ORIGINAL ARTICLE

Bullet trajectory detection in the lung: Multiplanar reformatted imaging of multidetector computed tomography in children

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ABSTRACT

BACKGROUND: Trauma is a leading cause of childhood injuries. Although blunt traumas in children are more common in penetrating traumas, children in civilian life and near conflict areas can often be affected by gunshot wounds. Among all gunshot wounds, thoracic injuries constitute a significant proportion. In our study, we detected bullet trajectory in children with gunshot wounds penetrating the thorax by analyzing reformatted images of multidetector computed tomography (CT).

METHODS: Nineteen pediatric patients with thoracic gunshot wounds were evaluated retrospectively. After all patients admitted the emergency service, their hemodynamics were stabilized first. Then, PA-AC radiography and thorax CT were taken and necessary imaging studies of other body parts were performed. CT scans were performed with multi-detector CT.

RESULTS: Using reformatted axial, sagittal, and coronal and oblique images of multidetector CT, we detected projectile trajectory in the lung parenchyma in 74% of patients. In 26% of the patients, the projectile trajectory could not be detected due to excessive parenchymal hemorrhage, hemothorax, and pneumothorax.

CONCLUSION: In our study, a standard could not be made due to the fact that the types of weapons used could not be determined, the firing distances could not be known, different ages and different bullet entry and exit angles. However, detecting the trajectory of the bullet in the lungs will assist the physician in making the treatment plan and following up the patient. In addition, the evaluation of the data obtained will be beneficial to forensic medicine physicians and scientists interested in wound ballistics.

Keywords: Bullet trajectory; children; gunshot injuries; thoracic trauma; wound ballistic.

INTRODUCTION

Trauma is an important cause of mortality, morbidity, and disability in childhood. Although blunt traumas are the most common reason for children, today, they are increasingly injured and damaged by firearms in military and civilian life. Especially, children can be affected by conflicts near residential areas, and the thorax is one of the main affected body areas. In a study in children, 11 of 31 cases with penetrating thoracic injuries were the result of a gunshot.[1] Among combat injuries, thoracic injuries were reported between 3% and 25.2%, of which 45% were penetrating injuries caused by bullets.[2,3] In gunshot wounds caused by free fall of a tired bullet, 3–11% of the cases affect the thorax and have high injury potential.[4]

Ballistics are a comprehensive interdisciplinary field of science in which medicine and law force work together. In the firearms, the science that examines the movement, behavior, and interaction of the bullet with the environment is called ballistics. If the target is a living creature, the ballistics branch that examines the movement of the bullet in the body tissues is called wound ballistics. The main research area of wound ballistics is to examine the permanent cavity formed by the

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bullet mass hitting the tissues and causing perforation, the energy transfer from the bullet to the tissue and the temporary cavity formed by the thrust of the tissues and organs to the environment due to pressure. Pressure gradients then cause radial tissue separation into the projectile path by tissue recoil, creating the temporary cavity. Temporary cavity size and distance from entry site will depend on projectile design and velocity and elasticity of the tissues it penetrates.[5–7]

In the lung tissue, once the bullet passes through the parenchymal zone, the trace of the bullet can easily be seen due to the difference between the injured lung and neighboring healthy lung tissue which is evidently clear on certain sections of thoracic computed tomography (CT)[8,9] but not in all slices. Therefore, additional studies are required on routine axial images recorded beforehand. Reformatting the multi-detector computer tomography (MDCT) images in a software environment can help us in this regard.

The aim of this study is to evaluate multi-plane reformatted images of MDCT to detect bullet trajectory in the lung parenchyma.

MATERIALS AND METHODS

After the approval of the Local Ethics Committee (approval no: HRU/21.15.15), 19 patients who were followed up in our clinic for thoracic gunshot wounds between 2014 and June 2021 were evaluated retrospectively. Patients with single penetrating ballistic injury to the thorax were included in the study. Mediastinal injuries and injuries other than bullets, such as those caused by shrapnel fragments, were excluded from the study.

