EXPERIMENTAL STUDY

Experimental wounding models of different bullet types and diameters on extremities

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ABSTRACT

BACKGROUND: Gunshot wounds are the second leading cause of life-threatening injuries and frequently affect the extremities, accounting for 63% of combat-related cases over the past 50 years. Although extremity injuries have lower mortality rates, they still require urgent treatment to reduce complications. Wound ballistics studies often use tissue surrogates like ballistic wax and gelatin, which have limitations due to their dissimilarity to living tissues. There is insufficient data on the effects of gunshots on extremities composed of bone and muscle, which differ in resistance and elasticity. This study aims to analyze the damage caused by commonly used ammunition in living tissue and provide healthcare professionals with critical insights to improve emergency care.

METHODS: The study involved six Adana-breed sheep, aged 3-4 years, previously used in another study and showing no vital signs. Ethical approval was obtained from the local ethics committee. Test shots were conducted using 9×19 mm (M822), 5.56×45 mm (SS109), and 7.62×51 mm (M80) bullets from a distance of 300 cm, targeting the front legs of sheep positioned laterally. Following the shots, entry and exit wounds were photographed, and anteroposterior and lateral X-ray images of the extremities were taken for analysis. The aim was to examine the effects of different types of ammunition on extremities and provide insights into the characteristics of gunshot wounds.

RESULTS: In the first test group (subjects A and B), X-ray imaging revealed joint integrity loss, multi-part fractures, and cavitation in the soft tissue, with bone fragments distributed along the exit trajectory. No bullet fragments were found within the wound cavity. The M822 bullet produced a typical entry wound and a smaller, more defined exit wound. In the second group (subjects C and D), SS109 bullets caused fragmentation of bone, muscle, tendon, and skin. Bullet fragments created a shrapnel-like effect. The exit wounds were larger and had irregular edges. In the third group (subjects E and F), M80 bullets caused extensive tissue disruption due to their high kinetic energy. The resulting exit wounds were wide and irregular.

CONCLUSION: This study found that M80 bullets caused the most severe bone and soft tissue damage compared to M822 and SS109 bullets, primarily due to their higher kinetic energy density and structural characteristics. Unlike prior research using synthetic tissue models, this study demonstrates the real-tissue effects of different ammunition types. Radiologists, forensic medicine experts, and other healthcare professionals should be aware that firearm injuries vary depending on the bullet's characteristics. Applying this understanding can lead to appropriate diagnoses and improved treatment strategies, ultimately enhancing patient outcomes.

Keywords: Gunshot wounds; terminal ballistics; wound ballistics; extremity injuries.

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INTRODUCTION

Globally, firearms are a leading cause of life-threatening injuries, second only to traffic accidents.[1] In 2016, approximately 251,000 deaths were attributed to firearm injuries worldwide, compared to around 209,000 in 1990. In Türkiye, 2,790 people died from firearm injuries in 1990, while the number decreased to 2,430 in 2016.[2] In the United States of America, which has the highest rate of civilian gun ownership, the number of deaths due to firearms was 39.740 in 2018,[3] 39,707 in 2019, 45,222 in 2020, 48,830 in 2021,[4] and 48,117 in 2022,[5] resulting in a total of 221,616 firearm-related deaths over five years. In Türkiye, 376 of the 1,433 murder cases (26%) investigated by the Gendarmerie General Command involved firearms.[6] An analysis of firearm-related injuries sustained during wars over the past 50 years reveals that 63% of these injuries, classified by primary anatomical zones and region, occurred in the upper and lower extremities.[7]

The damage caused by a bullet to a target varies depending on several factors, including the bullet's structure, velocity, kinetic energy density (the amount of kinetic energy applied per unit area), effective kinetic energy (the amount of kinetic energy transferred to the tissue), ballistic constant, gyroscopic stability at the moment of impact, tissue flexibility, and the threshold velocity of the tissue at the impact location.[8]

Gyroscopic stability is defined as the ratio of the angular velocity (w) imparted to the bullet by the rifling in the barrel to the linear velocity (v) generated by the combustion of gunpowder. This value is ideally close to or greater than "1" (Sg=w/v>1). When the bullet strikes the target, its linear velocity decreases rapidly and continuously due to the density of the material it encounters, while its angular velocity remains relatively unchanged. As a result, the bullet loses gyroscopic stability and begins to tumble.[8]

Since the difference between the diameter and length of the bullet increases the impact surface during tumbling, it alters the ballistic constant and the bullet's kinetic energy density. This, in turn, increase the amount of kinetic energy transferred to the target, which is also referred to as "effective kinetic energy," which determines the severity of the firearm injury.[9] The amount of kinetic energy adequately transferred to tissue varies depending on the bullet's velocity, weight, design, and the characteristics of the tissue at the point of impact.[10]

