Ballistic Wound Management and Infection Prevention

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Key Points

1. No ballistic wound (with the possible exception of head and neck wounds) should be closed primarily.
2. Ballistic casualties need urgent systemic antibiotics.
3. Ballistic wounds should be irrigated with saline.
4. Wounds with retention of the round, fragmentation or bone strike should be regarded as higher energy transfer: consideration should be given to fasciotomy and more aggressive wound exploration.
5. Low energy transfer wounds should be considered for less aggressive surgical management if the wider healthcare context permits easy return to theatre.
6. Tissue excision should be performed after extension of the wound beyond the zone of injury.

21.1 Introduction

The primary surgical manoeuvres in the treatment of ballistic injuries are to save life and limb, in accordance with the principles of damage control resuscitation. In subsequent procedures the focus of surgical treatment shifts to preventing morbidity,

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J. Breeze et al. (eds.), *Ballistic Trauma*, https://doi.org/10.1007/978-3-319-61364-2_21

and to the optimisation of reconstruction. Surgical treatment of wounds should take place as soon as possible after wounding once life-threatening injuries and haemorrhage control have been addressed.

Gunshot wounds (GSWs) are typically less contaminated than injuries caused by projectiles energised by explosive munitions. However they are occasionally associated with considerable tissue destruction, which may be deep within the wound, as described in Chap. 5. Infection following open fractures caused by GSWs and explosive weapons occurs in approximately 25% of cases [1, 2] and is associated with revision surgery and subsequent amputation [3]. Prevention of infection is achieved by creating a clean vascularized wound bed by excising all non-viable or contaminated tissue, and by reducing the number of viable microorganisms present by copious irrigation. The residual burden of contamination is thereby reduced to a level where the patient's immune system is able to suppress the development of infection.

In this chapter the term 'debridement' is not used in order avoid confusion. This term entered the English-speaking surgical lexicon after the Inter-Allied Surgical Conference of 1917, and in the 100 years since then it has been used interchangeably to mean either, or both, the act of *incision* and decompression (or un-bridling the tissue) and/or the *excision* of necrotic or grossly contaminated tissue. For simplicity, this chapter will use the terms *excision*, *incision* and *decompression*.

All ballistic wounds, both GSWs and those from explosive weapons, evolve over time. They should never be closed at the first surgical episode and may require recurrent surgical episodes for further assessment, tissue excision and eventually closure or coverage. Time between surgical episodes is usually 2 days, though they can be safely delayed for 5 days in a patient not showing any signs of sepsis. The only exception to the rule of delayed closure are head and neck wounds which are typically more forgiving due to their vascularity.

The majority of GSWs affect the limbs in both the military [4] and civilian setting [5]. This chapter will focus on the prevention of infection in limb wounds, and will predominantly consider those injuries caused by firearms.

21.2 The Ballistic Wound and Infection

The Jackson model of burns [6] describes a wound in three zones, as shown in Fig. 21.1 below. Devitalised, dead tissue is described as the *zone of necrosis* while only slightly traumatised tissue is referred to as the *zone of hyperaemia*. In between these extremes lies the *zone of stasis,* which can most usefully thought of as being *vulnerable but viable* tissue.

This conceptual model provides a useful theoretical construct for understanding ballistic wounds and the rationale behind their treatment. Key to this is preserving the vulnerable but viable tissue by preventing further damage and necrosis.

In practice, application of this principle is a dynamic process. The clinician must make a judgement on the status of the wound, the patient's comorbidities and resuscitative status, together with the constraints of the environment and the chronicity of presentation.

