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# IMAGING of THORACOABDOMINAL GUNSHOT WOUNDS

Under the general editorship of Academician of the National Academy of Sciences and National Academy of Medical Sciences of Ukraine, Doctor of Medical Sciences, Professor V.I. Tsimbaliuk

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**Imaging** of thoracoabdominal gunshot wounds [V.I. Tsymbaliuk, R.Ya. Abdullaiev, I.A. Lurin, V.V. Lazoryshynets, O.Y. Usenko, I.M. Dykan, O.I. Grechanyk]. – Kharkiv: Fact, 2024.- 152 p.

***"Imaging of thoracoabdominal gunshot wounds"*** is the 15th edition of a series of books summarizing the experience of combat medical support of our armed forces of Ukraine, prepared by well-known specialists-practitioners and scientists of military medicine, the National Academy of Medical Sciences of Ukraine and the Ministry of Health of Ukraine. The main goal of this work is to improve the quality of diagnosis of gunshot wounds. The book will be useful to a wide range of doctors of various specialties, students of institutions of higher and postgraduate education of the Ministry of Health of Ukraine.

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***Military and civilian doctors who dedicated themselves to the struggle for the Independence of Ukraine are dedicated.....***

**Content**

## Foreword

From the first days of the full-scale invasion of the Russian Federation into Ukraine, the National Medical Academy of Ukraine has been involved in providing medical care and assistance to wounded, injured, injured and sick servicemen of the Armed Forces of Ukraine and other defense forces participating in hostilities.

Having considerable experience in providing highly specialized medical care to the participants of the anti-terrorist operation, the specialists of the state scientific institutions of the National Medical Academy of Ukraine were ready for a possible aggravation of the situation. The leadership of the NMA of Ukraine introduced certain organizational and management solutions that made it possible, to solve urgent issues related to ensuring the functioning of subordinate scientific institutions in a difficult political and socio-economic situation.

The atlas presents the results of X-ray, computed tomography, ultrasonography in diagnostics of injuries of the chest and abdominal organs in gunshot thoracoabdominal wounds. Numerous works by the authors on this topic indicate the relevance of this atlas, which is the **15th** in this series.

The atlas reveals the issues of radiation diagnostics of gunshot wounds and combat injuries, determining the further development of this direction. Representatives of various specialties took part in writing the work: military surgeons, surgeons, radiologists, specialists in ultrasound diagnostics. Today, the institutions of the NAMS of Ukraine have a powerful material and technical base, highly professional personnel potential, formed from highly qualified specialists who use modern high-tech diagnostic methods in their work and are ready to make significant efforts to further provide comprehensive medical care to servicemen of the Armed Forces of Ukraine and other security agencies, defenders of Ukraine, who heroically resist the full-scale armed aggression of Russia.

*President of the National Academy of Medical Sciences of Ukraine, editor-in-chief of a series of scientific and practical works on the generalization of combat experience of medical support, academician of the National Academy of Sciences and National Academy of Medical Sciences of Ukraine*

**V. Tsimbaliuk**

## Introduction

Injuries to the thorax and abdomen are on the top among other sites of gunshot traumas in warfare and armed conflicts and are frequently presented as combined thoracoabdominal injuries. The latter is associated with a high rate of lethal outcomes and longer rehabilitation in those, who survived due to injuries of multiple organs and major vessels of the chest and abdomen, bone fractures [Kotwal R.S. et al., 2018; Swiech A. et al., 2021; Roman P. et al., 2023.]. The modern weapon is designed to cause critical and severe damage in multiple organs which is presented by separate injuries to the chest or abdomen, or combined trauma, including abdominal and thoracoabdominal cases. In the hybrid war in Ukraine, 4% of all wounds are gunshot wounds to the abdomen, of which 33% are penetrating, 67% are non-penetrating. In the structure of gunshot wounds of the abdomen, gunshot fragmentation and explosive wounds predominate, accounting for 62%; pelvic wounds account for 1% [Gumeniuk K. et al., 2023; Gybalo RV. et al., 2022; Rogovskyi VM. et al., 2022; Golovko S. et al., 2023; Tsymbaliuk V. et al., 2023].

Thoracoabdominal injury is considered a combination of abdominal injury with chest and diaphragm damage [Lurin I. et al., 2023]. In the ongoing war in Ukraine, thoracoabdominal injuries constituted 0.5% out of all cases. In the structure of gunshot wounds to the abdomen, the share of thoracoabdominal wounds is 5%, the lethality ranges from 28 to 31%. Thoracoabdominal injury due to high-energy weapon application is always associated with lung failure, hemoand pneumothorax, hemorrhagic shock, cardiac tamponade, and upper airway obstruction with blood and mucus due to post-traumatic hypersecretion of mucous membranes. On the other hand, the abdominal trauma is also severe, presenting with injury to the liver, intestine, or mesenteric and other major vessels, resulting in massive hemorrhage and peritonitis. Thoracoabdominal injury is also frequently associated with diaphragm damage, which might be hidden. The so-called “hidden” damage to the diaphragm is especially difficult to establish, however, it is usually suspected at the preoperative stage as well as intraoperatively. The most common clinical signs of a rupture of the diaphragm are considered to be the presence of a gunshot wound entrance below the V rib, bruises and fractures of the ribs in the same location, decreased breath sounds, sounds of intestinal peristalsis during lung auscultation, or signs of intestinal obstruction. However, in combat patients, the classical signs of damage to the diaphragm are not always detected or are hidden by the clinic of injuries to other organs. The management of patients with thoracoabdominal injury should include the application of Advance Trauma Life Support (ATLS) protocol, focused assessment with sonography in trauma (FAST) protocol as well as computed tomography of chest and abdomen [Kotwal RS. et al., 2018; Quinn J. et al., 2023; Chen S. et al., 2019].

In a hybrid war, non-invasive methods of medical imaging are important for the diagnosis of gunshot wounds to the abdomen: ultrasound diagnostics, digital radiography for urgent sorting of the wounded, detection of markers of damage to the abdominal organs and multidetector computed tomography (MDCT), which makes it possible to assess the nature and volume of injuries, the topography of postoperative complications, and in some wounded patients to refuse laparotomy, while maintaining the possibility of dynamic observation of them. However, well-known invasive diagnostic interventions (laparocentesis, diagnostic laparotomy) are often unreasonable and can lead to the development of complications [Abdullaiev R.Y. et al., 2023; Gumeniuk K. et al., 2023; Abdullaiev R.R. . et al., 2024].

The use of FAST, e-FAST protocols plays an important role in the sorting of the wounded and victims, and guides the further selection of medical imaging methods. The effectiveness of the FAST protocol has been proven in the evaluation of blunt abdominal trauma, but its role in penetrating trauma is less clear. Therefore, MDCT is considered the best method of medical visualization of closed abdominal trauma and penetrating wounds in hemodynamically stable wounded. However, FAST remains the preferred medical imaging modality for hemodynamically unstable patients. MDCT allows surgeons to safely observe selected stable patients without referring them to the operating room [Richards JR. et al., 2017].

Selective nonoperative management of abdominal gunshot wounds is increasingly used as computed tomography has become a diagnostic adjunct for the evaluation of intraabdominal injuries including hollow viscus injuries (HVIs). Currently, there is scarce data on the diagnostic accuracy of CT for identifying HVIs [Lian T. et al., 2023 ].

Repeated MDCT for gunshot wounds to the abdomen in hemodynamically stable wounded allows to avoid unnecessary laparotomies. The advantage of using MDCT is non-invasiveness, high sensitivity, specificity regarding the localization of injuries, foreign bodies, assessment of the degree of injury, trajectory of wound channels, visualization of hemorrhages in body tissues. MDCT makes it possible to detect more than 50% of additional injuries: head, neck, chest, abdomen, pelvis, which are not provided by other methods of medical imaging, physical examination, Advanced Trauma Life Support (ATLS) protocols. In addition to the clinical assessment of the severity of the condition in the context of trauma, it is necessary to improve the methods of medical visualization of intraoperative conditions, since the difficulty in diagnosis is caused by a large number of combined and multiple injuries and complications in the postoperative period [Saher S. et al., 2016].

Given the multifactorial nature of gunshot wounds to the abdomen, non-contrast tomography of the head, spinal cord, angiography of the thoracic and abdominal cavities, pelvis with contrast in the portal venous phase and urography are performed, since it is difficult to predict the path of a bullet or fragment. It should be noted that the thoracoabdominal, abdominopelvic, thoracocardial cavities are unique, since wound channels can be located in any part of these cavities. Transthoracic, transabdominal, transperineal, transpelvic trajectories of wound channels are especially complex due to the large number of anatomical structures, therefore, in such cases, the most effective method of medical imaging will be MDCT with dynamic contrast enhancement. MDCT is sensitive to the detection of air and fluid in any part of the body. Postmortem MDCT is considered the "gold standard" for retrospective evaluation of the diagnosis and treatment of penetrating combat trauma if an autopsy is not possible. Therefore, postmortem MDCT can be used as an autopsy of penetrating wounds of different localization [**Grabherr S.** et al.**,** 2018]. The information obtained is adequate and exceeds the information content of the autopsy results. The experience of using MDCT of the whole body in wounded without an entry wound was made public by Ukrainian military surgeons. Thus, the basis for the formation of effective diagnostic and therapeutic tactics in modern conditions is the choice of a highly informative method of medical imaging for the complete diagnosis of thoracoabdominal wounds.

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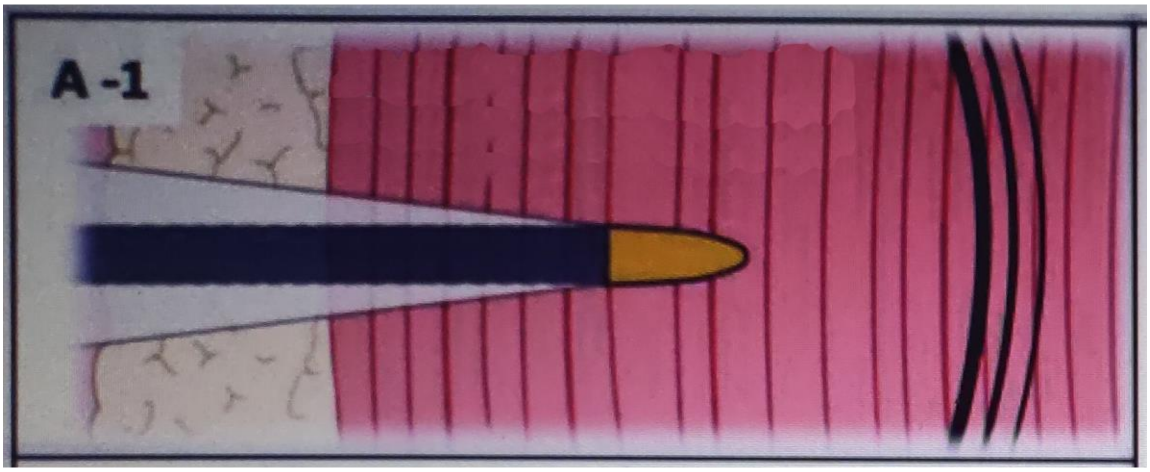
## Chupter 1.

Radiation diagnostics of thoracic gunshot wounds.

*Dykan I.M.*

The frequency of injuries of the thoracic cavity organs (ThCO) in the general structure of combat surgical trauma (CST) is equal to 7-12% and remains unchanged from the Second World War to modern military conflicts [Lichtenberger J. P. et al., 2018]. The vast majority of combat surgical trauma of the thoracic cavity organs – shrapnel gunshot wounds (up to 72% of observations). The classification of gunshot thoracic wounds is given in the table. The mechanism of the formation of a gunshot wound is quite complex (Fig. 1. A): primary contusion damage to tissues due to the action of a shock wave (A1); the formation of a permanent cavity of the wound channel (WCh) by a directly injuring projectile and the formation of a temporary pulsating cavity from the energy of a side impact (A2); action of the vortex trace (A3). Morphological changes in tissues in the area of a gunshot wound are demonstrated by Figure 1.B [Truesdell W. et al., 2020]. The shape, size, and features of the wound channel are determined by the kinetic energy of the wounding agent and the physical properties of the damaged tissues (density, elasticity, consistency, etc.). The pulmonary parenchyma is loose and elastic, therefore small-caliber balls with low energy cause minimal damage to it (Fig. 2) [Melo A. S. A. et al., 2017]. In penetrating wounds of the thoracic cavity organs (Fig. 3), most of the blood flows out. The wound channel contains a large amount of blood and outside. In its lumen there are air bubbles and fragments of damaged tissue. The contusion zone surrounding the gastrointestinal tract is at the site of a temporary pulsating cavity, visualized on CT in the form of a ground-glass (GG)-type compaction of the pulmonary parenchyma [Lichtenberger J. P. et al., 2018].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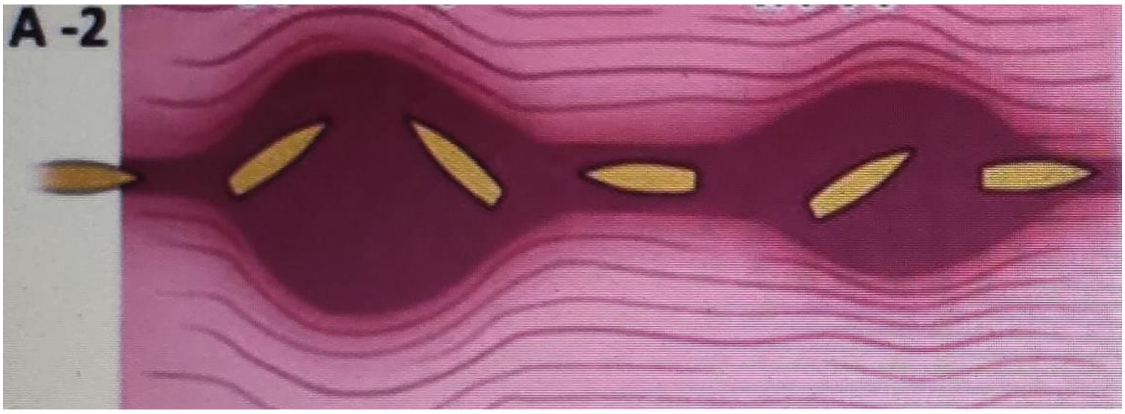
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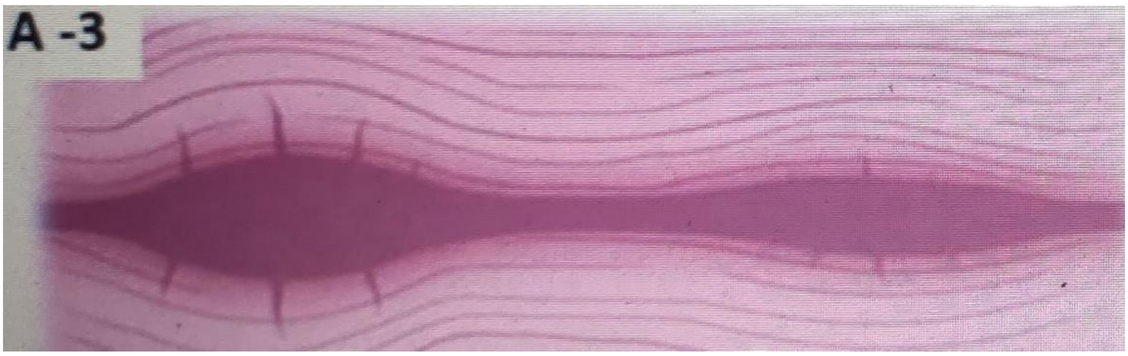
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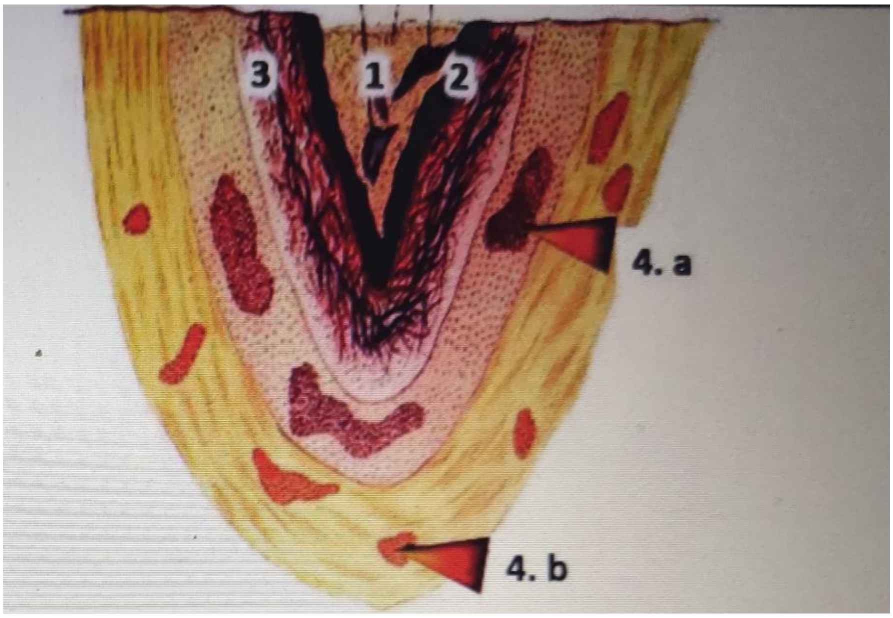



