

# Evaluation of Cranial Gunshot Injuries with 3 Dimension Computed Tomography

## Kraniyal Ateşli Silah Yaralanmalarının 3 Boyutlu Bilgisayarlı Tomografi ile Değerlendirilmesi

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### ABSTRACT

**Objective:** Despite the widespread use of tomography in different forensic situations and gunshot injuries, the use of new radiological methods in patients receiving care at hospitals has lagged, and there are limited publications on the use of 3D imaging in gunshot injuries. This study aimed to investigate the findings obtained with 3D reconstruction in cranial gunshot injuries.

**Material and Methods:** Reconstructed 3D images produced by tomographic scanning of 12 sheep heads were used. Radiological images were obtained using a Vimago GT30 CT (Epica Animal Health, USA). Images recorded as DICOM were exported to digital media, then reconstructed and evaluated by two researchers using the HORUS apps.

**Results:** The location and size of the entry-exit wounds, the size and spread of bone fragments, the location and size of skull fractures, the integrity of the bones and joints forming the joints in the shooting region, and the damage in complex anatomical areas are shown using 3D reconstruction.

**Conclusion:** 3D reconstruction provides essential information to clinicians, surgeons, and radiology, and emergency professionals, including damage to the skin, the number, course, and length of skull bone fractures, the number and distribution of bone fragments, joint integrity, and the relationship between bone fragmentation and joint integrity, creating lifelike images without performing an autopsy. 3D reconstruction provides early, non-destructive, and critical information to legal authorities for forensic investigations, in cases under post-injury healthcare and a forensic autopsy is not possible. In cranial gunshot injuries, 3-dimension reconstruction should be part of the radiological evaluation.

**Keywords:** Computed tomography, 3D tomography, cranial gunshot injuries, firearm injury

### ÖZ

**Giriş:** Tomografi farklı adli olgularda ve ateşli silah yaralanmalarında yaygın olarak kullanılmasına rağmen, hastanelerde tedavi gören hastalarda yeni radyolojik yöntemlerin kullanımı geride kalmış olup, ateşli silah yaralanmalarında 3D görüntülemenin kullanımına ilişkin sınırlı sayıda yayın bulunmaktadır. Bu çalışmada, kraniyal ateşli silah yaralanmalarında 3D rekonstrüksiyon ile elde edilen bulguların incelenmesi amaçlanmıştır.

**Gereç ve Yöntemler:** On iki adet koyun kafasının tomografi görüntülerine 3D rekonstrüksiyon uygulandı. Radyolojik görüntüler Vimago GT30 CT (Epica Animal Health, ABD) kullanılarak elde edildi. DICOM olarak kaydedilen görüntüler dijital ortama aktarıldı, ardından iki araştırmacı tarafından HORUS uygulaması kullanılarak yeniden yapılandırıldı ve değerlendirildi.

**Bulgular:** Giriş-çıkış yaralarının yeri ve büyüklüğü, kemik parçalarının boyutu ve yayılımı, kafatası kırıklarının yeri ve büyüklüğü, atış bölgesindeki eklemleri oluşturan kemik ve eklemlerin bütünlüğü, kompleks anatomik bölgelerdeki hasarlar 3D rekonstrüksiyon ile gösterilmiştir.

**Sonuç:** 3D rekonstrüksiyon, klinisyenlere, cerrahlara, radyoloji ve acil servis çalışanlarına deri hasarı, kafatası kemiği kırıklarının sayısı, seyri ve uzunluğu, kemik parçalarının sayısı ve dağılımı, eklem bütünlüğü ve kemik parçaları ile eklem bütünlüğü arasındaki ilişki gibi temel bilgiler sağlayarak otopsi yapılmadan gerçekçi görüntüler oluşturur. 3D rekonstrüksiyon, yaralanma sonrası sağlık bakımı altındaki, adli otopsi yapılamayan olgularda adli makamlara adli soruşturmalar için erken, tahribatsız ve kritik bilgiler sağlar. Kraniyal ateşli silah yaralanmalarında 3D rekonstrüksiyon radyolojik değerlendirmenin bir parçası olmalıdır.

**Anahtar Kelimeler:** Bilgisayarlı tomografi, 3D tomografi, kraniyal ateşli silah yaralanması, ateşli silah yaralanması

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**Received:** 01.11.2025 **Accepted:** 07.01.2026 **Publication Date:** 26.02.2026

**Cite this article as:** Arslan İ, Öğünç Gİ, Koç AS, Yöntem A, Avcı Ç. Evaluation of cranial gunshot injuries with 3 dimension computed tomography. J Eur Med Sci. 2025;6;(3):48-57



## INTRODUCTION

Penetrating cranial gunshot injuries (GSIs) are forensic incidents associated with high morbidity and mortality, causing considerable damage to the scalp, skull, and brain parenchyma. Accurate and rapid assessment of medical injury severity and forensic clarification of the event necessitate the immediate determination of the location and size of entry-exit wounds, intracranial damage, and trajectory. Previous cases have demonstrated that radiological imaging performed promptly after initial intervention reduces morbidity and mortality (1-5). Cranial tomography (CT) provides critical findings about entry-exit wounds, Hounsfield unit values in different tissues, brain damage, intracranial gas, cranial bone fractures, distribution of bone fragments, bullet trajectory, foreign bodies, and bullet core residues (6-9). Cranial CT is an appropriate method for clinicians to guide medical or surgical treatment in emergencies, monitoring and clinical follow-up processes, and for forensic physicians in detecting gunshot wounds, determining the type of weapon and injury characteristics, investigation of death etiology, disaster victim identification, crime scenes reconstruction, and shooting reconstruction (10-14). Tomography has remarkable potential for rapid isotropic documentation, generation of 2D reformats, and 3-dimension reconstruction (3DR) (15-18).

