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16

Advantages and Disadvantages of Computed Tomography in Cranial Gunshot Injuries: Experimental Animal Study

Kraniyal Ateşli Silah Yaralanmalarında Bilgisayarlı Tomografinin Avantaj ve Dezavantajları: Deneysel Hayvan Çalışması

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ABSTRACT

Objective: Tomography is the gold standart method for gunshot injury cases but there are limited information in the literature on the use of tomography in shooting analysis. This study aimed to examine the findings required for shooting reconstruction, clinical, forensic evaluation and to show the advantages-disadvantages in gunshot injuries.

Material and Methods: The head of 12 Adana sheep and Canik Mete TP9 9x19 mm were used. Shots were made to the frontal, temporal, and occipital regions from distances of 50 cm, 1, 5 and 10 meters. Vimago GT30 (Epica animal health, USA) computed tomography was used for scanning.

Results: The time required to obtain images for all heads were less than 1 minute. Entry and exit wounds findings were obtained from axial and sagittal images for frontal and occipital shots, and from axial and coronal images for temporal shots. Bullet core trajectory and brain damage were examined from axial and sagittal images for frontal and occipital shots, from axial and coronal images for temporal shots, and Hounsfield unit (HU) values were measured from axial images for all shots. HU values -808±164 (from -530 to -1024) in cavitation area, +2512±200 (from +2332 to +3071) in pathological tissues, +831±85 (from +707 to +966) in brain tissue, and +2683±359 (from +2128 to +3071) in bone were found.

Conclusion: Tomography provides critical information about the location and size of entry-exit wounds, HU values in different tissues, trajectory, cavitation and intracranial foregin bodies. It is possible to determine the azimuth and vertical angles necessary for shooting reconstruction using tomography.

Keywords: Bullet core trajectory, cranial gunshot injuries, computed tomography, shooting reconstruction

ÖZ

Giriş: Kraniyal ateşli silah yaralanması olgularında bilgisayarlı tomografi altın standart yöntemdir fakat adli atış analizi hakkında literatürde yeterli veri yoktur. Bu çalışma adli atış analizi, klinik ve adli değerlendirme için gerekli bulguları araştırmak, kraniyal ateşli silah yaralanmalarında tomografinin avantaj ve dezavantajlarını göstermek amacıyla yapılmıştır.

Gereç ve Yöntemler: On iki adet Adana cinsi koyunun baş bölgesi ve Canik Mete TP9 9x19 mm (M822) tabanca kullanıldı. Deney atışları 50 cm, 1, 5 ve 10 metre mesafeden frontal, temporal, ve oksipital bölgeye gerçekleştirildi. Vimago GT30 (Epica animal health, USA) bilgisayarlı tomografi kullanılarak aksiyal, sagital ve koronal görüntüler elde edildi..

Bulgular: Tüm taramalarda görüntüleme için geçen sürenin 1 dakikadan az olduğu gözlendi. Giriş ve çıkış yarasına ait bulgular frontal ve oksipital atışlarda aksiyal ve sagital, temporal atışlarda aksiyal ve koronal görüntülerden elde edildi. Mermi çekirdeğinin seyri ve beyin dokusunda oluşturduğu hasara ait bulgular frontal ve oksipital atışlarda aksiyal ve sagital görüntülerden, temporal atışlarda aksiyal ve koronal görüntülerden, HU değerleri tüm atışlarda aksiyal görüntülerden elde edildi. Hounsfield birimi (HU) kavitasyon alanında -808±164

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ÖZ

(minimum -530 maksimum -1024), yaralanma alanında +2512 ± 200 (minimum +2332 maksimum +3071), beyin dokusunda +831±85 (minimum +707 maksimum +966), ve kemikte +2683±359 (minimum +2128 maksimum +3071) bulundu.

Sonuç: Tomografi, giriş-çıkış yaralarının yeri ve boyutu, farklı dokulardaki Hounsfield değerleri, traje, kavitasyon ve kafa içi yabancı cisimler hakkında bilgi sağlar. Atışın rekonstrüksiyonu için gerekli olan azimuth ve vertikal açıları tomografi ile tespit etmek mümkündür.

