Bullet Trajectories in Maxillofacial Injuries: Understanding the Pathways of Damage

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Abstract

Ballistic injuries to the maxillofacial region present unique challenges in both emergency management and long-term rehabilitation. These injuries result from the high-velocity impact of projectiles such as bullets or shrapnel, causing complex wounds that involve bones, soft tissues, and often adjacent structures crucial for facial aesthetics and function. This abstract reviews the current understanding and management strategies for ballistic injuries specifically affecting the maxillofacial region. The primary focus is on the pathophysiology of such injuries, emphasizing the mechanisms of tissue damage and the immediate and delayed complications that can arise. Special attention is given to the assessment of injury severity, including the role of advanced imaging modalities in accurate diagnosis and surgical planning.

INTRODUCTION

One of the most frequent causes of severe injuries is citizen gun ownership. The majority of the knowledge pertaining to gunshot wound (GSW) injuries and treatment came from firsthand experience gained throughout the 20th century's main conflicts. The guidelines that are in place were created during a time when military use was the only option for high-velocity rifles and deforming bullets, which cause more significant tissue damage. However, the nature of domestic GSW injury has altered due to advancements in weapons technology and the easier access to military-grade weaponry for civilians, making clinical decision-making more difficult[1].

Even in trauma centers with high patient volumes, where GSWs are more common, anecdotal evidence still plays a major role in treatment decisions. There's a widespread misconception that the bullets can be sterilized by the heat generated when gunpowder ignites during firearm discharge. In order to refute this idea, Wolf et al. coated bullets with a little quantity of S. aureus, fired them into sterile ballistics blocks, and then cultured the same S. aureus from the bullet tracts[2].

The literature also lacks comprehensive guidelines for managing retained bullets and large data sets. Only 14.5% of surgeons who responded to a survey in 2022 stated that their organizations had bullet removal protocols[3]. Many medical professionals think that in every situation, complete debridement and bullet removal are necessary. However, the precise tissue involvement and presentation of the injury vary greatly and determine the type and extent of intervention.

Frequently, formal debridement and bullet removal are not required and can result in more tissue damage or consequences including infection or iatrogenic Citizens' possession of firearms is one of the most common causes of serious injuries in the United States An estimated 120,232 gunshot injuries occurred annually from 2009 to 2017. Most of the information on gunshot wound (GSW) injuries and treatment was gathered from personal experience throughout the major conflicts of the 20th century.

Face trauma surgeons face a special and difficult problem when dealing with ballistic injury patterns to the cranio-maxillofacial area. Even the most skilled facial trauma specialist may find it difficult to identify typical anatomic planes because they may be lost in the blood and destroyed soft and hard tissues that result from ballistic injuries to the head and neck region.

HISTORY

Although there have been significant advancements in the field of wound ballistics since the 1830s, it wasn't until the 1870s that Kocher developed a hydrodynamic theory to explain the effects of gunshot wounds.

La Garde also studied the catastrophic injuries caused by high-velocity rifle bullet strikes, which were referred to as the "explosive effects" of rifle bullets.

FIREARMS AND AMMUNITION

A firearm is a weapon that uses extremely flammable, gas-producing gunpowder to shoot a projectile. This covers what are known as small arms, which include rifles, pistols, and shotguns[4].

The breech (the chamber where the bullet is seated and from which the combustive reaction is started), the barrel (which serves as the projectile's guide), and the handling section (stock) make up the basic anatomy of small arms, which are comparatively simple mechanical devices. The length of the barrel and the amount of pressure the breech can sustain serve as major distinguishing factors amongst small guns. Gunpowder combustion produces extremely high pressures (50,000–60,000 psi), which is why rifles are shoulder-fired weapons.

The word "ammunition" refers to full cartridges that hold a firearm's projectile, also known as a bullet. More appropriately, ammunition for rifles and pistols is referred to as a cartridge or round, which comprises the bullet as well as the primer, propellant (gunpowder), and casing[5].

The bullet known as an FMJ bullet is a nonexpanding solid bullet with a sharp tip and a thin metal jacket (typically made of copper). The military forces of the United States utilize these bullets. FMJ bullets are designed for three purposes. First, solid and expanding bullets typically weigh the same for a given caliber. Over the past 150 years, military rifles have changed to smaller calibers with lighter, quicker bullets that fly more steadily.

