Contemporary Approaches To Definitive Extremity Reconstruction Of Military Wounds.

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Introduction

The concept of 'the military wound' is not an easy entity to define as the wounds seen in conflict can be of many types: those caused by recognised or improvised weapon systems may have similarities to civilian wounds as well as the wounds soldiers sustain outside of battle. This paper will focus on the current treatment approaches to wounds sustained by deployed UK Armed Forces Personnel and caused by a weapon system.

Since 2001, the majority of military wounds sustained by UK Armed Forces Personnel have been caused during conflicts in Iraq and Afghanistan. During this time, there have been evolutions in the conduct of the conflicts and modifications to medical care. These have led to a change in the types and severity of injuries now requiring reconstruction.

Explosive devices used against coalition forces are increasingly popular owing to their low cost, ease of construction, magnitude of devastation and their ability to be detonated remotely with little or no risk to the perpetrator. Use of such devices has been shown to produce a higher proportion of extremity injuries than seen in previous conflicts fought with conventional firearms [1]. Explosive munitions were the mechanism of injury in 75% of wounds sustained by 1281 US service personnel in Operations Iraqi Freedom (OIF) and Enduring Freedom (OEF) between October 2001 and January 2005. Only 16% of wounds were gunshot injuries [2]. Of 68 Navy and Marine Corps casualties treated at the Naval Medical Centre, San Diego between April 2003 and December 2005, Improvised Explosive Devices (IEDs) were responsible for 55% of wounds treated [3]. 54% of casualties presenting to a British Field Hospital in Iraq between January and October 2006 had sustained injury secondary to improvised explosive devices, representing the most common mechanism [4].

In response to this changing threat, there have been rapid adaptations of Personal Protective Equipment and in design and armouring of vehicles. This has led to a reduction in the proportion of casualties sustaining fatal torso or head penetration.

The effects of blast have been fully described [5-7] and the resultant injury patterns are well recognised (Figure 1). These are predominantly traumatic amputations with extensive bony fractures and soft tissue disruption associated with heavy contamination. The limbs are most commonly involved, extremity injury being found in 67.8% of casualties seen at a British Field Hospital in Iraq during the first ten months of 2006 [4]. Geiger et al found that extremity injuries accounted for 91.2% of injuries in OIF 1 and 2 [3].

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Figure 1. Extremity injury as a result of close proximity to explosive device

There have also been changes in medical care, such as formalised training for all troops in controlling massive external haemorrhage, increasing the medical skill-set in the evacuation chain, early interventions in managing coagulopathy and a growing corporate knowledge in the Surgical Teams as a result of high casualty flow rates. This is reflected by the increase in numbers of survivors with high injury severity scores.

All these factors have led to a large number of casualties surviving severe injuries with massive extremity tissue loss affecting multiple limbs (Figure 2). Current doctrine of repatriating all serious injuries back to UK has meant the UK designated Role 4 hospital has been presented with a large burden of cases requiring complex definitive reconstruction.

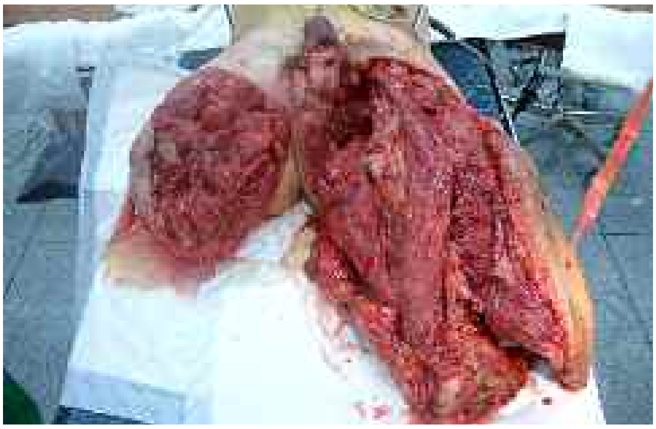

Figure 2. The devastating extent of extremity war injuries seen in the modern-era

