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Management of ballistic soft tissue injuries: a review

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Abstract: *Civilian populations are increasingly vulnerable to ballistic injuries resulting from firearms or from bomb blasts. Injuries of the extremities are most common with firearm- related violence and wounds of greater complexity are seen with explosive devices. Initial management is targeted to dealing with life-threatening conditions and stabilizing the patient followed by subsequent care in a well-equipped setting. In this paper, we review and discuss various management modalities specifically for ballistic soft tissue injuries which include conservative or surgical management, appropriate wound care, use of antibiotics and definitive management and reconstruction of soft tissue injuries. Initial evaluation can usefully classify the ballistic injury into a high-risk or a low-risk category and this influences subsequent management. Low-risk ballistic injuries can benefit from conservative non-surgical management. Experience acquired from the treatment of military ballistic wounds can be used in civilian settings especially in the case of wound debridement and use of antibiotics. Definitive management of soft tissue injuries usually involves the use of flaps for reconstruction.*
Keywords *- ballistic injuries, reconstruction, soft tissue injuries, wound care*

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I. INTRODUCTION

Ballistic injuries in civilian settings appear to be on the rise throughout the world although global statistics are limited by lack of reliable data in many countries. A recent paper [1] estimated that deaths, unrelated to conflicts and military or police action, due to firearms throughout the world were in the range of 196 000 to 229 000 adjusted to year 2000 population estimates. However, firearm related injuries and deaths currently remain rare in the United Kingdom and Wales. A retrospective study looking at firearm injuries from the Trauma Audit and Research Network database from 1998 to 2007 showed that only 0.53% of cases were due to firearm injury [2]. Moreover, recent Home Office figures in the United Kingdom revealed that "firearm offences involving any type of injury decreased by seven per cent, from 2,568 in 2009/10 to 2,399 in 2010/11" [3].

Many advances in the understanding and management of ballistic injuries have been made by military surgeons over the past five centuries as the nature of wounds changed with the introduction of new weapons with different capabilities [4]. Increasingly though, it is anticipated that civilian orthopaedic surgeons would be required to be familiar with the management of ballistic injuries especially of gunshot fractures of the extremities [5]. In developing countries with inefficient firearm control, armed robbery and firearm related violence accounted for ballistic injuries in civilian populations. In a study carried out in Nigeria investigating the pattern of civilian gunshot injuries, it was found that the extremities were most affected by such injuries followed by the face and chest [6]. In contrast, recent military action has witnessed an increasing use of improvised explosive devices. The use of vehicular and body armour by soldiers have fortunately led to fewer thoracic and abdominal wounds; however an increased incidence of wounds affecting the head, neck and extremities with more complex wounding patterns have been observed [7]. Hence, surgeons are being required to deal more frequently with gunshot wounds of the extremities and also wounds of greater complexity.

Ballistic injuries commonly occur either from firearms or as a result of blasts from explosive devices. Where firearms are concerned, bullets can be classified as expanding bullets maximising tissue damage or non-expanding bullets maximising penetration [8]. Bullet or projectile injuries have been usefully classified into "high-energy" or "low-energy" injuries reflecting the degree of tissue damage. The amount of energy transferred at impact with the tissues is influenced by the nature of the tissues; more rigid tissues offer a greater resistance and result in higher energy transfers and hence sustain greater damage, for instance, bone would be more readily injured than a more pliable tissue [9]. The zones of injury have been classified into three zones and this is a useful way of conceptualising tissue damage. Firstly, there is the permanent cavity caused directly by the projectile and this consists of crushed dead and necrotic tissue. Secondly, there is the contusion (or inflammatory) zone consisting of injured tissue adjacent to the permanent cavity. Thirdly, the concussion zone or temporary cavity is due to temporary tissue displacement or stretch [10]. The temporary cavitation is thought

to be related to the local transfer of energy [11] and the extent of damage to tissues depends both on the nature of the projectile and on the nature of the affected tissues.

