"FIREARM INJURIES AND THEIR MANAGEMENT IN THE CONTEXT OF A METROPOLITAN EMERGENCY DEPARTMENT"

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ABSTRACT

Firearm wounds, a type of injury associated with increased rates of disability and mortality, are described as an upward trend in many developed countries worldwide in the last years. Because of their medical importance and economic impact to health systems, they have to be treated by established therapeutic protocols; towards this direction the understanding of basic principles of ballistic theories is vital. This paper reviews the physics of ballistics as it relates to the tracts and patterns of tissue injury caused by different types of firearms and the current evidence for managing gunshot wounds to the head, neck, thorax, abdomen, spine, bones and soft tissues, as well as the controversial matter of the prophylactic antibiotic treatment in this kind of injuries.

Key words: *firearm injury, penetrating wound, ballistic trauma*.

(Περίληψη στα ελληνικά) Τα τραύματα από πυροβόλα όπλα, ένα είδος τραύματος που σχετίζεται με αυξημένους δείκτες αναπηρίας και θνητότητας, περιγράφεται να έχουν μια τάση αυξημένης επίπτωσης σε αρκετές ανεπτυγμένες χώρες παγκοσμίως τα τελευταία χρόνια. Εξαιτίας της μεγάλης ιατρικής τους σημασίας και του οικονομικού τους αντίκτυπου στα συστήματα Υγείας πρέπει να αντιμετωπίζονται με καθιερωμένα θεραπευτικά πρωτόκολλα και σ' αυτή την κατεύθυνση η κατανόηση βασικών αρχών των θεωριών Βαλλιστικής είναι απαραίτητη. Αυτό το κείμενο είναι μια ανασκόπηση των αρχών βαλλιστικής που σχετίζονται με την έκταση και το πρότυπο ιστικής καταστροφής που προκαλούν τα διάφορα είδη πυροβόλων όπλων και των τρεχουσών οδηγιών για την αντιμετώπιση τέτοιου είδους τραυμάτων στο κεφάλι και τον τράχηλο, τον θώρακα, την κοιλιά, την σπονδυλική στήλη, το ερειστικό σύστημα και τους μαλακούς ιστούς˙ θίγεται επίσης το υπό συζήτηση θέμα της αντιβιοτικής προφύλαξης στην αντιμετώπιση αυτών των τραυμάτων.

INTRODUCTION

Although firearm injuries remain an uncommon case of injuries in total, an upward trend is to be noticed in many countries all over the world. Firearm associated crime increased up to 30% in the UK between 1998 and 2002[1] and this tendency was still to be

observed during the period 1998-2007 in England and Wales[2]. At the same time, firearm crime was markedly decreasing in Germany[3]. In American countries, as demonstrated in a study in 1998, gunshot death rates were found to be 5-6 times higher than in Europe and Oceania and 95 times higher than in Asia[4]. In high income countries suicides are more often, in contrast with lower income countries in which firearm injuries are usually a result of assaults and homicides. Additionally, self-inflicted wounds are more common among elder people[5], in contrast with younger men who get injured because of homicide attempts[2].

As seen in the United States, gunshot violence has besides its medical importance, an enormous economic impact as well, as the third most costly etiology of injury and the fourth most expensive form of hospitalization[6]. Therefore, treatment algorithms for emergency care of gunshot injuries have to be established in trauma departments worldwide. An understanding of general ballistic principles is of major importance to guide clinical management of patients with gunshot injuries.

METHODS

This article is based on a literature search in the National Library of Medicine and the National Institutes of Health MEDLINE database using PubMed http://www.pubmed.gov. Search terms have been "firearm injury", "gunshot wound" and "ballistic trauma".

RESULTS

Ballistics. Ballistics is a term referred to the motion of a projectile through the barrel of a firearm (internal ballistics), during its subsequent flight (external ballistics), and during its final complicated motion after it strikes a target (terminal ballistics). Wound ballistics is a special case of terminal ballistics[7]. Although wound ballistics is at best sets of approximations, its principles enter usefully into an evaluation of a gunshot wound and its treatment.

