Civilian gunshot injuries in orthopaedics: a narrative review of ballistics, current concepts, and the South African experience

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Abstract

The incidence of civilian gunshot injuries is on the rise worldwide.Unfortunately, there is a lack of high-level evidence guiding management. The treatment of orthopaedic injuries from gunshots is complex and requires consideration of multiple aspects, including energy transfer to the tissue, severity of the wound, possible contamination, presence of fractures and associated injuries. With this narrative review we aim to discuss some of the relevant ballistics, current concepts, and controversies in the general management of civilian gunshot-related orthopaedic injuries based on the available evidence and personal experience. Important points which will be highlighted are the initial management in the emergency room, the assessment and management of soft tissue injuries, associated injuries, use of antibiotics, indication and techniques for fracture fixation, and gunshot injuries to joints.

Keywords: Gunshot; Ballistic; Bullet; Civilian; Orthoballistic

Introduction

Civilian gunshot related injuries are on the rise worldwide with several countries, including the United States of America and the United Kingdom, reporting an increased incidence [1]. In the United States (US) civilian death by firearm has increased more than fourfold since the 1950s and outnumber gun-related deaths associated with military conflicts that the US are involved in across the world [2, 3]. Civilian trauma surgeons in regions with a high incidence require battlefield-like training experience to manage civilian gun-related trauma adequately. Incidents of terror attacks across the globe further highlighted that this experience could be needed at any major trauma centre [4]. Ballistic trauma can result in some of the most challenging orthopaedic injuries to treat. An understanding of basic ballistics and injury characteristics can help the orthopaedic trauma surgeon to properly evaluate and care for the gunshot victim.

Unfortunately, there is a lack of evidence-based guidelines for the management of civilian gun-related trauma as guidelines are often derived from military experience [5]. Military injuries are mostly high-velocity injuries and available resources are vastly different, especially when compared to resources in lower-income countries. Furthermore, most literature is produced in high-income countries which might not be applicable in areas of high burden.

With this narrative review we aim to discuss some of the relevant ballistics, current concepts, and controversies in the general management of civilian gunshot-related orthopaedic injuries based on the available evidence. Important points which will be highlighted are the initial management in the emergency room, the assessment and management of soft tissue injuries, associated injuries, use of antibiotics, indication and techniques for fracture fixation, and gunshot injuries to joints. We are associated with major trauma centres in South Africa, treating high volumes of civilian gunshot-related injuries and hope that our personal experience provided will add relevance to centres treating similar injuries.

Relevant ballistics: treat the injury, not the weapon!

When pulling the trigger of a firearm it releases a firing pin which strikes the primer of the cartridge. The primer ignites and combusts the powder in the main chamber of the cartridge. The generation of gas and heat produces pressure that ejects the bullet. The gas trapped in the bore of the firearm behind the bullet further accelerates the bullet prior to exit. Rifling in the barrel introduces spin along the bullet's longitudinal axis to improve its stability during flight [3].

Historically emphasis has been placed on the velocity of the bullet as a predictor of damage to the victim and has been a source of confusion in the literature. Firearms are classified as high velocity if they discharge a projectile at a speed of more than 2000 feet per second, i.e. most military- and hunting rifles. Low velocity guns include most handguns that discharge a projectile at less than 2000 feet per second. Shotguns are classified as intermediate velocity [1] and a number of characteristics of the cartridge determine the diversity of shotgun wounds [6]. More important than velocity is the efficiency of energy transfer to tissue [3]. Kinetic energy is calculated as the product of half the mass of an object and the velocity to the second power ($e = {}^{1}/_{2}mv^{2}$). Velocity therefore does play an important role, although energy transfer to the tissue is more important than the absolute velocity at discharge. This amount of energy transferred predicts tissue damage. For example, a high-velocity gunshot wound (GSW) might cause less destruction where the projectile passes through the victim, retaining some energy, compared to a low-velocity gunshot injury where the bullet is retained, and all the kinetic energy is transferred. Therefore, classifying gunshot injuries as high or low energy according to the amount of damage to the tissue is more helpful, although this is more difficult to accurately quantify.