The bullet's ability to maintain its shape, mass, and kinetic energy density at the moment of impact, and to resist deformation upon hitting the target, depends on its structure and design. A high kinetic energy density at the moment of impact enables the bullet to penetrate deeper into the tissue, enhancing its capacity to neutralize the target. If the bullet is deformed or fragmented upon striking rigid structures such as bone tissue within the cavity, or due to the stress caused by tumbling, it may lose its gyroscopic stability. Similarly, if the bullet strikes a harder or denser intermediate target before reaching the tissue, it may begin to tumble or fracture before hitting the primary target.[11] In such cases, the kinetic energy density decreases, and most of the bullet's kinetic energy is transferred to the superficial layers of the tissue.[9,10]

The amount of effective kinetic energy is also a primary determinant of the volume of the transient cavity formed in the tissue. For example, the change in impact surface and the volume of the temporary cavity formed by the tumbling of a 9 mm bullet (M822 type; diameter: 8.97 mm, length: 15 mm), which has a slight difference between diameter and length (Fig. 1a), can be compared to the energy transferred to the tissue and the temporary cavity volume (Fig. 1b) formed by a high-kinetic-energy 7.62 mm bullet (M80 type; diameter: 7.82 mm, length: 28.6 mm), which has a more significant difference between diameter and length. The large temporary cavity formed in tissue by high-energy bullet, often referred to as the "blast effect" in the literature, is primarily due to the loss of gyroscopic stability.[12,13] The expansion and increase in the volume of the temporary cavity formed in the tissue continue even after the bullet exits the tissue. The extent of injury caused by this transient cavity depends on the elasticity limit of the affected tissue.[8,10]

This study aims to investigate the damage mechanisms of the M822-type bullet from the 9×19 mm cartridge, which has been the most common pistol caliber worldwide since 1901; the M80-type bullet from the 7.62×51 mm cartridge, the standard NATO (North Atlantic Treaty Organization) infantry and assault rifle caliber; and the SS109-type bullet from the 5.56×45 mm cartridge, focusing on their effects on soft and bone tissues of the extremities, where approximately 50% of gunshot wounds occur.

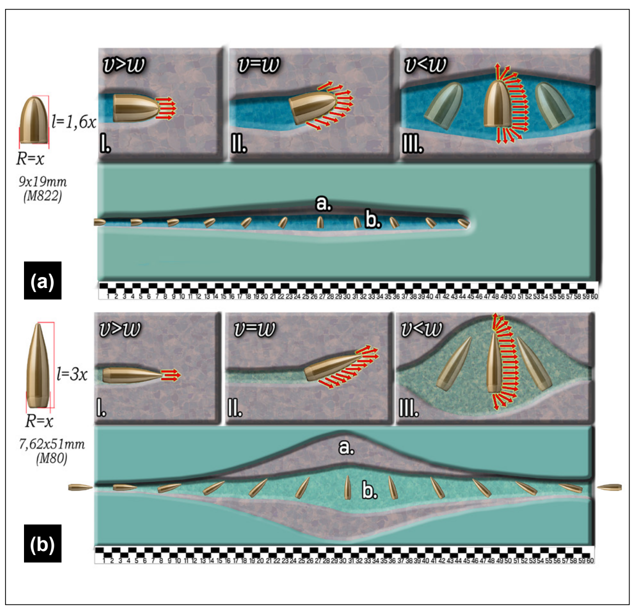

Figure 1. Temporary cavity mechanisms of 9 × 19 mm (M822 type) and 7.62 × 51 mm (M80 type) bullets in tissue. **(a)** Temporary cavity; **(b)** Permanent cavity; R: Bullet diameter; l: Bullet length.

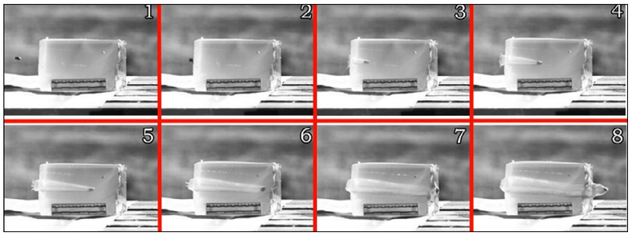

Figure 2. Temporary cavity formation of the 9 × 19 mm (M822-type) bullet in Ballistic Candle© (6,000 fps). *(High-speed camera images of wound ballistics experiments conducted by Ali İhsan Uzar, Mustafa Tahir Özer and Gökhan İbrahim Öğünç, 2015.)*