The clinical effects of tissue wounding by ballistics can also vary due to the influence of several factors. Identified variables influencing clinical outcomes include the nature of the tissue and its sensitivity to injury, the extent of tissue damage caused by the effects of energy transfer, the extent and nature of bacterial and other microbial contamination and the presence of foreign bodies in the wound. Crucially the quality and timing of medical care are also important factors to be taken into account [12].

This paper's main focus is a review of the management of ballistic soft tissue injuries and excludes visceral and neurological injuries and bone fractures resulting from ballistics.

II. MATERIALS AND METHODOLOGY

A literature search was performed of the U.S. National Library of Medicine National Institutes of Health PubMed database using the following search items ballistic _ firearms _ gunshots _ trauma _ injuries _ wounds _ soft tissue _ management _surgical reconstruction _ outcomes. Inclusion criteria included the following: A) Recent articles (1990 onwards) discussing the management and/or reconstruction of soft tissue injuries caused by ballistics/firearms/shotguns B) Articles discussing human subjects. Articles which were excluded were: A) Articles discussing exclusively visceral, neurological, vascular or bone injuries caused by ballistics, B) Articles discussing wounds not caused by ballistics, C) Articles discussing aspects other than management of soft tissue injuries D) Articles before 1990. 2148 abstract on firearm injuries were reviewed out of which 46 abstracts were selected as they fulfilled the inclusion criteria and full articles were viewed. Articles in a language other than English (French and German) were translated. 34 articles were found to be relevant to this study and are summarized in the result section.

III. RESULTS

General guidelines for the management of ballistic soft tissue injuries in the papers reviewed included initial wound cover by a sterile dressing, prophylactic antibiotics if required, wound irrigation, careful excision of non-viable tissues in theatre, surgical exploration if required, wound dressing with saline-soaked gauze and crepe bandage or topical negative pressure wound therapy and delayed wound closure at 4 to 5 days. The results of reviewed articles [8, 11-17] are summarized in chronological order in Table 1.

Table 1. Summarizes the different strategies for the initial management of soft tissue injuries

Authors	Initial management strategies of ballistic soft tissue injuries
Bowyer & Rossiter, 1997 [11]	• Initial sterile dressing • Antibiotic cover • Incision and irrigation with copious saline • Excision of damaged subcutaneous fat and fascia and of devitalised muscle • Fasciotomy if required • Dressing the open wound with fluffed-out gauze • Delayed primary suture at 4 to 5 days after injury • Primary closure to be considered for specific areas: face, neck, scalp, genitalia • Split-skin grafting for large defects • Splintage of injured limb even in the absence of fractures to protect soft tissues • Non operative management and outpatient treatment for low-energy soft tissue wounds by wound irrigation, dressing and antibiotic
Hill *et al.*, 2001 [12]	• Early management of small fragment, low energy-transfer small ballistic wounds (especially in civilian settings) without permanent cavitation, neurosurgical or neurovascular injury and with stable fractures by non-surgical protocols: early wound irrigation, dressing, early oral antibiotics and outpatient management • Surgical exploration and management to be considered in the presence of non-viable tissue
Volgas *et al.*, 2005 [13]	• Initially ABC sequence of management followed by imaging to identify any visceral injury and location of path of projectile • Main management strategy is to assess and excise necrotic or contaminated tissue • Wounds with limited soft tissue injury should require excision of entrance wound and irrigation of bullet track