Fig. 1. The mechanism of formation of a gunshot wound: A-1 – shock wave action; A-2 – wounding projectile action, side impact energy effect; A-3 – vortex wake action; 1 - primary wound channel (caliber + 2.0 (3.0) mm, 2 - zone of primary necrosis (2.0-5.0 mm), 3 – zone of molecular shock (> 2.0 mm), 4a – field of primary necrosis; 4b – field of secondary necrosis.

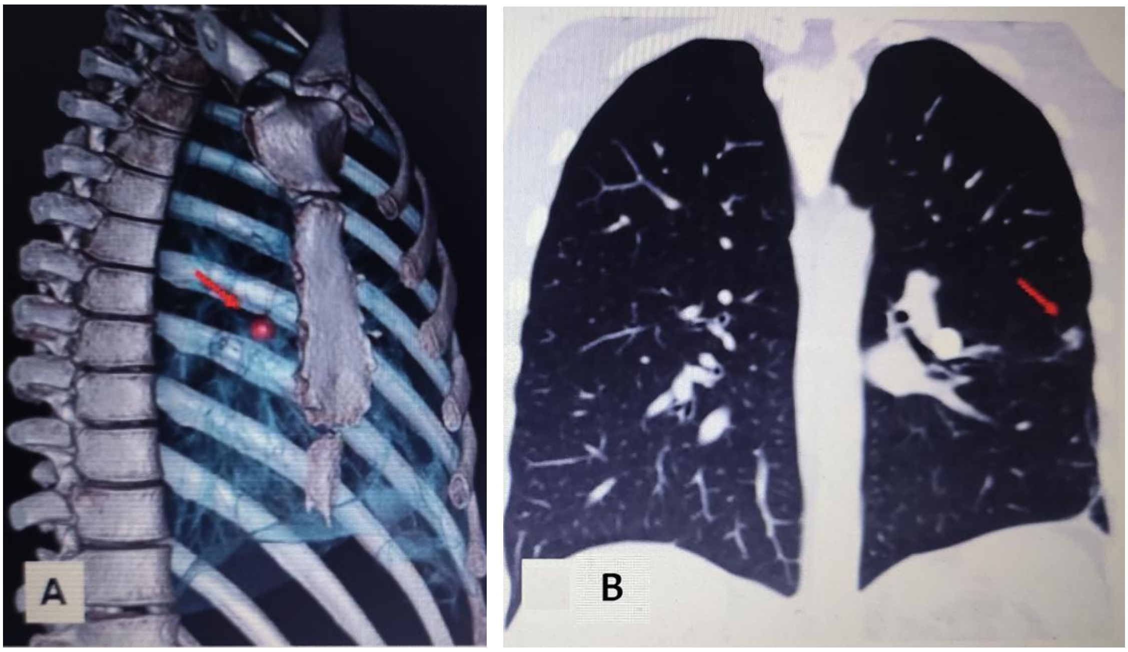
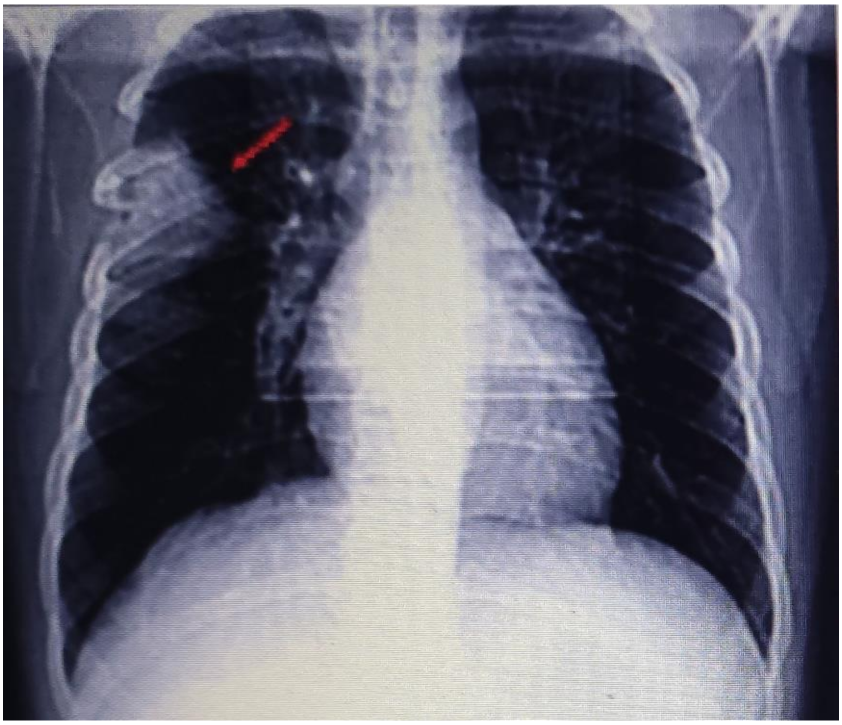



Fig. 2. Blind bullet gunshot wound (small caliber rifle) with minimal damage to the lung parenchyma.



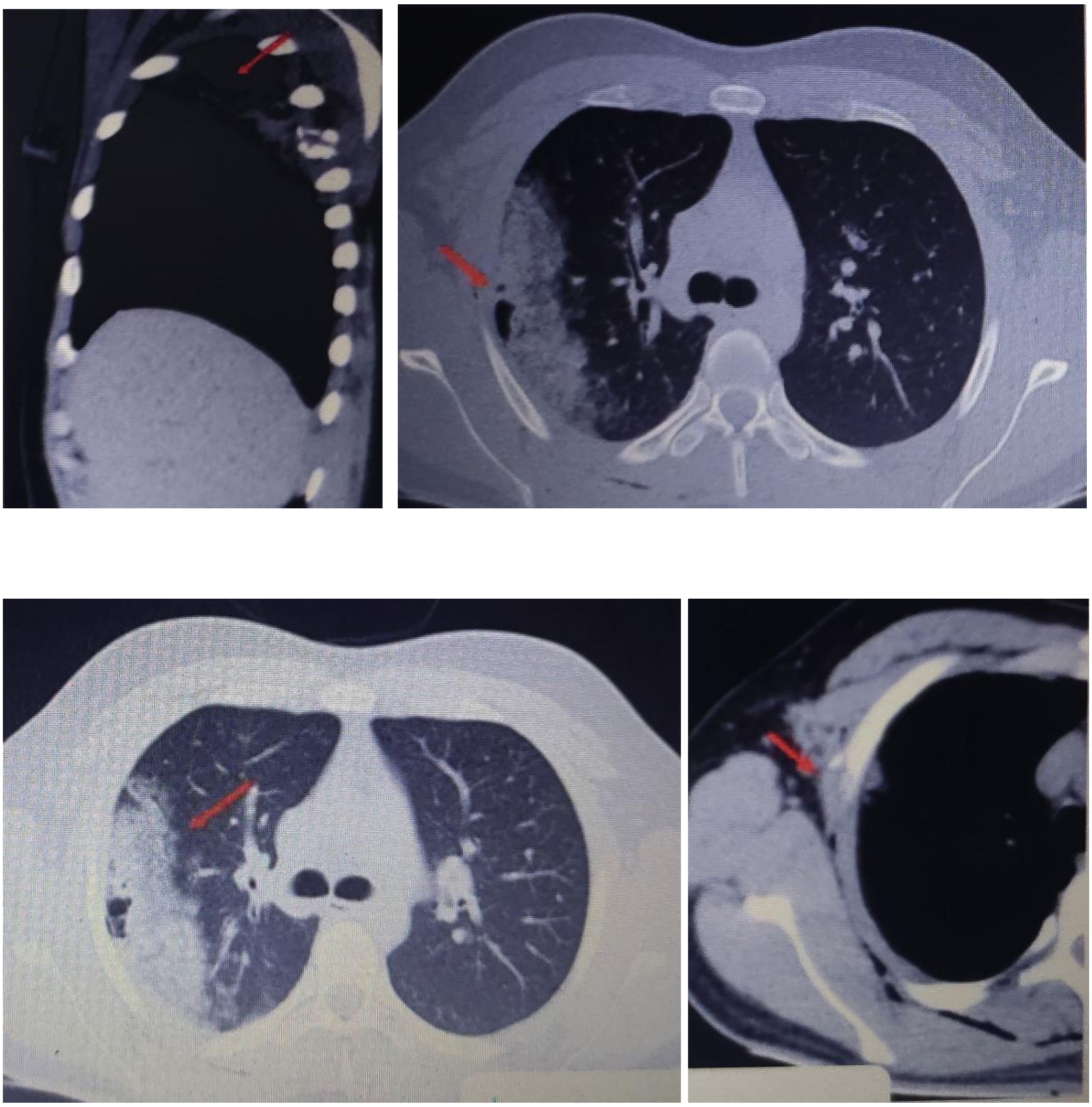
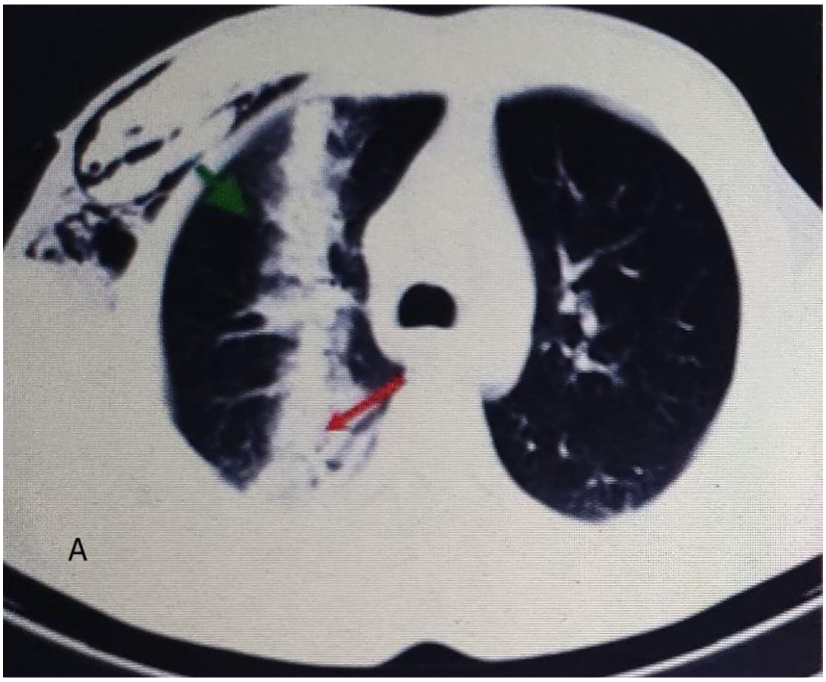
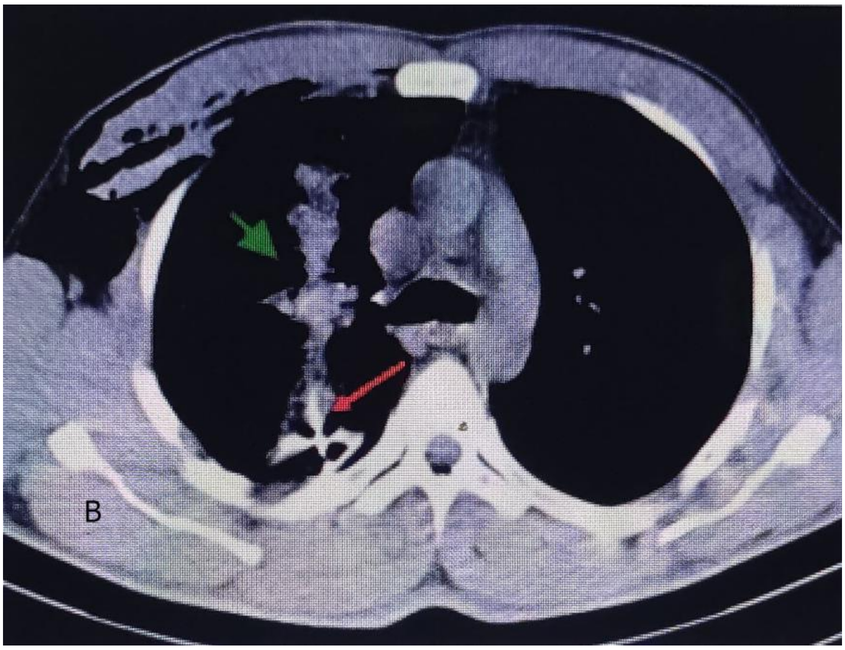


Fig. 3. Penetrating spherical wound: wound channel containing blood, fragments of destroyed parenchyma and surrounded by a contusion zone (ground glass induration). Parietal local laceration of the lung. Rib fracture (Case contributed by Dr. David Cuete ).