Anahtar Kelimeler: Mermi çekirdeği trajesi, kraniyal ateşli silah yaralanması, bilgisayarlı tomografi, adli atış analizi

INTRODUCTION

Cranial gunshot injuries (GSIs) are severe traumas associated with high mortality and morbidity. Computed tomography (CT) is the gold standard imaging modality for these cases (1-3). Cranial imaging is recommended as soon as possible after arrival at the hospital. Brain damage depends on the type of firearm, the distance of the shot, and the entry angle, mass, and velocity of the bullet. While the majority GSI cases die at the scene, mortality can be reduced in those who reach the hospital with rapid, appropriate and aggressive treatment (3,4). Tomography provides critical information about the location and size of entry and exit wounds, determination of brain damage, bullet trajectory, cranial bone fractures, detection of foreign bodies, and bullet residues (bullet core or jacket fragments). It plays a pivotal role in surgical decision-making and in determining the surgical strategy. Given the high mortality rate associated with GSIs, physicians must make rapid decisions. At this stage, CT provides rapid information among all radiological imaging methods (1,3,5,6).

The first postmortem CT scan was reported in the late 1970s in a fatal cranial GSI. The VIRTOPSY project, presented in 2003, described minimally invasive imaging methods to complement traditional autopsies. Medical imaging methods, particularly CT, are increasingly used for forensic purposes (7-9). Images obtained using this non-invasive method can be re-examined, stored, shared, presented in courts, and used to create 2D and 3D images (10-12). CT has proven particularly effective in detecting fractures, foreign bodies, and gases (13-16). Forensic physicians detect entry-exit wounds and trajectory, determine the type of weapon, and ascertain the cause of death (17-21). Rapid and accurate identification of victims is essential after disasters. Interpol has deemed CT-based data suitable and useful. The interpretation of reconstructed images, independent documentation from observers, the ability to reconstruct various images long after the event, the sharing of workload through digital transmission of CT data, and the reduction in time and expertise required in the disaster area have demonstrated that it is a valuable tool for disaster victim identification. Age determination and identification through comparison of antemortem and postmortem CT images have become possible with CT (22,23).

Limited literature exists on the use of CT for crime-scene and shooting reconstruction. CT scans detect bullet fragments in decomposed, skeletal, mummified, or charred corpses. Limited data regarding ammunition and caliber support the usefulness of CT. CT findings are valuable in cases with minimal skin findings or intraoral GSIs. While limited number of publications report that shooting distance with CT, these studies are generally based on animal experiments and the detection of gunshot residue (24-26). Shooting reconstruction is the study conducted to identify the person who pulled the trigger and the shooting location (27). Azimuth (horizontal) and vertical angles are the necessary for shooting reconstruction (28). Existing literature provides insufficient information on the contribution of CT to shooting reconstruction by determining azimuth and vertical angles. This study aimed to fill this gap. We aimed to examine the findings required for shooting reconstruction and discuss the advantages and disadvantages of CT in GSIs.

MATERIALS and METHODS

Study Population

Although no ideal subject species has been defined in the literature for use in GSIs, organ models, pigs, and sheep have been used most frequently in ballistic studies (29-32). Sheep were preferred for the study because pigs were unavailable after the regional earthquake. Moreover, sheep were more accessible and required fewer anaesthetic agents for control purposes. The study utilized the heads of 12 Adana breed sheep. The heads were obtained at no cost from a slaughterhouse that processes sheep daily, and the animals were automatically slaughtered at the distal part of the C1 vertebra (Atlas). External examination revealed no differences among the heads used. The heads were stored at +4 °C in sterile conditions and transported to the experimental area.

Ammunition used were 9×19 mm calibre M822 type (Full Metal Jacket) rounds (340 m/s), fired from a Canik Mete TP9 semi-auto handgun; this calibre is the most common in civilian injuries. Experienced tests were performed by the staff of the xxxSpecial Operations Directorate, Special Operations Department, General Directorate of Security, Ministry of Internal Affairs, at the same department shooting range.

Test Shots Plan

Test shots were performed from distances of 0.5, 1, 5, and 10 meters, targeting the frontal, temporal and occipital regions (Table 1).

Table 1. Fire region and distance of heads

Head		Region			Distance		
	FR	T	OC	0.5 meter	1 meter	5 meter	10 meter
1	X			X			
2		X		X			
3			X	X			
4	X				X		
5		X			X		
6			X		X		
7	X					X	
8		X				X	
9			X			X	
10	X						X
11		X					X
12			X				X

FR: Frontal, T: Temporal, OC: Occipital

Cranial Imaging

Heads were positioned with the nape and chin aligned, keeping the heads in the midline. Axial images were obtained using a Vimago GT30 (Epica Animal Health, USA) high-resolution CT scanner. Tomography parameters were as follows: 120 kVp, 80 mAs, gantry rotation time =0.6 s, slice thickness =0.35 mm. The time required for imaging was recorded, and a veterinarian appropriately disposed of the imaged heads.