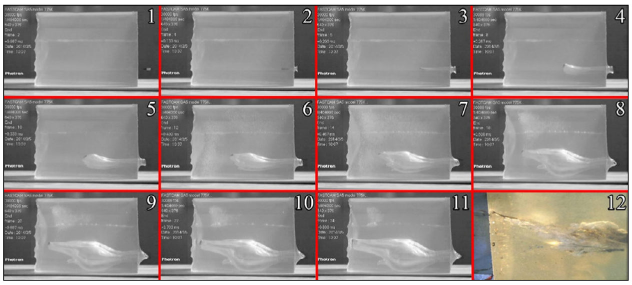

Figure 3. Temporary cavity formation of the 5.56 × 45 mm (SS109-type) bullet in Ballistic Candle© (30,000 fps). *(High-speed camera images of wound ballistics experiments conducted by Ali İhsan Uzar, Mustafa Tahir Özer and Gökhan İbrahim Öğünç, 2015.)*

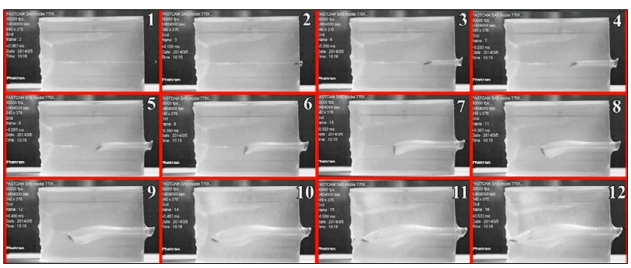

Figure 4. Temporary cavity formation of the 7.62 × 51 mm (M80-type) bullet in Ballistic Candle© (30,000 fps). *(High-speed camera images of wound ballistics experiments conducted by Ali İhsan Uzar, Mustafa Tahir Özer and Gökhan İbrahim Öğünç, 2015.)*

As noted in previous paragraphs, the "tumble" movement, which increases the amount of kinetic energy transferred to tissue and disrupts the bullet's structural integrity, also applies to the M822-type bullet. However, the low kinetic energy of the M822-type bullet compared to other bullets used in the tests, along with the minimal difference between its diameter and length, limits the size of the temporary cavity it creates (Fig. 2). If the M822-type bullet does not encounter a hard structure such as bone tissue, the likelihood of fragmentation is low. This observation has also been confirmed in experimental studies in the literature.[8,12,14]

The SS109-type bullet (diameter: 5.69 mm, length: 23 mm) is an improved version of the earlier M193-type ammunition and has become the standard NATO ammunition. A "steel penetrator" has been incorporated at the tip to enhance target penetration (Fig. 3). Its weight was increased (from 3.63 grams to 4 grams), and its velocity was reduced (from 990 m/s and 890 m/s±10 m/s) to improve gyroscopic stability. Additionally, modifications were made to its center of gravity and internal pressure. Due to its structural design, diameter-to-length ratio, and high velocity, the SS109 bullet begins to tumble upon encountering sudden resistance when it hits soft tissue and fragments before reaching deeper tissue layers. This results in a rapid transfer of kinetic energy to the surrounding tissue, creating a large temporary cavity. However, because the bullet does not penetrate deeply, its ability to neutralize the target is more limited compared to other bullets (Fig. 4, Table 1).[8,12]

As observed with the M80-type bullet tested in this study, bullets from long-barreled firearms begin to lose their gyroscopic stability after penetrating approximately 10-12 cm into soft tissue. This loss of stability initiates tumbling and the formation of a temporary cavity. After penetrating 20-30 cm, the diameter of the temporary cavity reaches its maximum (typically between 15-25 cm). If the cavity extends to a length of 40-45 cm, the bullet is likely to exit the tissue in reverse orientation. The M80-type bullet is one of the most effective designs in this regard; it retains high kinetic energy even at greater tissue depths and produces a significant destructive effect.[8,12]

Studies on gunshot wounds to the extremities in the literature primarily focus on case analyses and the development of treatment methods. Due to the complex nature of wound ballistics, experimental studies often utilize homogeneous and isolated tissue or extremity surrogate models, typically prepared using Ballistic Candle© or Ballistic Gelatin®.[15] In other experimental approaches, test firings are conducted on bare animal (porcine or sheep) or human extremity bones, as

Table 1. Technical specifications of the ammunition used in the tests (*measured values)

Caliber (mm)	Bullet Type	Average Muzzle Velocity (m/s) *	Bullet Diameter (mm)	Bullet Mass (g)	Bullet Sectional Density (g/mm²)	Kinetic Energy (J)	Kinetic Energy Density (J/mm²)
9×19	M822	370	8.97	8	0.14	548	8.67
5.56×45	SS109	885	5.69	4.03	0.18	1579	62.09
7.62×51	M80	840	7.82	9.446	0.22	3334	69.41

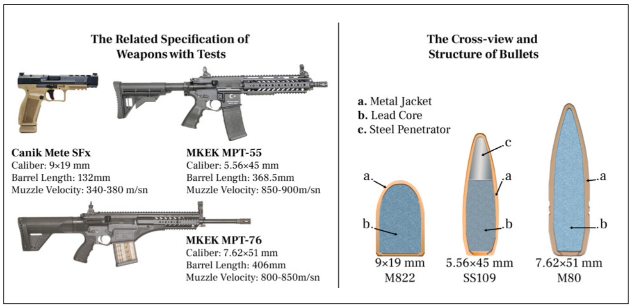

Figure 5. Specifications of the weapons and cross-sectional views and structures of the bullets used in the test fires.