3DR is a simulation software that enables comprehensive examination of the entire body or any of its parts, which is always accessible and repeatable. 3D imaging techniques have been accepted by Thali et al. (15) as an important part of the Virtopsy project. 3DR techniques have been reported in different forensic situations, such as GSIs, traffic accidents, explosions via virtual animation of the body, facial reconstruction, height estimation, gait analysis, crime scene reconstruction, determination of weapon type, and shooting reconstruction (19-23).

However, in cases with nonfatal injuries receiving medical care at advanced intervention centers, the use of new radiological methods has remained limited (24). Although CT is widely used in GSIs, there are limited publications regarding the use and benefits of 3D images. In this study, the aim was to investigate 3DR's findings in cranial GSIs.

## MATERIALS and METHODS

Reconstructed 3D images produced through CT scanning of 12 sheep heads were used. CT images obtained from our previous CT study. Since it is the most used weapon in civilian injuries, a 9×19 mm caliber Canik Mete TP9 semi-auto handgun with 9×19 mm M822 type (Full Metal Jacket) ammunition was used. Shots were made to the frontal, temporal, and occipital regions from distances of 50 cm, 1m, 5m, and 10m. Radiological images were obtained using a Vimago GT30 CT (Epica Animal Health, USA). Images recorded as DICOM were exported to digital media, then reconstructed and evaluated

by two researchers using the HORUS apps. The final reports were written by consensus of the two researchers.

Ethical approval for the previous CT study was received from the Çukurova University Local Ethics Committee for Animal Experiments on (decision number: 6, date: 30.04.2024). Since no living organ, animal, or human tissue was used in this study, ethics committee approval was not required.

### Statistical Analysis

Statistical methods were not used during image review and evaluation in this descriptive study.

## RESULTS

As a result of the experiments performed with sheep skulls, the location and size of the entry-exit wound, the size and distribution of bone fragments, the location and size of skull fractures, the integrity of the bones forming the joints in the shooting area, and the damage occurring in anatomically complex regions were demonstrated using 3DR.

Shot characteristics and 3DR findings of sheep:

**Sheep 1:** The shot was taken 50cm from the frontal region. A well-defined, round, millimetric entry wound was detected on the skin in the frontal region, to the right of the midline. In the bone images, a bone defect measuring 90×88 mm corresponding to the entry wound was observed in the frontal bone, to the right of the midline, along with a 33×45 mm displaced, fragmented bone piece at the margin of the defect. In the posterior cervical region, to the right of the midline, an irregular-edged, large exit wound causing tissue loss in the muscle tissue, occipital bone, and C1 vertebra was detected.

**Sheep 2:** The shot was taken 50cm from the temporal region. A well-defined, round, millimetric entry wound was detected on the skin in the right temporal region, between the eyeball and the ear. In the bone images, an irregular-edged entry wound was observed in the temporal bone, with the first fracture line extending from the entry wound toward the occipital bone and another toward the eyeball. In contrast, the zygomatic bone and temporomandibular joint were intact. A bone defect corresponding to the exit wound was detected in the area close to the lateral wall of the orbit, between the left temporomandibular joint and the eyeball, and the temporomandibular joint was observed to be intact.

**Sheep 3:** The shot was taken 50 cm from the occipital region. There is no skin present in the shot area. In the bone images, an entry wound measuring 90×113 mm was detected in the occipital bone, along with four separate fracture lines originating from the entry wound. The millimetric nasal bone and skin defect at the exit wound, detected on CT, was not visualized in the 3DR images.

**Sheep 4:** The shot was taken 1m from the frontal region. On the skin, a well-defined, round, millimetric entry wound was detected in the frontal region, to the left of the midline. In the bone images, an entry wound measuring 130×90 mm,

involving the midline, was observed in the frontal bone, with a single fracture line extending from the entry wound toward the temporal bone. The Integrity of the occipital bone was disrupted due to a large exit wound containing multiple bone fragments around it, and a fracture line originating from the exit wound was seen extending toward the frontal bone.

**Sheep 5:** The shot was taken 1m to the temporal region. On the skin, a well-defined, round, millimetric entry wound was detected in the right temporal region, between the eyeball and the ear. In the bone images, a fracture in the mandible and damage to the temporomandibular joint associated with the entry wound were observed. Millimetric comminuted fractures were detected in the left temporal bone and zygomatic bone, and a skin defect corresponding to the exit wound was observed in the left ear.

**Sheep 6:** The shot was taken 1m to the occipital region. On the skin, a well-defined, round entry wound was detected in the occipital region. In the bone images, a well-defined bone defect measuring 1.8×1.4 cm was observed in the occipital bone, with one fracture line extending from the bone defect toward the left lateral side and two fracture lines extending toward the right lateral side. In the right frontal bone, to the right of the midline and adjacent to the nasal bone, an exit wound measuring 1.8×1.0 cm was detected, along with millimetric fragmented bone pieces around the exit wound.