	• Low risk wound with little bullet fragmentation and without bone comminution may be minimally excised • High energy wounds, marked fragmentation of bullet and comminution of bone require extensive debridement • Retained bullet fragments may be left in situ unless located in areas which cause pain. The latter may be removed electively • All wounds recommended to left open to close by second intention • For prevention of infection, high risk wounds are treated by triple antibiotics until 72 hours after wound closure and tetanus antitoxin if required. Low risk wounds may not require antibiotics or may require only a short course only
Lichte *et al.*, 2010 [14]	• General removal of bullet in all cases is not recommended and it can be left in situ if difficult to retrieve • Low energy bullets require superficial debridement, irrigation, sterile dressing, healing by secondary intention; antibiotics may or may not be required. • High energy injuries are usually associated with severe soft tissue damage and require aggressive debridement, second look surgeries, excision of wound margins and wound track as well as removal of foreign material • Healthy tissue should not be unduly excised • Low energy wounds may not require antibiotics • High-energy ballistic injuries and those with bowel injury, craniocerebral injury and extensive soft tissue injury require intravenous antibiotics with duration of antibiotics depending on type of injury
Eardley *et al.*, 2011 [15]	• Initially wound cover with a sterile dressing and stabilization of fractures as required followed by a single dose of antibiotics if surgical intervention not possible within 4 hours • Assessment of injuries to determine whether conservative treatment (for selected soft tissue injuries only) or surgical treatment is appropriate. • A short course of narrow spectrum intravenous antibiotics to be commenced within 3 h of injury • Routine gram-negative cover for all wounds not useful • Tetanus immunization as required • Debridement with wound track excision, compartment decompression and removal of all devitalized tissue, debris and ballistic fragments within reach with extension of wound beyond the zone of injury for comprehensive assessment, extremity fractures to be stabilized • All wounds to be left open and dressed with saline-soaked gauze and crepe bandage or topical negative pressure wound therapy (TNPWT) if available. • Delayed primary closure at 4-5 days
Guthrie *et al.*, 2011 [16] on behalf of the Limb Trauma and Wounds Working Groups	• Consensus recommendations for initial extremity war wound debridement are described • Irrigation and early wound debridement to be performed in operating theatre • Irrigation with warm sterile saline delivered via a low pressure system preferred • Careful debridement limited to non-viable skin and macroscopically damaged fat and fascia only • Fasciotomies of muscle compartments to be performed as required • Excision of non-viable muscle if needed • Primary vascular reconstruction as required at initial debridement but primary reconstruction of tendons and nerves not recommended at that time • Sterile gauze and topical negative pressure to be used as wound dressings • Delayed primary closure advisable at 5 days • Small superficial wounds require cleansing and irrigation with normal saline and can be left to heal by secondary intention
Hospenthal *et al.*, 2011 [17]	• Systemic antimicrobials to be administered as soon as possible after injury to prevent early infectious complications caused by common bacterial flora • Post injury antimicrobials should be given ideally within 3 hours of injury. • Extremity injuries involving skin, soft tissue, and/or bone require 1-3 days

	of cefazolin 2 g IV every 6 hours to 8 hours • Additional gram-negative coverage not felt to be beneficial • Tetanus prophylaxis to be given as required
Bruner *et al.*, 2011 [8]	• ATLS protocol used initially followed by rapid transfer to a suitable hospital facility • Small isolated wounds to skin, subcutaneous tissue and muscle require simple irrigation and debridement • High velocity wounds require operative debridement and second look procedures • Direct closure of wounds not advised • Assessment of intracompartmental pressure for compartment syndrome in case of penetrating injuries of lower limbs • Antibiotics required for ballistic injuries associated with fractures, large soft tissue injury or for shotgun injuries

Following initial wound care, the next step in the subsequent management of soft tissue injuries usually involves definitive reconstruction. Different strategies used for the reconstruction of soft tissue injuries were reviewed regionally. The results of reviewed articles [18-43] are summarized in Table 2.

Table 2. Summarizes the different strategies for the subsequent management and reconstruction of soft tissue injuries regionally