well as synthetic bone surrogates.[16,17] Unlike these studies, the present research examines the effects of three different, commonly used bullet types and calibers under controlled conditions on sheep extremities, which are considered anatomically comparable to human extremities according to the literature. [10]

MATERIALS AND METHODS

Ethical Approval of the Study Protocol

This study was conducted according to the World Medical Association's ethical standards, the 1964 Helsinki Declaration, and its later amendments or comparable ethical standards. Ethical approval was obtained from the Çukurova University Local Ethics Committee (Approval number 5, date 20.07.2023).

Animal Grouping and Test Setup

The experiment was conducted on six sheep, aged between 3 and 4 years, divided into three groups of the Adana breed. These animals were previously used in another study and exhibited no vital signs. Test shots were performed on the front leg while the subjects were positioned on their right or left side.

Execution of the Test Fires

The test fires were carried out at the firing ranges of the Turkish National Police, Special Operations Division in Adana, under official authorization. All shots were conducted at a distance of 300 cm, which is considered optimal for bullet stability and impact velocity. This range was selected to minimize variables and ensure a minimal yaw angle and bullet stability.[18]

Test Weapons and Ammunition Specifications

In the tests conducted as part of this study, three different calibers and types of firearms and ammunition were used: a 9×19 mm handgun (Canik METE SFx), a 5.56×45 mm assault rifle (MKEK MPT-55), and a 7.62 × 51 mm infantry rifle (MKEK MPT-76) (Fig. 5).

Table 1 presents primary data on the bullets of three different calibers and types of ammunition used in the experiments, along with their impact on wound ballistic performance. All test fires were conducted at a distance of 300 cm to eliminate differences between muzzle and impact velocity.

Distribution of Subjects and Bullet Impact Locations

The distributions of subjects (test groups), bullet impact (targeting) locations, bullet types, and the weapons used are shown in Table 2.

Measurement and Recording of Test Results

Following the test shots, photographs were taken to document the external examination of bullet entry and exit wounds. Additionally, two-way X-rays (anteroposterior and lateral) were obtained and recorded.

The muzzle velocities of the test shots were measured using a Labradar® (V1.5) ballistic chronograph, and the average velocity values were documented.

The dimensions of the entry and exit wounds were measured using the photometry software ImageJ® (version 1.54b).

RESULTS

Test Group 1:

The results obtained from shooting at a distance of 300 cm using an M822-type bullet to the front right legs of Subject A and Subject B are as follows:

Subject A:

The edges of the bullet entry hole were smooth and typical. The bullet struck the tissue at a -38o angle (relative to NATO 0°), and a 7 × 5 mm oval, regular-edged entry wound was observed at the junction of the distal humerus and the elbow joint, along the midline. The skin tissue surrounding the entry hole was intact, with only a 1-2 mm laceration present. No

Table 2. Bullet impact locations, bullet types, and weapons used in the test fires

Testing Group (Subjects)	Bullet Impact Location	Caliber (mm) / (Bullet Type)	Test Weapon
1 (A, B)	Front Leg	9 × 19 / (M822)	Canik METE SFX Handgun
2 (C, D)	Front Leg	5.56 × 45 / (SS109)	MKEK MPT-55 Assault Rifle
3 (E, F)	Front Leg	7.62 × 51 / (M80)	MKEK MPT-76 Infantry Rifle

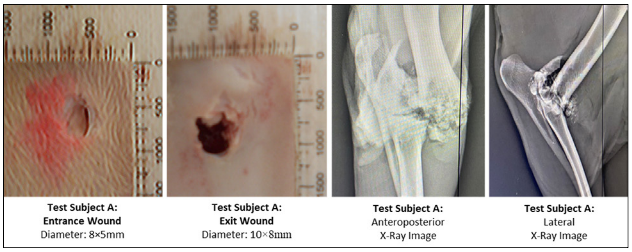

Figure 6. 9×19 mm (M822) bullet entry and exit wounds and X-ray images of Subject A.

edema, hemorrhage, or ecchymosis was noted (Fig. 6).

Anteroposterior X-ray radiography revealed a multi-fragmented fracture at the distal end of the humerus, lateral displacement of the humerus bone, disruption of elbow joint integrity, and a fracture on the radius facing the elbow joint. Cavitation areas were visible in the soft tissue between the fractures bones. Lateral X-ray radiography showed a comminuted fracture of the distal humerus, a large cavitation zone around the fracture, and millimetric bone fragments within the soft tissue along the bullet's exit path (Fig. 6).

