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Review Article

Fundamentals of ballistics for the treatment of firearms injuries in reconstructive surgery

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ABSTRACT

Firearm injuries constitute a significant global public health challenge, whit more than one billion firearms in circulation and an estimated 600 daily fatalities. This review explores fundamental ballistics concepts and their relevance to injury mechanisms. It highlights the critical role of kinetic energy and projectile behaviour, such as velocity, trajectory, and design, in determining injury severity. High velocity firearms, expanding bullets, and shotgun shells create complex injury patterns, emphasizing the emphasizing the importance of distinguishing between permanent and temporary cavities during clinical assessment. The knowledge of ballistic principles is indispensable for plastic and reconstructive surgeons managing firearm injuries. Understanding projectile and tissue interactions informs precise surgical planning for soft tissue and bone reconstruction, enhancing patient outcomes. This expertise is essential in addressing the rising number of firearm related cases in region whit prevalent armed violence such as Mexico. Continuous integration and updating of ballistic knowledge in surgical practices are vital to improving care and minimizing long term sequelae in affected patients.

Keywords: Firearms, Injuries, Reconstructive

INTRODUCTION

There are more than one billion firearms in circulation in the world. Eighty-five percent are in the hands of private individuals, 13% in military arsenals and 2% in the hands of security forces.[1] It is estimated that more than 600 people die every day as a result of firearm injuries; two thirds of these injuries occur in only 6 countries: Brazil, United States, Venezuela, Mexico, India and Colombia.[2]

In Mexico, according to INEGI data, in 2022, there were 24,000 homicides, of which 71% were executed with firearms. Most of the victims are young men between 18 and 35 years of age. Firearm injuries leave a lasting impact on mental and physical health. Some victims require lifelong medical follow-up, while others may be permanently disabled.[3,4]

The increase in firearm injuries overburdens Mexico's health care system in some states, requiring prolonged stays, multiple procedures and considerable increases in the cost of care.[5,6]

The knowledge acquired regarding firearm injuries derives mainly from experience in the great wars of the 20th century, so that some concepts are outdated and of little use today, given the constant evolution of weaponry. Most treatment guidelines were created when high-velocity

weapons were predominantly for military use. However, today their use by criminal organizations and civilians is increasingly common.[1]

BASIC CONCEPTS

The path of a firearm projectile is studied in terms of internal, external and terminal ballistics. Firearms can be classified in many ways, including shape, action and ammunition type. According to the velocity of the projectile, weapons can be classified as low velocity and high velocity (Figure 1).

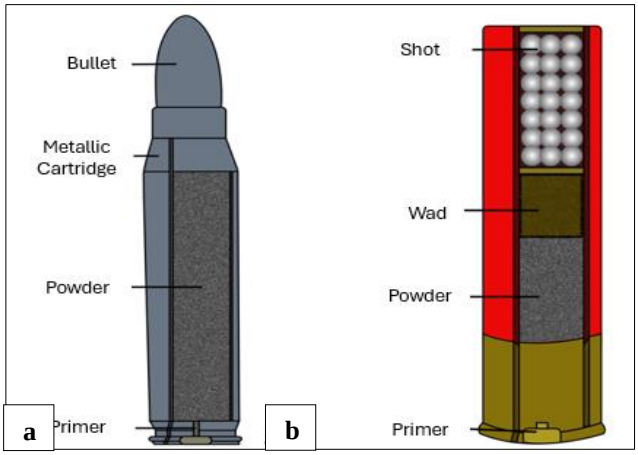

Figure 1: General appearance and components of different types of ammunition (a) high velocity/energy cartridges, and (b) low velocity/energy bullets.

High velocity

These are those that expel projectiles with an initial velocity (velocity of the projectile at the moment it leaves the barrel of the weapon) of more than 600 meters per second. Examples include assault rifles, sniper rifles and heavy machine guns (700–1000 m/s).

Low velocity

Corresponds to weapons with an initial velocity of less than 600 meters per second (common pistols). Shotguns are considered low velocity weapons. However, their projectiles have a behavior that differs considerably from others. In the classification of weapons, it is convenient to consider velocity. However, this variable omits several factors to be considered. When a low velocity weapon is fired at a short distance, it behaves like a high velocity weapon, due to the energy transferred. Therefore, in addition to velocity, it is important to consider the amount of kinetic energy transferred to evaluate injuries.[8]

Law of kinetic energy

Kinetic energy is the energy an object has due to its motion and is proportional to half the mass of the body multiplied by the square of the velocity of motion.

$$KE = 1/2\, mv^2$$

The amount of energy transferred depends on multiple factors such as: stability of the projectile, the amount of wobble (angulation of the projectile in relation to the long axis of the bullet). The caliber, material, type of tissue impacted, trajectory inside the body. Therefore, in firearm projectile injuries, it is much more useful to describe them as low or high energy injuries.