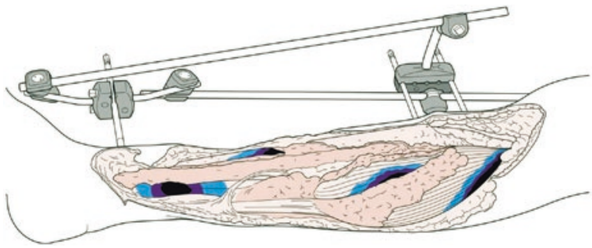

Fig. 21.1 Diagram of complex open fracture wounds showing zones of necrosis (*black area*); surrounded by vulnerable but potentially viable zones of stasis (*violet area*); surrounded by the zones of hyperaemia (*blue area*)

In the absence of other constraints, the excision of tissues that may have large functional impact should be subject to a more expectant approach. Examples of where this may be appropriate would be injuries to major nerves, those involving structures of the head and neck, and in cases of urogenital injury.

21.3 Wound Incision and Compartment Decompression

The passage of bullets and fragments through muscular compartments imparts energy into those tissues. Muscle tissue can survive the stretching effect of the temporary cavity but will be left inflamed, leading to swelling and the generation of exudate. Whether or not this occurs with significant haemorrhage, there is great potential for compartment syndrome to develop.

In the presence of features associated with high-energy transfer, prophylactic full fasciotomies should be considered. This approach is particularly important in an austere or mass-casualty setting, where the ability to monitor a patient or rapidly return to theatre, is limited. Obviously, clinical symptoms of compartment syndrome mandate formal fasciotomies following ballistic trauma as it would with any other injury mechanism.

Wounds should be extended longitudinally along the limb. The incision should be sited to permit formal fasciotomies and avoid perforating vessels that may be required for future reconstruction. Longitudinal incisions across flexor creases should be avoided in favour of oblique or curved incisions. Even in cases where formal, full fasciotomies are not judged necessary, local decompression of fascia to well outside the zone of injury is a safe strategy which will permit post-operative swelling as well as aiding drainage.

The benefits of wound incision should not be negated by tightly packing the wound or application of restrictive, circumferential bandages.

21.4 Wound Excision

The aim of wound excision is to convert a necrotic and contaminated wound to a clean and healthy one.

Necrotic tissue is a potential site for microbial organisms to colonise as it provides a source of nutrients and is isolated from the patient's immune system. The accepted treatment strategy is to remove this potential site of colonisation by surgically excising all necrotic tissue.

Skin is an elastic tissue that tolerates the stretch of temporary cavitation well. In the words of Sir H Ogilive “one lesson that must be relearned in every war is that skin is very viable and very irreplaceable and as little of it as possible should be removed.” [7].

The common pitfall for those not familiar with excising ballistic wounds is to start from within the wound, enlarging it until all the contaminated tissue has been removed: this approach risks both inadequate tissue excision and inadvertent damage to neurovascular structures.

A preferable approach is to ensure that the wound is extended to outside of the zone of injury. If neurovascular structures are suspected to cross the zone of injury, then they should be identified in uninjured tissue and traced along their path. This approach also permits easier identification of the wound zones described above facilitating decision-making regarding non-viable tissue.

21.4.1 High-Energy Versus Low Energy Gunshot Wounds

In order to identify and excise all necrotic tissue in a GSW, exposure or *laying open* the entire wound tract wound be necessary. This could potentially require the transection of otherwise un-injured muscle compartments and result in greater functional damage than the original injury. Despite this concern, this aggressive surgical strategy has previously been advocated in military GSWs [8]. It is now recognised that in a low-energy wound, there may only be a small amount of necrotic tissue of a quantity manageable by the patient’s immune system. Surgeons with experience of GSWs from the pre-antibiotic era in the First World War regarded the laying open of a through and through wound as a ‘cardinal sin’, since they healed up well without invasive surgery and the further insult this involved [9].

After the major conflicts of Korea and Vietnam, military surgeons used animal models to confirm their clinical experience that ‘simple’ through and through wounds of the limbs can be managed with wound lavage, local fascial decompression and delayed closure or secondary healing [10, 11].

Civilian surgeons working in an environment where they can be confident of the low energy nature of the injury, for example due to the use of handguns, and with adequate resource to enable early access to the operating theatre if required, have even advocated non-operative treatment of these wounds. The safety of this approach is supported by randomised controlled trials which demonstrate no greater rate of infection in GSWs from handguns treated operatively versus non-operatively [12, 13]. However, when the weapon and circumstances are unknown, it is important to treat the wound and not the weapon.