A 10×7 mm regular-edged exit hole was observed along the midline, distal to the humerus and proximal to the elbow joint. The skin tissue surrounding the exit wound was intact, with no signs of edema, hemorrhage, or ecchymosis (Fig. 6).

Subject B:

The edges of the bullet entry hole were smooth and typical. The M822 bullet struck the tissue at a -48o angle (relative to NATO 0o), and an 8×6 mm oval, regular-edged entry hole was observed along the midline, distal to the humerus. The surrounding skin tissue was intact, and no edema, hemorrhage, or ecchymosis was observed (Fig. 7).

Anteroposterior imaging revealed cavitation areas in the soft tissue in and around the elbow joint, where the joint structure was completely destroyed due to comminuted fractures. Large and small bone fragments had spread into the surrounding soft tissue, resulting in a loss of soft tissue integrity. Lateral X-ray radiography showed that joint integrity was completely disrupted due to multi-part fractures in the distal humerus, as well as in the proximal radius and ulna. Cavitation areas were observed around the bone fractures and within the surrounding soft tissue (Fig. 7).

A 20×17 mm, regular-edged exit hole was observed in the distal humerus. The skin tissue surrounding the exit wound was intact, with no edema, hemorrhage, or ecchymosis detected (Fig. 7).

Test Group 2:

The results obtained from shooting at a distance of 300 cm using a 5.56 × 45 mm (SS109) bullet to the front right legs of Subject C and Subject D are as follows:

Subject C:

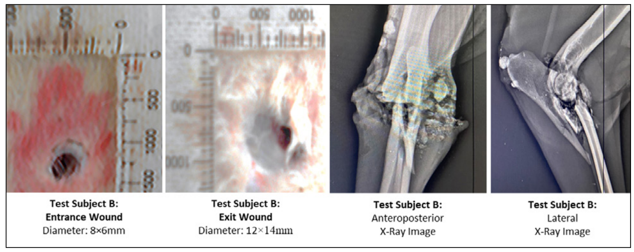

Figure 7. 9×19 mm (M822) bullet entry and exit wounds and X-ray images of Subject B.

The edges of the entry wound caused by the supersonic SS109-type bullet were smooth. The surrounding skin tissue was intact, and no edema, hemorrhage or ecchymosis was observed. However, the entry wound measured 24.5×44.3 mm, larger than typically expected, due to the tension of the skin tissue at the impact site. On the surface of the humerus bone, a large, oval, wide entry hole with regular edges was observed along the midline.

Anteroposterior X-ray imaging showed that the integrity of the humerus was completely disrupted due to multiple fragmented fractures. Large and small bone fragments were dispersed into the soft tissue along the exit trajectory, acting as secondary projectiles. The soft tissue structure was also disrupted, and fragmented bullet pieces and cavitation areas were observed between the bone fragments. No pathology was found in the elbow joint, radius, or ulna.

At the site of the exit wound, broken bone fragments, bullet fragments, and cavitation areas were observed, along with disruption of skin integrity. Lateral X-ray imaging confirmed that the integrity of the humerus was completely disrupted due to multiple fractures. Large and small bone fragments were scattered posteriorly into the soft tissue. Fragmented bullet pieces and cavitation areas were observed between the fracture fragments and within the surrounding soft tissue. A prominent exit hole with irregular edges, measuring 50.3×34.1 mm, was observed in the proximal humerus along the midline. The skin tissue surrounding the exit wound was intact, and no edema, hemorrhage, or ecchymosis was noted (Fig. 8).

Subject D:

A 5×7 mm oval, regular-edged entry hole was observed along the midline in the distal humerus, where the SS109-type bul-

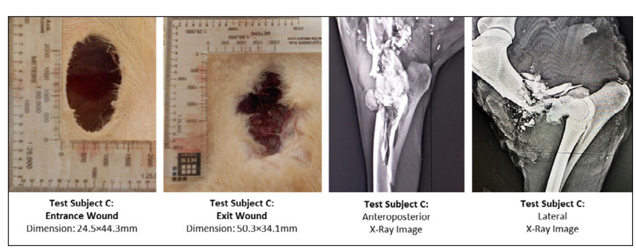

Figure 8. 5.56×45 mm (SS109) bullet entry and exit wounds and X-ray images of Subject C.

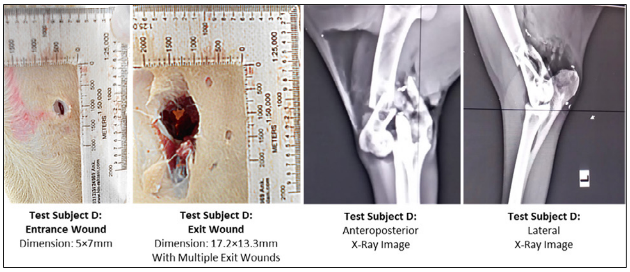

Figure 9. 5.56 × 45 mm (SS109) bullet entry and exit wounds and X-ray images of Subject D.