After the patient's airway patency, respiration and circulation were evaluated in the emergency department, laboratory studies were performed, erythrocyte and plasma products were prepared for a probable immediate transfusion. After the patients were stabilized hemodynamically, detailed examination of the patient was performed. Then, radiology examination consisting of plain films, thoracic MDCT, and imaging studies of other body parts deemed necessary were performed. If it is very urgent, the chest tube of the patient was placed in the emergency room after a plain thorax X-ray was taken without waiting for the thoracic MDCT. Then, the patients were transferred to the intensive care unit, where the vital signs and hemoglobin values of the patients were followed closely, and medical treatments were planned according to the patient's needs. At this stage, the patients who were decided to undergo tube thoracostomy were taken to the operating room and a thorax tube was inserted.

In our study, the very first thoracic MDCT taken after admission was used in the study. Then, the images were interpreted on native slices using axial, coronal, sagittal, and oblique views using multi-plane reconstructions in parenchymatous window. Among the multiplanar reformatted images, the viewpoint in which the bullet tracing is best seen was selected. Image analysis was performed by the same radiologist (AD) in all cases.

Follow-up in the intensive care unit and ward was done with plain chest films, but a new thoracic MDCT was requested when necessary and these images were not used in the study.

MDCT

The thorax CT examinations were acquired using a multidetector row CT (Revolution, GE Healthcare, Milwaukee, WI, USA) following a standard protocol. Full inspiratory scans were obtained with or without administration of intravenous contrast medium. Slices were taken from the thoracic inlet as far as the level of lowest diaphragm in supine position. Scanning parameters were 100 kW, effective tube current 55 mA, collimation 16 × 0.6 mm, pitch 1.5, section thickness 1 mm, reconstruction interval 0.8 mm, and tube rotation time 280 ms. The images obtained were transferred to a picture archiving and communication system workstation. The axial images and multiplanar reconstruction reformatted images were evaluated together. All images were processed with standard mediastinal (width, 410 HU; level, 503 HU), bone (width, 2500 HU; level, 500 HU) and lung (width 1695 HU; level, −505 HU) window settings.

RESULTS

The identities of 19 patients with gunshot wounds in the thorax were determined. Seven of the patients were female and 12 were male, and their ages ranged from 5 to 17 (mean 10.8).

Four of the patients had thoracic injuries due to free falling bullets, two had anterior, five had posterior, and eight had oblique access. Entry and exit holes of a patient with oblique tracing are seen in the photograph (Fig. 1a and b). While 13 patients had entry and exit holes, in five patients, the bullet persisted in the thoracic wall or thoracic cavity. In one patient, a bullet which had an anterior entry hole in the thoracic wall, passed through the diaphragm and immediately lodged in the liver dome. No intrathoracic bullet fragmentation was encountered in our series.

Pneumothorax was present in five patients and hemopneumothorax in 13 patients. Eight patients were brought to the emergency room with a thoracic tube inserted from the scene of the first intervention or from the primary care center. Tube thoracostomy was performed in the emergency department in three patients and in the operating room in seven patients. One patient was only followed up without tube thoracostomy. No patient underwent thoracotomy at this stage.

All patients had varying degrees of increased density (Figs. 1c and 2a) and appearances of hemothorax and/or pneumothorax on plain X-rays. When axial, coronal, sagittal, and oblique reformats of MDCT images are made, bullet tracing or tracing and cavity were detected in 14 (74%) patients. Bullet tracing was completely observed in 10 (53%) of the patients (Fig. 1d, 3a-d), and an idea of the bullet tracing was obtained in 4 patients despite pneumothorax and hemothorax (Fig. 2b and c). No trace of bullet could be detected in five patients due to extensive intraparenchymal hemorrhage (26%). In one patient, bone particles were detected in the bullet trace (Fig. 2b and c).