Projectiles and weapons are typically divided into two categories: high-velocity (such as rifle bullets or

explosive fragment missiles > 2000 f/s) and low-velocity (shotgun and pistol rounds, typically < 2000 f/s)[6].

There are five general categories of small arms: handguns, rifles, shotguns, submachine guns, and machine guns.

There are four basic types of handguns:

1. Single-shot pistols
2. Derringers
3. Revolvers
4. Auto-loading pistols (automatics)

Cartridge cases are classified into five types according to the configuration of their bases:

- Rimmed
- Semi-rimmed
- Rimless
- Rebated
- Belted

HARD TISSUE INJURIES AND THEIR MANAGEMENT

According to research on patterns and trends in injuries received in low-intensity military conflict scenarios, injuries to the extremities account for 73% of all injuries, followed by injuries to the head and neck (22%), thorax, and abdomen (5%). Ballistic projectiles and GSWs are their most frequent cause (41.4%), followed by blasts from improvised explosive devices (IEDs) that cause splinter and shrapnel injuries (39.2%).Low-intensity conflicts (LICs) have replaced conventional warfare as the more common kind of conflict.

SOFT TISSUE INJURIES IN MAXILLO-FACIAL REGION

One of the most frequent injuries to the head and neck region are soft tissue injuries, which are particularly common in emergency rooms and surgical casualties. Both separate soft tissue injuries and injuries with concurrent bone trauma are possible. Burns, bites, avulsions, contusions, and simple cuts are among the common soft tissue injuries on the face(Fig no.1).

The presence of important anatomical structures like muscles, ducts, arteries, and nerves complicates these injuries. Soft tissue injuries are made more complicated by the presence of hemorrhage and foreign debris. The face is an area with significant aesthetic and functional value. Thus, a variety of factors have a role in the management of these injuries.

The most frequent cause of soft tissue injuries in the face varies depending on the age, sex, and geographic location of the population. Depending on the underlying cause, some regions of the head are more likely to experience facial soft tissue injuries. The forehead, nose, lips, and chin make up the T-shaped area that is usually included, followed by the occiput and anterior temporal regions.

The most common etiology are:

a) Fall
b) Non Fall Impacts
c) Assaults
d) Road Traffic Accidents
e) Sporting Injuries
f) Others include occupational injuries, bites from humans or animals, and other miscellaneous causes

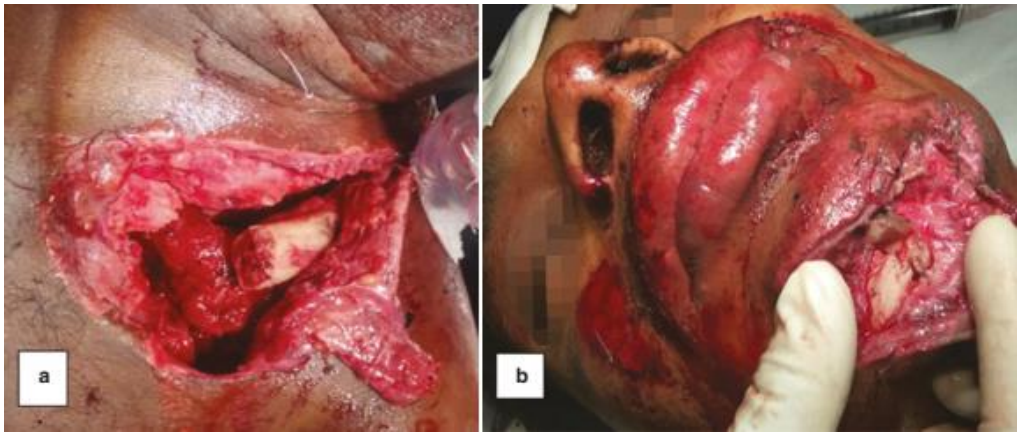

Figure 1: (a) Showing open wound where fractured left clavicle is visible from the wound surface. (b) Open wound of maxillofacial region where underlying mandible

CLASSIFICATION OF SOFT TISSUE INJURIES

(A) **Based on mechanism of injuries**

(I) Mechanical or physical injuries:

- When injury is caused due to blunt force:
  1. Abrasions
  2. Contusions
  3. Lacerations
- When injury is caused due to sharp force:
  1. Incised wounds
  2. Chop wounds
  3. Stab/punctured wounds

(II) Thermal injuries:

- Due to excessive cold: e.g., frostbite
- Due to moist heat: e.g. burns and scald wounds

(III) Chemical injuries: Due to corrosive acids and alkalis

(IV) Miscellaneous: Electricity, lightning, etc.