Shin et al. [2] summarised that energy transfer is dependent on projectile calibre and design, projectile velocity, kinematic energy at impact, distance travelled prior to impact, entrance profile and characteristics of penetrated tissue. The characteristics of the projectile are extremely important and influence the amount of tissue damage. Bullets are usually composed of lead combined with other metals depending on the desired hardness. Military bullets are mostly sharp tipped full metal jackets, designed to stay intact and pass through the victim causing less damage. Blunt nosed ammunition allows deformation of the soft lead upon impact causing greater tissue destruction. As such, hunting bullets are designed to deform upon striking an object and cause maximal tissue damage. The Hague Peace Conference in 1899 banned military ammunition modifications to increase tissue damage and bullets which does not stay intact on impact [7]. Certain bullets are even designed to pierce armour by utilising a hardened core.

When a bullet strikes tissue, it creates a temporary cavitation effect. The temporary cavity collapses leaving a smaller permanent cavity [8]. For low-velocity projectiles the temporary cavitation effect is limited, and tissue damage is proportionate to the size of the projectile. High velocity projectiles have a larger temporary cavitation effect. The clinical relevance of the temporary cavity seems variable as most of the tissue involved in the temporary cavity remains viable [9]. This temporary cavitation seems more important with blast injuries, especially improvised explosive devices (IED's) causing contamination with debris.

Another important concept is yaw, defined as the deviation of the long axis of the bullet from its line of flight. This potentially leads to increased tissue damage, although some authors suggest that the effect is overstated and does not correlate clinically with more destruction [9].

Burden and evidence: a mismatch

Almost half of all homicides globally are caused by firearms and Central and South America, the Caribbean and Southern Africa remain the epicentre of civilian gun-related violence [5, 10]. Venezuela has the highest rate of intentional homicide by firearm injury of 53.7 per 1,00,000 population, followed by Brazil (25.2 per 1,00,000). Other countries with a high burden include Columbia (23.7 per 1,00,000) and South Africa (10.2 per 1,00,000), compared to 2.8 per 1,00,000 in the USA [5]. Homicide by firearm makes up 60% of total homicides in the USA [5]. Accurate data on the incidence of non-fatal civilian GSWs worldwide are not available and most likely underreported. But it estimated that there are more than 3 injuries for every death by gunshot, which suggests a large clinical burden to hospitals in these areas [3, 6]. In South Africa it is reported that 105 GSW injuries occur per 1,00,000 population [11].

Gunshot injuries are also expensive to treat with a high percentage of victims requiring operative intervention when compared to blunt trauma [11,12,13]. Complications will likely further add to the healthcare burden. Most of civilian gun-related injuries occur in young male patients in lower-income countries where healthcare is already under-resourced [1, 5, 6, 10, 13, 14]. Except for the direct cost of the healthcare event there is also indirect costs like loss of income and need for ongoing care which further compounds the significant public health concern.

Some units in South Africa report more than 450 orthopaedic gunshot injuries per year, with just under half requiring operative care [12, 14]. This excludes gunshot injuries to other body regions, including head, chest, and abdomen.

A recent bibliometric analysis assessed the most influential publications on gunshot induced orthopaedic trauma and included 128 studies from 50 different journals. Most publications were from the USA (83%), retrospective in nature (66.4%) and represented low levels of evidence (70.3% level 4 and below). Only 3 of the 128 most influential publications originated from areas with the highest burden of civilian gun-related trauma. It was concluded that there was a need for higher level of evidence in the field, specifically from regions with a high burden of these injuries [5]. But most importantly, this shows that evidence to treat civilian gunshots is often not produced in countries with a high burden and might therefore not apply to these areas.

Lessons from advances in trauma critical care during military conflicts can translate to civilian health care [2]. However, civilian gunshot injuries are different from military ballistic injuries and not all aspects of treatment can be extrapolated to the civilian setting. Thus, a significant portion of gunshot injury literature originates from the military setting and is not always relevant when dealing with civilian gun-related trauma [5].