Firearm associated wounds are classified in high velocity wounds (>600m/sec or >2000feet/sec velocity of the projectile), which are caused by arms designed for military acts, and low velocity wounds (<600m/sec velocity of the projectile) caused by handguns[8]. However, these terms can be misleading. More important is the efficiency of energy transfer, which is dependent on the projectile's physical characteristics including deformation and fragmentation, kinetic energy, stability(**Table 1**), entrance profile, path traveled through the

body, and the biologic characteristics of the tissues[9]. For example, when a bullet passes through the tissue, it creates a lateral displacement of size 10 to 40- fold of its diameter. Elastic tissue, such as a muscle, will rebound back to its first position while unelastic tissue as liver or bones will suffer total destruction. Besides that, a low velocity projectile will destroy mostly the tissue along its straight passage through the body, while the projectile of a military or a hunting gun will cause much more damage, creating a permanent cavity in the space of the initial temporary cavity ("cavitation"/**Figure 1**) [8, 10]. A really interesting fact is that even blank pistols and blank cartridges, contrary to public opinion, are dangerous and may inflict potentially fatal injuries when fired at close or contact range[11].

Full Metal Jacket ammunition	A metal casing around a lead core	These bullets are dimensionally stable and produce non-expanding and deep penetrating wounds.
Jacket Hollow Point ammunition	Bullets with an exposed, hollowed lead tip which allows expansion on the impact.	Tissue penetration is less deeply than in Full Metal Jacket ammunition but more energy is transferred to the tissue.
Soft Point ammunition	An exposed lead tip causes a rapid expansion of the bullet on impact at lower velocities.	This rapid expansion is responsible for wounds which are significant wider than the diameter of the bullet.
Altered ammunition	Ammunition can be altered to increase the severity of injury. An infamous example is the Dum Dum projectile, produced by cutting a cross in the soft lead tip of the bullet.	This modification ensures that the bullet will fragment at the impact. Dum dum projectiles are responsible for very high energy transfer to the tissue and therefore tall inner wounds. They are banned for usage in war by an amendment of the Geneva Co

Table 1 : Design and effects of different types of bullets.

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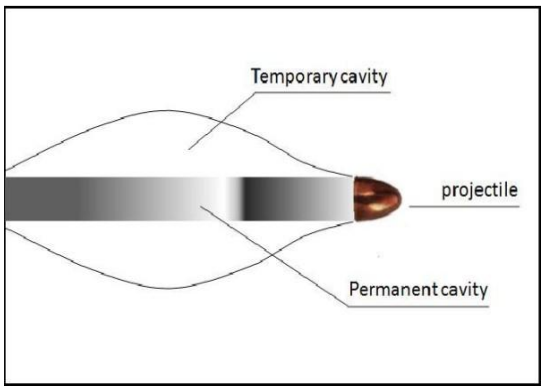

Figure 1. The mechanism of cavitation can cause tissue destruction along the bullet diameter.
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Initial assessment. The initial approach of the patient reaching the emergency department has to be done according to the ABCDE protocol (airways, breathing, circulation, disability, exposure). A first clinical examination, duration 5-10 minutes, targets to the identification of immediate life threatening issues. Then, a secondary and most detailed reevaluation will provide all the information about the patient's clinical condition[12].

Head and neck. Penetrating craniocerebral injuries are associated with a high lethality rate, especially after attempted suicide. The mortality rate is described of being up to 88%. The Glascow coma scale shows a correlation with the extent of the injury and the patient's prognosis. Patients with GCS 3-5 suffer mortality 94%, whereas others with GCS 6-8 suffer mortality 70%[13]. CT scan remains the main diagnostic tool, and in some cases MRI is additionally needed. The use of CT angiography will reveal the size of vascular damages. As for the treatment tactics, the aggressive removal of the foreign materials is not recommended as it doesn't seem to offer better results in the final outcome[14]. More disagreement arises on the treatment of the intracranial haematomas; some authors support the opinion of the evacuation of these damages in general[15] while others claim that surgical intervention is needed only when high intracranial pressure is measured or suspected by clinical and imaging evidence[16].