Coupland suggested that all GSWs with a skin wound greater than the diameter of 2-fingers involved significant energy transfer suggestive of cavitation and therefore the wound tract should be fully explored and laid open [14, 15]. This strategy was based on the hospital experience of the International Committee of the Red Cross (ICRC) when dealing with injuries that were often presenting after a delay of several days without antibiotic treatment. In a similar setting, and with delayed presentation, a more aggressive approach may be mandated. A more aggressive approach is also appropriate if there uncertainty about if repeat surgical treatments may be possible.

However, rather than relying on absolute ‘rules’ a more nuanced approach to GSWs is possible: In the recent experience of management of GSWs from high-energy military weapons in Afghanistan, it has been possible to stratify wounds according to the amount of energy transferred from the projectiles into the tissues. As described in Chap. 5, greater energy transfer occurs with bone strike, bullet fragmentation or bullet retention. These factors can all be determined at time of initial assessment by radiological and clinical examination [4]. High-energy transfer wounds require thorough and careful assessment of the whole wound tract for potential deep pockets of necrotic tissue.

If a GSW lacks the features of high-energy transfer surgeons can consider minimal debridement of visible wounds, local release of fascia and fluid lavage. This can possibly be augmented by flossing the tract with saline soaked ribbon gauze introduced by the passage of a Rampley’s clamp along the wound tract. This conservative treatment of low energy transfer wounds can only be safely carried out in specific circumstances. The initial surgical exploration should be done within 24 h from point of wounding, in a patient who has had early administration of systemic antibiotics and when circumstances easily permit return to theatre should signs of local or systemic infection develop. If these conditions are not met, a more aggressive surgical exploration is likely to be a safer strategy.

Cases of delayed reconstruction may be expected in a mass casualty terrorist firearms attack, either due to local facilities being overwhelmed or prolonged transfer timelines to supporting hospitals. This is especially pertinent in the case of limb injuries requiring reconstruction as they are likely not life-threatening and may therefore be triaged into lower categories. In these situations the presence of bacterial biofilms covering wound surfaces is a key concept in the management of infection [16]. Authors have coined the term “tumour like excision” in orthoplastic practice, and suggested practical techniques including staining the wound cavity with blue ink and excising all the stained tissue, or stapling a gauze pad into the wound and excising the tissue with the gauze in continuity [17].

21.5 Wound Irrigation

At the start of the First World War, GSWs were irrigated with a variety of antiseptic solutions. Sir Alexander Fleming was working as a Lieutenant in a British Field Hospital in Belgium and recognised the hundreds of ballistic wounds being treated with various irrigation solutions were a grim natural experiment. He took numerous samples of wound tissue from injured soldiers and demonstrated that there was increased bacterial loads in wounds that had been treated with antiseptics.

He ascribed this counter intuitive observation to the toxicity of chemical antiseptics to the host tissue: “it also makes it necessary in the estimation of the value of an antiseptic, to study its effect on the tissue more than its effect on the bacteria” [18].

In terms of the Jackson wound model, this effect is the chemical damage of antiseptics on the vulnerable but viable traumatised tissue, tipping the balance towards necrosis. This effect has been demonstrated in animal models of traumatic wounds [19]. Since Fleming's work in the First World War, there have been no clinical or pre-clinical studies that have demonstrated superior efficacy of anti-septic chemicals over saline [20]. The recent FLOW study in 2015 confirmed the superiority of wound irrigation with low-pressure saline [21].

In summary minimising infection in gunshot wounds is achieved by physically removing contaminants and wound exudate. This is best done by irrigating the wound with large amounts of normal saline delivered at low pressure.

21.6 Antibiotics

Ballistic wounds are always contaminated; in fragmentation injuries this contamination can be massive. The administration of systemic antibiotics is a priority; early administration of systemic antibiotics, even in the pre-hospital context, can allow surgical treatment of wounds to be more safely delayed [22], an important consideration in a mass casualty situation or in an austere environment.