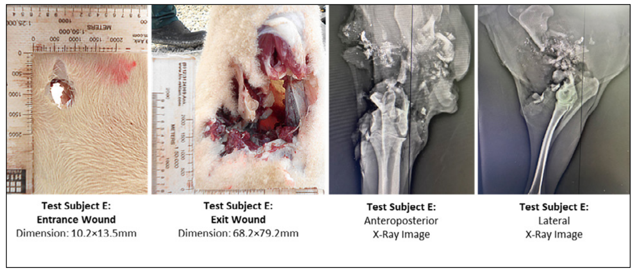

Figure 10. 7.62×51 mm (M80) bullet entry and exit wounds and X-ray images of Subject E.

let struck the tissue at a -45o angle (relative to NATO 0o). The skin tissue surrounding the entry wound was intact, except for a millimetric laceration. No edema, hemorrhage, or ecchymosis was noted.

Anteroposterior X-ray imaging showed that the shaft of the humerus had separated from the joint due to a displaced fracture in the distal region. Extensive cavitation was present along the edge of the fracture line. The radius and ulna remained intact; however, joint integrity was disrupted. Bullet fragments and cavitation areas were observed within the fracture zone. Lateral X-ray imaging revealed a fracture in the distal humerus, a large cavitation area adjacent to the fracture, additional cavitation areas in the soft tissue surrounding the joint, and the presence of bullet fragments.

An exit hole measuring 17.2×13.3 mm with irregular edges was observed on the medial side of the distal humerus. There was a 20 mm laceration on the medial and proximal sides of the exit wound, along with a 10 mm disruption in skin integrity on the proximal side. Disintegration of muscle tissue was also observed. Approximately 10 mm lateral to the exit hole, three millimetric satellite shrapnel exit wounds were found, aligned from top to bottom (Fig. 9).

Test Group 3:

The results obtained from shots fired at a distance of 300 cm using an M80-type bullet into the distal femoral region of the forelimb of Subject E and Subject F are presented below:

Subject E:

A shot was fired with an M80-type bullet into the humerus of the left forelimb. A 10.2×13.5 mm oval, regular-edged entry hole was observed along the midline, proximal to the upper arm bone. The edges of the entry wound were intact except for a laceration on the distal side. No edema, hemorrhage, or ecchymosis was noted. A cavity extending from the entry to the exit wound was observed, consistent in diameter with the size of the entry hole.

Anteroposterior X-ray imaging showed that the bone structure was completely disrupted due to multiple fractures of the humerus. The joint structure was also compromised by fractures at the distal end of the humerus, where it connects to the joint. Bone fragments had spread into the surrounding soft tissue, resulting in disrupted soft tissue integrity. Bullet fragments and cavitation areas were observed between the fractured bone segments and within the soft tissue. At the level of the exit wound, bone fragments, bullet fragments, and cavitation areas were visible in the skin tissue, with some bone and bullet fragments protruding from the skin. Lateral X-ray imaging showed that the structural integrity of the humerus was completely disrupted due to a multi-part fracture, except for the epiphyses that connect to the hip and knee joints. Fragmented bullet pieces and cavitation areas were visible among both large and small bone fragments (Fig. 10). A prominent exit hole, measuring 68.2×79.2 mm with irregular borders, along with fragmented muscles, tendons, and bones, was observed in the midline of the proximal humerus.

Subject F:

An M80-type bullet was fired into the humerus of the left forelimb. A 7.5×7.1 mm round, regular-edged entry hole was observed along the distal midline of the humerus. The skin tissue surrounding the entry wound was intact, except for a millimetric laceration. No edema, hemorrhage, or ecchymosis was noted.

Anteroposterior X-ray imaging revealed extensive damage involving the shaft and distal part of the humerus, the elbow joint, and the proximal radius. Complete disruption of the bone and joint structures was observed as a result of a multi-part fracture. The fracture fragments were scattered throughout the soft tissue. Fragmented bullet pieces and cavitation areas were identified between the fracture lines and within the soft tissue. Soft tissue and skin integrity were also impaired. At the level of the exit wound, bone fragments, bullet fragments, and cavitation areas were present in the skin tissue, with some bone and bullet fragments protruding from the skin. Lateral X-ray radiography confirmed that the structural integrity of the bone and joint was completely disrupted due to numerous large and small fragmented fractures in the shaft and distal part of the humerus, the proximal radius, and the joint. Bullet fragments and cavitation areas were observed between the fracture fragments and within the surrounding soft tissue (Fig. 11). In the proximal part of the humerus, a large midline exit hole measuring 45.5×74.2 mm with irregular borders was observed. The wound contained fragmented skin and muscle, with muscle tissue visibly protruding from the exit site.