Internal ballistics

It studies the behavior of the projectile inside the weapon from the chamber to the tip of the barrel. It is influenced by the type of powder, primer and other characteristics of the ammunition, as well as the chamber, rifling, choke (material constriction), barrel length and other engineering properties of firearms. Technical advances in internal ballistics have made it possible to increase the velocity, energy and accuracy of projectiles. Bullets are available in a wide range of materials, sizes, shapes and designs that affect flight behavior, wobble, kinetic energy, penetration capability and injury potential (Figure 2). They are primarily composed of lead. However, high barrel temperatures cause them to deform, so they are commonly produced with lead alloys or coated with copper or alloys, referred to as jacketed bullets.

Figure 2: Types of ammunition, from left to right 0.50 caliber Barrett rifles, 7.62 mm, NATO, AK47, 5.56 mm, M16, 45 mm and 9 mm, used in low velocity guns.

External ballistics

The path of the projectile between the weapon and contact with the target is called external ballistics. The type of bullet, casing, length, and caliber are the main factors that influence its behavior. The main movements that determine the stability of the projectile are: yaw, precession and nutation (Figure 3). Wobble is defined as the variation of movement according to the longitudinal axis of the projectile, precession is the gyroscopic movement around the axis of the projectile and nutation is

the circular movement of the tip of the projectile along the axis of its trajectory.[9]

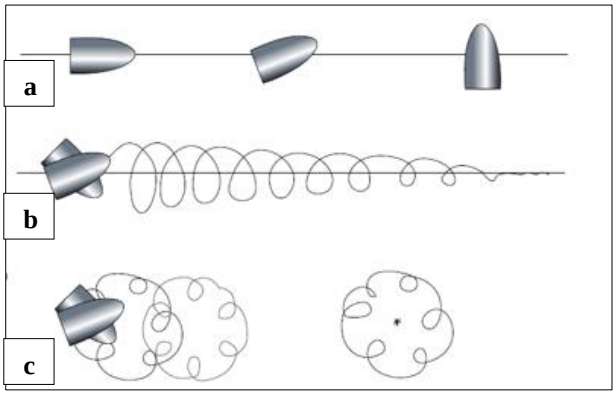

Figure 3: Examples of different movements of ammunition (a) yaw, is the movement around its longitudinal axis, (b) presession, describe small circular movement, and (c) nutation, oscillation related to the stability of the rotation.

The rotation caused on its own axis secondary to the rifling of the barrel improves stability and accuracy, and also reduces the drag force, which is the action of gravity pulling the bullet to the ground.[7]

The distance between the weapon and the target as well as the initial velocity play an important role in injury potential. High velocity weapons retain large amounts of kinetic energy over short distances, while low velocity weapons lose energy substantially over short flight paths. Drag force is determined by the shape, size and in-flight behavior of the bullet. A bullet, ideally in flight, should have minimal wobble, tumble and roll. This maximizes the kinetic energy accumulated before impacting the target. The wobble and tumble increase the drag force (tumble) and decrease the kinetic energy (KE).

Terminal ballistics

Its study is the most important for reconstructive surgeons. It evaluates the behavior of the projectile in relation to that of the tissue in response to the projectile, the tissue and the injury. Bullets, according to their behavior, can be classified as expansive or non-expansive. Non-expansive or non-deformable bullets have greater penetration, less damage contiguous to the trajectory and are more likely to find an exit orifice.[8] In contrast, expansive or deforming bullets immediately expand on impact, increasing the contact surface, resulting in greater cavitation and rarely exit. This type of projectile causes great defects and sequelae, which is why, in the 1899 Hague Convention of 1899, their use in wartime was prohibited. Even with the above, several law enforcement agencies have opted for expanding or hollow point bullets, because they reduce collateral damage such as potentially injuring another person by not having an exit orifice.[8]

Shotgun shells have a unique and complex behavior, as they disperse into multiple small projectiles that scatter before impact.

Mechanism of injury

The injury process of a firearm projectile depends on multiple factors, such as caliber, velocity and design of the projectile, as well as distance and angle of fire, and can be divided into 2 types.[10,11]

Perforating

The projectile penetrates and exits through an exit wound.

Penetrating

Associated with low velocity projectiles. This is when the projectile penetrates but has no exit wound.

The interaction of the projectile with the tissue considers mainly two main regions of injury. The permanent cavity is the final injury and corresponds to the central area of tissue disruption in the final path of the projectile (Figure 4). The temporary cavity is generated when the projectile transfers its kinetic energy, creating a pressure area and causing a transient expansion of the tissues.[11] The temporal cavity can injure nearby tissues even if the projectile does not pass directly through them. The higher the velocity, the greater the pressure wave that directly affects the surrounding tissue, depending on its density and elasticity. Solid organs and tissues such as bone, liver, spleen, kidney and brain have low distensibility and are more sensitive to injury.[7,10,12]

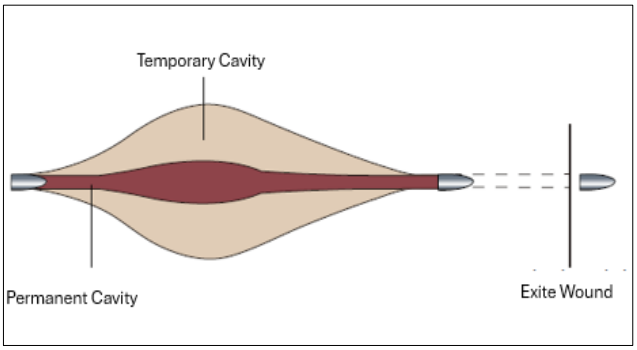

Figure 4: Example of a high energy wound.