Thoracic tube of the patients was removed between 3 and 21 days (mean 6.1). The patients stayed in the intensive care unit for between 1 and 17 days (mean 4.9). Afterward, the patients were transferred to the ward. The mean hospital stay of the patients was between 4 and 37 days (mean 9.3). No blood transfusion was given to four patients. Between 1 and 12 units of blood were transfused to 15 patients (mean 3.4). After the patient's vital signs were stable and clinical improvement was achieved, one bullet core located under the thoracic wall and the skin were removed with minor surgical intervention, one intrathoracic bullet core was removed through thoracoscopy. The bullet core stuck in the liver dome was removed by mini laparotomy. The bullet core embedded in the tissue at the apex of the thoracic cavity and adjacent to the left brachiocephalic artery was left unremoved.

One patient developed hemiplegia due to spinal cord injury and one patient developed plegia in the left arm due to brachial plexus injury. One patient was hospitalized 15 days later due to empyema and was treated only with tube thoracostomy. This patient developed hemiplegia due to spinal cord injury. A patient who underwent long-term cardiopul-

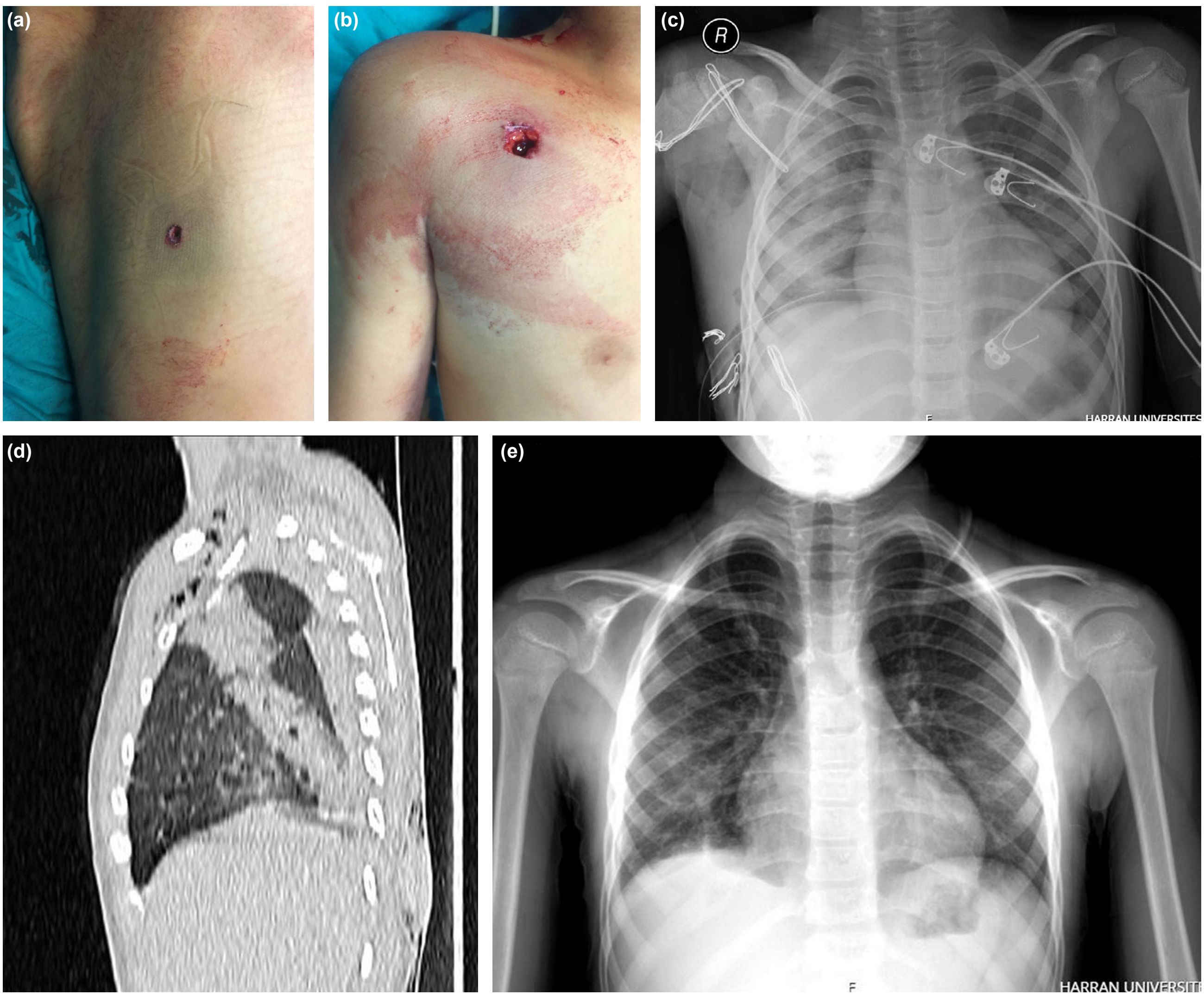

Figure 1. In a 9-year-old male patient, when the bullet passed the lung tissue obliquely, entry hole is seen at the level of the posterior nineth rib **(a)** and the exit hole is seen at the level of the anterior mid-clavicular line in the second intercostal space **(b)**, plain chest X-ray showed a slightly increased opacity in the posterior right lung and a slightly blunted costophrenic sinus **(c)**, In the section taken from the reformatted sagittal image, increase in density is visualized consistent with parenchymal hemorrhage and/or contusion of the bullet trace with an air density in the form of millimetric foci showing an oblique course from posterior to anterior obliquely **(d)**. Plain chest X-ray: Normal chest radiograph at patient discharge **(e)**.