Region	Authors	Subsequent management strategies and reconstruction of ballistic soft tissue injuries
Head and neck region	Gruss *et al.*, 1991 [18]	• Early definitive bone and soft tissue reconstruction • A combination of flaps used for soft tissue reconstruction e.g. free vascularized omental flaps
	Shuker, 1994 [19]	• Tissue traction technique used successfully in 20 patients with soft tissue facial disfigurement
	Siberchicot *et al.*, 1998 [20]	• Early (rather than immediate) bone and soft tissue reconstruction using local or distant flaps
	Motamedi & Behnia, 1999 [21]	• Use of regional flaps to treat facial soft tissue defects followed by revisions
	Hollier *et al.*, 2001 [22]	• Early bone and soft tissue reconstruction
	Safak & Akürek, 2001 [23]	• One stage reconstruction of cheek defect using free latissimus dorsi musculocutaneous flap with good result
	Motamedi, 2003 [24]	• Early definitive simultaneous treatment of maxillofacial hard and soft tissues
	Futran et al, 2005 [25]	• Use of free tissue transfer techniques for simultaneous reconstruction of the bony framework and overlying soft tissues followed by secondary procedures to optimise aesthetics
	Doctor & Farwell, 2007 [26]	• Early definitive reconstruction of bone and soft tissue deficits with vascularized flaps as treatment of choice
	Kaufman *et al.*, 2009 [27]	• Immediate definitive reconstruction (within 24 to 48 hours) after stabilization of patient • Initial skeletal fixation • Free flap transfer (using distant free flap transfers) consisting of fasciocutaneous flaps or osteocutaneous flaps • Secondary revisions to improve function and aesthetics
	Danino *et al.*, 2009 [28]	• Early definitive reconstruction of soft tissue compartments of the face (within first 10 days) with single free composite latissimus dorsi musculocutaneous flap with multiple skin islands after debridement and bony stabilization followed by refinements to improve the result
	Barret *et al.*, 2011 [29]	• Full face transplant in a case of a patient with ballistic trauma to the face
Thoracic and back region	Klink *et al.*, 1994 [30]	• Muscle flaps (using trapezius and latissimus dorsi muscles) successfully used for closing complex thoracolumbar wounds

		with extensive tissue defects
	Veber *et al.*, 2012 [31]	• Ballistic chest trauma in a female managed by use of a musculocutaneous latissimus dorsi pedicled flap for coverage of soft tissue injuries followed by complex breast reconstruction
Abdominal region	Glezer *et al.*, 1993 [32]	• Laparotomy, debridement of injured soft tissues and reconstruction of abdominal wall for severe abdominal injuries
	Paletta *et al.*, 1999 [33]	• Reconstruction of large abdominal wall defects using prosthetic mesh and tissue expanders with good outcomes
Upper extremity and hand region	Iselin *et al.*, 1991 [34]	• Ballistic hand trauma classified into injuries due to a single projectile, injuries due to multiple scattered projectiles and injuries due to explosions. • Large flaps used for primary cover of skeletal and soft tissue lesions • Finger amputations frequently required in explosion injuries • Other injuries required reconstruction
	Evans & Luethke, 1993 [35]	• A latissimus dorsi/scapula combined myo-osseous free flap used successfully for elbow reconstruction after a shotgun injury
	Lukas *et al.*, 2008 [36]	• Pedicled and free flaps used to reconstruct soft tissue defects of hands and forearms with the lateral upper arm flap felt to be the most suitable flap
	Oliveira *et al.*, 2009 [37]	• Fibula osteoseptocutaneous free flap used to manage upper extremity ballistic wound with soft tissue and significant bone loss
	Kumar *et al.*, 2009 [38]	• Upper limb battlefield extremity injuries managed successfully with fasciocutaneous flaps in 66% of cases, muscle flaps in 19% of cases and adipofascial flaps in 15% of cases
	Deal *et al.*, 2011 [39]	• Turnover adipofascial flap used successfully to cover dorsal hand and finger soft tissue defects
Lower extremity, foot and ankle region	Redett *et al.*, 2000 [40]	• Successful lower limb salvage by reconstruction of soft tissue defects using free gracilis muscle
	Lickstein & Bentz, 2003 [41]	• Complex lower extremity trauma in the paediatric population managed by skin graft and/or local flap with good outcome
	Hasmi, 2004 [42]	• Use of free scapular flap for reconstruction of lower extremity defects
	Brown *et al.*, 2009 [43]	• Early amputation may be required for ballistic mangled extremity injuries of lower limbs

IV. DISCUSSION

4.1 Pre-hospital management

At the site of any ballistic injury, the current recommended management is a primary survey of the patient to rapidly identify life-threatening conditions in a well-established ABCDE (A: Airway, B: Breathing, C: Circulation, D: Disability, E: Environment and Exposure) resuscitation sequence as per approved resuscitation guidelines such as ATLS® Advanced Trauma Life Support® guidelines [44]. This should be followed by the prompt transfer of the patient to a trauma centre [8] for more advanced assessment of injuries including the use of imaging techniques followed by appropriate surgical management of the wounds. However in military settings, where haemorrhage from extremity wounds arising from ballistic and blast injuries is a major concern, some authors advocate a modified management sequence proposing that the ABC sequence of resuscitation be replaced by <C>ABC, where <C> emphasizes the control of catastrophic haemorrhage [45].

