokines, chemokines and wound tissue for corresponding gene transcript expression patterns. They concluded that these biomarkers demonstrated a condition of inflammatory dysregulation and are associated with wound failure rates. Hence, these biomarkers may have an objective role in determining the timing of traumatic wound closure and thereby reducing the number of surgical procedures.

Wound closure and reconstruction

Satisfactory wound closure can be achieved with meticulous planning and execution of principles of reconstruction. Reconstructive surgeon therefore plays a key role in the management of these patients.

Reconstruction in war wounds: The role of plastic surgeon

Reconstruction in war wounds is challenging and begins at the forward echelon of medical care in the theatre of war. Aggressive care in the forward area and speedy air evacuation enable the casualty to reach the reconstructive surgery centre for timely intervention. Missile and blast injuries introduce foreign debris into the depths of tissues and hence most of the war wounds are heavily contaminated and serve as good culture medium for the proliferation of invasive organisms, both aerobic and anaerobic. Murray *et al.*^[18] found 93% Gram positive infection in war wounds with predominant organism being coagulase negative staphylococcus. However, there has been an emergence of multidrug resistance *Acinetobacter* species in recent military conflicts.^[19] Most of these organisms were sensitive to carbapenem group of antibiotics.

In war wounds, initial debridement is often inadequate, and therefore a primary reconstruction is associated with high failure rate. The arrival of casualty to a reconstructive surgery centre may be delayed by several days to weeks. Several factors are responsible for this - heavy casualty load, unfavourable weather conditions, poor general condition of the patient and vital organ injuries, make long distance transfers a risky affair. Concomitant injuries to head and neck, chest and abdomen take priority in their management and hence wound cover may be delayed. A flap cover in the subacute period is associated with high complication rate.^[20] High velocity missile injuries often produce extensive damage over the body surface. Hence,

reconstruction using local or regional flaps becomes a risky affair. In a war time, the reconstruction can be achieved in three different time zones-

- Early or primary reconstruction,
- Delayed or secondary reconstruction, or
- Late reconstruction

Early or primary reconstruction

Early reconstruction will be mandatory in conditions, which after wound debridement, leave vital structures like brain, lungs or repaired vessels, exposed. Immediate closure of such wounds cannot be overemphasised. High energy transfers cause tissue loss and this requires additional tissue to be brought into the defect. Cranio-cerebral defects arising out of missile injuries require early cover to prevent brain infection. When available, scalp rotation or transposition flaps are rapid and simplest way to cover the defect. When elevated with galea scalp, flaps can be left directly over the brain without duraplasty.^[21] Large maxillofacial defects with paucity of local tissues invariably require microvascular free flap reconstruction. Facial lacerations, following debridement, can be closed primarily [Figures 1 and 2]. Similarly, large facial defects are amenable to primary flap coverage. Major chest wall defects with exposed underlying lungs also require urgent reconstruction. Pedicled latissimus dorsi flap is simplest and faster method to seal off the pleural cavity. Defects

in limbs with vascular injuries not only require vascular repair but also immediate cover to protect the vascular repair. Local muscle flaps or myocutaneous flaps provide rapid cover of such defects. Segmental loss of vessels along with tissue requires microvascular reconstruction. Such defects can be reconstructed with flow through flaps.

Delayed reconstruction or secondary reconstruction

Most war wounds fall in this time zone of reconstruction [Figures 3-5]. The extremity injury are the most common war injuries and account for majority of work load in a combat hospital. Hemodynamic stability and wound conditions are the two most important factors which guide the timing of reconstruction. Gustilo and Anderson classification helps in predicting the severity of extremity injuries.^[22] Pedicled flaps in the extremities [Figures 6-8] provide rapid and reliable cover in extremity wounds.^[23] They are easy to raise and do not require microvascular expertise. The choice of flaps will depend upon the location of defect, size of defect and the zone of trauma. The choices of various pedicled flaps in extremities are given in Table 3.