Current Role 4 Practice

The multidisciplinary approach to wound management

The multiply injured soldier has multiple contaminated wounds, is systemically unwell, immunocompromised following massive blood transfusion and requires multi-system support in a critical care environment. Care needs to be multidisciplinary with input from anaesthetists, multiple surgical disciplines as well as therapists, dieticians and the acute pain team. Soldiers prior to injury will often have been involved in high intensity work, away from regular high calorie meals and ready access to fresh fruit and vegetables. Consequently they may be nutritionally compromised from the outset. Their nutritional requirements are great and they are subject to regular planned starvation for surgical procedures. Very close attention needs to be paid to feeding. Optimal nutritional status maximises wound healing. It is our practice that soldiers are weighed on arrival and early nutritional support commenced for all but minor wounds. If possible this should be in the form of enteral feeding to minimise bacterial translocation and development of sepsis. Nasojejunal feeding as opposed to nasogastric feeding is preferred as this negates the need to stop feeding each time the patients requires operative intervention. The role of how Injury Severity Scores may be used to predict the need for early nutritional support is currently being investigated.

Pain management has been a significant issue in the holistic management of these injured soldiers. High levels of analgesia have been required, even for perceived minor procedures such as removal of staples at dressing changes. The effects of pain are not to be underestimated and are not conducive to wound healing. Inadequate analgesia only serves to produces a patient who is uncomfortable, irritable and primed to expect agony at every intervention. This quickly causes a breakdown of trust between patient and carers and uncooperativeness, which is not helpful in the overall aim of achieving wound healing and a return to function. Adequate analgesia is particularly important during transportation and soldiers are increasingly arriving with continuous regional infusion analgesia. This has proven to be very effective and can often be maintained for many days. It is essential that a thorough neurological assessment be made of involved limbs prior to the commencement of regional anaesthesia. Increasing requirements for analgesia may be due to dislodgement of the catheter or due to the development of compartment syndrome.

Photographing Wounds

The documentation of wounds is best served by digital photography with appropriate consent. It can show the pattern of injury, the complexity of wounds and degree of contamination. Photography avoids unnecessary disturbance of dressings by subsequent receiving medical teams and can be sent ahead of the patient to help in forward planning of resources required for appropriate management. It can aid classification of wounds and retrospective analysis of injuries, which plays a vital part in being able to assess management and facilitate ongoing development of best practice. The frequent return visits to the Operating Theatre means it is impossible for the same Surgical Team to always perform all procedures for any given patient. Photographic documentation of the wounds at each visit is a vital aide for continuity of care.

Microbiology of military wounds

Injuries sustained through explosive mechanisms often have contamination that is driven deep between tissue planes. With the emergence of resistant organisms, control of this contamination and subsequent infection is challenging. One study has suggested that wound contamination at the time of injury within military theatres of operation is typically caused by gram-positive bacteria with no gram-negative resistant bacteria [9]. In contrast between September 2004 to February 2007, 46 lower extremity flap reconstructions were performed on 43 patients from Operation Iraqi Freedom at the National Naval Medical Centre, Bethesda, California. Cultures on admission to Role V were positive in half of cases, of which 57% were positive with Acinetobacter species [10]. Acinetobacter is a gram-negative bacillus commonly found in soil and was the most common bacteria found in Vietnam conflict injuries. It is the most prevalent wound pathogen in the current conflicts and is frequently multi-drug resistant. Whether or not wound swabs should be taken at first presentation or at first debridement is not clear. Patakis et al. suggested that those taken at this early stage were of little use as they often failed to identify the organisms that subsequently caused infection [11-12]. More recently in one civilian report of extremity injuries, 119 out of 225 patients had positive cultures of which only 8% of pre-debridement cultures identified the causes of subsequent infections [13]. The use of broad-spectrum antibiotics early in the course of treatment may well lead to the emergence of more drug-resistant organisms. Of 68 patients treated at the Naval Medical Centre, San Diego between April 2003 and December 2005, 21 had received a 1-10 day course of antibiotics, 10 had received a full 10-day course and 37 had not been started on antibiotics prior to admission in their course of repatriation. Of these 37 patients, 81% had positive wound cultures at admission and 20 of these patients had previously undergone 2-5 serial debridements at the US medical facility in Ramstein Germany. Despite a 22% incidence of acute osteomyelitis, they reported only one case of eventual chronic osteomyelitis after a regimen involving the use of broad-spectrum antibiotics, antibiotic-impregnated beads for bone defects, negative pressure therapy and flap reconstruction [3]. Murray et al. suggest that if wound surveillance cultures at Role IV/V medical care are taken as part of infection control, their findings should have no bearing on clinical decision-making. Only cultures taken because of concern for an ongoing wound infection, such as systemic signs or symptoms of infection, persistently raised inflammatory markers or radiographic changes suggestive of infection, should be used to influence management [14]. In our experience Meticillin-Resistant Staphylococcal Aureus (MRSA) and Acinetobacter infection do not compromise wound healing directly, but have indirect effects by causing the patients to be isolated. Current policy is for patients to receive intravenous Co-amoxiclav as soon after wounding as possible. At the first wound inspection on arrival at Role 4 wound cultures are taken and plated the same day. In contrast to Acinetobacter and MRSA, fungal infection has played a significant detrimental role on wound healing and reconstruction. Live muscle specimens should be sent for fungal analysis.