The projectiles do not follow a linear trajectory within the tissue; they are subjected to rotational forces that produce wobbling or yaw as they decelerate, which increases the diameter of the lesion. Due to this behavior, the exit orifice is usually considered to have a larger diameter than the entrance orifice.[13]

While the kinetic energy determines the penetration capacity of the projectile. The capacity of injury depends

on the organs impacted by the projectile. Tissues have variations in density, elasticity and resistance.[14]

When the projectile passes through the skin, it displaces the tissue radially in a centrifugal fashion. High-energy projectiles create temporary cavities up to 10–30 times the size of the permanent cavity, while low-energy projectiles create permanent cavities very similar in size to the temporary ones.[12,14]

CONCLUSION

It is important to update and keep in mind the knowledge of ballistics and firearms injuries, a crucial topic in the current context of armed violence, especially in countries such as Mexico. A thorough understanding of the effects of different types of projectiles and their trajectories allows plastic and reconstructive surgeons to more accurately assess the damage caused. This information is essential for planning complex surgical interventions, ranging from soft tissue reconstruction to bone repair. This knowledge is essential not only for immediate care, but also for long-term follow-up, which improves functional outcomes and reduces sequelae in patients with firearm injuries. The integration and updating of ballistic concepts in the practice of plastic and reconstructive surgery is indispensable to effectively address the growing number of cases and provide more precise and personalized care to patients.

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REFERENCES

1. Denonville O, Kosirnik L, Lazaro K. Small Arms Survey, Annual Report. Geneva, Switzerland. 2023. Available at: https://www.smallarmssurvey.org/highlight/small-arms-survey-annual-report-2023. Accessed on 23 October 2024.
2. Institute for Health Metrics and Evaluation (IHME). Global Burden of Disease 2021: Findings from the GBD 2021 Study. Seattle, WA: IHME. 2024. Available at: https://www.healthdata.org/research-analysis/library/global-burden-disease-2021-findings-gbd-2021-study. Accessed on 23 October 2024.
3. Cook PJ, Lawrence BA, Ludwig J, Miller TR. The medical costs of gunshot injuries in the United States. JAMA. 1999;282(5):447-54.
4. Instituto Nacional de Estadística y Geografía (INEGI). Homicide deaths from January to December 2023 (preliminary). 2023. Available at: https://www.inegi.org.mx/app/saladeprensa/noticia/9207. Accessed on 23 October 2024.
5. Secretaría de Salud. Epidemiological Bulletin National Epidemiological Surveillance System Single Information System. 2023. Available at: https://www-gob-mx.translate.goog/salud/documentos/boletinepidemiologico-sistema-nacional-de-vigilancia-epidemiologica-sistema-unico-de-informacion. Accessed on 23 October 2024.
6. Hernández-García Adriana, Trueba-Lozano Demian, Vázquez-Minero Juan C. The cost of care for abdominal vascular injuries caused by firearm projectiles. Its impact on the patient, their family and the hospital. Cir Cir. 2020;88(4):467-72.
7. Giannou C, Baldan M. War surgery: working with limited resources in armed conflict and other situations of violence - Volume 1. Ginebra, Suiza. 2011.
8. Baum GR, Baum JT, Hayward D, Mackay BJ. Gunshot Wounds: Ballistics, Pathology, and Treatment Recommendations, with a Focus on Retained Bullets. Orthop Res Rev. 2022;14:293-317.
9. Magaña Sánchez IJ, Javier Torres Salazar J, Manuel García-Núñez L, Núñez-Cantú O. Basic concepts of ballistics for the general surgeon and its application in the evaluation of abdominal trauma. Cir Gen. 2011;33(1):48-53.
10. Volgas DA, Stannard JP, Alonso JE. Ballistics: A primer for the surgeon. Injury. 2005;36:373-9.
11. Stefanopoulos PK, Pinialidis DE, Hadjigeorgiou GF, Filippakis KN. Wound ballistics 101: the mechanisms of soft tissue wounding by bullets. Eur J Trauma Emerg Surg. 2017;43:579-86.
12. Von See C, Bormann KH, Schumann P, Goetz F, Gellrich NC, Rücker M. Forensic imaging of projectiles using cone-beam computed tomography. Forensic Sci Int. 2009;190(1-3):38-41.
13. Maiden N. Ballistics reviews: Mechanisms of bullet wound trauma. Forensic Sci Med Pathol. 2009;5:204-9.
14. Jussila J, Kjellström BT, Leppäniemi A. Ballistic variables and tissue devitalisation in penetrating injury - Establishing relationship through meta-analysis of a number of pig tests. Injury. 2005;36(2):282-92.

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