**Sheep 7:** The shot was taken 5m from the frontal region. On the skin, a laceration area extending from the right frontal region toward the vertex and the occipital bone was observed. In the bone images, a wide, irregular-edged bone defect originating from the entry wound in the frontal bone was seen extending up to the exit wound in the occipital bone. Multiple bone fragments were scattered into and around the trajectory. In the occipital bone, a large exit wound was detected, with two separate fracture lines originating from the exit wound extending toward the right and left lateral sides.

**Sheep 8:** The shot was taken 5m to the temporal region. On the skin, a well-defined, round, millimetric entry wound was detected in the right temporal region, between the eyeball and the ear. In the bone images, the entry wound caused damage to the temporal bone and the temporomandibular joint, with a fracture line originating from the entry wound extending toward the occipital bone. In the left temporal bone, adjacent to the temporomandibular joint, an exit wound was observed, along with two fracture lines originating from the exit wound.

**Sheep 9:** The shot was taken 5m to the occipital region. On the skin, a well-defined, round entry wound measuring 5×5 mm was detected in the occipital region. In the bone images, a well-defined bone defect measuring 90×80 mm was observed in the occipital bone, with a single fracture line originating from the bone defect extending to the right frontal bone. The nasal bone was intact, and a 3×5 mm exit wound was observed on the skin between the nostrils.

**Sheep 10:** The shot was taken 10m from the frontal region.

On the skin, a well-defined skin defect measuring 4×3 mm was detected distal to the nasal bone, to the right of the midline. In the bone images, an irregular-edged defect measuring 1.1×1.0 cm was identified adjacent to the nasal bone in the frontal bone. A large exit wound causing damage to the lateral part of the occipital bone and the C1 vertebra, to the right of the midline, was observed.

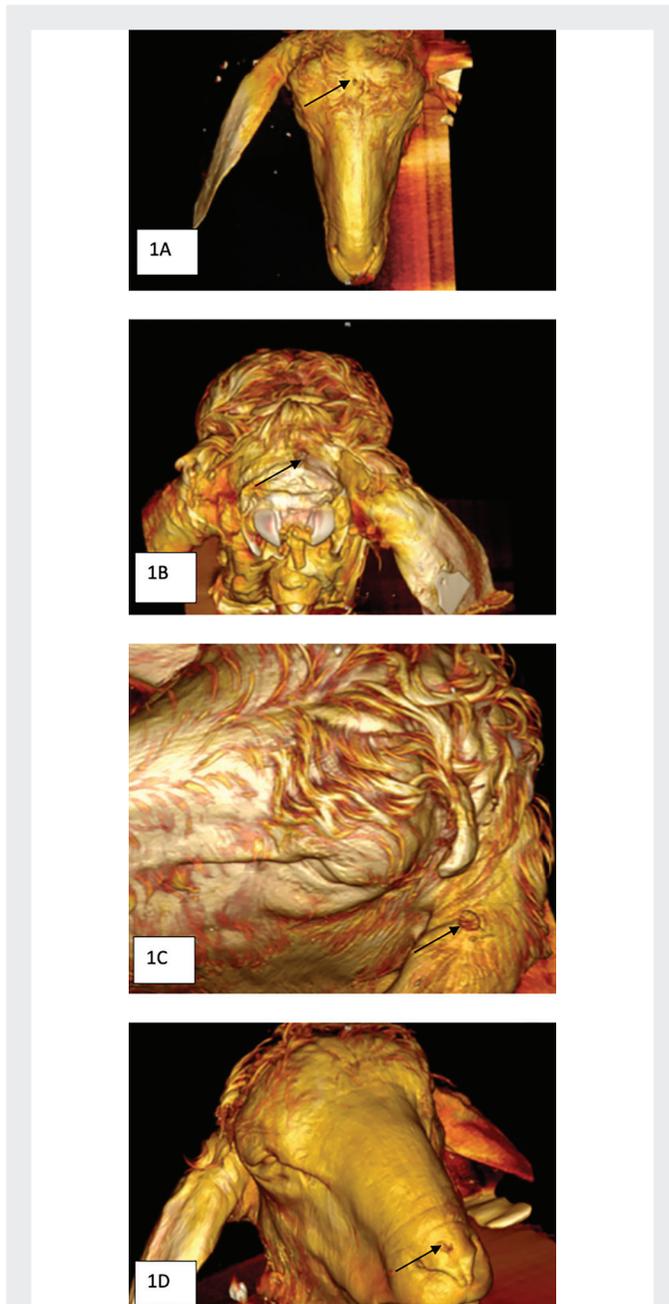
**Sheep 11:** The shot was taken 10m to the temporal region. On the skin, a well-defined, round, millimetric entry wound was detected in the right temporal region, behind the eyeball. In the bone images, damage to the temporomandibular joint and a mandibular fracture were observed. In the left temporal region, behind the eyeball, a millimetric exit wound was detected, along with damage to the temporomandibular joint and a mandibular fracture.

**Sheep 12:** The shot was taken 10m to the occipital region. In the bone images, a large entry wound causing a bone defect in the corpus of the C1 vertebra, to the left of the midline, was detected. In the nasal bone, to the right of the midline, a wide, irregular-edged exit wound was observed, with fragmented bone pieces spreading outward from the exit wound.