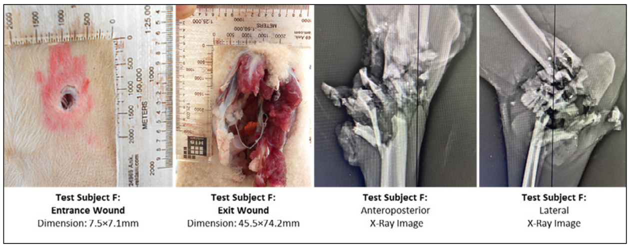

Figure 11. 7.62×51 mm (M80) bullet entry and exit wounds and X-ray images of Subject F.

DISCUSSION

According to the results of the shots fired at the humerus of the forelimbs of Subjects A and B from a distance of 300 cm using an M822-type bullet, the entry wounds were smaller than the bullet diameter, with regular edges. The M822-type bullet did not cause damage to the surrounding tissues at the entry site. These entry wound characteristics are consistent with findings reported in forensic pathology examinations and observations.[19] As seen in the direct radiographs, the M822-type bullet caused disruption of bone and joint integrity due to multiple fragmented fractures in the extremities. The dispersion of bone fragments into the soft tissue also resulted in soft tissue damage. In both subjects, an exit hole larger than the bullet diameter, with regular edges and no damage to the surrounding tissue, was observed. These findings are consistent with those reported in the literature.[19,20] Because the M822-type bullet maintains its gyroscopic stability as it travels through tissue, it expends a significant portion of its kinetic energy penetrating bone. Additionally, the relatively small difference between the bullet's diameter and length is a contributing factor to the absence of temporary cavity formation. Since the kinetic energy of the M822-type bullet, which travels at transonic velocity, is relatively low, its shrapnel effect on bone tissue is more limited compared to bullets traveling at supersonic speeds.[15]

In the results of shots fired at the humerus of the forelimbs of Subjects C and D from a distance of 300 cm using an SS109-type bullet, the entry wound was found to be equal to or larger than the bullet diameter, with regular edges. The SS109-type bullet did not cause visible damage to the surrounding tissues at the entry site. As seen in the direct radiographs, the SS109-type bullet expends a significant portion of its kinetic energy while penetrating bone tissue, fragmenting in the process and causing severe damage to the bone and joint structures through multiple fractures. It is believed that both bone and bullet fragments observed in the soft tissues between the entry and exit wounds contribute to additional damage to muscles, tendons, and skin through a shrapnel effect. This also results in an exit wound larger than the bullet's diameter, with irregular edges. Due to its fragile structure and high velocity, the SS109-type bullet tends to fragment within the first 15-20 cm of tissue. As a result, the damage caused by the SS109-type bullet was more severe than that caused by the M822-type bullet.[21]

According to the results of the shots fired at the humerus bones of the forelimbs of Subjects E and F from a distance of 300 cm using an M80-type bullet, entry wounds measuring 14×11 mm in Subject E and 6×5 mm in Subject F were observed. Both wounds had regular edges, and no significant damage to the surrounding tissues at the entry sites was detected. As seen in the direct radiographs, the supersonic M80-type bullet transfers its high kinetic energy to the bone tissue, resulting in multi-part fractures and severe damage to the bones and joints. During this process, fragmentation of the bullet further increases the extent of bone damage. The radiographs also showed that fragmentation of the M80-type bullet occurred in the muscles, tendons, and skin due to its high kinetic energy. This fragmentation extended from the entry wound to the exit wound, which appeared wide and irregular.[21]

The damage caused by the M80-type bullet was more severe in the extremities and soft tissues compared to the M822 and SS109-type bullets. These findings are consistent with results reported in the literature. If the bullet passes only through soft tissue without striking bone, the M80-type bullet does not cause significant damage, as the cavity length is insufficient for substantial temporary cavity formation. However, if the bullet strikes bone tissue in the extremity, it rapidly transfers its high kinetic energy to the bone and surrounding soft tissues. This increases the extent of damage by forming a temporary cavity, although its volume is low compared to that formed in soft tissues.[19,21,22]

A limitation of this study is the small number of subjects. However, considering the complexity and cost of live animal experiments, as well as the ethical requirement to use the minimum number of animals, this limitation does not affect the validity of the results. Furthermore, while surrogate models have been used in previous studies on firearm injury mechanisms, this study adds valuable experimental data by demonstrating extremity and soft tissue damage caused by different types of ammunition, supported by X-ray radiographic evidence in line with the existing literature.

CONCLUSION

Based on the findings from anteroposterior and lateral X-ray imaging of the subjects' right forelimbs, as well as the analysis of entry and exit wounds, the deformation, fragmentation, and penetration effects caused by high-energy SS109 and M80-type bullets resulted in extensive tissue damage. This included destruction of bones forming the joint, as well as injury to muscle, tendons, and even the skin around the exit wound area.