As far as the neck injuries are concerned (**Figure 2A**), three anatomical zones can be distinguished: Zone I from the clavicle to the cricoid, zone II from the cricoid to the jaw angle and zone III from the jaw angle to the skullbase. Because of the existence of major vessels, larynx and trachea, the injuries in this area can be potentially life threatening and may need immediate treatment for the patient's clinical stabilization. The diagnostic procedure may include CT angiography[17], laryngoscopy or even operative exploration. The initial operation aims to establish bleeding vessels occlusion, stabilize bone and close soft tissue defects. Serial debridement of wounds with delayed reconstruction has given way to early definitive repair with vascularized tissue. This has led to improved function, fewer operations, and shorter hospitalization[17]. Endovascular methods-embolism also gain an increasing importance in the treatment of injuries of the neck vessels, especially pseudoaneurysms[18]. An operative exploration is indispensable only if relevant organs are injured. Otherwise a conservative treatment can be considered, especially for zone II injuries[19].

Thorax injuries (Figure 2A, 2B). The most common life threatening injuries of the thorax are haemato- or haematopneumothorax(36%of the total incidence[20]), tension pneumothorax and pericardial tamponade (cardiac injuries are rare in patients who reach the hospital because these injuries are often lethal at the scene[20, 21]). They should be diagnosed within the first physical examination and be treated immediately. If the patient is in a minimum stable condition a chest X-ray is helpful to show the expansion of the lung and mediastinum[3]. Unstable patients require immediate operation, as they suffer from major cardiovascular injuries or great pulmonary and tracheobronchial injuries . However, in most cases the most important therapeutic intervention is the insertion of a chest tube[22, 23] which is indicated in all cases of pneumothoraces larger than 2 cm and haematothoraces extending over the seventh rib[20]. For stable patients, contrast-enhanced helical CT scanning is an efficient and safe diagnostic tool[24]. Positive CT scan results direct the further evaluation of potentially injured structures. Evaluation may include angiography, bronchoscopy, esophagoscopy, esophagography-barium swallow and echocardiographic pericardial imaging[25, 26]. Patients with negative results can safely be observed in a monitored setting without further evaluation. In the last few years, thoracoscopy has gained wider acceptance since it is more sensitive for small diaphragmatic lesions as compared to CT-scans and it easily allows diaphragmatic repair in hemodynamic stable patients(diaphragmatic damage occur in 59%[27, 28])[29].