## DISCUSSION

As first stated by Thali et al. (15) in 2003, radiological methods have opened new horizons in the evaluation of forensic cases (16,17). Over the past 20 years, technological advancements in multi-slice CT scanners have enabled higher resolution and the acquisition of truly isotropic data sets. These data sets can be reconstructed in any desired plane, processed volumetrically, and restructured using various algorithms to obtain realistic 3D images. By integrating resolution and color information into sectional radiological methods, 3DR enables non-destructive, permanent documentation of findings in both living and deceased individuals, while providing detailed information and records about the incident and injury (22,25,26). Tomography is ideal for visualizing radiopaque materials and bone structures, yet it is limited in evaluating soft tissues and parenchymal organs. 3DR is a highly effective approach for demonstrating the damage caused by the bullet core on the skin in GSIs, overcoming the soft tissue limitations of CT and providing critical information for wound reconstruction. With 3DR, it is possible to visualize, preserve, and present the damage inflicted by the bullet core on the skin, as well as provide visual evidence regarding entry and exit wounds. In cases that reach advanced intervention centers after injury, the examination of entry and exit wounds is performed by the first physician evaluating the patient and is recorded in the forensic report. Radiological examination with 3DR reduces external examination errors dependent on personal experience and measurements, assists in distinguishing entry and exit wounds, enables visual presentation of the anatomical localization, size, and morphological characteristics of wounds, and ensures accurate recording of findings (20,24,27).

In patients receiving medical care, entry and exit wounds may undergo temporal changes during wound healing or due to medical treatments. However, thanks to the preservable and archivable nature of findings obtained with 3DR, wounds can be reassessed later and presented to legal authorities when necessary. Entry and exit wounds caused by the 9×19 mm pistol used during this study in various anatomical regions are shown in Figure 1.