Wound debridement

Wound debridement is the fundamental stage in wound management and significantly influences the final result. This is often only achieved in the heavily contaminated wounds of military injuries after several stages. The initial debridement may be performed within the limitations of 'Damage Control Surgery.' It should be thorough but not excessive. The debridement classification described by Granick & Chehade [15] is a useful concept. It is based on a view that tissue injury is similar to the Jackson burn wound model [16]. Within the centre of the wound most exposed to insult is an area of necrosed tissue, surrounded by an area of injured and marginal, but alive tissue. Surrounding this is healthy tissue. Based on these zones Granick and Chehade classified wounds according to the level of debridement into: non-debrided wound (0), incomplete (1), marginal (2), complete (3) and radical (4). Incomplete debridement describes a wound in which not all of the necrotic material has been removed. This level of debridement is to be avoided, as retained necrotic material will serve as a nidus for infection. Marginal debridement implies that all necrotic tissue has been removed but injured and potentially viable tissue is retained. This is the most appropriate level of debridement at the initial procedure, as removal of potentially viable tissue at this stage may unnecessarily create a larger wound and need more complex reconstruction. Complete debridement removes both necrosed and marginal tissue and radical debridement includes some normal tissue within the field of excision. Debridement should be performed with the use of a tourniquet where possible. Large, complex wounds as seen in the military patient are irregular and contain numerous pockets into which foreign contaminated material may be forced deep between tissues. Without tourniquet control these areas are quickly obscured with blood such that effective excision of necrotic and contaminated tissue is difficult to achieve [17]. Furthermore blood loss can be significant in an already compromised patient. In proximal wounds, the surgeon can apply a sterile disposable tourniquet once the skin has been prepped. Bleeding from tissues is a poor indicator of potential viability so, in experienced hands, use of a tourniquet does not alter decision making in debridement.

It has become perceived wisdom that initial debridement should be performed within 6-8 hours of wounding, though there is little reliable data supporting this. It was recommended in the landmark paper by Gustillo and Anderson in 1976 describing the prevention of infection after 1,025 open fractures, but the statement is unreferenced [18]. The suggestion is that this was based largely on the pre-antibiotic war experience, animal data, and an inappropriate extrapolation of basic science data on bacterial doubling times [19]. In Pollak's review of the timing of initial debridement, he states that mandatory debridement within 6 hours is minimally supported in the literature and that in most studies, including the report published by the LEAP (Lower Extremity Assessment Program) study group on 315 patients with limb-threatening open lower extremity fractures, it was not found to be a predictive indicator for subsequent wound infection. None of the studies, however, have looked at a military population and it is still the case that the initial debridement should be performed as soon as possible following injury. Once soldiers reach definitive care within the UK, reassessment is made of all wounds. It is our practice that this is done under general anaesthetic unless injuries are trivial. This can usually wait until next normal working hours unless the viability of a limb is in question, there is gross undebrided contamination or there is suspected sepsis. This assessment should be carried out by a combined team of senior Orthopaedic and Plastic Surgeons, so that a definitive plan for reconstruction of both bony and soft tissue injuries is made from the outset.

Debridement of wounds at this stage should be complete. This aspiration can be difficult to achieve; current treatment modalities can leave the traumatic wound with viable but tenuous soft tissues on the surface of the wound, laden with bacterial contamination. This is particularly the case with high-energy military wounds in which contamination is exploded deep into the tissues and driven far between tissue planes. It is impossible to completely sterilise these wounds. The notion that pulse-lavage may be able to dislodge contaminants by mechanical means has been questioned and recent investigations suggest that it may well drive contamination deeper [20]. We have found that sharp dissection under tourniquet control is best for removing all necrotic tissue and that the Versajet™ hydrosurgery dissection device (which by use of the Venturi effect, draws contamination away from the tissues) is an extremely useful adjunct in ensuring ingrained mud, dirt and sand as well as less obvious contaminants are thoroughly removed from the wound surface.