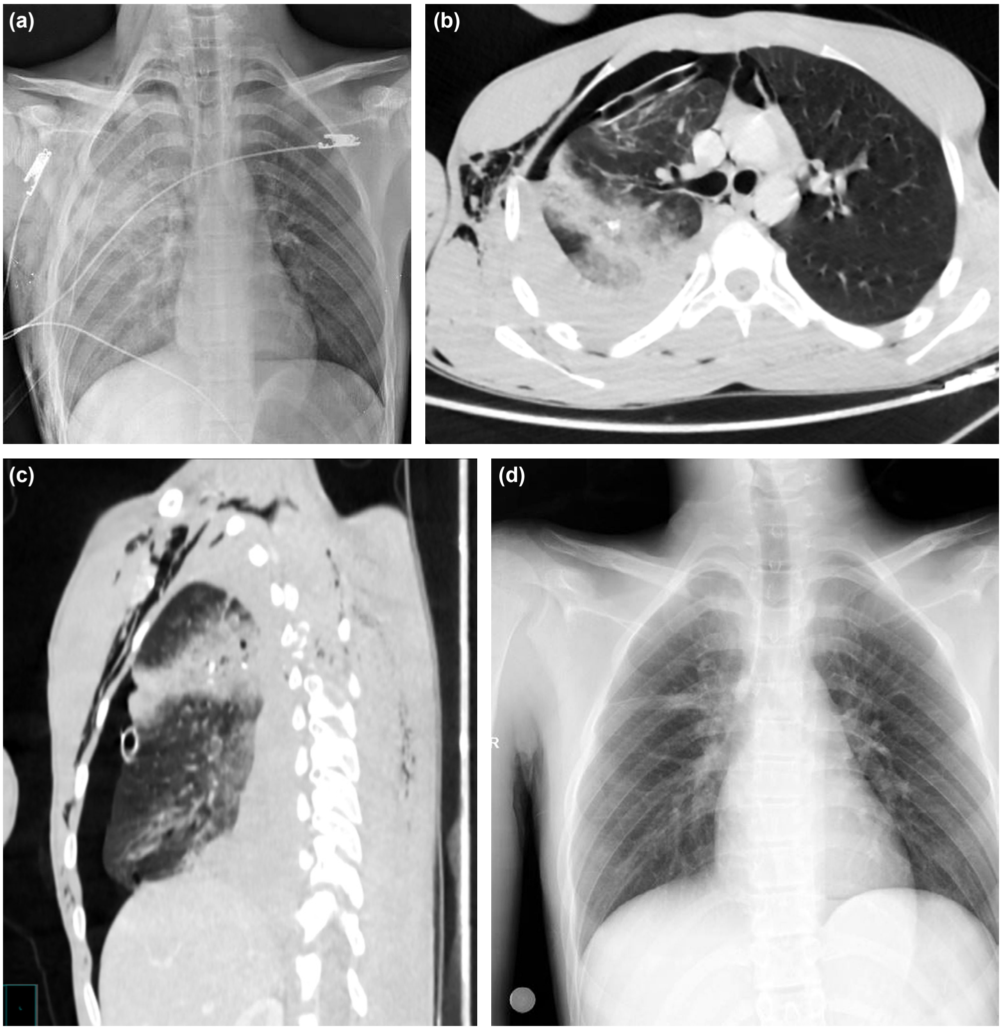

Figure 2. In a 14-year-old male patient – whose bullet entry hole is at the level of the fifth thoracic vertebra with a fragmented displaced fracture in the vertebral cortex and whose exit hole is in the mid-axillary line second intercostal space – bullet tracing can be seen in the reformatted images despite the confusion in the radiographs. Chest X-ray shows fragmentation compatible with rib fracture in the upper-middle zone of the right lung, subcutaneous emphysema, pneumothorax, minimal hemothorax, increased opacity in the upper-middle zone of the right lung, and inhomogeneous aeration areas **(a)**. In the section taken from the axial parenchyma window, minimal pneumothorax, hemothorax and density increments consistent with parenchymal hemorrhage-contusion of the bullet trace showing a posterior-anterior oblique course in which millimetric air density and the appearance of millimetric bone fragments (HU: 357) are observed **(b)**. In the section taken from the reformatted sagittal parenchyma window, air density increases consistent with the parenchymal hemorrhage – contusion of the pneumothorax, hemothorax, and the posterior-anterior course in which the millimetric air density and the appearance of millimetric bone fragments are observed **(c)**. Plain chest X-ray: Normal chest radiograph at patient discharge **(d)**.

monary resuscitation died 8 days later due to multiorgan failure. Eighteen patients whose plain X-rays were evaluated as normal (Figs. 1e and 2d) were discharged with clinical improvement. No problem was encountered in the follow-up from 3 months to 7 years.

DISCUSSION

Ballistic science is subdivided into internal ballistic, external ballistic, and terminal ballistics. Internal ballistic studies the movements of the bullet inside the barrel, external ballistic studies the forces acting on the bullet in the air and its movements on its flight path, and terminal (target) ballistic studies its movement and destruction on the target once it reaches a target. If the bullet hits a live target, the terminal ballistic is called wound ballistics. In the researches, penetration and temporary cavity formation between the mechanisms of gunshot wounds are well defined.[5,7]

Penetration created by the mass of the bullet by tearing and piercing the tissues is the first and main effect of the bullet,