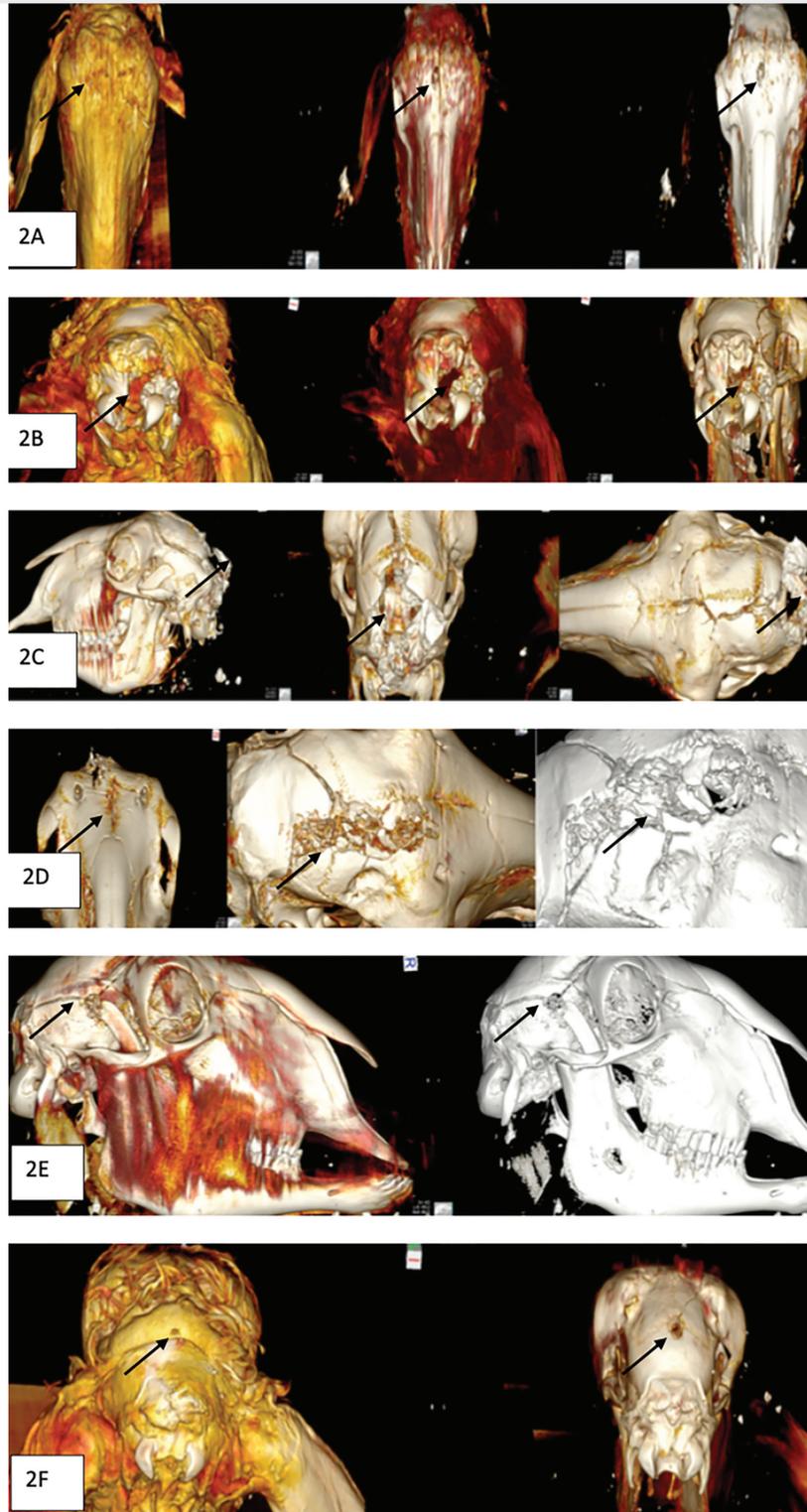


**Figure 1:** 1A: Entry wound (black arrow) observed on the skin in the frontal region (Sheep 1). 1B: Entry wound (black arrow) observed on the skin in the occipital region (Sheep 6). 1C: Exit wound (black arrow) located in the left ear (Sheep 5). 1D: Exit wound (black arrow) at the distal part of the nose, between the nostrils (Sheep 9).

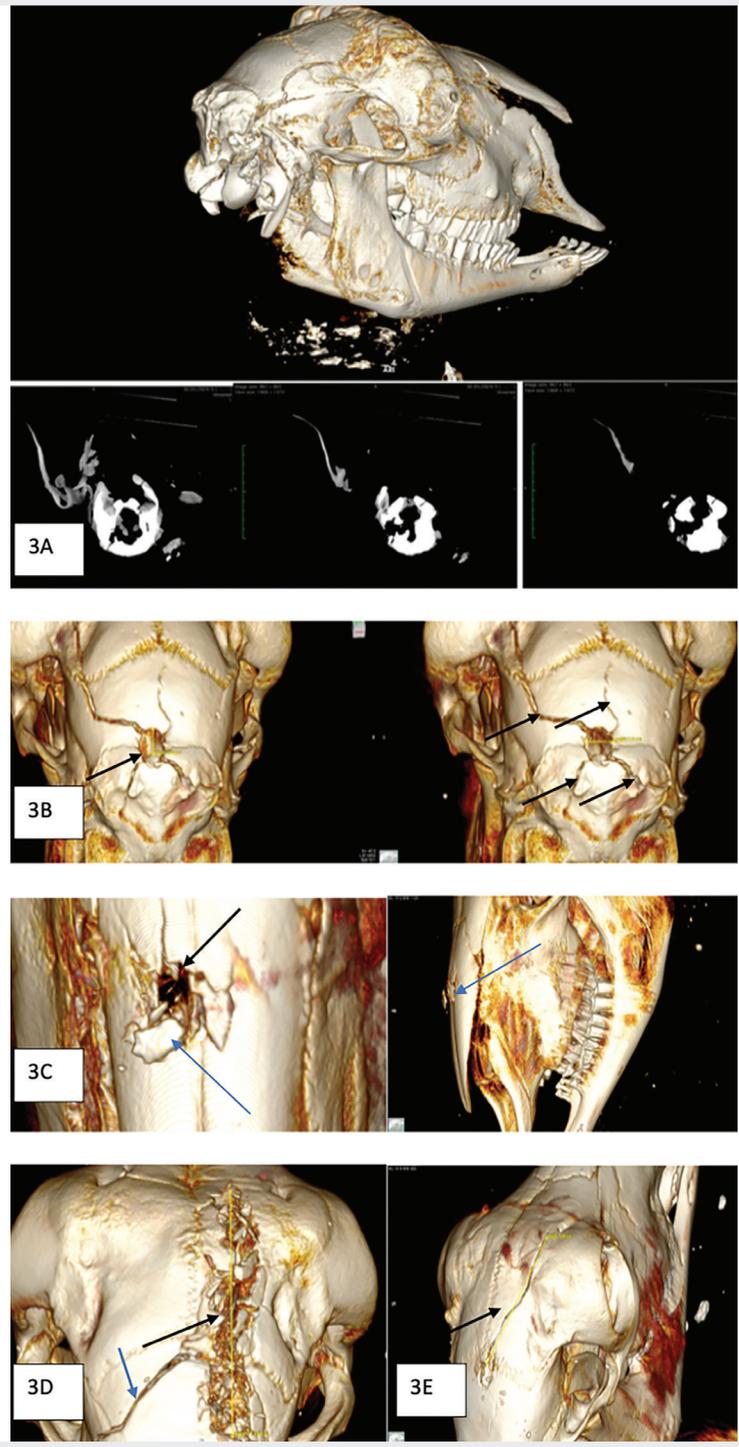
Images processed with 3DR provide improved visualization of bullet damage through virtual rotation and color options (Figure 2). It illustrates in detail the relationships among bones, fracture fragments, and soft tissues, presenting health professionals with near-realistic images and contributing to decision-support systems. It offers surgeons the opportunity to conduct virtual simulations, assessments, and material selection before interventions. It also aids clinicians, surgeons, radiologists, and forensic physicians in understanding the interrelations of anatomical structures. In cases receiving health care after injury, where wound-related findings may change due to medical or surgical treatments, or when a forensic autopsy cannot be performed, 3DR enables early non-destructive acquisition of critical information essential for forensic investigation (20,24).