Initial resuscitation and management: 〈C〉 ABC and keep count of number of gunshot wounds

The most common cause of death in the gunshot victim is exsanguination. Therefore, during resuscitation specific attention should be given to identifying and stopping bleeding [6]. A modification to the Advanced Trauma Life Support (ATLS) primary survey algorithm is proposed, namely 〈C〉 ABC to focus on circulation when dealing with victims of penetrating ballistic trauma [15]. The threshold for surgical control of bleeding should be low. For extremity gunshot injuries, the use of tourniquets in the preclinical setting has increased survivability by reduced death from haemorrhage [2]. The adoption of massive transfusion protocols has improved outcomes by identifying the need to replace individual blood components in a 1:1:1 ratio of red blood cells, plasma and platelets in massive haemorrhagic injuries [16, 17].

Although a large percentage of extremity gunshot injuries are isolated, careful examination is crucial to rule out associated life-threating injuries [2]. With the proximity to the chest and abdomen, upper limb injuries are associated with a higher injury severity score and associated life-threating injuries when compared to lower limb gunshot wounds [14, 18].

It is extremely important to identify the number of gunshot injuries. Careful examination is required when counting entry and exit wounds and retained bullets. The number of entry wounds should always match the sum of the exit wounds and retained bullets. A missed, concealed additional gunshot injury can have catastrophic consequences for the patient. Radiographs are critical to identifying associated fractures, retained bullets or fragments, assess the course of the bullets, and identified associated life-threatening injuries. Low dosage full body radiography (Lodox® Statscan, Lodox solutions, South Africa) is a useful adjunct to the secondary survey in victims of ballistic injuries to identify associated fractures and other injuries, as well as retained missiles (Fig. 1) [19,20,21].

Fig. 1. A section of a Lodox® Statscan image showing injuries and retained bullets from multiple GSWs

Prolonged limb salvage procedures are inappropriate in the setting of under-resuscitation and the principles of damage control should be applied. It is unusual for civilian gunshot injuries to result in early amputation [12], but the decision to attempt limb salvage versus amputation is always a difficult one in the acute setting. Scoring systems guiding decisions are not specific for gunshot wounds and not always relevant [22]. The Red Cross classification of war wounds [23] has been described to allow a systematic description, although it is not always practical in daily clinic use [24]. Amputation is usually the result of arterial injuries with a delay in presentation or failed repair. Delayed presentation with a cold ischaemic time of more than 6 h has a high risk of reperfusion injury which can be fatal after reperfusion [2].

Soft tissue injury: appropriate debridement and antibiotics

Management of the soft tissue injury associated with GSWs remains one of the most controversial aspects in the treatment of gunshot injuries. Soft tissue injuries can vary greatly and depends on a number of factors (Fig. 2). Treatments recommendations range from non-operative management, simple tractotomy to extensive debridement [9].

Fig. 2. A variety of entry wounds caused by different gunshots

Most entry wunods lead to punched out, clean circular to oval skin defects, unless the bullet was unstable prior to entry (by passing through another object). The presence of an abrasions ring around an entry wound can suggest a near-contact or close-range injury [3]. Exit wounds are typically more irregular and larger in nature.

The principle of debridement was first formally defined at the Inter-allied Surgical Conference in 1917, where it was determined that an adequate debridement consisted of excision of nonviable skin, generous extension of the wound through all layers, excision of damaged muscle and contaminants, followed by copious lavage. Devitalized tissue and gross contamination act as a possible source for infection. Debridement is guided by an assessment of the viability of tissue looking at abnormal colour, consistency, contractility, and circulation (4Cs). It has, however, been shown to be inaccurate following gunshot injuries as some tissue with abnormalities in the 4C assessment might recover [9].