In blind wounds, the wound channel cavity is well differentiated on CT (Fig. 4, 5). It is filled with blood, fragments of destroyed tissue, and air bubbles. A contusion zone (ground glass opacity) is determined along the periphery [Lichtenberger J. P. et al., 2018]. Shrapnel wounds can lead to ruptures of the lung parenchyma with hemorrhages, bilateral contusions of the lungs, damage to the bone frame and soft tissues of the chest wall (Fig. 6)

[Melo A. S. A. et al. 2017]. Damage to blood vessels with massive hemorrhage into the pleural cavity with tension hemopneumothorax is one of the main causes of mortality in penetrating chest wall wounds (Fig. 7) [Lichtenberger J. P. et al., 2018].



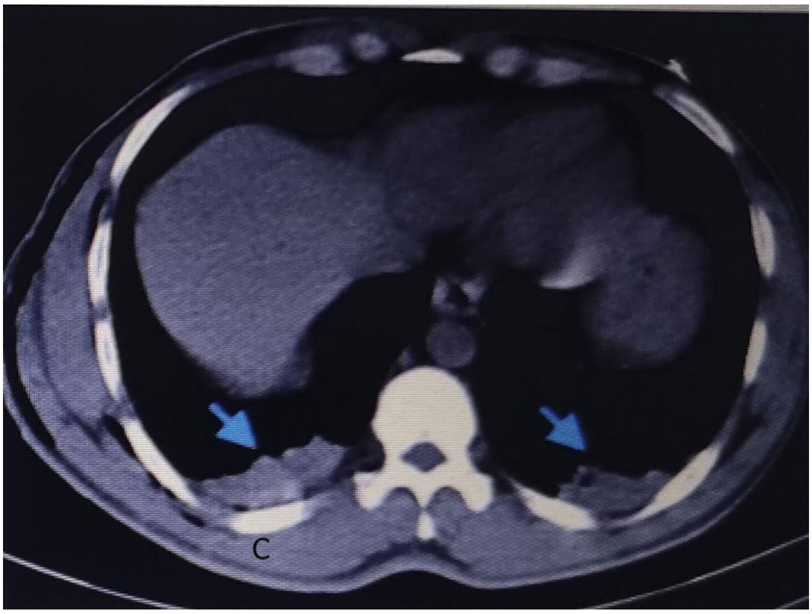
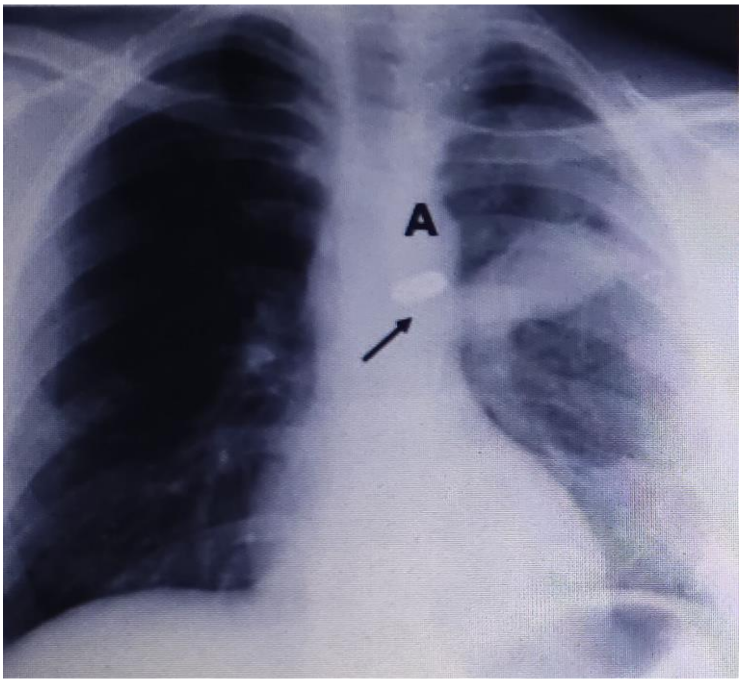



Fig. 4. Bullet penetrating blind wound. A - ball in C6 on the right (red arrow). B - linear compaction – rupture and hemorrhage along the wound channel (green arrow). C - bilaterally - hemothorax (blue arrow). Subcutaneous and intermuscular emphysema of the right anterior-lateral chest wall (Case contributed by Dr. David Cuete.



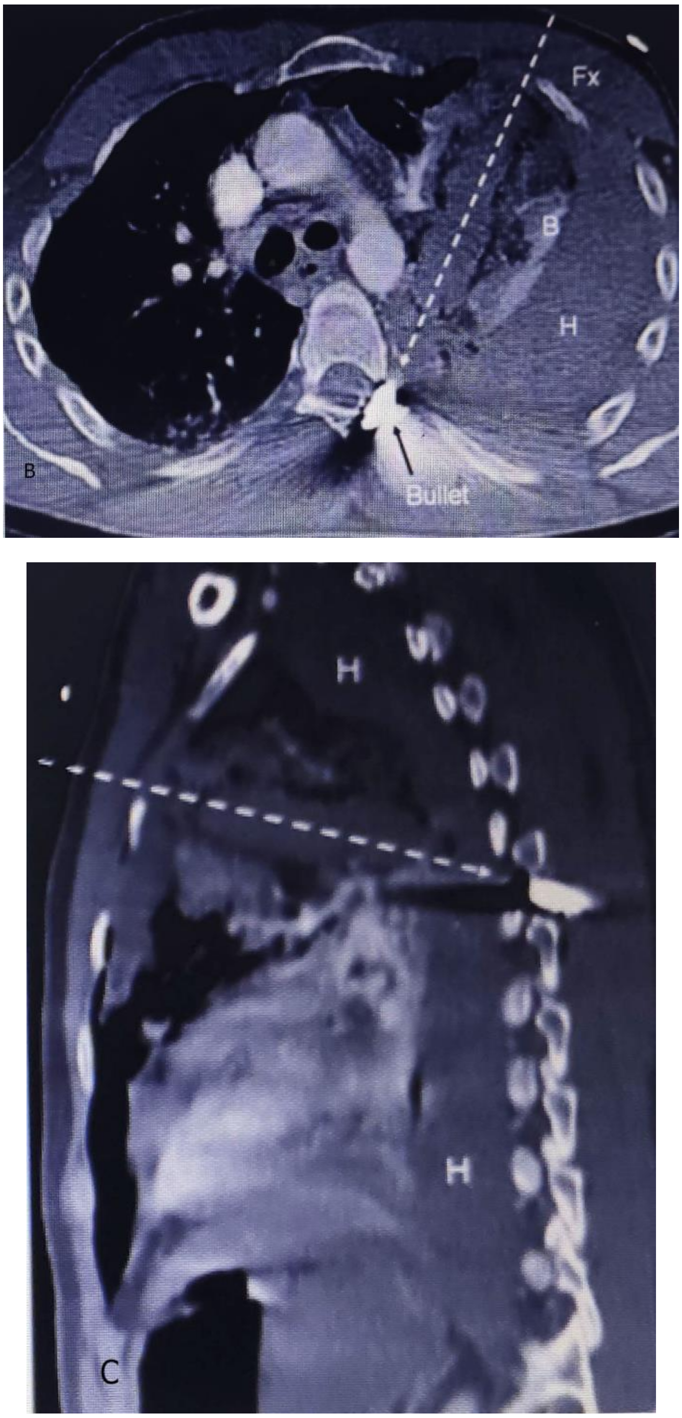



Fig. 5. Bullet penetrating blind wound. Metal ball in the projection of the mediastinum on the left (A). The contusion zone (compaction with fuzzy contours) is adjacent to the ball with its apex. "Foggy" (cloud-like) compaction (hazy opacity) in the lower parts of the left lung and costophrenic angle is caused by hemothorax. Paraxial oblique (along the wound channel) CT. The wound channel is filled with blood, fragments of destroyed tissue. Compaction of the lung tissue in the zone of temporary pulsating cavity corresponds to fluid on the Hounsfield scale. Large hemothorax (H). C - large vessels are intact, signs of active bleeding from small vessels. Bullet in the costovertebral angle.

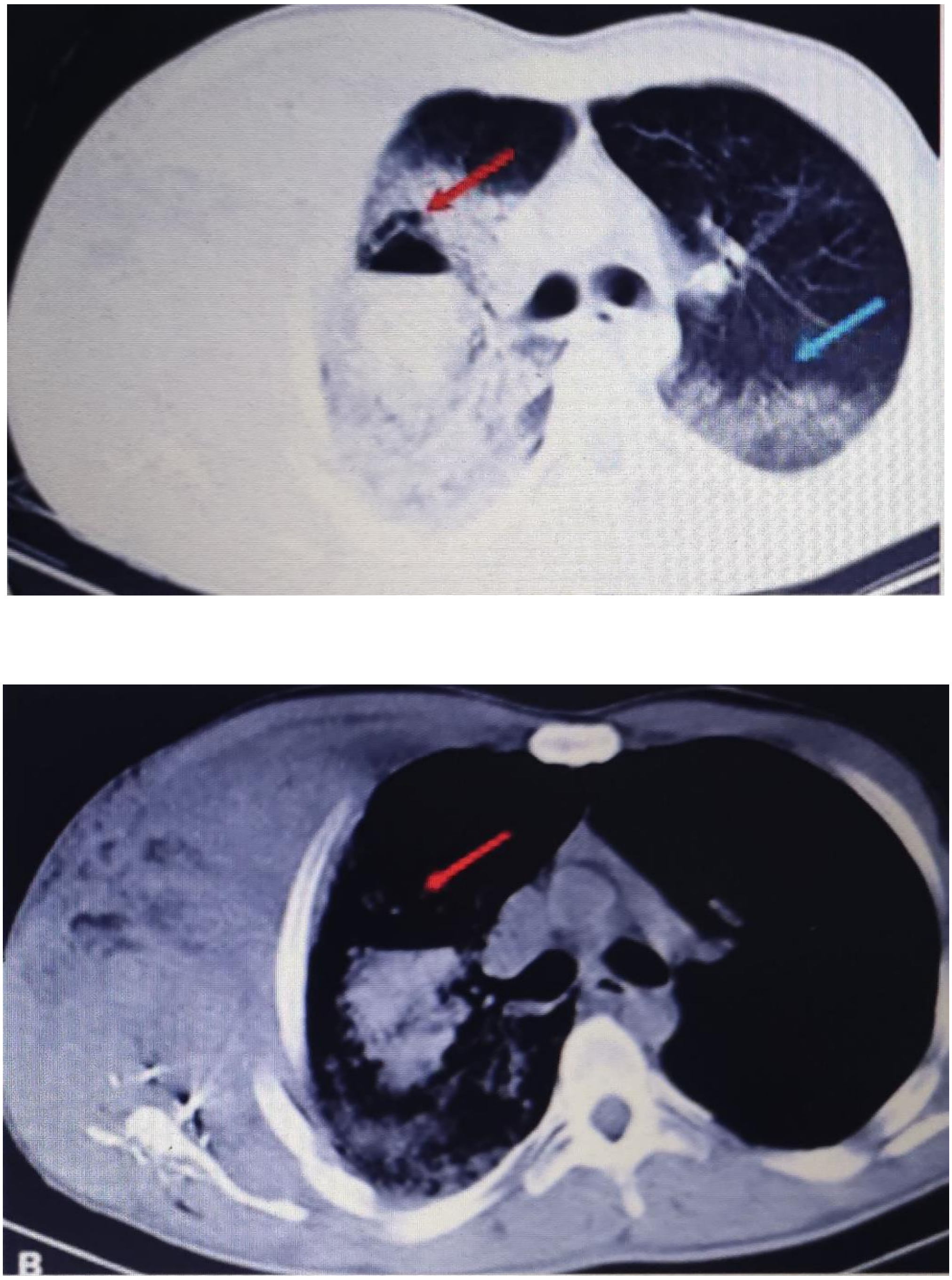



Fig. 6. Blind, gunshot shrapnel wound. A - rupture of the lung hemorrhage (horizontal air/blood level), which is surrounded by a widespread area of pulmonary contusion (red arrow). B - dorsally in the contralateral lung - ground glass consolidation - contusion zone (blue arrow). Metal fragments in the right scapular region, widespread hematoma of soft tissues, fracture of the scapula and rib.