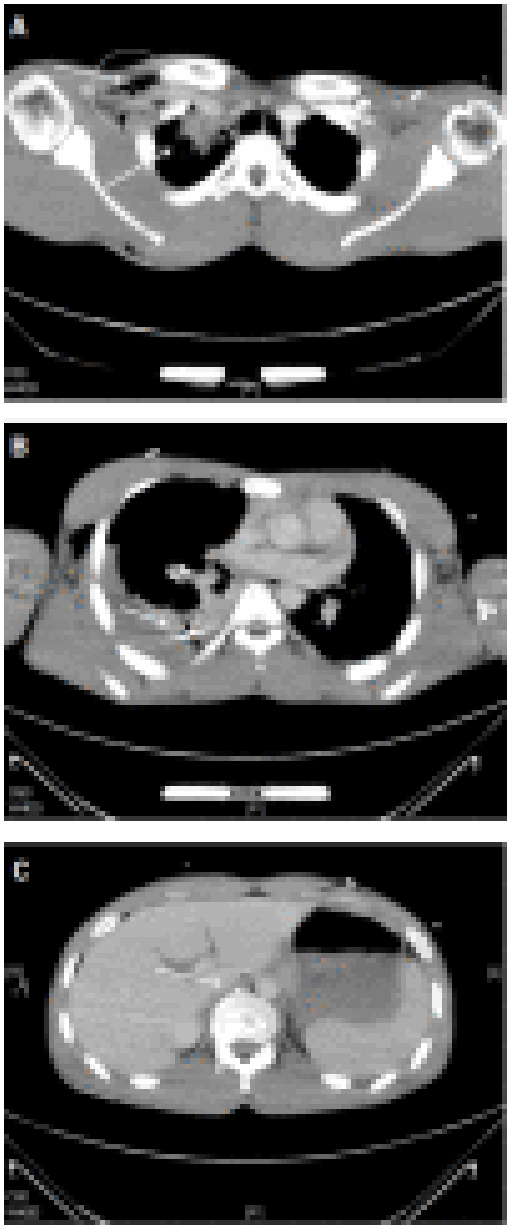

Figure 2. The post-chest drain CT scan demonstrates air in the soft tissues of the right side of the neck (circled) with fragments and contusion at the lung apex (A); haemopneumothorax with fragments inside the chest, see arrow (B); and a small fragment anterior to a vertebral body within the abdomen, circled (C).
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The management algorithms for gunshot injuries to the chest are very similar in most trauma centers, indicating that most gunshot injuries can be managed successfully without explorative thoracotomy[22, 23, 30]. Indications for thoracotomy however are: clinical or echocardiographic evidence of cardiac tamponade, unstable cardiac circulation, or a chest tube delivering more than 1 to 1.5 liters of blood immediately after the insertion or continued bleeding of more than 200 ml/h for 3 hours[20]. Nowadays, advancement in technology has revolutionized thoracic surgery and established video-assisted thoracoscopic surgery (VATS), providing an alternative method for accurate and direct evaluation of the lung parenchyma, mediastinum, and diaphragmatic injuries[31].

Abdominal injuries (Figure 2C, 3). The incidence of simultaneous injuries of thorax and abdomen ranges between 6%-42%[3]. Conversely to the thoracic injury therapeutic tactics, there is much controversy about the abdominal trauma treatment strategies. In the past, the established standard of care indicated that every patient with gunshot abdominal trauma underwent laparotomic exploration; however, due to high rates(41%) of potentially avoidable complications of unnecessary laparotomies [32, 33] this tactic was reconsidered and non operative treatment protocols gained wider acceptance[34-36]. The diagnostic evaluation begins nowadays with ultrasound sonography and CT scan[35, 37]. Diagnostic peritoneal lavage may also give some additional information about the presence of blood in the peritoneal cavity.

Figure 3. A sagittal CT section through the abdomen showing a trajectory of a gunshot missile through the liver (white arrow). A fragment of the missile is also seen posteriorly (black arrow). This patient was successfully treated nonoperatively.
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The main indications of laparotomy remain hemodynamic instability, clinical signs of peritonitis and signs of evisceration[34, 37-39] . Factors related with the final outcome and increasing mortaliy of surgeries for major abdominal traumas are increasing age , low base excess, low pH, low core temperature and high blood transfusion requirement over 24 hours.[40] In hemodynamic stable patients with penetrating wounds mainly on the left thoraco-abdominal region, laparoscopy is the preferred diagnostic tool with its specialty in detecting smaller diaphragmatic or intraabdominal injuries[41].

Spinal injuries. Spinal ballistic injuries aren't usually immediately life threatening and they are treated in the second phase. After the completion of the neurological examination and the determination of the patient's neurological status a CT scan will identify the total size of the destruction. Additionally, an MRI may be needed although this examination is always associated with a potential risk, due to the unknown load of magnetic materials[42]. Many

patients are treated non-operatively, because unstable vertebral fractures are not often[43, 44]. The general removal of the bullet is not recommended, but it must be done if the projectile creates secondary incomplete neurological deficits or infection or in the case of vertebral disc fracture where the projectile can induce lead(Pb) poisoning[45, 46]. Primary neurological deficits cannot be inverted in most cases[47]. The use of corticosteroids is totally deplored by the current guidelines[48, 49].