(V) Explosions: Blast injuries

(B) **Legal Classification**

1. Simple - soft tissue injuries without much tissue loss and can be managed conservatively. Heals rapidly without any permanent deformity.

2. Grievous injuries - described under Section 320 of Indian Penal Code as any injuries that endanger life and cause severe disfigurement or deformities like permanent hearing loss, vision loss, and severe head injuries. Tooth fracture or tooth loss following a blow in an interpersonal violence is also considered a grievous injury and penalized by the court of law. These injuries heal slowly and incompletely.

3. Dangerous - the grievous injuries that endanger life immediately after impact

COMMON SOFT TISSUE INJURIES

The common clinical presentation of soft tissue injuries included abrasions, contusions, and lacerations.

Figure 2: Showing multiple abrasions over face involving the supraorbital region nose, upper lip and chin

Figure 3: Showing contusion wound over right cheek and periorbital ecchymosis of right eye. The color changes can be appreciated intraorally

Figure 4: Showing split lacerated wound over nose, columella, lower lip and chin

Figure 5: Showing incised wound extending from dorsum of the nose till preauricular region caused by knife in case of assault

1. Abrasions - (also known as gravel rash) -It is destruction of the superficial layer of skin only. It is caused by frictional forces that are light enough to erode only the superficial layer of epidermis (Fig no.2).

2. Contusions (bruising) -This is effusion of blood into the tissues, due to the rupture of small blood vessels at the site of impact. There is no destruction of the superficial layer of skin (Fig no.3).

3. Lacerations-It is the tear or split of skin, mucous membrane, muscle, or internal organs produced by the application of blunt force to a broad surface area, which crushed or stretched tissues beyond the limits of their elasticity. They can be split lacerations , stretch lacerations, shearing lacerations, and cut lacerations(Fig no.4).

4. Incised wounds—The wound is longer than it is deep. It is caused by the pressure and friction of any sharp object against the soft tissues(Fig no.5).

5. Chop **wounds (slash wounds)**—They are deep bigger wounds with gaping caused by a blow with the sharp cutting edge of a heavy weapon, like an axe or chopper.

6. Stab or punctured wounds—Produced when the force is delivered along the long axis of a narrow or pointed object, such as knife, sword, chisel, scissors, nail, needle, spear, arrow, screw driver, etc. into the depths of the body. This type of wound is deeper than its length and width.

7. Crush **injury**—A crush injury typically occurs when the body part is crushed between two heavy blunt objects. Most severe trauma cases will have this type of injury.

Crush injuries have ragged edges, varying amounts of devitalized tissue, and, sometimes, tissue loss.

8. Avulsion **injuries**—These involve significant tissue loss. Avulsion can be considered a very severe form of abrasion, wherein all layers of skin are torn off and the underlying structures are grossly exposed. The term avulsion can also mean complete loss of a small body part such as eyelid, fingertip, part of ear, etc

DIAGNOSIS AND IMAGING

Initial imaging assessment of gunshot wounds (GSWs) typically occurs with radiographs in the trauma bay. It is good practice for the trauma team to mark each surface wound with a radiopaque marker, which provides the radiologist with information from which bullet trajectory can be inferred.

Trauma bay Focused Assessment with Sonography in Trauma (FAST) scan is used to evaluate for intraperitoneal and pleural free fluid, pericardial effusion, and pneumothorax and is typically performed by the trauma team.An unstable patient with a positive FAST scan should be taken to operating room for damage control surgery.[7]

Computed tomography (CT) is the most sensitive and specific modality with which to identify and evaluate ballistic injuries.[8] It is fast and provides excellent spatial resolution, allowing identification of all but the most subtle injuries. In stable and semistable patients, CT is the gold standard of evaluation. Although there are numerous CT scanning protocols proposed in the literature,[9] by consensus the authors of this article advocate the protocol in phase or CT cystography based on the ‘‘at the scanner’’ radiologist review of the initial imaging.