CT images were evaluated by two authors. The axial images and the sagittal and coronal reformats, recorded in DICOM format, were transferred to digital storage and analysed by researchers on personal computers. During the evaluation, factors such as the location, diameter, and angle of the entry wound, the presence of bullet core residue, the bullet trajectory, brain tissue damage, bone fractures, the distribution of bone fragments, Hounsfield unit (HU) values, and the location and diameter of the exit wounds were examined.

Ethical approval for the study was received from the Çukurova University Experimental Animals Local Ethics Committee on 30.04.2024 (meeting number: 4, decision number: 6).

Statistical Analyses

For this descriptive study, HU values were performed using SPSS 20.0 (Chicago, IL), findings are presented as mean ± standard deviation (minimum-maximum).

RESULTS

The time required to obtain images for all 12 heads was less than 1 minute. Findings of entry and exit wounds were obtained from axial and sagittal images for frontal and occipital shots and from axial and coronal images for temporal shots. Bullet trajectory and brain damage were examined on axial and sagittal images for frontal and occipital shots, on axial and coronal images for temporal shots; HU values were measured on axial images for all shots. HU values -808±164 (from -530 to -1024) in cavitation area, +2512±200 (from +2332 to +3071) in pathological tissues, +831±85 (from +707 to +966) in brain tissue, and +2683±359 (from +2128 to +3071) in bone were found (Tables 2 and 3).

DISCUSSION

In recent years, advancements in tomography and computer technology have created new opportunities for radiologists, clinicians, surgeons, and forensic physicians to evaluate GSI cases. Research on the advantages and disadvantages of CT in forensic cases, particularly in cranial GSIs, has demonstrated that CT is a suitable and beneficial method (Table 4) (33,34).

Multi-slice CT scanners equipped with 64 detectors rotate around the patient at three revolutions per second. At this speed, whole-body screening takes less than 10 minutes, offering significant dose-time advantages (14,35). In our study, the time to obtain images with the multi-slice CT device designed for veterinary use was less than 1 minute in all cases, highlighting CT's efficiency.

During the evaluation, the diameters of skin and/or bone defects were measured after their locations were determined. In frontal and occipital shots, the skin entry wounds were smaller than the bullet diameter, while the bone entry wounds were equal to or larger than the bullet diameter. Millimetric entry wounds were observed on the skin in shots to the temporal region. The skin elastic structure resists penetration, causing the tissue to pit and stretch until the elasticity limit is exceeded, after which the bullet pierces the skin (36,37). This explains why the observed skin entry wound was smaller than the bullet diameter in this study.

Table 2. Cranial computed tomography findings of entry and exit wounds

Head	Entry wounds angle	Entry wounds region	Enrty wounds defect region	Enrty wounds diameter	Exit wounds region	Exit wounds defect region	Exit wounds diameter
1	9.75° Azimuth -31.7°Vertical	FR region right of midline	Skin Bone	1.7x3.8 mm 9.4x88.0 mm	OC bone, right arcus of C1	Bone	150x270 mm
2	0° Azimuth -3.5° Vertical	Right T bone	Skin	3.3x3.0 mm	Left T bone	Bone	20.0x14.0 mm
3	1.0° Azimuth -20.0° Vertical	OC region midline	Bone	9.2x12.0 mm	Nose, right of midline	Bone	3.3x5.0 mm
4	6.0° Azimuth -23.0° Vertical	FR region left of midline	Skin Bone	3.0x3.8 mm 7.5x16.0 mm	OC bone, Midline	Bone	3.8x3.5 mm
5	14.0°Azimuth -8.0° Vertical	Right T bone	Skin	4.0x5.2 mm	Left ear	Skin	7.0x6.0 mm
6	10.0° Azimuth -4.0° Vertical	OC region Midline	Bone	28.0x23.0 mm	Maxilla bone	Bone	7.4x12.0 mm
7	6.6° Azimuth -23.0° Vertical	Vertex-FR region right of midline	Bone	5.8x8.0 mm	OC bone right of midline	Bone	7.2x4.7 mm
8	12.1° Azimuth -6.3° Vertical	Right T bone	Skin	Milimetric	Left T bone	Skin	Milimetric
9	0° Azimuth -20.0° Vertical	OC region midline		8.0x13.0 mm	Nasal region right of midline		4.1x5.2 mm
10	10.0° Azimuth -12.7° Vertical	Maxilla region right of midline	Skin Bone	6.1x6.5 mm 10.0x12.0 mm	Right arcus of C1	Bone	4.0x10.0 mm
11	8.0° Azimuth 1.2° Vertical	Right T bone		7.1x5.3 mm	Left T bone	Skin	6.6x5.7 mm
12	28.0° Azimuth 21.0° Vertical	Posterior arcus of C1	Bone	10.0x14.0 mm	Nasal bone Midline	Bone	10.0x10.0 mm