The optimum timing for reconstruction in war wounds is generally considered 4-5 days after the final debridement. This is associated with low complication rate, shorter

Table 3: Pedicled flaps in extremity reconstruction

<i>Extremity</i>	<i>Site of defect</i>	<i>Pedicled flap</i>
Upper	Proximal defect	Latissimus dorsi
	Middle and elbow	Latissimus dorsi, staged chest flap,
	Forearm and Hand	Abdominal flap, groin flap, Reverse radial forearm, posterior interosseous flap
Lower	Proximal thigh	Rectus abdominis, pedicled anterolateral thigh flap
	Upper and middle leg	Gastrocnemius, soleus
	Lower leg and ankle	Distally based sural flap



Figure 1: Blast injury face



Figure 2: Healing with primary repair



Figure 3: Mutilating injury to external genitalia following blast injury



Figure 4: Following debridement



Figure 5: Normal functions after delayed skin cover



Figure 6: Gunshot wound upper end tibia



Figure 7: Gastrocnemius muscle flap raised



Figure 8: After healing of muscle flap

hospital stay and early recovery.^[24] However, recent experiences gained in the Iraq conflict suggest that war wounds of the extremities can be reconstructed in subacute period between 7 days and 3 months with low

flap failure rate and infection rates.^[25,26] While planning reconstruction in war wounds, where multiple injuries are common, the simplest and the least complicated solution should be preferred.



Figure 9: Gunshot wound chest (Wound of entry)



Figure 10: Gunshot wound chest (Exit wound)



Figure 11: NPWT dressing on wound of entry



Figure 12: NPWT dressing on exit wound



Figure 13: Healing of entry wound with NPWT in 10 weeks



Figure 14: Healing of exit wound with NPWT in 10 weeks

Role of negative pressure wound therapy in war wounds

In 1997, Argenta and Morykwas^[27] reported their clinical experience with the use of negative pressure

therapy in wounds. This became an accepted modality in management of wounds in civilian trauma. Using this form of wound therapy, the lower extremity wounds could be covered in subacute period with low rate of

infection and flap failure. The use of Negative Pressure Wound Therapy (NPWT) in war wounds was first reported in 2004, and it represents a new approach in war wounds reconstruction. NPWT is indicated to stabilise the wound, reduce tissue oedema and prepare for final closure. This therapy, when used in 90% of extremity wounds, reduced the overall time period for wound closure.^[28] Some of the complex wounds can be successfully managed with the judicious use of NPWT alone [Figures 9-14]. The use of NPWT in theatre of operations and across the evacuation chain has been evaluated with promising results.^[28]

Microvascular reconstruction in war wounds

Microvascular tissue transfer has added a new dimension in the management of war wounds. Large complex defects of extremities can be reconstructed as one stage procedure. Geiger *et al.*^[29] report a success rate of



Figure 15: Grenade blast injury hand



Figure 16: Healing after anterolateral thigh flap cover

88.9% with free flaps in reconstruction of war wounds. Swartz and Mears^[30] have classified lower extremity wound defects based upon reconstructive requirements. This classification helps in planning the appropriate

reconstructive procedure. Bony defects of the lower limbs have been reconstructed using one stage osteocutaneous free flaps with reduced hospitalisation and an early recovery.^[31] However, Dzepina *et al.*^[32] observed a considerable difference in functional results and the complication rate following one stage reconstruction of war wounds, when compared with time of injury to definitive reconstruction. The final outcome was better with 75% of the patients achieving good functional results and a low complication rate in the primary reconstruction group. Contrary to this, only 50% of the patients achieved good functional results when reconstructed was delayed by several weeks. The flap failure rate was also higher in this group of patients.

The principles of microvascular free tissue transfer in war wounds are not different from civilian trauma. Muscle flaps are preferred over fasciocutaneous flaps to fill the large size defects and to combat the local infection. Today, the reconstructive surgeon with the help of microvascular techniques is able to reconstruct large complex defects as compared to an era before the advent of this technique. The free tissue transfer has increased the ability of reconstructive surgeons to restore functions of severely damaged limbs [Figures 15 and 16].

Late reconstruction

Late reconstruction involves the correction of deformities to improve the functional and aesthetic appearance in war wounded soldier. This may include reconstruction of post burn deformities, management of nerve injuries, tendon injuries, maxilla-facial reconstruction and reconstruction of amputated parts. The basic principles do not differ significantly from conventional reconstructive procedures.

CONCLUSION

War wounds are complex wounds and require a planned reconstruction. A battle casualty requires the best possible resources for an optimal outcome. A faster evacuation to a tertiary care centre, wound preparation by serial debridements, NPWT and timely reconstruction can save precious lives and reduce the morbidity. The overall reconstructive goal is to keep the soldiers 'fighting fit'.

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