It is our continued experience, however, that residual deep seated pockets of contamination can be discovered even after several serial debridements. The use of X-ray image intensification is being considered to help identify occult particulate contamination.

Dressings and Topical Negative Pressure (TNP) therapy

Current doctrine is to employ dry fluffed gauze to the wound following initial debridement at the field hospital. This allows some absorption of exudate, and on removal, adherent exudate is lifted acting to further debride the wound surface. It is frequently observed, however, that the dressings seen following repatriation to the UK show heavy soiling and strike-through due to the excessive exudative nature of the wounds (Figure 3).

Figure 3. The typical appearance of dressings on arrival at the Royal Centre for Defence Medicine, Selly Oak Hospital – Heavy soiling and strike through due to the excessive exudate generated by military wounds

There is much experience of using topical negative pressure (TNP) dressings following initial debridement of large wounds in the UK civilian setting. This serves to effectively manage exudate and allow a sealed and clean dressing during repatriation. There are concerns however regarding its ability to maintain negative pressure during the aeromedical repatriation process and logistical challenges with administering its use in-flight. The VAC freedom® (KCI, San Antonio, TX) has been approved for aeromedical transport by the Air Mobility Command US Air Force in July 2006 and a clinical prospective study assessing feasibility of TNP dressings during aeromedical evacuation between Germany and the United States received approval in 2007 [21]. The possibility of utilising TNP during aeromedical evacuation to the UK is currently under investigation.

Following the initial debridement at Role 4, significant wounds that are not closed surgically are managed with TNP. This is in the form of gauze dressings connected to vacuum suction devices. TNP allows for clean and closed wound management. In addition by actively removing excessive tissue fluid and inflammatory mediators TNP can help minimise further tissue necrosis in viable but compromised tissues [22]. Reports of successful reconstruction in the sub-acute period in extremity war injuries [3, 10, 23] have involved the use of TNP following the first debridement at Role 5 and between subsequent operations prior to definitive wound closure [17,24], although numbers of patients are few and mid to long term follow-up is limited. This appears to reinforce the similar experience of using TNP in the management of open fractures in the civilian setting [25]. We have had success using gauze vacuum dressings in significant upper limb injuries, which require functional splinting to minimise contraction. The use of gauze vacuum dressings allows this to be achieved in a quick and easily manageable way (Figures 4 & 5).

The amount of exudate that can be removed from these wounds through TNP may well be in the order of 4-5 litres per day and therefore careful fluid balance management must take account of this and losses replaced appropriately. This fluid also contains protein, and this must be recognised when assessing nutritional requirements.

Figures 4 & 5: Difficult upper extremity wounds to dress can be managed well with safe and functional splinting using gauze-based Topical Negative Pressure (TNP) dressings

Soft tissue reconstruction

The principles of extremity reconstruction are to establish a clean and non-contaminated wound through adequate debridement of both soft and hard tissues, stabilization and rigid fixation of associated fractures and early soft tissue closure to deliver a useful and functional limb. The body of evidence within the civilian literature suggests that early soft tissue coverage of open fractures minimizes infective complications, flap loss and shortens times to bony union.