Some authors, based on an over-estimate of the effect of the temporary cavity upon impact, even suggest debridement of a core up to 30 times the bullets diameter might be necessary [9]. This is not well supported by the literature and likely to cause more iatrogenic injury. Most authors, however, still recommend excision of the wound and debridement of the tract [9]. Some authorities have abandoned the practice of wide debridement of gunshot wounds, and this is the practice in most high-volume units in South Africa. Simple soft tissue injuries caused by bullets can safely be treated non-operatively as it involved little tissue damage, provided that there is confidence in the assessment of wound severity [3, 25]. Questions remain regarding the best way to assess wounds and select patients for surgical versus nonsurgical management [26]. The best guide is that wounds should be treated on individual merit. Multiple factors must be taken into consideration including the size of the entrance and exit wounds, obvious devitalised tissue and contamination, bone exposure in case of associated fracture and an estimation of the ballistic characteristics. Decision-making is not as simple as classifying injuries into high versus low velocity, leading to the recommendation to treat the wound and not the weapon![3] Some studies are suggesting no benefit of debridement of gunshot wounds over non-operative treatment, against the urge of the surgeon to treat the wound surgically [9]. Judicious use of debridement depending on the severity of the wound therefore limits the extent of iatrogenic injury in these patients [9]. Retained bullets or bullet fragments in soft tissue also do not need to be surgically removed, providing they cause no discomfort, do not cause compression on neurovascular structures or communicates with synovial fluid or cerebrospinal fluid [6].

High energy wounds should be treated similarly to blunt trauma with debridement of all devitalised tissue and wound irrigation. For these complex injuries, open fracture protocols including primary versus delayed closure, temporary stabilisation with external fixation and longer antibiotic cover apply. To prevent overzealous debridement marginally viable tissue may be preserved and should undergo repeat evaluation and debridement after 48–72 h [3].

The myth that bullets are sterile should also be dispelled. The pressure and temperature on the surface of a bullet are not high enough to sterilise a bullet. Studies have shown that bullets can carry bacteria [27]. Bullets have also been shown in vitro to bring foreign material into gunshot wounds, although this is rarely encountered in clinical practice [27]. In shotgun wounds, wadding is commonly associated with wound contamination [3]. Most authors recommend routine prophylaxis for all gunshot wounds, although some studies report similar infection rates with or without antibiotics [3]. There is however no consensus on the choice of antibiotic or the duration. Clostridial infection (gas gangrene) has been described following gunshot injuries and antibiotic prophylaxis should therefore include this pathogen. A short duration of a first-generation cephalosporin generally suffices, although some authors recommend a more prolonged course of antibiotics [2].

Tetanus prophylaxis booster is indicated for all gunshot wound patients who are not completely immunised. It is our routine practice to give a single dose of intravenous first-generation cephalosporin (cefazolin), except in obviously contaminated wounds where more comprehensive antibiotic cover is indicated. In cases of contamination associated with large bowel injuries we recommend early treatment with broad-spectrum antibiotic cover [6, 28].

Neurovascular and other associated injuries

Gunshot-related injuries to the limbs are often complex injuries involving soft tissue, skeletal, vascular and nerve injuries. The presence of fractures increases the risk for neurovascular injury and a high index of suspicion is required with careful and serial neurovascular examination.

Nerve injuries are reported in up to 10% of gunshots to the extremities [12, 14]. Upper extremity gunshots more frequently injure peripheral nerves compared to gunshots to the lower extremities [14]. Nerve injuries are most often neuropraxia and can be observed for recovery [2]. In contrast to sharp, penetrating trauma (stabs), complete motor and sensory deficits are not indications for early exploration. There is no consensus regarding the optimal timing for exploration. In the acute setting there is a combination of contusion and laceration injury to the nerves. It can be challenging, if not impossible, to determine the extent of the injury and subsequent resection needed [3]. Spontaneous recovery occurs in up to 70% of nerve injuries over 3–6 months. Nerve injuries should only be explored once there are no signs of recovery or nerve conduction studies suggest complete injury. Associated nerve injuries are concerning as it may significantly impact the functional status of the limb in future. Associated vascular injury requiring surgical repair is a relative indication for early nerve reconstruction [3]. Depending on the length of nerve resected during exploration, primary repair might not be possible and reconstruction techniques including nerve grafting, nerve transfers or tendon transfers might be required to restore function.