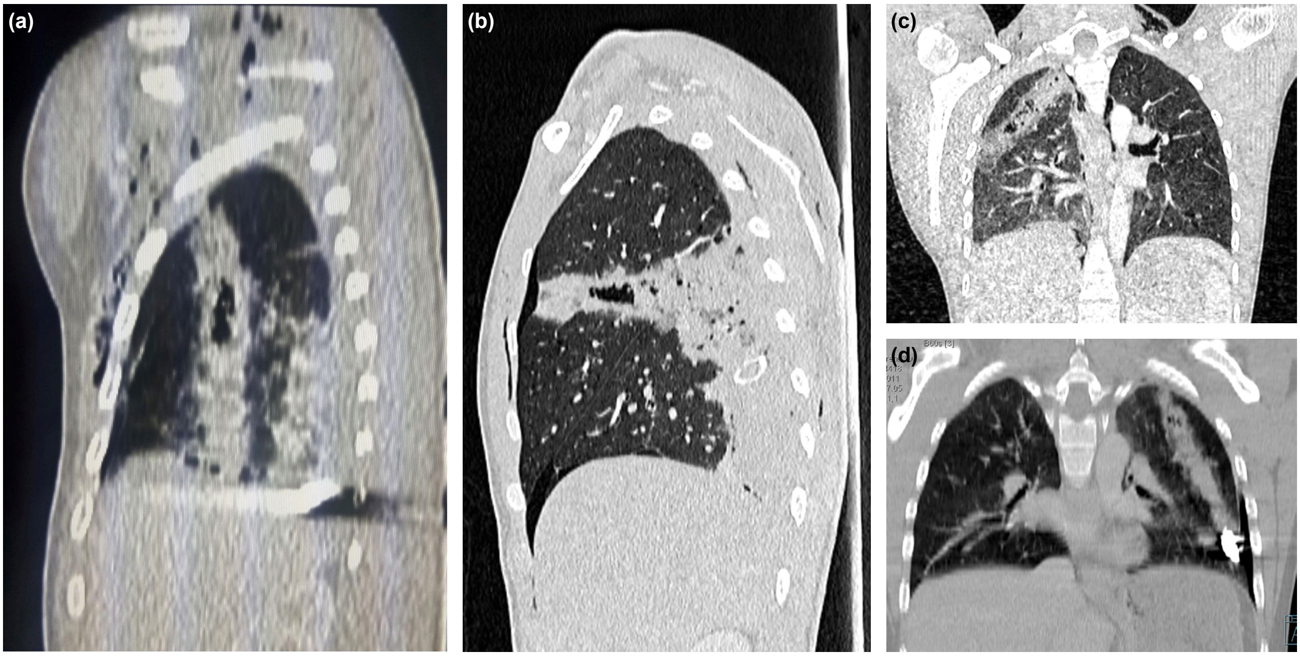

Figure 3. Selected views in different patients with bullet projectory are shown. In the section taken from the reformatted sagittal parenchyma window, increase in air density consistent with parenchymal hemorrhage and/or contusion of the bullet trace with air density in the form of millimetric foci with craniocaudal course are observed. In addition, a longitudinal artifact trace is also visualized in the basement of the lung created by the bullet core that is lodged in the costodiaphragmatic sinus **(a)**. In the section taken from the reformatted sagittal parenchyma window, increase in air density consistent with the parenchymal hemorrhage-contusion of the bullet trace with an air density in the form of millimetric foci, and minimal pneumothorax and thorax tube in the hemothorax are observed in the anterior-posterior course **(b)**. In the section taken from the reformatted coronal parenchyma window, increase in air density consistent with parenchymal hemorrhage-contusion of the bullet trace, in which the air density is observed in the form of milimetric foci, showing a craniocaudal oblique course are observed **(c)**. In the section taken from the reformatted coronal mediastinum window, air density in the form of millimetric foci within the craniocaudal slightly oblique course and increase in air density consistent with the parenchymal hemorrhage and/or contusion of the bullet trace with a hyperdense appearance of the bullet core at the end of the trace are observed **(d)**.

and the bullet must have velocity, kinetic energy, and kinetic energy density to overcome the elasticity limit of the tissue it hits. As the bullet pierces the body tissues and moves through the tissues, it tears the tissues with its mass and creates a wound path called the permanent cavity.[5,7,10–12]