Civilian Experience

Byrd in the early 1980s undertook a prospective study of open Grade III tibial fractures in which patients were treated with either non-surgical wound management or more complex, early debridement and flap cover [24]. Flap cover was performed either within 6 days (acute phase), between 6 days and 6 weeks (subacute phase) or after 6 weeks post injury (chronic phase). The highest rate of wound complications and secondary amputations were seen in the non-surgical group and those reconstructed in the acute group experienced fewer infections, fewer hospitalizations and decreased time to union. Within the reconstructed group, the highest rate of complication (50%) was seen in the subacute phase. In a subsequent study Cierny et al. established similar results in a review of 36 open tibial fractures, 24 of which were treated with early soft tissue cover within 7 days and 12 after the initial 7 days. Average healing times were reportedly 4.0 months compared with 6.4 months and infective complications were 20.8% versus 83.3% when comparing those open fractures covered before the seventh day with those closed after this time [26]. The landmark paper of Godina in 1986 presented data on 532 patients who underwent soft tissue reconstruction for open extremity injuries [17]. Rates of infection, flap failure and time to bony union were stratified for wounds that had received flap reconstructions within the first 72 hours, 72 hours to 3 months and later than 3 months. Rates of infection were 1.5% in the early group, 17.5% in the delayed group and 6% in the late group. Flap failure was 0.75% in the early group, 12% in the delayed group and 9.5% in the late group. Bony union was achieved in 6.8 months in the early group, 12.3 months in the delayed group and 29 months in the late group. This data has been accused of bias however for a number of reasons. The first is that the author acknowledged that the flap failure rates decreased and that the percentage of early reconstructions increased progressively during the study period and therefore the effect of the learning curve cannot be accounted for. The second is that patients at the beginning of the study were transferred late and as the study progressed patients were either treated early at the definitive treatment centre or transferred early. Therefore improvement in outcome may well have been due to treatment, aside from flap coverage at the definitive treatment centre. Finally no attempt was made to account for differences in injury severity or patient co-morbidities. Many more studies have replicated similar findings, but fail to focus on the independent effect of timing of soft tissue cover on overall outcome and are subject to criticism regarding selection bias [27]. This is important when looking at the military population and the possible outcomes of delays in soft tissue reconstruction.

Differences in Military Patients

Many factors influence the opportunity for soft tissue coverage in the injured military patient. Firstly patients may pass through several echelons of care on a lengthy journey from point of wounding to definitive care. In current Operations, UK Armed Forces casualties are normally repatriated to Role 4 within 48 hours of wounding. The second is the extent of multiple injuries sustained to multiple limbs and body compartments, which require the co-coordinated efforts of several surgical disciplines, which may take time. Thirdly soldiers are often systemically compromised. In order to allow them to physiologically recover, complex reconstruction may have to be delayed until after the acute period (i.e. beyond 72hrs). Infection may also delay reconstruction. Heavy contamination of multiple wounds is difficult to treat and achieving a non-contaminated wound bed can be almost impossible without total loss of useful extremity tissue. Reconstructive efforts must not be undertaken if there is any suggestion of fungal infection which is not uncommonly encountered in casualties injured in the Middle East or Asia. Prior to having positive fungal histology and microbiology, they may show prolonged pyrexia. Certain fungi can extend up the intima of blood vessels, thrombosing side braches and perforators and produce mycotic emboli. This may lead to flap failure and wastage of donor sites. All patients who have been injured whilst on foot patrol within the so called "Green Zone" (heavily cultivated land around irrigated areas) now have debrided tissue sent for biopsy and receive antifungal prophylaxis in the form of Amphotericin until sensitivities are available. The other constraint to extremity reconstruction is the availability of donor sites for local or free flap soft tissue closure, due to the large zone of injury and widespread wounding patterns. Reconstruction relying on local perforator flaps should be used with caution as the zone of trauma is often underestimated in military injuries. Primary blast wave is likely (although not yet demonstrated in a research setting) to cause intimal damage to surrounding local blood vessels beyond the obvious margins of wounding. This is particularly likely at sites where perforating vessels are relatively tethered i.e. where they penetrate the fascia. Angiography does not appear to be helpful in determining this.

An additional consideration of flap donor site selection is the potential effect of the donor defect. The standard "workhorse" muscle flaps, such as Latismus Dorsi and Rectus Abdominus have key core stability functions and their harvesting may compromise physical rehabilitation.