The application of local antibiotics after wound incision and excision enables a higher concentration of antibiotic to be achieved in the wound whilst avoiding systemic toxicity. Presently there is no ideal vehicle for the administration of local antibiotics [23], but the use of antibiotic impregnated Polymethylmethacrylate (PMMA) beads to create a high local concentration of antibiotics is well accepted [2, 24].

The choice of antibiotics will be guided by local policy and the circumstances of wounding. For example, wounds sustained in an aquatic environment may require gram negative cover and those potentially contaminated by faeces (as with some suicide bombings) or sewage may need anaerobic cover [25].

It is important not to regard ballistic injuries as exotic or inherently different from other injuries; even in wounds sustained on the battlefield, *S. aureus* is the most common causative agent of wound infection [2].

21.7 Dressings

Once wounds have been rendered clean and healthy dressings need to be applied. The primary aim of the dressings is to prevent secondary contamination, and allow exudate to safely drain from the wound.

For the same reason that antiseptic solutions should not be used to irrigate wounds, antiseptic-soaked wound packs should never be applied to traumatised tissue [26]. Loosely packed gauze, either dry or soaked in saline or impregnated with petroleum jelly, and secured with wool and crepe bandages is a safe, and low-cost dressing. However in large wounds these dressings can rapidly become saturated

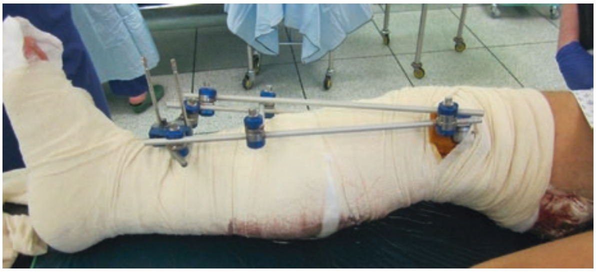

Fig. 21.2 Excessive exudate saturating the dressing covering a open tibia fracture caused by a high-energy transfer GSW. The ankle is immobilised with a gypsum plaster splint to prevent movement of tissues in the lower leg, necessary despite the tibia being stabilised with an external fixator

with exudate, causing an unpleasant odour for the patient and a site for bacterial colonisation [27], as shown in Fig. 21.2.

The use of nanocrystalline silver dressings has not been shown to be more effective than plain gauze dressings in a randomised, controlled trial performed on patients with ballistic wounds [27].

Topical Negative Pressure (TNP) dressings, also referred to by their proprietary names (e.g. Vacuum Assisted Closure (VAC®)), provide an alternative dressing for ballistic wounds once they have been adequately treated surgically. These dressings satisfy the aims of ballistic wound dressings by effectively sealing the wound from outside contamination while simultaneously removing exudate as it is discharged. They have the added advantage of being able to keep patients clean and comfortable in cases of very large wounds, e.g. bilateral lower limb amputation [28]. It is important to state that TNP dressings do not negate the need for adequate surgical treatment of wounds as soon as possible after wounding. In the absence of clinical signs of sepsis, TNP dressings can safely be left over an adequately debrided wound for up to a week [29].

All limbs traumatised by a ballistic wound should be splinted, even in the absence of a fracture. In those limbs with an underlying fracture, splints should be used to rest the tissues, which are susceptible to infection if used excessively (Fig. 21.2).

Conclusion

Prevention of infection is the priority for managing a ballistic casualty as soon as life and limb threatening injuries are addressed. Administration of systemic antibiotics and the surgical treatment of ballistic wounds should take place as soon as possible after injury. It is possible to judge the likely amount of energy transfer into the wound by use of clinical and radiographic evaluation. Surgical treatment should be tailored according to energy transfer: wounds sustained through higher energy transfer require more aggressive tissue excision. Low pressure saline irrigation should follow adequate wound incision and excision. Ballistic wounds should never be closed at the first surgical episode with the possible exception of head and neck injuries. Topical Negative Pressure dressings are an ideal choice for covering wounds in between surgical episodes.

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