The temporary cavity is also called the "blast effect" and is formed by the pressure effect of the bullet on the surrounding tissue. It is probably the most important factor in injury. A bullet flying in a certain balance in the air encounters a resistance when it enters body tissues. With the effect of this resistance, a deviation occurs in the axis of the bullet, and this deviation is sufficient for the bullet core to start somersaulting within the body tissue. With the tumble, the surface area of the bullet core in contact with the tissue expands and the kinetic energy transferred to the tissue by the bullet core creates pressure waves. As the amount of kinetic energy transferred to the tissue increases, the tissues around the cavity expand radially and form the temporary cavity. The temporary cavity continues to form after the bullet passes through the tissue and collapses within milliseconds to become a permanent cavity and the diameter of the temporary cavity is larger than the diameter of the permanent cavity.[5–7,10–12]

Experimental studies were carried out to evaluate the damage caused by the bullet while passing through the tissues, and in these studies, many materials were used as tissue simulant besides ballistic gelatin. To further understand wound ballistics, organ models have been developed. Studies have been made on different types of weapons, different bullet sizes, different shooting angles and shooting from different distances in experimental models. In studies with high-speed cameras, permanent cavity, temporary cavity formation, and characteristics of the cavity were observed in gunshot wounds and the factors causing damage were investigated, and numerical analyzes were made.[6,13,14] In addition, CT was proposed as a non-invasive technique and multi-plane reconstructed images and three-dimensional (3D) reconstructions were used.[15–17]

However, it is not possible to recreate such standards mentioned above in conflict areas. While the initial evaluation of traumas was made with conventional methods, MDCT has been increasingly used in the evaluation of trauma patients and has gained an important place. Multi-plane (two-dimensional) and volumetric (3D) reformatted MDCT has been widely used to evaluate anomalies encountered in blunt or penetrating thoracic trauma. In this way, detailed information about the thoracic wall and bone structures, mediastinal structures, and lung parenchyma was obtained.[8,18,19] Moreover, also, virtual animation of 3D models obtained from CT scans of living and dead subjects was made and suggested for forensic reconstructions.[20,21]

Since it shoots bullets in the body, the reaction and injury level of each organ will be different. In temporary cavity formation; when the bullet makes contact, less elastic tissue (e.g. brain, liver, or spleen), fluid-filled organs (e.g., heart, bladder, or gastrointestinal tract 1) and dense tissues (e.g. bone) form a large temporary cavity and are severely damaged. Organs with more elastic tissue (e.g., skeletal muscle) are less susceptible to temporary cavity formation. Lung tissue, on the other hand, is one of the organs that show the most resistance to the temporary cavity effect due to the air sacs surrounded by strong connective tissue. Therefore, most lung injuries can be treated with tube thoracostomy, provided there is no major vascular injury.[8,11,12]

Our study concerns the trajectory of the bullet in the lung parenchyma after the bullet has passed through the thoracic wall. In our study, we followed the bullet trajectory with a rate of 74%, and the cases where we could follow the bullet trajectory exactly was 52%. However, the images that we used in our study were images taken in the emergency department to evaluate the patient after the patient was stabilized hemodynamically. If the images had been taken after pathologies such as pneumothorax/hemothorax had decreased, we would perhaps have encountered a better ratio.

We interpreted the areas with air density observed throughout the bullet trajectory as permanent cavity. The most important feature of the lungs is their ability to expand, although the permanent cavity is perhaps larger, due to the expandability of the lungs, we tracked the permanent cavity as millimetric air densities along the trajectory of the bullet. We interpreted the consolidated area along the bullet trajectory as parenchyma injured during temporary cavity formation.

In this study, it was not possible to establish a standard because of different patient ages, different thoracic regions where the bullet hits, different entry angles of the bullet to the thoracic wall, different firing distances, different bullet velocities, bullets of different shapes and calibrations, and different types of weapons. Since we have many variables, we did not measurements related to the bullet trajectory in our study, and we could not comment on the degree of blast effect. However, our findings may be useful in planning scientific studies on wound ballistics. In addition, a special interpretation can be made for each case, which can be useful both in the therapeutic physician and in forensic medicine.