Pollak et al. reviewed 195 flap procedures as part of a wider prospective multicentre study looking at short term complications following flap coverage of high energy lower extremity injuries. Limbs were separated into three groups based on timing of soft tissue coverage: <4 days, 4-7 days and >7 days. They found no significant difference in incidence of short-term complications in relation to timing of soft tissue coverage [28]. Several reports have now appeared demonstrating successful reconstruction of extremity war injuries in the sub acute period. Çeliköz et al. conducted an eight-year retrospective review of 215 patients with extremity war injuries seen at their tertiary level referral centre in between 1993 and 2001. Of 226 extremity injuries, 209 defects in 203 patients were reconstructed between 7 and 21 days, i.e. the subacute period (mean 9.6 days) using 18 local pedicled muscle flaps and 208 free muscle flaps. The success rate of free muscle flaps was 91.3% and the average full weight bearing times for lower leg defects was 8.4 months. Mean follow-up time was 25 months (range = 9-47) [29]. Chattar-Cora et al. published a small series of 17 patients with high-energy extremity injuries sustained during Operation Iraqi Freedom with eight free tissue transfer reconstructions at the Brook Army Medical Centre. They do not state precisely when flap coverage was performed, but the average time from injury to presentation at their institution was 10.9 days. All flaps were successful [30]. Kumar analysed the Operation Iraqi Freedom reconstruction database and identified all flap reconstructions performed from September 2004 to June 2006 at the National Naval Medical Centre, Bethesda, MD. Seventy-six flap reconstructions were performed including 59 pedicled and 12 free flaps. All were performed within the subacute period and they report no early free flap losses and a pedicle flap loss of 1.4%. Early post flap infections occurred at a rate of 7% [31]. We have had success with pedicled-flap and free-flap reconstruction of upper and lower extremity war injures during the subacute period, although our data remains unpublished. Pedicled flap options for the lower limb include gastrocnaemius, perforator based fasciocutaneous flaps and sural artery perforator-flaps. Free muscle flaps have been used as well as free antero-lateral thigh flaps with success (Figure 6).

With reference to the most appropriate timing of soft tissue reconstruction, particularly of open fractures, we have taken the view that current civilian guidelines such as those produced by the British Association of Orthopaedic Surgeons and the British Association of Plastic, Reconstructive and Aesthetic Surgeons [32] may not be applicable to military injuries. The aim of achieving soft tissue closure within 5 days is inappropriate for the multiply injured and heavily contaminated blast injured soldiers seen in the modern-era.

Figure 6. Free anterolateral thigh (ALT) fasciocutaneous flap used to cover an 8cm sural nerve cable graft to the ulnar nerve and an ulnar nerve perforator rotation flap used to cover exposed tendons

Peripheral nerve injuries

Major peripheral nerve injuries are increasingly common. This is a reflection of the frequency of upper limb injuries in combination with lower limb blast injuries. With pressure-plate devices, the contralateral leg to the initiating leg will usually have a major soft-tissue injury which may include a major nerve injury. Nerve injury in this context of multiple limb blast injury presents several challenges.

Neuropathic pain

An immediate problem in managing a patient with a nerve injury can be neuropathic pain. This requires the early involvement of an acute pain specialist at the Role 3 facility and continuation at Role 4. We have found that the multi-modality approach of the pain team has been of great benefit. Peripheral nerve block infusion catheters in particular have been very effective. If these are placed at Role 3 then good pain relief can be achieved early. This can be continued during the aeromed flight, when pain management can be difficult. In difficult neuropathic pain cases, the infusion catheters have been continued even after nerve grafting and have been kept in place for up to two weeks.

Size of nerve defect and lack of donor nerves

The nature of blast injuries means that often there is a large area of nerve loss, with a long gap in the nerve that needs to be reconstructed. This problem is compounded by the fact that in multiple limb injured patients many of the most common donor nerves for reconstruction, such as the sural nerve, may be absent. This paucity of donor nerves combined with the large size of the defects needing reconstruction makes dealing with these injuries very challenging.

Association with other injuries

The nerve injuries encountered in these patients is normally in combination with other injuries, such as an overlying soft-tissue defect, vascular or skeletal injury. All of these issues must be addressed in combination with the nerve injury to deliver a good outcome. This requires careful planning with other specialties so that the nerve repair has the best chance of a good outcome.

Dealing with the patient

Nerve injuries can be difficult for the patient to cope with. The recovery time is long and the end result is unpredictable. Neuropathic pain can be an early and enduring problem. All of these issues will influence the patient's outcome.

Conclusion

The current cohort of war injured patients present challenges to the modern era of reconstruction that has developed from a civilian type of practice. The effectiveness of the casualty chain means that severely injured soldiers who would have died in previous conflicts are now surviving. Though it is useful to look at civilian and previous military experience, it should be recognised that we are dealing with new problems which require rethinking of our management strategies. The surgical reconstruction must take place within a multi-disciplinary, holistic team approach to the multiply wounded soldier. The timing and the type of soft-tissue reconstruction will depend on the injury pattern and the physiological state of the patient. It is essential to ensure complete debridement even if this means delaying reconstruction beyond the civilian based guidelines on timings. There is a clear role for TNP for wound control prior to soft-tissue reconstruction.

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