Bony injuries. Low velocity bony fractures, most common among civilian population, have similar characteristics to closed fractures so they are treated with the relevant protocols[9, 50, 51]. Unstable fractures require an appropriate method of surgical stabilization; those that can be controlled easily may be treated non-operatively. High velocity fractures treatment is based on the open fracture protocols. The risk of infection and compartment syndrome in these injuries is extremely high and makes external fixation with or without fasciotomy the mainstay of primary fracture stabilization[52]. Ballistic fractures of the fibula and tibia are at increased risk for developing a compartment syndrome over others, especially those associated with the proximal aspect of the bone or with vascular injury[53].

Soft tissue injuries. Low velocity injuries are associated with low damage of the soft tissue. These traumas can be managed just with superficial debridement and they are left to heal in secondary intention. In case that the bullet cannot be palpated subcutaneously it should be left in situ; the risk of infection or lead poisoning[54] is extremely low[3]. High velocity wounds are associated with major soft tissue damage so they require more aggressive debridement and constant reevaluation[55]. Excision of the foreign materials and the devascularized tissue must be done, but the surgeon must always have in mind that the over-aggressive treatment can lead to greater disability than that caused by the bullet[56, 57].

Prophylactic measures. There has been a great debate over the last 3 decades about the issue of prophylactic antibiotic treatment in ballistic injuries[58-60]. It has been claimed that there is no difference in infection rates in low-energy gunshot fractures treated with intravenous antibiotics as compared to oral antibiotics[61]. It has been even claimed that no difference is observed in the infection rates of patients with low-energy gunshot fractures treated with or without antibiotics[60, 62]. For trauma patients sustaining penetrating abdominal wounds, current guidelines recommend a single preoperative dose of prophylactic antibiotics with broad-spectrum aerobic and anaerobic coverage as a standard of care[63]. Absence of a hollow viscus injury requires no further administration. The concepts of preventive antibiotic usage for penetrating chest trauma are controversial. Some authors showed benefits for antibiotic prophylaxis for patients from the insertion of a chest tube until

its removal[64, 65]; others showed the same results for single shot therapy and prolonged treatment[66].

However, the general belief is that gunshot injuries with bowel injury, penetrating craniocerebral injuries or high-energy gunshot injuries with moderate to severe soft tissue destruction require immediate intravenous antibiotic treatment [58, 67, 68]. In gunshot injuries having penetrated the head, broad spectrum antibiotics should be administered as fast as possible.

CONCLUSIONS

Craniocerebral injuries are often lethal, especially after suicide attempts. A correlation has been described between the patient's GCS and the final outcome. The evacuation of a haematoma can be an action of critical importance. Neck injuries need immediate treatment when major cardiovascular or respiratory structures of the area are damaged; the treatment techniques include occlusion, bone stabilization and debridement of soft tissues. The most threatening situations correlated with chest wounds are haemo-pneumatothorax, pneumothorax in tension and cardiac tamponade; the insertion of a chest tube is life-saving at many cases. Abdominal traumas need immediate laparotomy in case of haemodynamic instability, peritonitis and evisceration; the rest of the patients may be treated even conservatively. Spinal wounds are encountered in the second phase; incomplete neurological deficits must be treated operatively. The use of steroids is not recommended. As far as the bony injuries are concerned, the treatment of low energy fractures is based at closed fractures protocols, while high energy fractures are considered as open fractures. Low velocity soft tissue wounds are treated only with superficial debridement, while injuries created from high velocity guns require aggressive debridement and several second look surgeries. The use of prophylactic antibiotic treatment remains a controversial issue; despite that, there is general consensus that gunshot injuries with bowel injury, penetrating craniocerebral injuries or high-energy gunshot injuries with moderate to severe soft tissue destruction require intravenous antibiotic treatment.

CONTRIBUTIONS

Evanthia Georgala and Triantafyllio Andreiomenou also participated in the completion of this paper. EG performed philological correction of the manuscript and TA carried out the design correction of the final paper.

CONFLICT OF INTEREST STATEMENT

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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