Conclusion

Seeing the trajectory of the bullet in the lung tissue and the damage in the surrounding lung parenchyma will not only help physicians in making a treatment plan but would also be beneficial for forensic physicians. In addition, it would help scientists working on tissue ballistics to evaluate bullet movements in the tissue.

Our study is limited to the detection of bullet tracing in the initial thorax MDCT taken after the patient's transfer to our hospital. After this stage, decisions were made according to clinical recovery and plain chest X-rays.

Prospectively, the damage to the lungs after the healing of the bullet trace with fibrous tissue can be evaluated with pulmonary function tests.

Ethics Committee Approval: This study was approved by the Harran Univerity Clinical Research Ethics Committee (Date: 06.09.2021, Decision No: HRU/21.15.15).

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Authorship Contributions: Concept: M.E.B., A.D.; Design: M.E.B., V.K., M.E.D.; Supervision: M.E.B., A.D., M.E.D.; Materials: M.E.B., O.H.K., T.O., M.E.D.; Data: M.E.B., V.K., A.D., O.H.K., T.G.; Analysis: M.E.B., O.H.K., T.G.; Literature search: A.D., V.K.; Writing: M.E.B., T.G., V.K., A.D.; Critical revision: M.E.B., A.D.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Akciğerlerde mermi yörüngesinin tespiti: Çocuklarda multidedektör bilgisayarlı tomografinin reformatlanmış görüntüleri

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AMAÇ: Travma çocukluk çağı yaralanmaların önde gelen bir sebebidir. Çocuklarda künt travmalar penetran travmalardan daha sık olmasına rağmen gerek sivil yaşamda gerekse çatışma alanlarının yakındaki çocuklar ateşli silah yaralanmalarından sıklıkla etkilenebilmektedirler ve ateşli silah yaralanmaları arasında torasik yaralanmalar önemli bir oran oluşturmaktadır. Çalışmamızda, çocuklarda çok detektörlü bilgisayarlı tomografinin reformatlanmış görüntülerini analiz ederek toraksa nafiz ateşli silah yaralanmalarında mermi yörüngesini tespit ettik.
GEREÇ VE YÖNTEM: Torasik ateşli silah yaralanması olan 19 çocuk hasta geriye dönük olarak değerlendirildi. Bütün hastalar acil service giriş yaptıktan sonra, önce hemodinamileri stabil hale getirildi. Ardından PA-AC grafisi ve toraks bilgisayarlı tomografisi çekildi ve diğer vücut bölgelerinin gerekli görülen görüntüleme çalışmaları yapıldı. Bilgisayarlı tomografi çekimleri multi dedektör bilgisayarlı tomografi ile yapıldı.
BULGULAR: Multidedektör bilgisayarlı tomografinin, reformatlanmış aksiyal, sagittal ve koranal ve oblik görüntülerini kullanarak %74 hastada akciğer parankiminde mermi yörüngesini tespit ettik. Hastaların %26'sında ise çok fazla parankimal hemoraji, hemotoraks, pnömotoraks gibi nedenlerle mermi yörüngesi tespit edilemedi.
TARTIŞMA: Çalışmamızda kullanılan ateşli silah çeşitlerinin bilinmemesi, atış mesafelerinin tespit edilememesi, farklı yaşlar ve farklı mermi giriş çıkış açıları nedeniyle bir standart yapılamamıştır. Ancak, akciğer dokusunda mermi yörüngesini tespit etmek, hekime tedavi planını yapmasında ve hastayı takip etmesinde yardımcı olacaktır. Ayrıca elde edilen verilerin değerlendirilmesi adli tıp hekimlerine ve yara balistiği ile ilgilenen bilim insanlarına faydalı olacaktır.
Anahtar sözcükler: Ateşli silah yaralanmaları; çocuk; mermi yörüngesi; toraks travmaları; yara balistiği.

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