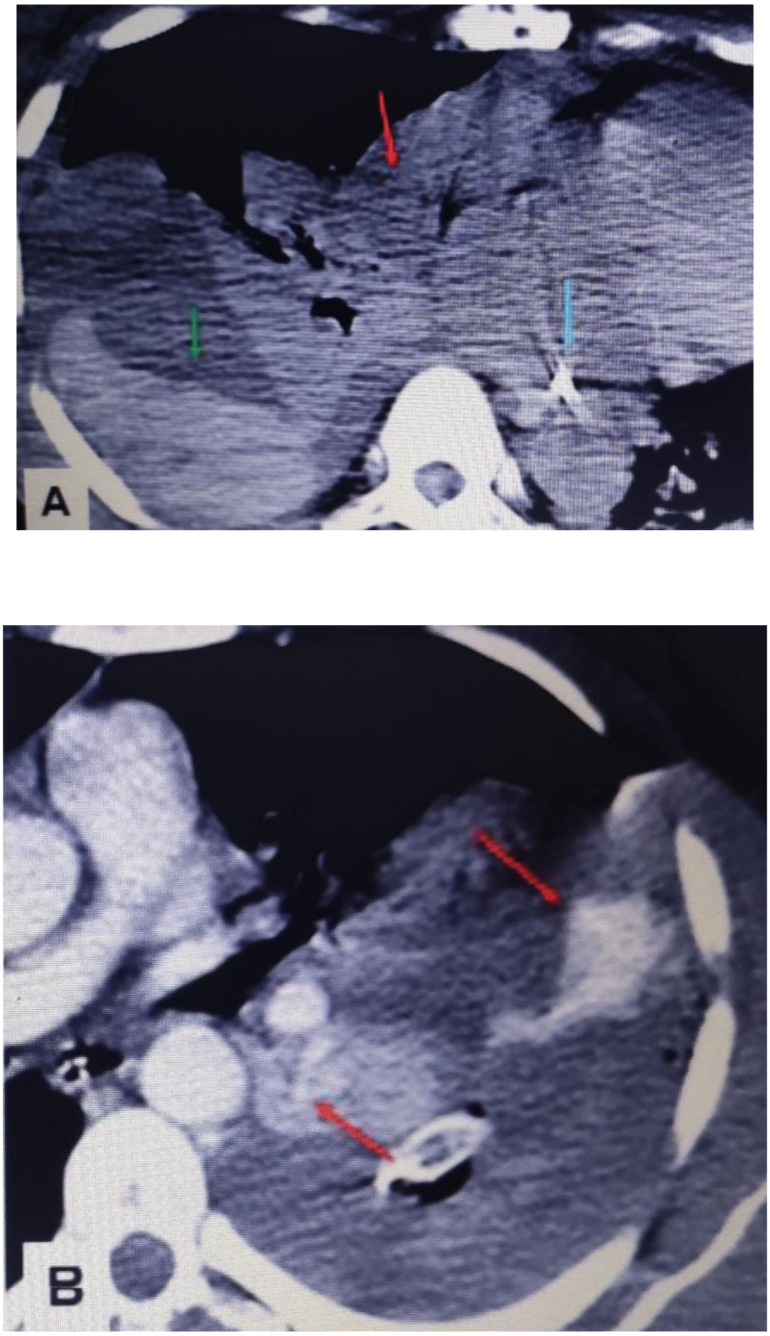
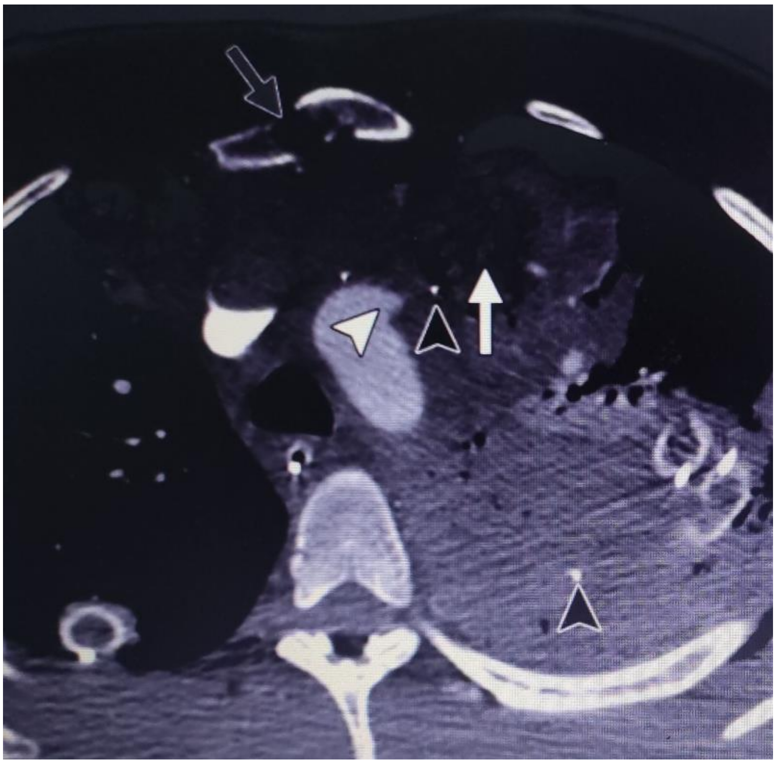



Fig. 7. Penetrating wound. Hemopneumothorax. A - penetrating gunshot wound. Tension (translocation of mediastinal organs to the uninjured side) hemopneumothorax. Native CT - high-intensity blood clot in the right pleural cavity (green arrow). Collapsed lung (red arrow). Metal fragment of the balloon in front of the descending aorta (blue arrow). B - penetrating gunshot wound. Tension hemopneumothorax on the left. Acute hemorrhage. Contrast-enhanced CT: rupture of the left lung and leakage of contrast medium from the lobar pleural cavity (red arrows).

Transmediastinal gunshot wounds are diagnosed intravitally only in 1-3% of cases. Typical combined injuries of the lung parenchyma with vessels (Fig. 8), pericardium, esophagus (Fig. 9, 10) [Gunn M. L. et al. 2014.]. According to statistics from military operations in Afghanistan and Iraq, spherical embolisms are recorded in 1.1% of surviving wounded [Khomenko I. et al., 2022]. They are observed in cases of injuries by spherical striking elements with low kinetic energy (small-caliber and brass rifle, pneumatic weapon, buckshot, mines and explosive devices). Arterial ball embolism occurs in approximately 75% of cases, the rest - venous embolism (25%). The latter is caused by direct injury to the external iliac, inferior cava, renal, portal, femoral, subclavian, and cervical veins; right ventricle; cranial venous sinuses.



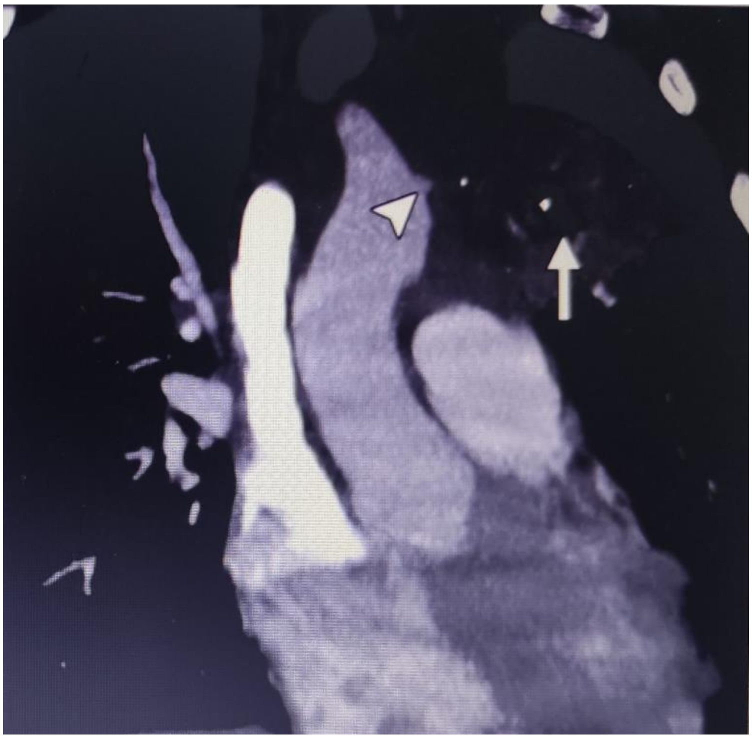


Fig. 8. Bullet transmediastinal injury. The bullet passed through the handle of the sternum (fragmentary fracture - black arrow) to the left lung. Metal fragments of the rupture ball in the mediastinum and left lung (black short arrows). Tears, contusion of the front upper segments of the lungs bilaterally (long arrows). Hemopneumothorax on the left. A small pseudoaneurysm of the aorta in the area of departure of the brachiocephalic artery (white short arrows).

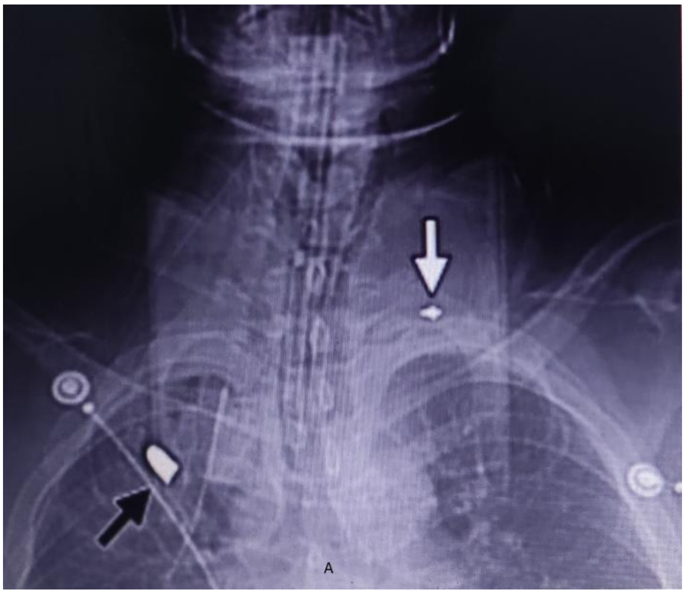


Fig. 9. Bullet blind transmediastinal injury. Rupture of the esophagus. A. X-ray: wound channel from the left supraclavicular area (white arrow) to the apex of the right lung (black arrow). B. MDCT – coronal projection, esophageal probe (black arrow), leakage of contrast material to the mediastinum through a defect in the esophageal wall (white arrow).

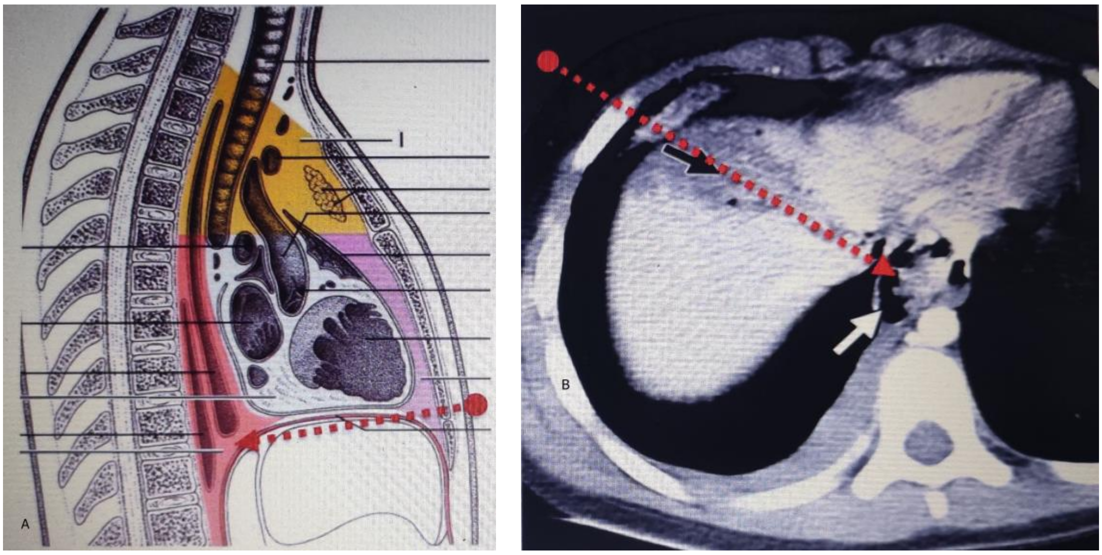
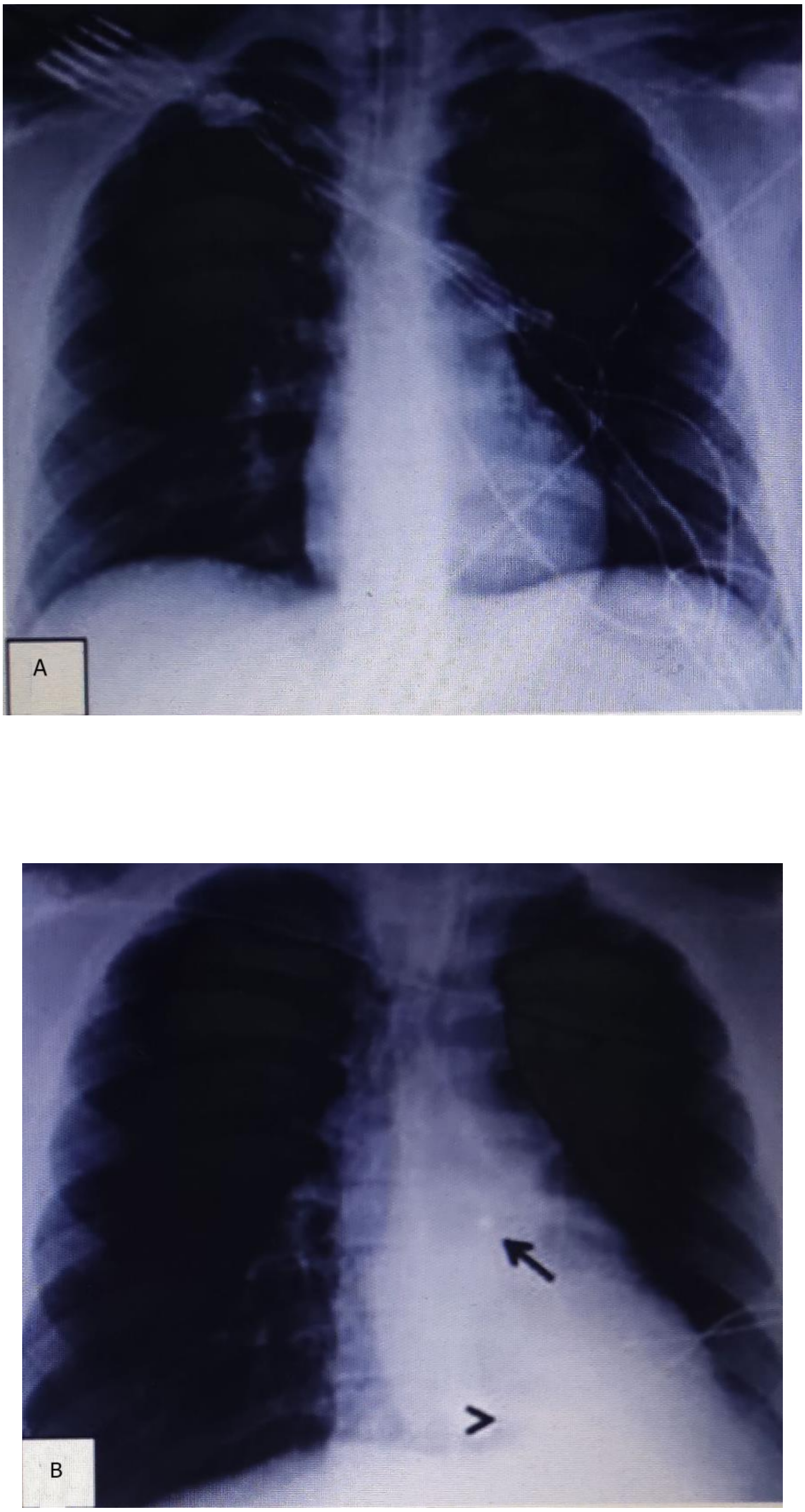



Fig. 10. Bullet transmediastinal thoracoabdominal injury. A. Wounded channel: lower part of the chest on the right > lower lobe of the right lung > diaphragm > liver > cardiac part of the esophagus. B. Air in the mediastinum around the rupture of the esophagus; hemothorax, consolidation, hemorrhage along the wound channel in the right lung. Wound channel in the liver: laceration, hemorrhage, air, perfusion disturbance in the zone of molecular contusion of the parenchyma.