FR: Frontal, OC: Occipital, T: Temporal, C1: First cervical vertebra

The azimuth angle was determined by measuring the angle formed between the entry wound and the midline in axial images. In contrast, the vertical angle was measured as the angle between the entry wound and the midline on sagittal and coronal images. The vertical angle represents the upward (+) or downward (-) component of the bullet's trajectory, while the azimuth angle reflects the lateral direction as seen from above. For forensic shooting analysis and reconstruction, knowing the impact angles and entry wound characteristics is crucial (28). Our most important findings suggest that CT provides essential data for forensic shooting analysis (shooting reconstruction studies).

Our evaluations also revealed that bullets create varying defects in the skin and bone. Two factors contribute to the variable sizes of exit wounds in GSIs. First is the bullet tumbling and exiting the body at different angles, and the second is the fragmentation and deformation of the bullet (36,38). The CT findings in our study aligned with established principles of wound ballistics.

Cranial CT HU values help differentiate tissues: -1000 represents air, negative values near zero (-10, -20) indicate fatty tissues, positive values near zero (+10, +30) indicate fluid structures, +300 to +350 indicate calcified tissues, and +1000 represents bone, the densest structure (15). Advanced reconstruction algorithms enable more detailed measurement of tissue attenuation and provide a wider HU range. The application used in this study had an HU range of -1024 to +3071. Air was represented by -1024 and bone by +3071. Bullet core residue, depending on its copper, lead, aluminium, or zinc content, can appear with extremely high HU values, such as +10,000 (39,40). In this study, HU measurements showed that air largely replaced brain tissue in the cavitation area, while bone fragments were detected as pathological tissue in the brain. No bullet core residue was found in brain tissue. The absence of bleeding from the vessels was attributed to insufficient blood flow in the cranial region following decapitation.

Table 3. Cranial computed tomography findings of bullet core trajectory and brain damage				
Head	**Bullet core trajectory**	**Location**	**HU**	**Brain damage**
1	At the posterolateral line in the right lobe From cranial to caudal	Cavitaion Pathological Brain Bone	-530 2351 889 2503	Fragmentation in FR sinusoids Fragmented bone pieces and cavitattion in the FR and OC lobes OC and C1 vertebral bone damage
2	From right to left At the midline From cranial to caudal	Cavitaion Pathological Brain Bone	-1024 2439 824 2388	Fragmentation in T bone Fragmented bone pieces and cavitation in the T lobe
3	In the midline From cranial to caudal From posterior to anterior	Cavitaion Pathological Brain Bone	-641 2578 837 2230	Large cavitation in OC lobe Fragmentation in maxillary sinusoids Defect In the nasal bone and distal nose skin
4	At the posterolateral line in the right lobe From cranial to caudal	Cavitaion Pathological Brain Bone	-886 2441 854 3071	Fragmentation in FR sinusoids Fragmented bone pieces in the FR and OC lobes OC bone damage
5	From right to left From cranial to caudal	Cavitaion Pathological Brain Bone	-1024 2659 715 3071	Fragmentation in T bone Fragmented bone pieces and cavitation in the T lobe
6	At the anterolateral line From cranial to caudal	Cavitaion Pathological Brain Bone	-665 2572 898 2601	Fragmentation in FR and maxiller sinosioids Fragmanted bone pieces and cavitattion in the FR and OC lobes
7	At the posterolateral line in the right lobe From cranial to caudal	Cavitaion Pathological Brain Bone	-708 3071 966 3071	Wide fracture line starting from entry wounds in the FR bone and extending posteroleteral line Fragmanted bone pieces and cavitattion in the FR and OC lobes
8	From right to left At the midline From cranial to caudal	Cavitaion Pathological Brain Bone	-816 2594 899 3071	Fragmentation in T bone Fragmented bone pieces and cavitation in the T lobe
9	At the midline From cranial to caudal From posterior to anteior	Cavitaion Pathological Brain Bone	-801 2361 825 2766	Cavitation in OC lobe Fragmentation in maxillary sinusoids and midline bones
10	At the posterolateral line in the right lobe From cranial to caudal	Cavitaion Pathological Brain Bone	-993 2452 707 2128	Extensive tissue loss along the maxillary sinosoids, nasopharyngeal region and posterior jaw
11	From right to left From caudal to cranial	Cavitaion Pathological Brain Bone	-770 2583 752 2513	Fragmentation in mandible, orbital wall Cavitation in brain tissue
12	At the anteromedial line From caudal to cranial	Cavitaion Pathological Brain Bone	-978 2332 713 3071	Bullet core passed from the left to the right of the midline in the nasopharyngeal region, creating fragmentation in the bones and extensive cavitation in the tissue
FR: Frontal, OC: Occipital, T: Temporal, C1: First cervical vertebra, HU: Hounsfield unit				