High-kinetic-energy weapons caused severe deformation of the limbs and a loss of structural integrity. In contrast, in the anteroposterior and lateral X-rays of sheep wounded by M822-type bullets, which have relatively low kinetic energy, no bullet fragmentation was observed. However, comminuted fractures of bone tissue and joint damage were still present.

Unlike body parts such as the torso and thorax, the transient cavity is not the primary cause of damage in the extremities due to insufficient cavity length. According to the results of this study, the M822-type bullet dissipates its kinetic energy during penetration, causing multiple bone fractures. The resulting bone fragments, in turn, lead to additional damage to joints and soft tissues. In contrast, the penetration and fragmentation of high-kinetic-energy SS109 and M80-type bullets cause extensive damage to the bone shaft, muscles around the joint, tendons, and even the skin around the exit area. The damage caused by the M80-type bullet is more severe than that caused by the SS109-type bullet.

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DENEYSEL ÇALIŞMA - *ÖZ*

Farklı çap ve tipteki mermi çekirdeklerinin ekstremiteler üzerindeki deneysel yaralanma modelleri

AMAÇ: Yaşamı tehdit eden yaralanmaların ikinci önde gelen nedeni olan ve son 50 yılda savaşla ilgili vakaların %63'ünü oluşturan ateşli silah yaralanmaları ağırlıklı ekstremitelerde meydana gelir. Ekstremite yaralanmaları daha düşük ölüm oranlarına sahip olsa da, komplikasyonları azaltmak için hala acil tedavi gerektirmektedir. Balistik mum ve jelatin gibi doku vekillerinin kullanıldığı yara balistiği çalışmaları, canlı dokulardan farklılıkları nedeniyle sınırlılıklara sahiptir ve bu testlerle elde edilecek veriler gerçekte mermi çekirdeğinin farklı direnç ve esnekliğe sahip kemik ve kastan oluşan ekstremiteler üzerindeki etkisi hakkında yeterli veri sağlamamaktadır. Bu çalışmanın amacı, yaygın olarak kullanılan mühimmatın canlı dokularda neden olduğu hasarı analiz etmek ve sağlık çalışanlarına acil bakımı iyileştirmek için kritik bilgiler sağlamaktır.

GEREÇ VE YÖNTEM: Bu çalışmada, daha önce başka bir çalışmada kullanılmış ve yaşamsal belirti göstermeyen 3-4 yaşlarında 6 Adana ırkı koyun kullanıldı. Yerel etik kurulundan etik onay alınmıştır. Deneme atışları 9×19 mm (M822), 5.56×45 mm (SS109) ve 7.62×51 mm (M80) mermiler kullanılarak 300 cm mesafeden, yan pozisyondaki koyunların ön bacakları hedef alınarak yapıldı. Atışların ardından, giriş ve çıkış yaraları fotoğraflanmış ve analiz için ekstremitelerin ön-arka ve yan röntgen görüntüleri çekilmiştir. Deney, farklı mühimmat türlerinin ekstremiteler üzerindeki etkilerini incelemeyi ve ateşli silah yarası özellikleri hakkında bilgi edinmeyi amaçlamıştır.

BULGULAR: İlk test grubunda (denek A ve B), röntgenler eklem bütünlüğü kaybı, çok parçalı kırıklar ve yumuşak dokuda kavitasyon gösterdi, kemik parçaları çıkış hattı boyunca dağıldı, ancak boşlukta mermi parçası yoktu. M822 mermisi tipik bir giriş yarası ve daha küçük bir çıkış yarası oluşturmuştur. İkinci grupta (C ve D denekleri), SS109 mermileri kemik, kas, tendon ve deri parçalanmasına neden olmuş ve mermi parçaları şarapnel etkisi yaratmıştır. Çıkış yaraları daha genişti ve düzensiz kenarlara sahipti. Üçüncü grupta (E ve F denekleri), M80 mermileri yüksek kinetik enerji nedeniyle geniş doku parçalanmasına neden olmuş ve geniş, düzensiz çıkış yaraları oluşturmuştur.

SONUÇ: Bu çalışma, M80 mermilerinin daha yüksek kinetik enerji yoğunluğu ve yapısı nedeniyle M822 ve SS109 mermilerine göre daha ciddi kemik ve yumuşak doku hasarına neden olduğunu ortaya koymuştur. Doku vekillerinin kullanıldığı önceki araştırmalardan farklı olarak bu deney, mühimmatın gerçek dokular üzerindeki etkilerini göstermiştir. Radyoloji, adli tıp ve sağlık uzmanları, ateşli silah yaralanmalarının mühimmat özelliklerine göre değiştiğini bilmeli ve hasta sonuçlarını iyileştirmek için bu anlayışla en uygun müdahale ve tedavi tekniklerini uygulamalıdır.

Anahtar sözcükler: Ateşli silah yaralanması; ekstrimite yaralanmaları; hedef balistiği; yara balistiği.

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