3DR presents the extent of damage caused by the bullet core as 3D images, non-destructively demonstrating the severity of the injury (28,29). Measurements can be taken using 3D models, such as in the stab wound case, the measurement of fracture height in the bones of the lower extremities, and the skull fracture lines (22). According to one study, skull fracture scores derived from the total length of fracture lines on 3D-CT VR images correlate with macroscopic evaluation. This score can be used as an index to assess fracture severity (30). In clinical and forensic radiology, initial assessments are primarily based on 2D sections. However, accurate interpretation of 2D images requires comprehensive anatomical knowledge, awareness of postmortem changes, understanding of treatment-related effects, spatial imagination, and 3D reasoning skills. For individuals working in non-medical fields, such as prosecutors, lawyers, judges, and police officers, who often lack this specialized expertise, understanding findings and incidents becomes challenging. Such information is generally presented through visual reports, including drawings, illustrations, and printouts. 3D models accurately reproduce spatial relationships between various elements, thereby visualizing the incident, the scene, and the injury (22,31). Figure 3, using 3DR, demonstrates the location and size of the entry and exit wounds, the course and distribution of skull fractures, and the trajectory.

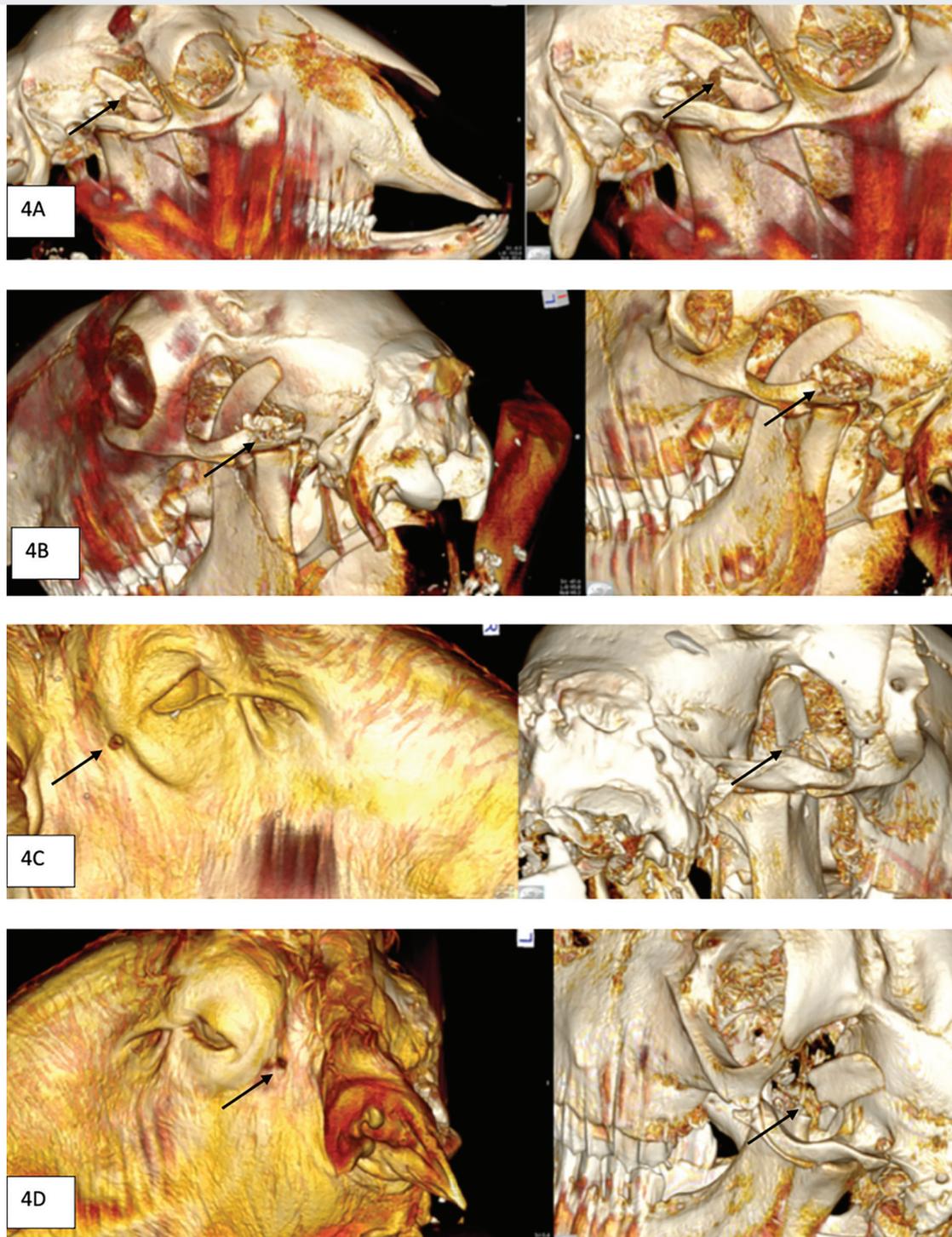
3DR enables zooming, focusing, and measurements on images, allowing examination of suspicious areas in detail. Thus, it allows assessment of the relationship between entry and exit wounds, bullet trajectories, and joints in the shooting area, as well as damage to the bones forming the joints and joint integrity. While preserving the integrity of the structures within the shooting region, 3DR simultaneously facilitates measurements and analyses. The visual data it provides offers a simple and practical means of understanding, explaining, and reporting the extent of damage. It ensures the acquisition of objective, non-invasive, storable, portable, and presentable scientific data independent of the observer (25,32-34). Figure 4 illustrates findings on joint and bone integrity by zooming into the joint structures within the shooting area.