Table 4. Advantages and disadvantages of computed tomography

Advantages	Disadvantages
Entry wounds localization can be detected	May not provide information in sudden deaths
Diameter of entry wounds can be measured	Necessity of device, computer, HIMS, DICOM, PACS
Two angles of entry wounds can be calculated	Cost
Skin and bone defect can be detected	Artifacts
Bullet core residue can be detected	Radiation risk
Fargmented bullet core can be detected	Experience required in technology, computers, radiology
Bullet core trajectory can be detecetd	
Intracerebral, intraventricular, epidural, subdural, subarachnoid hemorrhage can de shown	
Cerebral edema, pneumocephalus, shift, herniation can be detected	
Bone fragmantation can be detected	
Distrubution of fragmented bone pieces can be shown	
Soft tissue damage, cavitation can be shown	
Presence and distribution of foreign objects can be detected	
Hounsfield unit can be calculated	
Entry and exit wounds can be differentiated	
Exit wound localization can be detected	
Diameter of exit wounds can be measured	
Cause of death can be determinated	
It is a non-invasive method	
Body integrity is perserved	
Examination can be repeated with the same or different method	
Data can be stored digitally	
Data can be re-evaluated and commented on by different people and platforms	
Segmentation and seperation of tissues provide visual dissection in different planes	
Provides time and speed advantage	
Risk of infection transmission is low	
Contributes to the crime scene, wound and shooting reconstruction	
Allows 3Dimension reconstruction	

HIMS: Hospital information management system, DICOM: Digital ımaging and communications in medicine, PACS: Picture archiving and communication systems

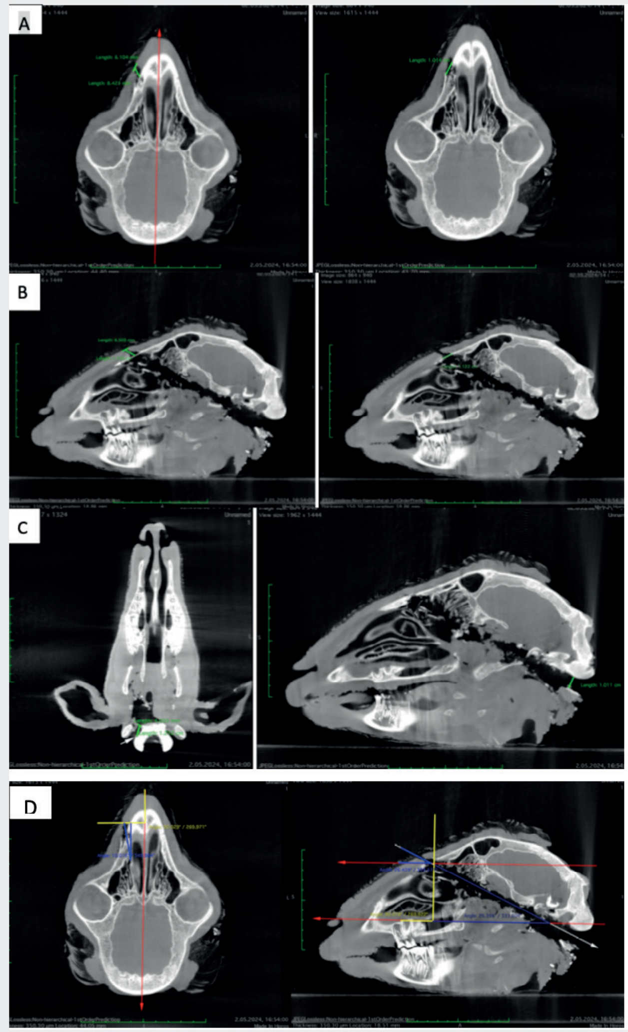

Figure 1. A) Axial view of skin and bone damage and bullet core enter wounds, **B)** Sagittal view of skin and bone damage and bullet core enter wounds, **C)** Axial and sagittal image of bullet core exit wounds, **D)** Bullet core trajectory, measuring azimuth angle in axial image, vertical angle in sagittal image