4.2 Initial assessment of the ballistic wound

During early assessment of an injury caused by a weapon, much consideration was given in the past to the type of weapon used, as to whether it was of a high-velocity or low-velocity type. However the emphasis has now shifted from the nature of the weapon to the nature of the wound. It is currently thought that classifying the ballistic wound into either a high-risk wound or a low-risk wound is more useful clinically [13]. Such classification takes into consideration the type of weapon utilized but also makes use of other variables such as the location of wound, the time to treatment, the path of the projectile, the size of the exit wound, the nature of any organ or bone involvement, the possibility of bullet fragmentation and the number of projectiles present

thereby providing a more accurate assessment of the injury sustained [13]. This concept serves to emphasize the wound rather than the weapon used and is a better clinical guide to management.

4.3 Initial management of soft tissue injuries

Whether ballistic injuries should be managed surgically or conservatively is still a topic for debate. Although it has been common practice to surgically operate on all ballistic wounds, recent literature suggests that some carefully selected wounds could be treated non-operatively by irrigation, dressing and antibiotics [8, 11-14]. Such ballistic wounds selected for non-operative management are ideally low-energy wounds, usually involving limited soft tissue damage. Other small, isolated wounds involving only the skin, subcutaneous tissues and muscle could also be appropriately managed with irrigation, superficial debridement, dressings and antibiotics [14]. Usually direct closure of the wound is not recommended as it is preferable to leave the wound to heal by second intention [8, 11, 13-16].

On the other hand, wounds which have sustained severe soft tissue damage and contain non-viable tissue have been successfully treated with excision of the wound margins and track, removal of injured subcutaneous fat and fascia, appropriate debridement of devitalized tissues, irrigation and removal of foreign bodies as required [11-16]. Regarding debridement, new recommendations for initial extremity war wound debridement have recently been published [16]. Relevant recommendations include early wound debridement of the extremity to reduce the risk of infection ideally taking place in an operating theatre after appropriate cleansing of the limb. Careful debridement of skin, fat and fascia should be limited to non-viable tissue only. Fasciotomies of muscle compartments may be necessary for to prevent the complications of the compartment syndrome. Muscle should be excised after a careful clinical judgement regarding the viability or non-viability of the muscle based on the traditional clinical evaluation of muscle colour, contractility, consistency and capillary bleeding. The presence of intact or injured nerves, tendons and blood vessels in the debridement zone should be documented. The wounds should normally be irrigated with warmed sterile saline. The use of sterile gauze dressings and negative wound therapy system are both felt to be acceptable options for wound care. Primary closure of the wound is usually recommended to be performed at 4-5 days after a successful debridement; however inspection of the wound in theatre may be necessary earlier at 2 days if traumatised but potentially viable tissue has been noted to be present [16]. Although these guidelines have been proposed for military ballistic wounds, they could also prove useful in civilian settings.

4.4 Wound contamination and use of antibiotics

Ballistic wound contamination remains a major concern. Historically, military wound infections were mostly caused by environmental contamination in unhygienic battlefield milieus with delays in the evacuation of the wounded and difficult access to medical treatment, poor sterile techniques, inadequate surgical care of wounds and lack of antibiotics exacerbating the situation. Hence the prevention and treatment of sepsis has long been a priority for careful management [4]. Even in modern days and in civilian settings, wound contamination is an important issue as it has been shown that bacteria could potentially be transferred to the entrance or exit points and within the wound canal by the projectile itself, by clothing or by other exogenous particles [11, 18]. Recent research also shows that tissues located far from the primary wound cavity could also be potentially contaminated by exogenous particles depending on the nature of the projectile (soft point or full metal jacket bullets) being used [46]. In both civilian and military ballistic wounds, identified factors that contribute to an increased risk of wound infection include the mode of wound injury, the wound site, any delay in wound management, the quality of wound care, the wound size, the viability of tissues, the presence of clothing and other foreign materials, any compromise of local blood supply and the presence of bone or neurovascular injuries [11, 15, 47]. Hence all these factors should be carefully evaluated and taken into consideration in the management protocol.