**Figure 2.** (A) Entry wounds (black arrows) in the frontal bone observed under different contrast levels (Sheep 1) (B) Large exit wound, occipital bone, and C1 vertebral damage (black arrows) observed under different contrast levels (Sheep 1) (C) Large exit wound and fragmented bone pieces (black arrows) in the occipital bone observed from multiple perspectives (lateral, posterior, and superior) (Sheep 4) (D) Large frontal bone defect (black arrows) between the entry and exit wounds observed under different contrast levels and angles (Sheep 7) (E) Bone defect and skull fractures originating from the entry wound (black arrows) in the temporal bone observed in different contrast levels (Sheep 8) (F) Entry wounds (black arrows) on the skin and in the occipital bone observed under different contrast levels (Sheep 9) (Sheep 9)



**Figure 3.** (A) In the upper image, a single skull fracture originating from the exit wound splits into two within the temporal bone; one fracture continues within the temporal bone, while the other extends to the frontal bone. In the lower images, the corresponding skull fractures are observed on CT images (Sheep 2) (B) In the first image, the entry wound (black arrow) is observed in the occipital bone, measuring 90×113 mm in diameter. In the second image, four skull fractures (black arrows) originating from the entry wound are observed (Sheep 3) (C) Exit wound (black arrow) and fragmented bone pieces (blue arrows) projecting toward the skin are observed in the nasal bone from different perspectives (anterior, lateral) (Sheep 12) (D) Multiple fractures of the frontal and occipital bones along the trajectory (black arrow), scattered bone fragments within and around the trajectory, and an additional skull fracture in the right occipital bone (blue arrow) are observed. The measured distance between entry and exit wounds is 72 mm (Sheep 7) (E) The skull bone fracture extending from the entry wound in the occipital bone to the frontal bone is measured as 6 cm (Sheep 9)



**Figure 4.** (A) In the first image, the entry wound (black arrow) is observed in the right temporal region. In the second image, a closer evaluation of the injury demonstrates damage to the temporomandibular joint and mandibular fractures (black arrow) (Sheep 5) (B) In the first image, the exit wound (black arrow) is observed in the left temporal region. In the second image, a closer evaluation demonstrates temporal bone damage and fractures of the zygomatic bone (black arrow) (Sheep 5) (C) In the first image, a millimetric entry wound (black arrow) is observed on the skin, posterior to the eyeball, in the right temporal region. In the second image, damage to the joint, complete fracture, and separation of the mandible (black arrow) are observed (Sheep 11) (D) In the first image, a millimetric exit wound (black arrow) is observed on the skin, posterior to the eyeball, in the left temporal region. In the second image, damage to the joint, complete fracture, and separation of the mandible (black arrow) are observed (Sheep 11)

Penetrating firearm injuries of the head and neck region are associated with high mortality, and the complex anatomical structures in this area, combined with the intricate nature of the injuries, require meticulous evaluation. Advanced 3D techniques and sectional radiological imaging can be used to detect injuries in soft tissues, parenchymal organs, and bones; to localize bullet cores and fragments; and to identify wound mechanisms and trajectories. CT and 3DR are fast and practical

tools for diagnosing fractures within the skeletal system (35-37). In our study, 3DR showed damage to the occipital bone and cervical vertebra. 3DR is a suitable method, especially for detecting anatomically difficult-to-reach areas (Figure 5). Our results indicate that 3DR is a fast, non-invasive, and non-destructive method for clinicians, surgeons, radiologists, and forensic medicine physicians in cranial firearm injury cases.