The entry wound, bullet trajectory, exit wound, and HU values of subject 10 (impacting the frontal region from a distance of 10 meters) are presented as examples in Figures 1 and 2.

While the need for infrastructure such as hospital information management system, digital imaging and communications in medicine and picture archiving and communication system can be seen as a disadvantage, the "Regulation on Health Information Management Systems (HIMS)" dated August 22, 2022, indicates that the current health system in our country has the necessary infrastructure to support the evaluation of cranial GSI cases using CT (41). During the study, the ability to share, export, and use DICOM-formatted data on personal computers enabled physicians to interpret images independently. Similarly, the HIMS regulation enables physicians to access and report data in certain situations, and telemedicine-integrated systems allow remote physicians to report data rapidly and without interruption. Another disadvantage is the presence of artifacts, including linear and ring artifacts, partial-volume effects, noise and motion artifacts, windmill effects, and beam hardening. However,

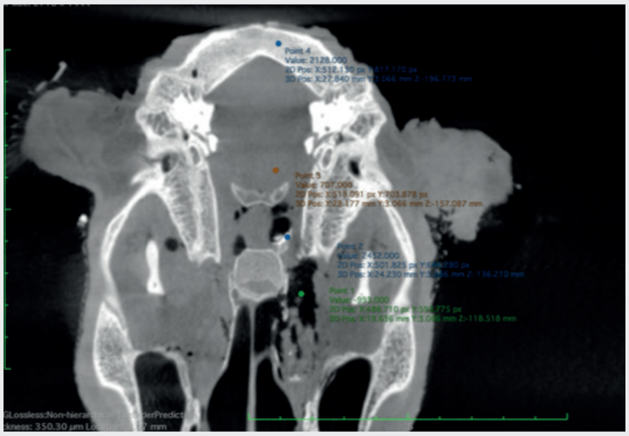

Figure 2. HU values of cavitation (green), brain (brown), pathological tissue (blue) and bone (blue)
HU: Hounsfield unit

these artifacts can be mitigated through various techniques and imaging adjustments (42).

Study Limitations

The limitations of this study include its animal-based design and the small sample size. The anatomy of the sheep head is similar to that of humans, and the small number of subjects does not alter the findings. The study demonstrated that, regardless of shooting distance and location, CT provides the necessary information for shooting reconstruction. The second limitation was that we could not observe intracranial haemorrhage because of insufficient blood volume resulting from post-decapitation bleeding. However, since CT has been shown in previous studies to be a suitable method for demonstrating intracranial haemorrhage, this will not negatively affect the study's value.

CONCLUSION

Cranial CT has numerous advantages, including speed and efficiency. Tomography provides critical information on the location and size of entry and exit wounds, the azimuth and vertical angles of entry, HU values in different tissues, the trajectory of the bullet core, cavitation, and bone fragmentation, and the distribution of bone fragments. The most important result of this study is that we have demonstrated that CT is a fast, non-invasive, and valuable method for forensic ballistic examination and forensic shooting analysis

Ethics

Ethics Committee Approval: Ethical approval for the study was received from the Çukurova University Experimental Animals Local Ethics Committee on 30.04.2024 (meeting number: 4, decision number: 6).

Informed Consent: It is not necessary for animal studies.

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Footnotes

This study was presented as oral presantation at 19th International Forensic Medicine Congress, 23-29 September 2024, Antalya, Türkiye.

Authorship Contributions

Concept: İ.A., G.İ.Ö., Design: İ.A., G.İ.Ö., A.S.K., Data Collection or Processing: İ.A., G.İ.Ö., A.S.K., K.İ., Ç.A., Analysis or Interpretation: İ.A., G.İ.Ö., A.S.K., Literature Search: İ.A., G.İ.Ö., K.İ., Writing: İ.A., G.İ.Ö., A.S.K., K.İ., Ç.A.

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