According to the nature of the migration of bullet in the bloodstream, they are divided into: antegrade, retrograde, paradoxical and "floating" sphere embolism. In antegrade embolism, the ball-embolus migrates with the blood flow to the right ventricle (when passing through the tricuspid valve - to the pulmonary artery system; in retrograde - under the action of gravity against the flow of blood in the distal direction; in paradoxical - embolus reaching the right parts of the heart through an arteriovenous fistula or an atrial septal defect, it enters the arterial system; in case of a "floating" intravenous fragment, it alternately moves in the distal direction, then in the proximal direction. The migration of the embolus to the contralateral vein of the same name is described [Khomenko I ., 2014; Stallings L.A. 2013.].

A distinction is also made between acute (within a day) and delayed (described up to 14 years) ball embolism. Figures 11 and 12 show examples of paradoxical and antegrade ball embolism [Khomenko I. et al., 2022; Duke E. et al. 2014; Stallings L.A. et al. 2013.]. Even when using personal protective equipment (body armor), a fighter can be injured in the organs of the chest cavity. This type of damage is called "armor injury" [Truesdell W., et al. 2020.]. According to the mechanism of their formation, they are divided into blunt (a contusion injury that occurs as a result of the transfer of the kinetic energy of the striking agent through the armor plate) and penetrating (a bullet or fragment that passed through the body armor and fragments of the armor plate). The main mechanism of lung damage (contusion and parenchymal tears) in case of armor injury is sudden powerful compression (Fig. 13). Local contusion of the heart and sharp hydrodynamic blood shock lead to damage to the myocardium and valvular structures.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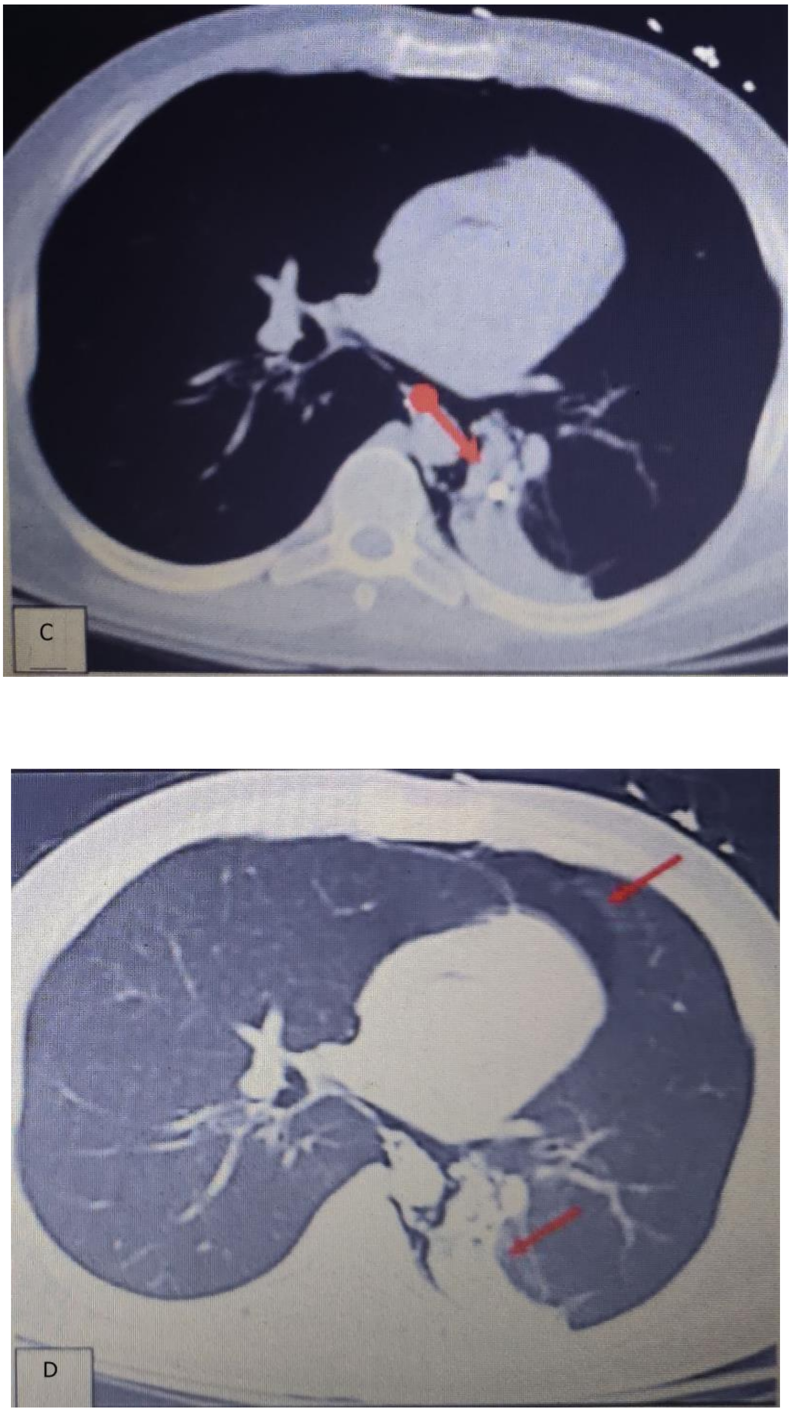


Fig. 11. Paradoxical bullet embolism. A metallic foreign body (5 mm) in the projection of the right transverse sinus. Ventriculostomy was performed due to intracranial hemorrhage. A round-sided body appeared in the projection of the left pulmonary root (A); signs of segmental atelectasis were detected (B). MDCT (C): foreign body in the lower lobe of the left lung, segmental atelectasis; small pneumothorax (D); pneumomediastinum.

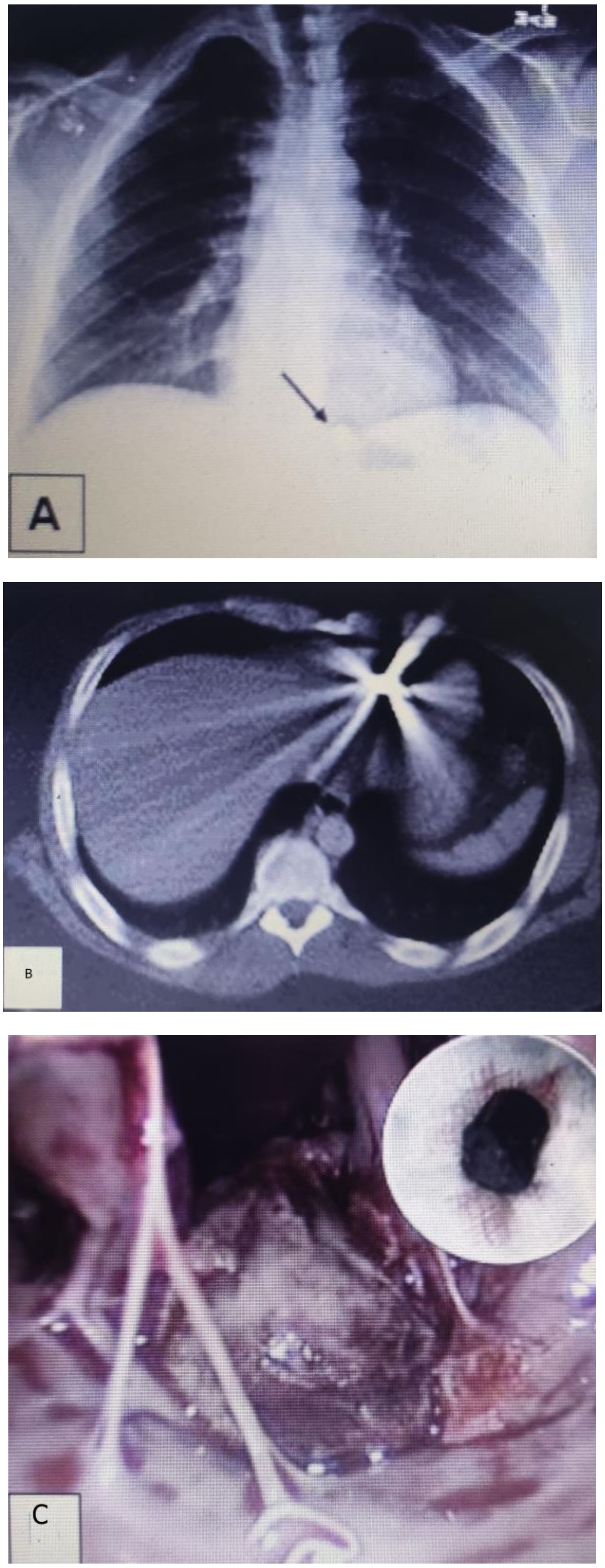


Fig. 12. Antegrade bullet embolism. The serviceman was wounded in the right shoulder. When the wound was examined, no bullet was found; instead, he complained of chest pain. X-ray (A) and CT (B) of the chest were performed. A metallic foreign body is visualized in the cavity of the right ventricle. C. surgical removal of the bullet.

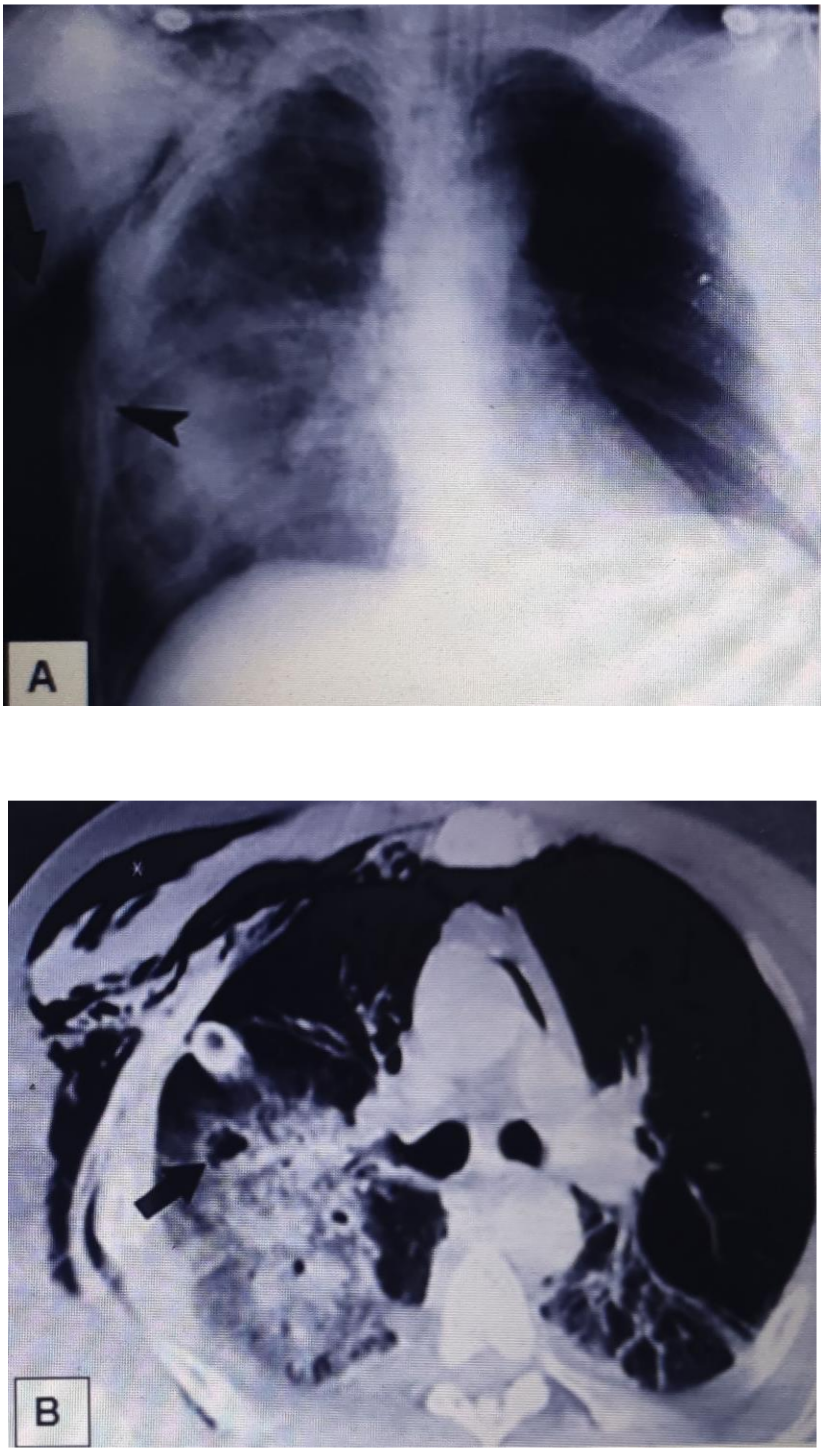


Fig. 13. Armor injury. X-ray (A): subcutaneous emphysema, multiple rib fractures on the right, decreased transparency of the right lung. MDCT with contrast (B): contusion of the lower parts of the lungs, mainly on the right, rupture of the lung.

The purpose of radiological diagnosis of modern combat trauma is to identify and fully characterize injuries and their complications. The amount of diagnostic information is determined by the level of medical care.