Magnetic resonance imaging (MRI) has no proven utility in the initial assessment of GSW but can be useful in the stable patient for evaluating the spinal cord, hepatobiliary system, brachial plexus, and brain parenchyma.

RECENT ADVANCES

Recent Advances in Soft Tissue Management

1. Use of growth factors - intimate role in the regulation of all phases of wound healing, i.e., chemotaxis, proliferation, matrix synthesis, inflammation, and angiogenesis. The enhancement of soft tissue wound healing can be done by various methods. Topical application of growth factors in a vehicle or by direct seeding of cells topically on the wound can enhance healing. Placement of growth factors or cells can also be done with a fibrin sealant or glue. Use of platelet-rich plasma (PRP) by degranulation of platelets with the secretion of its contents of growth factors into the surrounding fibrin matrix or, more recently, use of tissue-engineered equivalents of skin or mucosa can provide a scaffold that enhances healing.

2. Gene and stem cell therapy - in which the gene encoding for the therapeutic growth factor or protein is directly transfected into host cells. This is a promising approach for the treatment of acute and chronic wounds.

3. Tissue engineering - In 1987, the National Science Foundation bioengineering panel defined tissue engineering as "the application of the principles and methods of engineering and the life sciences toward the development of biologic substitutes to restore, maintain, or improve function."

Advances in management of gunshot injuries

Advances in Closed Reduction

MMF has a long history in the treatment of facial fractures dating back to 460 BC when Hippocrates used gold wire to fixate teeth for a mandible fracture.1 Over the years there have been many modifications, including Barton bandage, suspension wires, Ivy loops, arch bars, MMF screws, and embrasure loops.[10] Erich arch bars (Karl Leibinger Co, Mulheim, Germany) continue to be the most commonly used technique. MMF screw fixation has the benefit of speedy application, decreased risk of puncture injury to the surgeon, less damage to the periodontium, and simple application and removal. Their use is not without complications. The most commonly reported complications include screw loosening, iatrogenic damage to tooth roots, screw fracture, and ingestion. A combination between MMF screws and arch bars known as hybrid systems are the newest advances to closed reduction. Commonly used systems include the SmartLock System Hybrid MMF (Stryker, Kalamazoo, MI), the MatrixWave (DePuy Synthes West Chester, PA), and the OmniMax MMF System (Zimmer Biomet, Jacksonville, FL).

These systems are approved by the Food and Drug Administration for use in adults and children with fully erupted permanent dentition as a temporary means of fixation.These systems allow expeditious placement associated with MMF screws while maintaining lugs at crown level, allowing traction vectors closer to the occlusal table. Potential complications are similar to those of MMF screws. Although the hybrid systems are much costlier than Erich arch bars, Kendrick and colleagues' cost analysis of the Stryker SmartLock system versus traditional arch bars found no difference when accounting for operating room time, cost, and time saved.

Advances in Open Reduction

Virtual surgical planning/Stereolithography Among the greatest technological advances in craniomaxillofacial (CMF) surgery is computer-aided CMF surgery. Bell divides computer-aided CMF surgery into 3 main categories:

(1) computer aided presurgical planning,

(2) intraoperative navigation, and

(3) intraoperative computed tomography (CT)/MRI imaging.

Navigation/intraoperative computed tomography

The digital workflow makes it possible to visualize the entire mandibular and facial skeleton, which is somewhat unrealistic. Unfortunately, these conditions do not translate directly to the operating room. Blood, edema, and avulsive soft and hard tissue defects can make it difficult to see appropriate landmarks for repair. A custom-fabricated plate that looks perfect during VSP can result in malocclusion, facial asymmetry, and poor bony adaptation if the implant does not seat in its exact planned position.

CONCLUSION

In conclusion, ballistic injuries to the maxillofacial region present complex challenges that require a multifaceted approach to management and treatment. These injuries often involve significant trauma to both soft tissues and bone structures, leading to complications such as impaired function, aesthetic concerns, and increased risk of infection. Effective treatment typically necessitates a combination of surgical intervention, reconstructive techniques, and comprehensive rehabilitation to address both the immediate and long-term effects of the injuries.

The complexity of these injuries underscores the importance of an interdisciplinary approach involving maxillofacial surgeons, reconstructive specialists, and rehabilitation experts. Advances in surgical techniques, including the use of advanced imaging and biomaterials, have improved outcomes and facilitated more effective management of these injuries.

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