Associated arterial injuries occur in up to 17% of cases of gunshot wounds to the extremities [2, 3], with varying severity. The early presence of 'hard' signs of limb ischaemia is a poor prognostic sign and immediate surgical revascularisation is indicated. In the emergency setting displaced fractures should be reduced and splinted and haemorrhage controlled by direct pressure dressings. Doppler ultrasound assessment should be performed along with ankle-brachial indices (ABIs). Computer tomography angiography (CTA) is helpful and has the additional benefit of assisting the surgical planning of associated fractures [18]. In cases of concomitant fractures and vascular injuries the order of repair depends on the perfusion of the limb. Where the limb is well perfused through collateral circulation it is advised to perform skeletal stabilisation first. In the presence of hard signs of ischaemia, the limb should be reperfused first. Temporary shunting has been described prior to skeletal stabilisation, followed by permanent graft [29]. In clinical practice trauma or vascular surgeons often reperfuse the limb first followed by skeletal stabilisation. There is no increased failure for vascular repair following gunshot injuries when compared to other mechanisms [3].

Trans-articular gunshot injuries require special consideration. A recent publication suggested that the treating clinician should consider 3 questions:

1. Did the missile pass through the joint?

2. Is the missile or part thereof retained in the joint?

3. Did the missile pass through an organ prior to entering the joint? [6]

Systemic lead toxicity (plumbism) has been described following a retained bullet in a joint [30], but it is more common to cause mechanical cartilage destruction or lead arthropathy. Intra-articular or juxta-articular bullets or large fragments should be removed. If a missile passes through large bowel and then traverses a joint, it should be treated as septic arthritis with joint lavage and antibiotics [6]. Trans-articular injury without associated fractures or retained missiles in the joint and where the missile did not pass through contaminated hollow viscus prior to traversing the joint can be treated non-operatively with a single prophylactic dose of antibiotic and wound dressings [31]. Where retained bullets or fragments need to be removed, a variety of techniques can be utilised. A simple open arthrotomy can be used in most joints but arthroscopic removal has also been described [31, 32]. In the hip joint surgical dislocation allows for simultaneous fixation of fractures to the femoral head [33].

Orthopaedic injuries to the spine, pelvis and hips are often associated with abdominal penetration and visceral injury. Associated injury to the large bowel is of particular concern with a dramatic increase in the risk of sepsis [28]. These injuries should ideally be treated with a thorough washout, stool diversion and prolonged broad-spectrum antibiotics. If these injuries are initially missed or inadequately debrided it can lead to adverse long-term outcomes with chronic osteomyelitis. This is also one of the rare circumstances in which bullet removal and surgical debridement appear stringently indicated [3, 6].

GSW injuries to the spine with bullets retained in or around the spinal canal, with or without associated spinal cord injuries, represent another highly debated entity. Spinal fractures caused by GSW are generally stable and do not require surgical fixation [34,35,36]. Early literature recommended aggressive surgical debridement and removal of bullets in all GSW injuries to the spine [34]. More recent publications recommend a far more conservative approach in the civilian setting [36]. There appears to be consensus that not all bullets or fragments need to be removed. The indications for bullet removal from the spine include deteriorating neurology, intra-canal bullets in the lower part of the spinal canal with incomplete neurology, bullets that traversed large bowel, sepsis and lead poisoning should it occur [36].

Associated fractures: most fractures can be treated as 'closed injuries'

Civilian gunshot injuries can cause a variety of fracture patterns ranging from incomplete to highly comminuted fractures. Incomplete fractures generally occur in the metaphyseal regions of bone. On impact bone fragments are propelled to the periphery of the temporary cavity. Bone fragments can even become secondary missiles causing distant injury.

A gunshot-fracture with a simple, clean entry and or exit wound and no exposed bone does not necessarily require formal debridement following the principles of blunt trauma [6, 25, 37]. During fracture fixation skin margins can be debrided and wound cavities may be washed out, though formal extension of the wound to the fracture site and debridement of all the layers of tissue is not necessary. This 'closed fracture approach' is against most recommendations for open fractures, but is supported by evidence showing similar infection rates to closed fractures undergoing internal fixation [1, 37,38,39].