In Ukraine, at the 1st (pre-hospital) stage, examination of the wounded using a portable ultrasound device has been introduced in accordance with the FAST (Focused Assessment with Sonography for Trauma) and eFAST (Extended Focused Assessment with Sonography for Trauma) protocols [Schellenberg M. et al. 2018]. In case of thoracic combat trauma, pneumothorax, hemothorax, hemopneumothorax, pneumopericardium, hemopericardium are diagnosed (Fig. 14, 15 A, B).

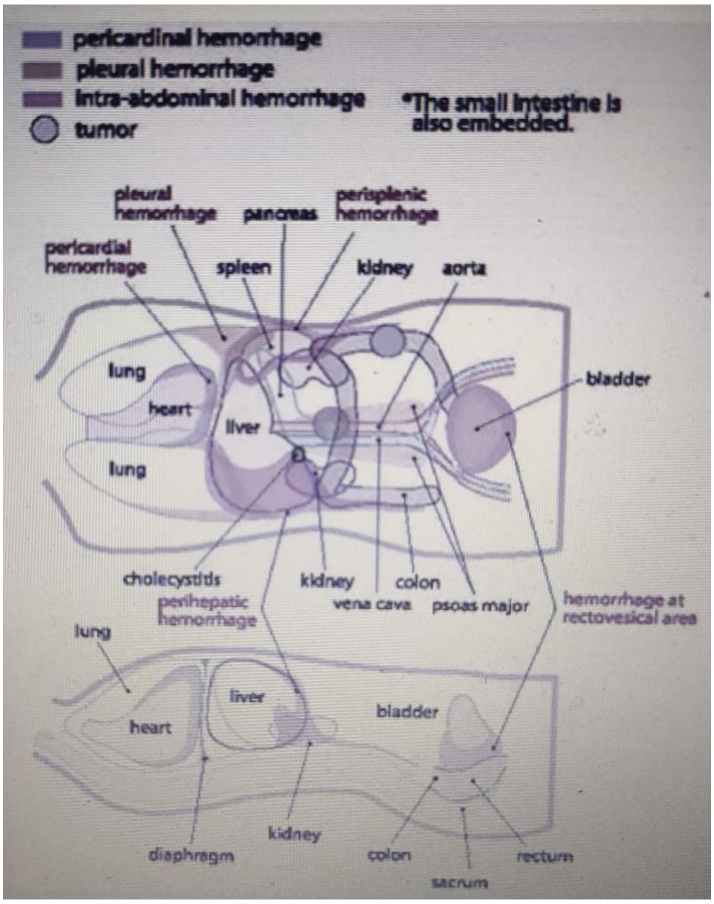


Fig. 14. FAST/eFAST procedure diagram – protocols. Transducer positions.

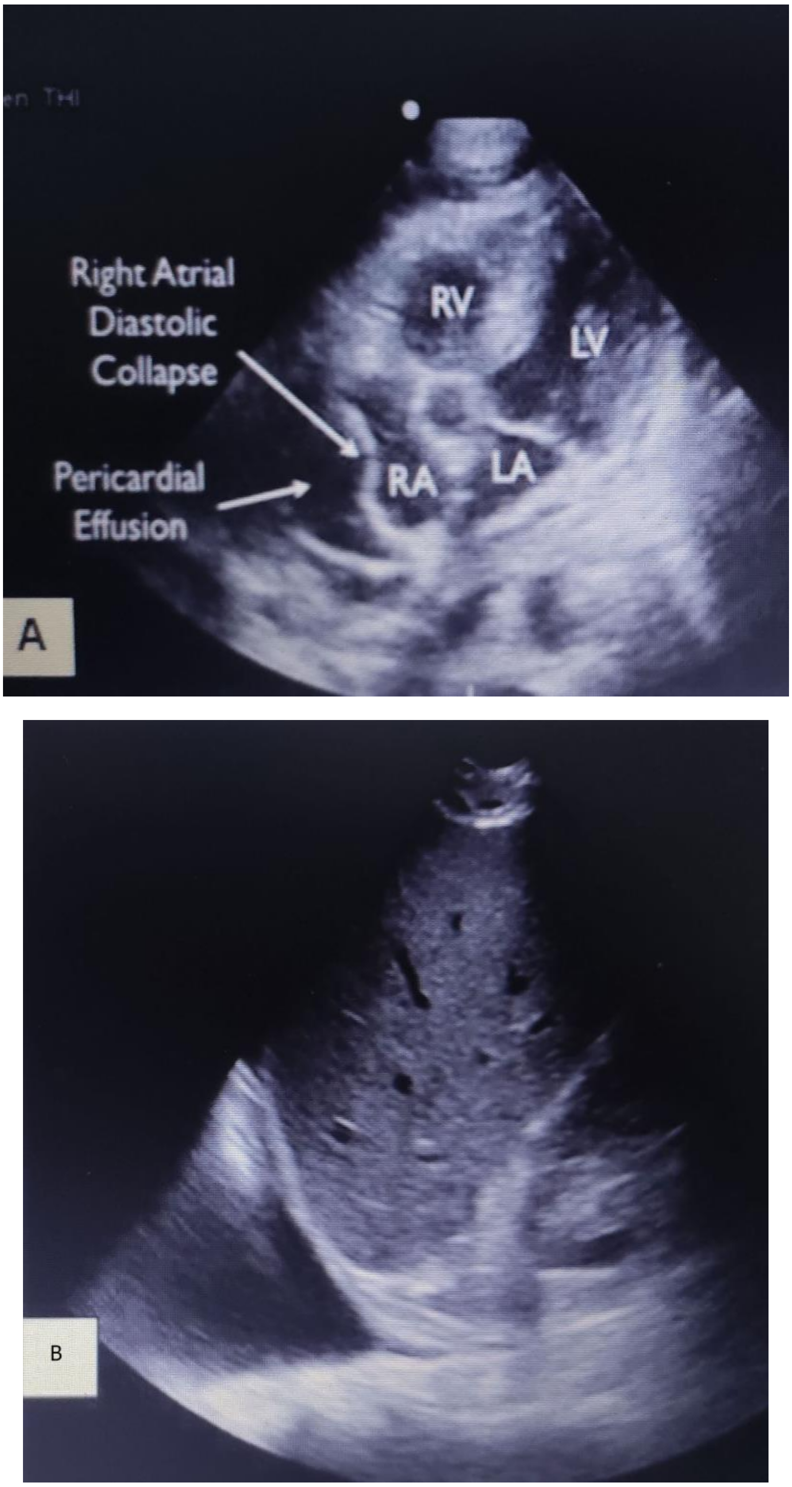


Fig. 15. FAST - protocol: hemopericardium (A); hemothorax (B).

At the hospital stage, X-ray is used at level II (first and specialized medical care), CT - at levels II (if equipment is available), III and IV (specialized and highly specialized) of medical care.

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# Chapter 2.

## Gunshot injury to the heart and great vessels of the chest

*Tsymbaliuk V.I., Lazoryshynets V.V., Usenko O.Y., Lurin I.A.*

The overall incidence of vascular injuries of the mediastinum remains unclear. In case of gunshot wounds to the chest, damage to the large vessels of the mediastinum should be ruled out first. The mediastinum extends from the thoracic inlet to the diaphragm vertically and is divided into two main compartments, superior and inferior. The latter is then divided into anterior, middle and posterior.

The mediastinal great vessels are relatively protected from both penetrating and blunt trauma due to the surrounding bony ribcage, clavicles and scapulae, along with the spine, however this does not prevent serious injury that may be rapidly fatal if not suitably addressed. The aorta and pulmonary outflow and inflow vessels constitute the most proximal aspect of these vessels with origin at the cardiac ventricles and atria respectively. The superior vena cava (SVC) is formed by the confluence of the two brachiocephalic veins (BCV) and this usually lies just anterior to the aortic arch and the confluence is mostly somewhat to the right of the midline. The Azygous vein enters the SVC from posterior near the right atrium on the right. The hemi-azygous vein forms on the left and anastomoses with the Azygous vein across the spinal column. The inferior vena cava (IVC) ascends via the diaphragm to the right of the midline, ending in a “T-junction” confluence with the SVC flowing into the right atrium. After blood flows through the right atrium and ventricle the pulmonary artery and its trunks dividing left and right curl around the inferior and posterior aspect of the aortic arch to supply the deoxygenated blood to the lungs, returning from the lungs as the lower-pressure pulmonary veins ending in the left atrium. Blood flows through the left atrium and ventricle and exits via the aortic arch into the three (sometimes two) major branches, the brachiocephalic artery (previously called “innominate”), the left common carotid and the somewhat more left posterolateral left subclavian. The former two vessels may have a common origin, sometimes called the “bovine” trunk, with an incidence reported in the population to be around 25–30% [Ahn SS, Chen SW, Miller TJ, et al. What Is the True Incidence of Anomalous Bovine Left Common Carotid Artery Configuration? Ann Vasc Surg 2014;28:381-5.; Muckart DJJ, Pillay B, Hardcastle TC, et al. Vascular injuries following blunt polytrauma. Eur J Trauma Emerg Surg 2014;40:315-22.].

The approach to suspected vascular injury of the mediastinal great vessels will depend on mechanism of injury (blunt versus penetrating) and hemodynamic status. In the case of penetrating injury there is always the added benefit of the entry or exit wounds that guide the probable tract location, while with blunt injury there must be an even higher level of suspicion, especially in case of high-energy acceleration-deceleration type injury.

For penetrating injury, it is important to include the junctional zone of the cervico-mediastinal region since Zone 1 neck penetrating injuries can easily affect the intra-thoracic vasculature [Islam J. et al., 2016]. The potential for an associated aerodigestive injury must always be considered. In patients with active uncontrolled hemorrhage, it is necessary to proceed directly to operative intervention, while with patients with potential injury and either “soft” or “hard” signs, with apparent controlled bleeding or stability, one would ensure hemodynamic normality and proceed to imaging. For actively bleeding patients attempts at digital or Foley catheter control should be attempted initially [Scriba M. et al., 2020].

Options for imaging include extended Focused Assessment with Sonar in Trauma (eFAST) to exclude hemothorax, pneumothorax or cardiac tamponade, or abdominal injury, performed in the resuscitation bay, followed by CTA and either contrast swallow or endoscopy to evaluate the esophagus, trachea and main bronchi, especially if surgical emphysema is noted on the CTA [Hundersmarck D. et al., 2021].

The potential injuries include vascular occlusions from intimal flaps, pseudoaneurysms and arterio-venous fistulae. Active bleeding would result from uncontained arterial and major venous lacerations and transections. Among the indirect symptoms of a gunshot wound to the chest can be a massive hematothorax or widening of the mediastinum, which is well defined by X-ray examination (Fig. 1).

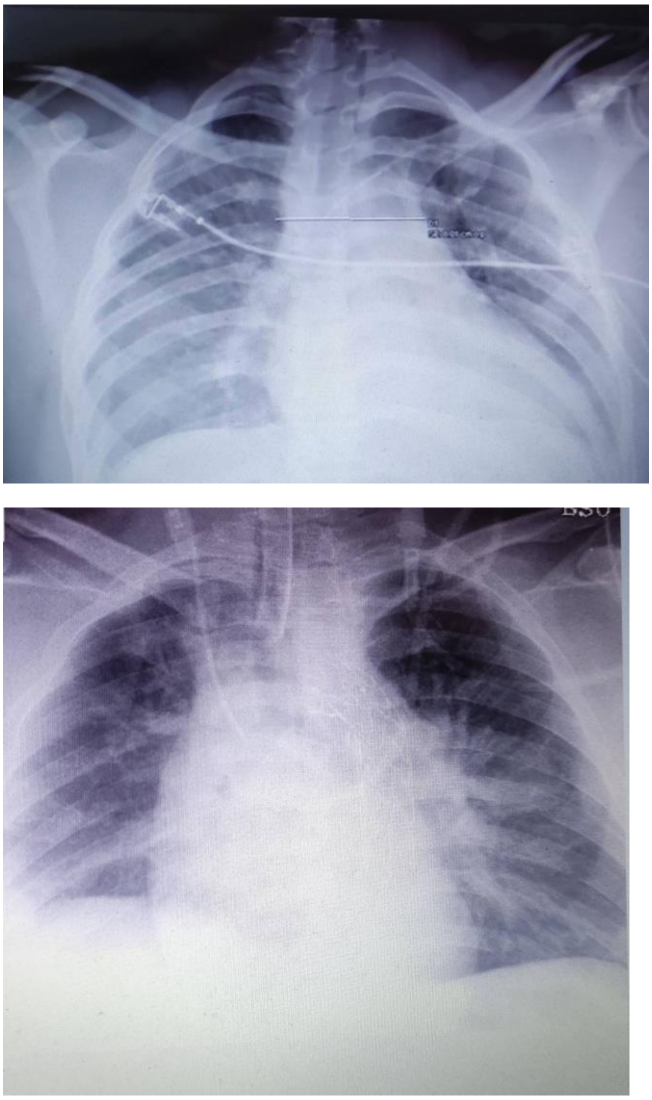
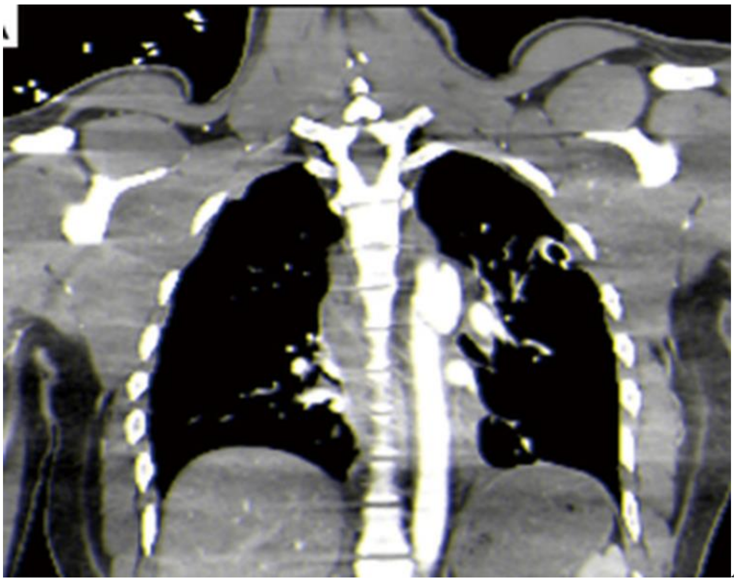


Fig. 1. Chest X-ray – wide mediastinum in patients with a gunshot wound to the chest.