The benefits of the early use of antibiotics after a ballistic injury have long been a subject of debate. In combat injury, authors of a recent publication recommend the use of intravenous benzyl penicillin only in those injured patients where surgery would be delayed for more than 4 hours [15]. However, recently published updated guidelines [17] for the prevention of infections associated with combat-related injuries recommend the use of systemic antibiotics as soon as possible after injury (within 3 hours) to prevent early infectious complications. Intravenous cefazolin is the main antibiotic recommended for extremity injuries involving skin, soft tissue, and/or bone; additional gram-negative coverage is not felt to be beneficial. Tetanus prophylaxis must also be considered. It must be noted that these are recommendations for military ballistic injuries taking into account the nature of combat injuries. Whether these same recommendations should be applied in a civilian setting remains to be evaluated. In addition it has been reported that wounds caused by secondary blast injuries are potentially contaminated and blast survivors should also receive appropriate antibiotics and tetanus prophylaxis to prevent wound infection [48].

Rarely, late infections can occur in ballistic wounds as a result of retained foreign bodies. Such cases have been described in the literature; for instance a case of late infection by methicillin-susceptible *Staph. aureus* in the neck has been reported seven years after a gunshot injury which had resulted in multiple pellets being embedded in neck tissues [49]. With reference to the guidelines for the prevention of infections in combat-related injuries [17], an intravenous dose of cefazolin is required for isolated retained deep extremity soft tissue metal fragments. Hence antibiotics play an important role in the management of ballistic injuries to prevent both early and late wound infections.

4.5 Definitive management of soft tissue injuries and reconstruction

The management of soft tissue injuries after the initial stages of wound care is aimed essentially at restoring both function and aesthetics. Such management usually comprises surgical intervention specific to the nature and location of the soft tissue injury. The use of flaps for the reconstruction of soft tissue injuries is well established. The timing of the reconstruction is a subject for debate. Some authors favour immediate definitive reconstruction within 24 to 48 hours [27] whilst others opt for an early reconstruction within the first 7 days [18, 20, 22, 24, 26, 28]. For injuries of the head and neck, free flap transfers (fasciocutaneous, osteocutaneous or musculocutaneous) for the reconstruction of soft tissue and bony injuries have resulted in good outcomes [18, 20-28]. New treatment modalities are being tried for instance a full face transplant has been used in the management of ballistic injury of the face [29]. Muscle flaps have been used in the thoracic and back regions [30] and complex breast reconstruction has been required in the case of an injured female patient [31]. Ballistic injuries of the abdomen have necessitated the reconstruction of the abdominal wall [32, 33]. Osteocutaneous flaps have been used for upper extremity wounds with significant bone loss [37] whilst fasciocutaneous, adipofascial and muscle flaps have been used in other instances [35, 36, 38, 39]. Lower limb injuries may be often salvaged by the use of local or distant flaps [40-42]. However amputations may be required especially in the case of mangled extremity injuries [43]. Overall the use of flaps in the management of ballistic soft tissue injuries has had good outcomes.

V. CONCLUSION

Ballistic injuries in civilians can result from firearms or from blast wounds in survivors. Initial management follows the well established ABCDE resuscitation sequence although haemorrhage from extremity wounds is of particular concern. The patient should be transferred promptly to an appropriate centre for further management. A careful assessment of the injury should indicate whether it is a high-risk or low-risk wound and this will determine further management. Selected low-risk wounds can be managed conservatively. Other wounds may require exploration, early debridement of devitalized tissues and removal of foreign bodies. Primary closure of wounds is ideally performed at 4-5 days. Relevant recommendations based in military settings regarding initial extremity war wound debridement and the prevention of infections could prove useful in civilian settings. Following early management, definitive reconstruction with the use of flaps is often the treatment of choice.

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