Fractures secondary to civilian gunshot wounds are typically treated according to accepted protocols similar to fractures from indirect causes and no increase in infective or non-union complications are seen with early versus delayed surgical fixation [6, 18, 28, 39,40,41,42]. Bullets or fragments do not require removal unless they prevent reduction or if likely to cause discomfort [6]. Non-operative management of complete fractures is possible, particularly in fractures of the upper limb and specifically in humerus or ulna fractures [6, 12, 18]. Due to the nature of most fracture patterns the aim is to achieve relative stability of metaphyseal and diaphyseal fractures. In the upper limb this is mostly achieved with bridge plating techniques. Diaphyseal fractures of the humerus and radius or ulna, can also be successfully treated with intramedullary nails [41].

Incomplete fractures of the metaphyseal regions of long bones in the lower limb can be treated conservatively. In certain areas with high stresses like the subtrochanteric region of the femur, there is a risk of incomplete fractures propagating and prophylactic fixation might be advisable [6]. Most complete long bone fractures of the lower limb require surgical stabilization [6]. Similar union rates, as well as rates of fracture related infections (FRI), have been demonstrated in cases treated with intramedullary nailing or external fixation [6, 43]. Some authors though have demonstrated faster time to union with intramedullary fixation [43].

Contrary to cases of high energy gunshot fractures, segmental bone defects are rare following civilian gunshot injuries [44]. It appears that the potential for union is retained, even with extremely comminuted fracture patterns and overaggressive debridement of bone fragments resulting in segmental bone defects is discouraged [9, 38, 39].

Intra-articular fracture due to gunshots remains a challenge to treat. Highly comminuted fracture patterns, with bone and cartilage loss are often encountered. Even with attempted anatomical reconstruction, these injuries remain a source of morbidity with joint stiffness and the development of post-traumatic arthrosis [45].

Jakoet et al. [12] reported on 1449 orthopaedic civilian gun-related injuries. Overall they reported low rates of FRI (3.2%) and non-union (3.1%) of all the patients that sustained fractures. Civilian gunshot injuries treated with intramedullary nail fixation showed similar infection rates and rate of non-union when compared to closed fractures [1, 37]. Of note is that the gunshot fractures were treated with routine fracture fixation, without emergent washout of the wounds. This is also the experience of the authors.

There are reports of delayed- and non-union in gunshot fractures with some authors showing an increased risk of non-union if the zone of comminution is greater than 120 mm in tibia fractures [39].

It should be highlighted that most of the studies reviewed are retrospective in nature with low levels of evidence [1, 5]. There is a need for high level prospective clinical research on civilian gunshot fractures to determine the optimal management strategies, complication rates and clinical outcome. From the available evidence, it appears that gunshot fractures do not behave like open fractures through blunt mechanisms. They are rather unique injuries that require a different approach- somewhere between open and closed fractures.

Limitations

There are several limitations to our narrative review. Firstly, many of the publications reviewed represent a low level of evidence as highlighted previously. Also, the approaches described are not always based on high-level evidence, rather local protocols developed over time. This is a key future research objective to obtain higher level of evidence with clinical research in the field.

Conclusion

The incidence of civilian gunshot injuries is on the rise worldwide. This growing burden of trauma demands an evidence-based approach, yet the field is underrepresented in the literature and more high-level evidence is needed to guide treatment. We need to understand the true epidemiology and then assess interventions prospectively to improve outcomes. The need for representation in the literature from areas with a high burden must therefore include the expert opinion of those that deal with the injuries on a daily basis. These expert opinions can guide future clinical trials and collaborations between high- and lower-income countries can help improve the available level of evidence.

The treatment of orthopaedic injuries from gunshots is complex and requires consideration of multiple aspects, including energy transfer to the tissue, severity of the wound, contamination, presence of fractures and associated injuries. Most civilian GSW fractures can be treated similar to fractures from indirect causes but should have a single dose of antibiotics with clostridium cover as soon as possible. Extensive debridement and the use of external fixation are reserved for injuries with complex soft tissue trauma. Surgical intervention for intra-articular GSW must be considered for fracture fixation, contamination by bowel, or retained intra-articular bullet fragments.

Contributions

The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010.

Conflict of interest

All authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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