Pleural capping may suggest aortic or cervical main branch injury. An ipsilateral major hemothorax or esophageal/tracheal displacement further raises concern for a mediastinal vascular injury. If there is a massive hemothorax then urgent ipsilateral anterior thoracotomy is preferred over imaging. For most injuries, however, the cause of any hemodynamic abnormality would be in another cavity, so an eFAST should be performed exists to direct the surgeon to the correct body cavity, most-often the abdomen. In most cases, however, the patient is hemodynamically almost normal, or responds to the basic fluid resuscitation regimen, thus a high index of suspicion is on the basis of either the mechanism of injury or chest-film findings. Since the likelihood of metal foreign body related scatter is small with blunt trauma, proceeding to CTA is the investigation of choice, considering that associated digestive injury is extremely rare and major airway injury is usually clinically apparent. The common injuries to exclude are blunt aortic rupture, carotid or subclavian intimal injury and pseudoaneurysm, or major venous injury [Haq A.A. et al., 2016; Hundersmarck D. et al., 2021].

Blunt thoracic aortic injury  are life-threatening surgical emergencies. Only 10–20% of patients with thoracic aortic injuries  present alive at hospital and the spectrum can be from asymptomatic, to dramatically shocked due to an isolated, contained aortic rupture or, polytraumatised with multiple injuries causing haemorrhagic shock. Blunt thoracic aortic injuryare the second most common cause of early trauma-related deaths following traumatic brain injuries and this accounts for approximately 1.5% of all thoracic trauma [Akhmerov A, DuBose J, Azizzadeh A. Blunt Thoracic Aortic Injury: Current Therapies, Outcomes, and Challenges. Ann Vasc Dis 2019;12:1-5. ]. The most common anatomic site of injury or tear in BTAI occurs at the aortic isthmus, on the medial luminal aspect of the descending thoracic aorta, distal to the origin of the left subclavian artery. This is where the relatively mobile aortic arch transitions to the relatively fixed descending aorta (Fig. 2).



A

B

C

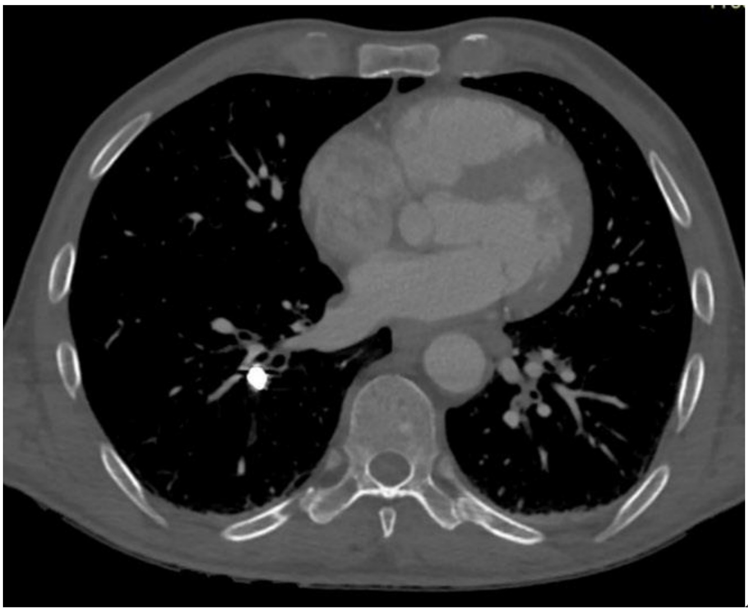
Fig. 2. Coronal (A), sagittal and 3D reconstruction images of blunt thoracic aortic injury.

Blunt thoracic aortic injuries are graded in terms of the layers of the wall involved coupled with luminal compromise or disruption. There are 4 degrees to the thoracic aortic injury: I - intimal tear; II - intramural haematoma; III - pseudoaneurysm; IV – rupture [Naidoo S., Hardcastle T.C. Traumatic injury to the great vessels of the chest. Mediastinum. 2021. V 5; doi: 10.21037/med-21-15]. The patient management tactics, the choice of treatment method and its effectiveness in case of damage to the thoracic aorta depend on the duration of the intimal tear, dissection of the intima and media, pseudoaneurysm formation and complete rupture of the entire wall.

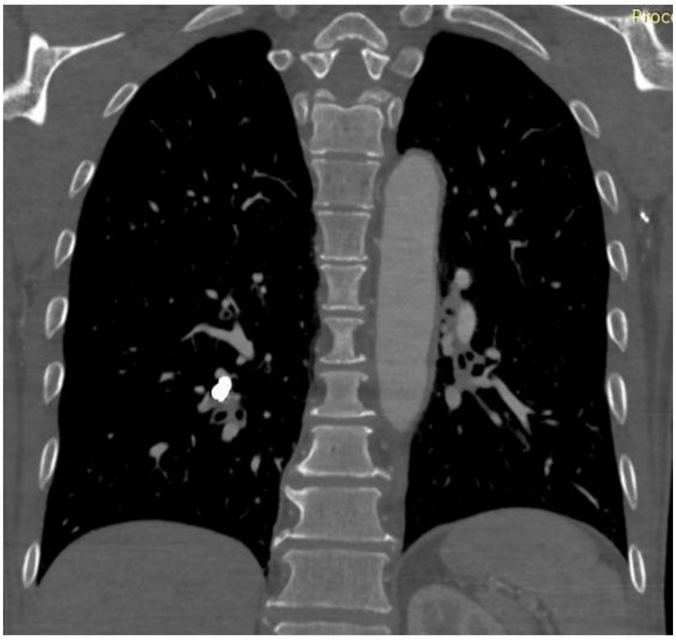
*Penetrating thoracic aortic injury* are less common than blunt thoracic aortic injury and are most frequently due to gunshot wounds. In most cases, patients with penetrating aortic trauma die before reaching the hospital. In most cases, patients with penetrating aortic injury die before reaching the hospital due to massive blood loss. CT angiography is only considered if the patient remains hemodynamically stable and if not, then they are swiftly taken to the operating room for open surgery. CTA in the stable patient with penetrating thoracic aortic injury may be challenging due to frequent scatter from in situ foreign bodies.

*Pulmonary artery*

Injuries to the main intrathoracic great vessels remain uncommon. Major transection of either the pulmonary artery (PA) or veins (PV) are often rapidly fatal, thus explaining the limited clinical data on these injuries. The PA is a low-pressure system and thus the likely presenting pathology is a large hemothorax, or a finding of a suspected pseudoaneurysm on CTA. The most common findings on chest CT in patients with non-fatal gunshot wounds to the chest are metal fragments near or on the wall of heart or large vessels. Migration of these metal fragments is often detected during surgery (Fig. 3-10).



**A**



B

C

Fig. 3. Spiral CT angiography of the pulmonary arteries: a metal fragment in the segmental branch of the right pulmonary artery. A – axial plane; B – coronal plane; B – sagittal plane.

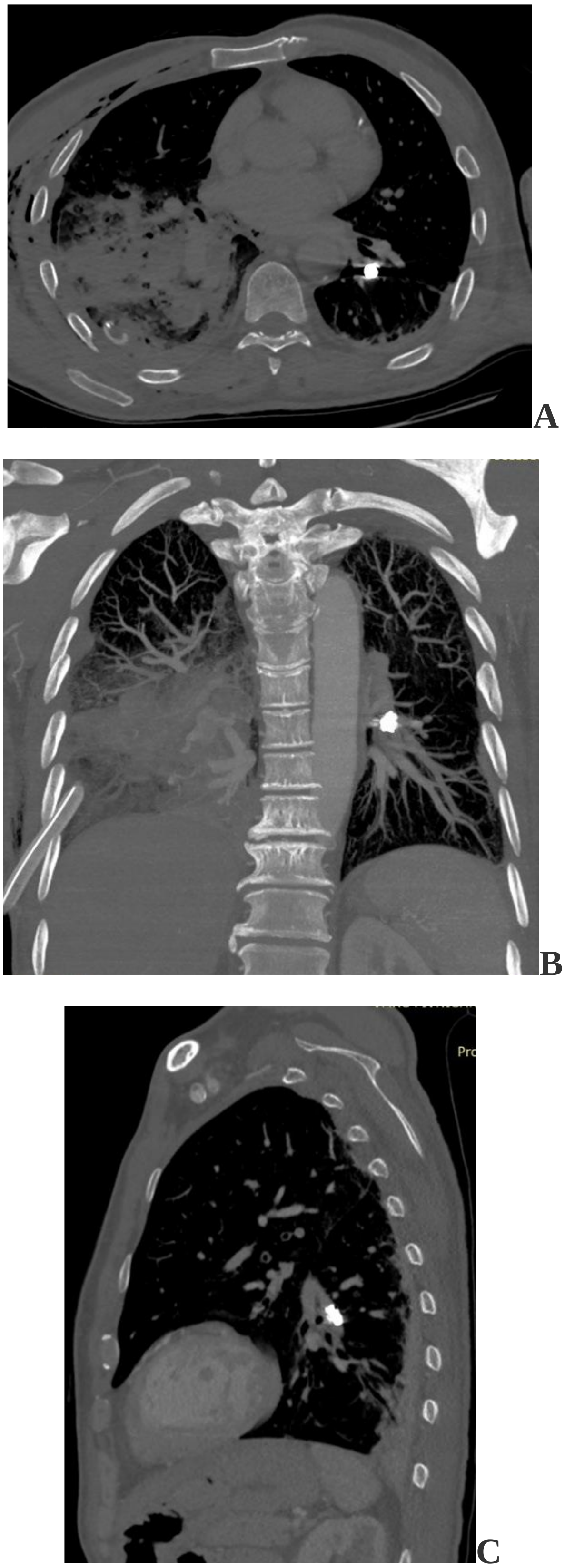



Fig. 4. Spiral CT angiography of the pulmonary arteries: a metal fragment in the segmental branch of the left pulmonary artery (migration of the fragment with the right pulmonary artery during surgery). A – axial plane; B – coronal plane; B – sagittal plane.

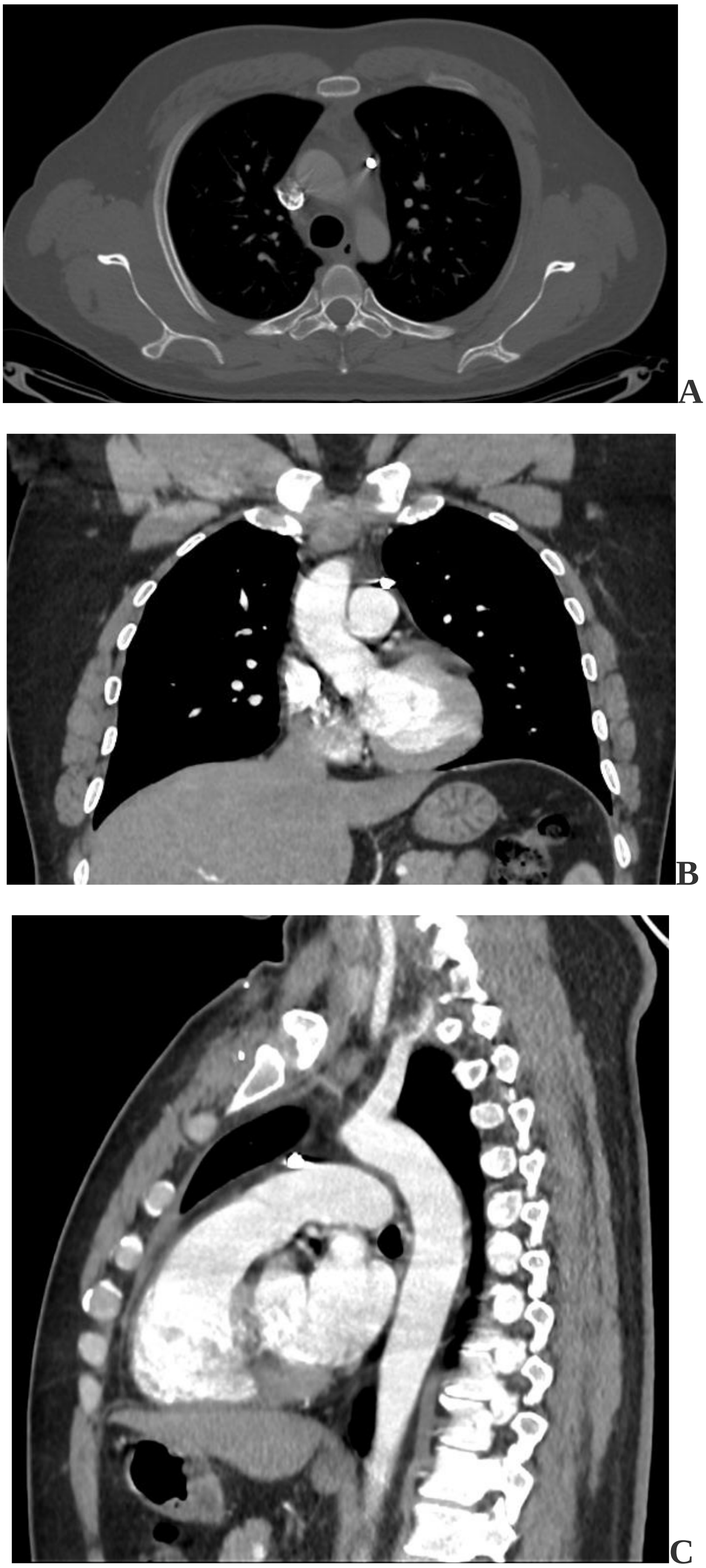
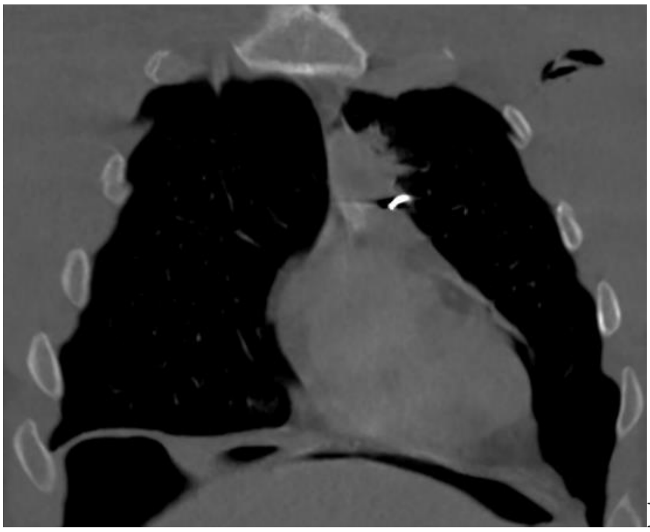



Fig. 5. Spiral CT aortography: a metal fragment located near the pulmonary trunk, no signs of extravasation were found. A – axial plane; B – coronary plane; B – sagittal plane.