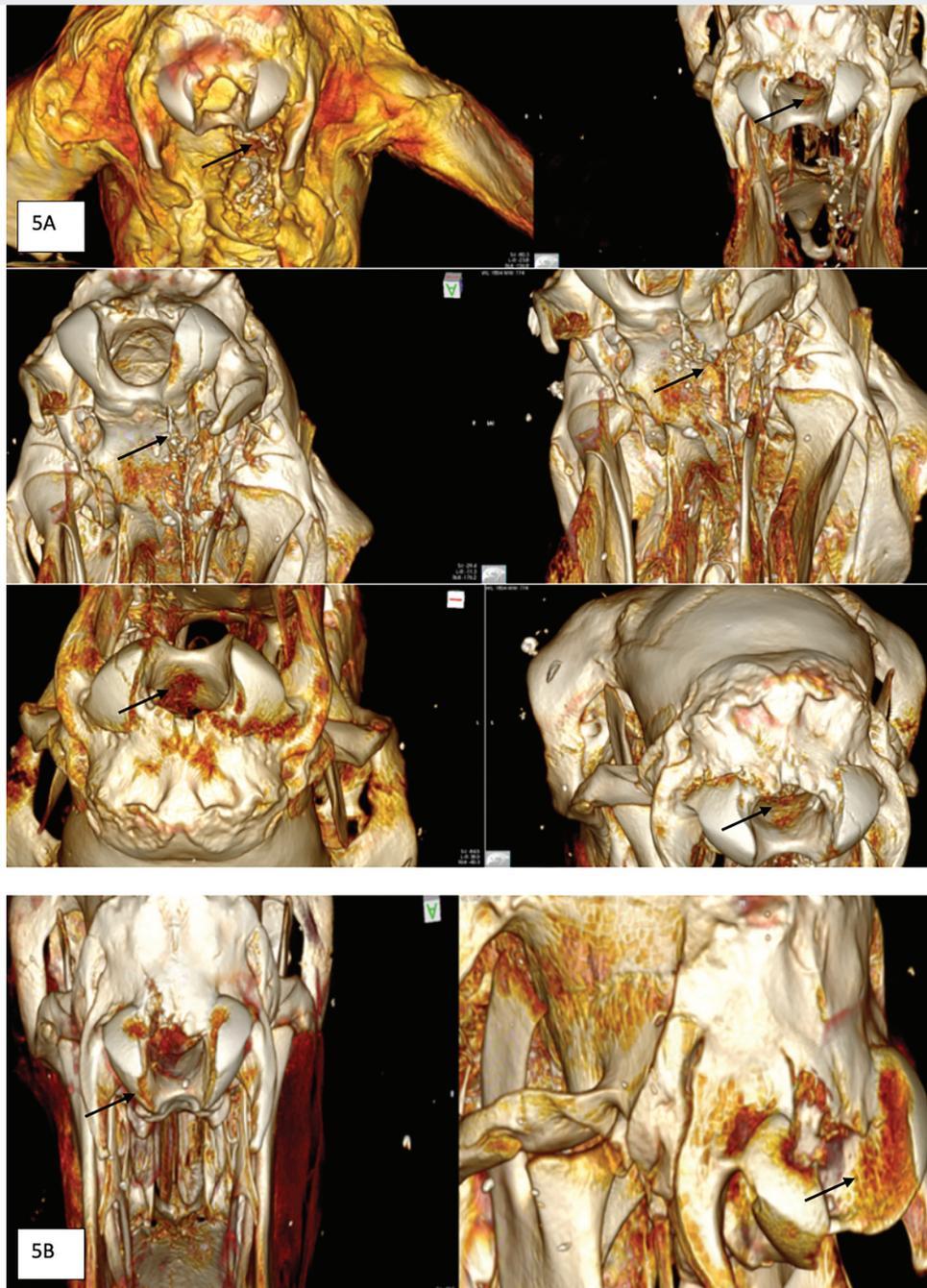


Figure 5. (A) In all images, the exit wound, occipital bone destruction, and C1 vertebral damage are observed under different contrast levels and from multiple angles (Sheep 10) (B) In the first image, a large entry wound (black arrow) is observed to the left of the midline in the C1 vertebra. In the second image, a large C1 vertebral defect (black arrow)

The 3DR findings obtained as a result of our study are listed below:

- The location of entry-exit wounds is determined.
- The diameter of the entry-exit wounds is measured.
- Bone damage in entry-exit wounds is determined.
- Bullet core trajectories are shown.
- The distribution of bone fragments is detected.
- The number, location, and course of skull bone fractures are detected.
- The length of skull fractures is measured.
- Bones forming the joint, and the Integrity of the joint are determined.
- Allows detailed examination of suspicious areas via zoom.
- Lesions in soft tissues such as skin are detected.
- Tissues can be examined at different contrasts.
- Anatomical areas that are challenging to reach, such as the skull, are evaluated.
- Objects can be rotated 360° on the X and Y axes. In this way, damaged areas are examined from different angles.

Although 3DR is a beneficial method in cranial firearm injuries, it has some disadvantages. CT is more effective than 3DR for showing parenchymal brain lesions. Equipment and application are required for reconstruction. However, the most significant issue is that accurate detection of pathological findings requires experience. This study can lead to the spread of using 3DR in cranial firearm injuries and lead to experienced authors.

### Study Limitation

The limitation of the study is that it was conducted with a small number of decapitated sheep's heads. However, the results are not affected by its similarity to human anatomical structure.

## CONCLUSION

The application of imaging methods for non-invasive documentation and analysis of findings in living persons has lagged behind the tremendous technical advancement in imaging methods. Whereas 3DR provides essential information to clinicians, surgeons, and radiology and emergency professionals, including damage to the skin, the number, course, and length of skull bone fractures, the number and distribution of bone fragments, joint integrity, and the relationship between bone fragmentation and joint integrity, creating lifelike images without performing an autopsy. In addition, in cases receiving health care after injury, where wound-related findings may change due to medical and surgical treatments and/or when a forensic autopsy cannot be performed, it enables the non-destructive acquisition of information critical for forensic investigation at an early stage. In cranial GSIs, 3DRs generated from CT images should be included in the radiological evaluation.

## Ethics

**Ethics Committee Approval:** Ethical approval for the previous CT study was received from the Çukurova University Local Ethics Committee for Animal Experiments on (decision number: 6, date: 30.04.2024).

**Informed Consent:** This study is an animal experiment.

## Footnotes

### Authorship Contributions

Surgical and Medical Practices: İ.A., G.İ.Ö., A.S.K., A.Y., Ç.A., 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.Y., Ç.A., Analysis or Interpretation: İ.A., G.İ.Ö., A.S.K., A.Y., Ç.A., Literature Search: İ.A., G.İ.Ö., Writing: İ.A., G.İ.Ö., A.S.K., A.Y., Ç.A.

**Conflict of Interest:** No conflict of interest was declared by the authors.

**Financial Disclosure:** The authors declared that this study received no financial support.

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