A



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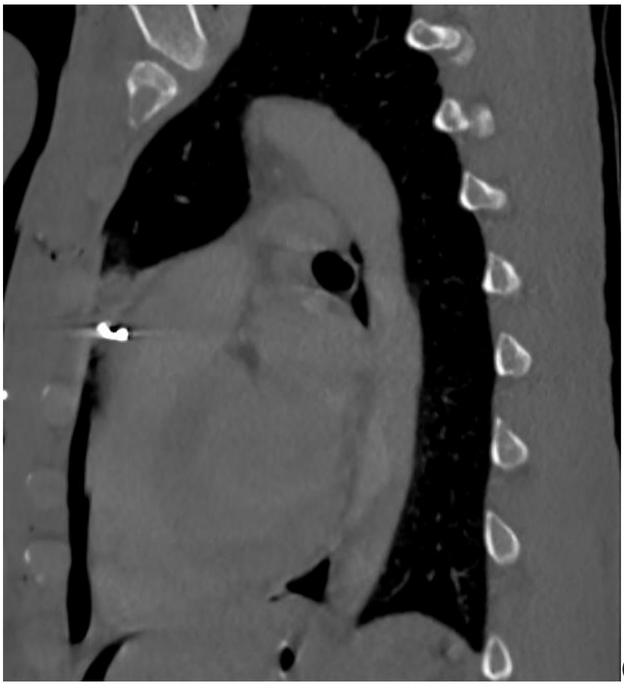


C

Fig. 6. Spiral CT aortography: a metal fragment in the anterior mediastinum near the initial part of the pulmonary trunk. A – axial plane; B – coronary plane; B – sagittal plane.

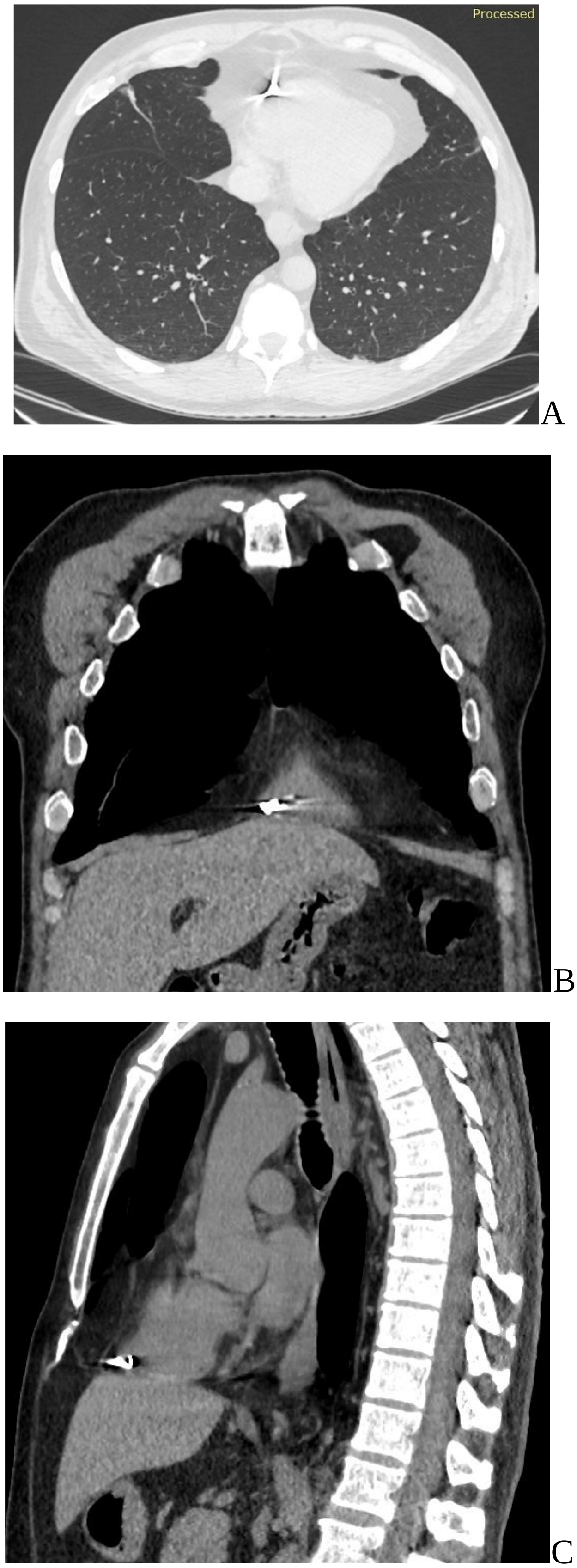
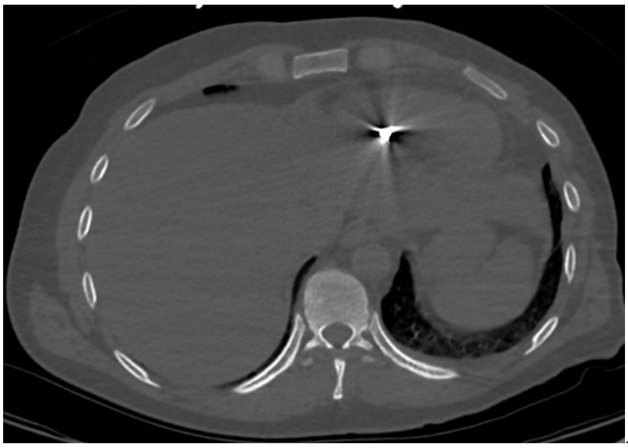
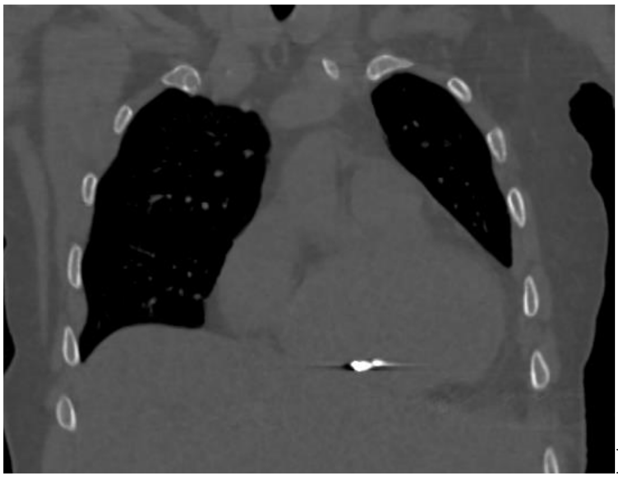



Fig. 7. Spiral CT of chest organs: a metal fragment in the wall of the right ventricle of the heart. A – axial plane; B – coronary plane; B – sagittal plane.



A



B

C

Fig. 8. Spiral CT of chest organs: a metal fragment in the wall of the left ventricle of the heart. A – axial plane; B – coronary plane; B – sagittal plane.

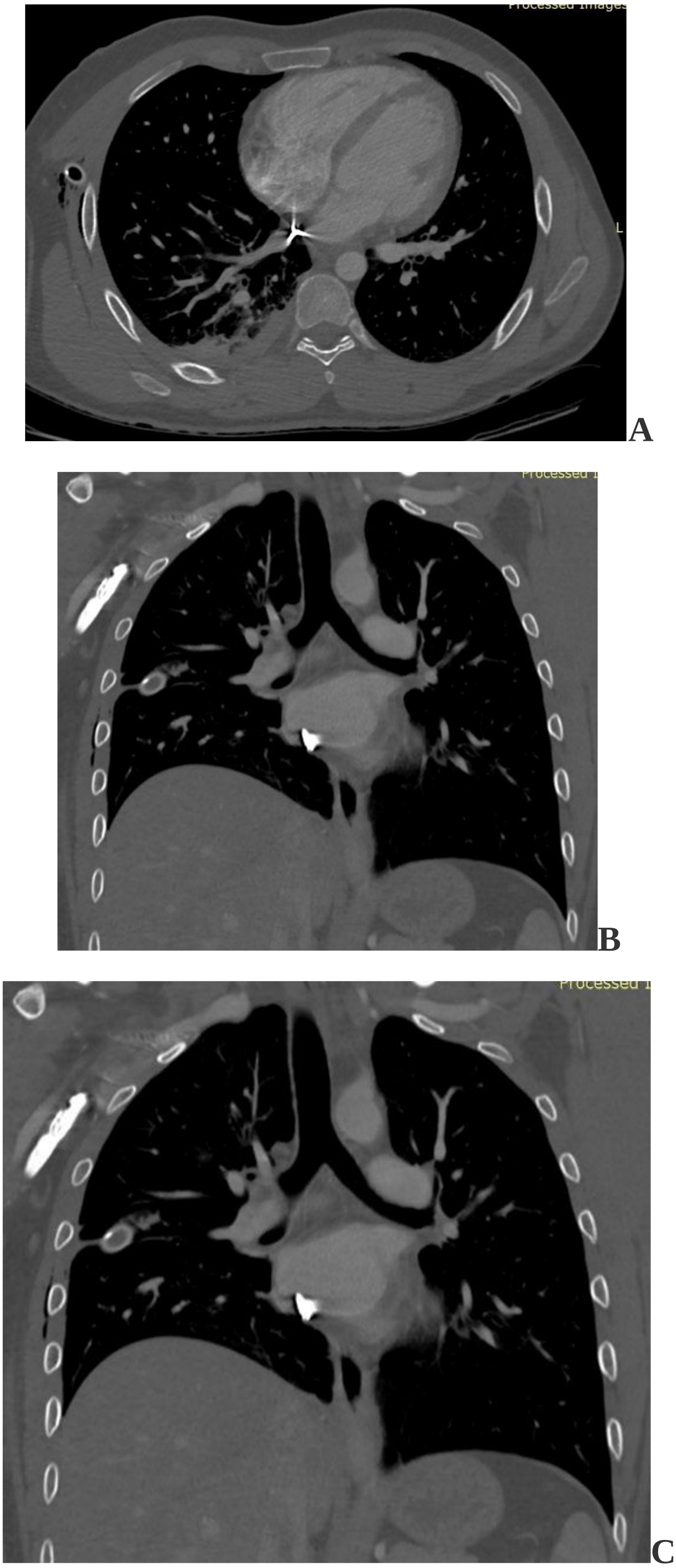
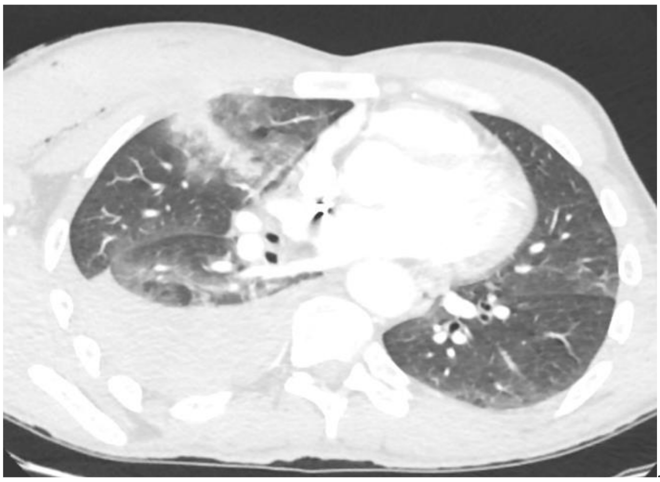



Fig. 9. Spiral CT angiography of pulmonary arteries: a metal fragment in the wall of the left atrium. A – axial plane; B – coronal plane; B – sagittal plane.



A

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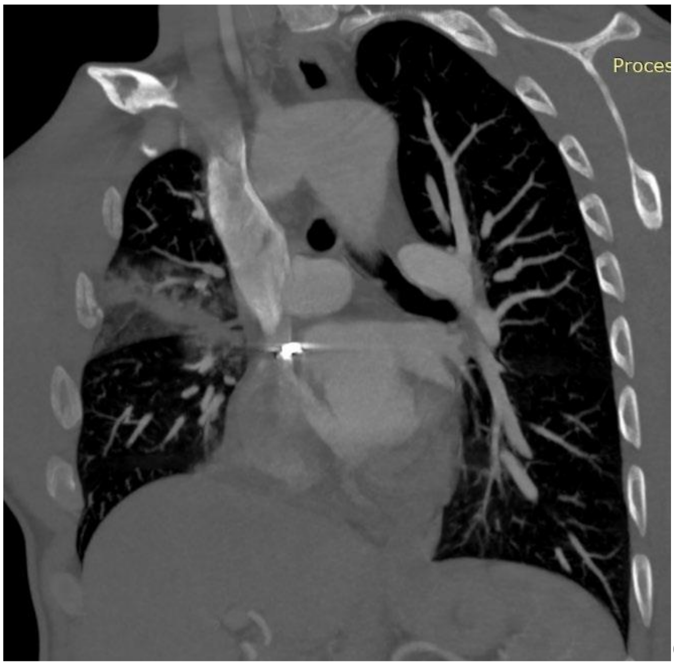
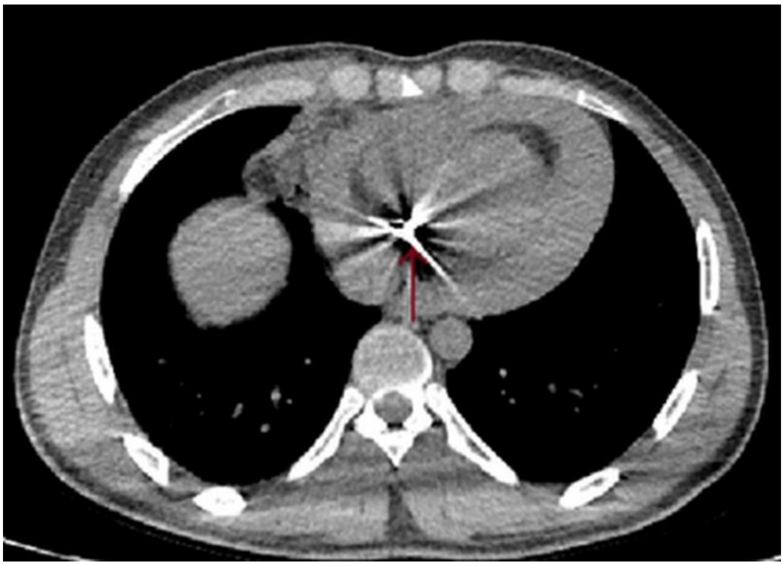


C

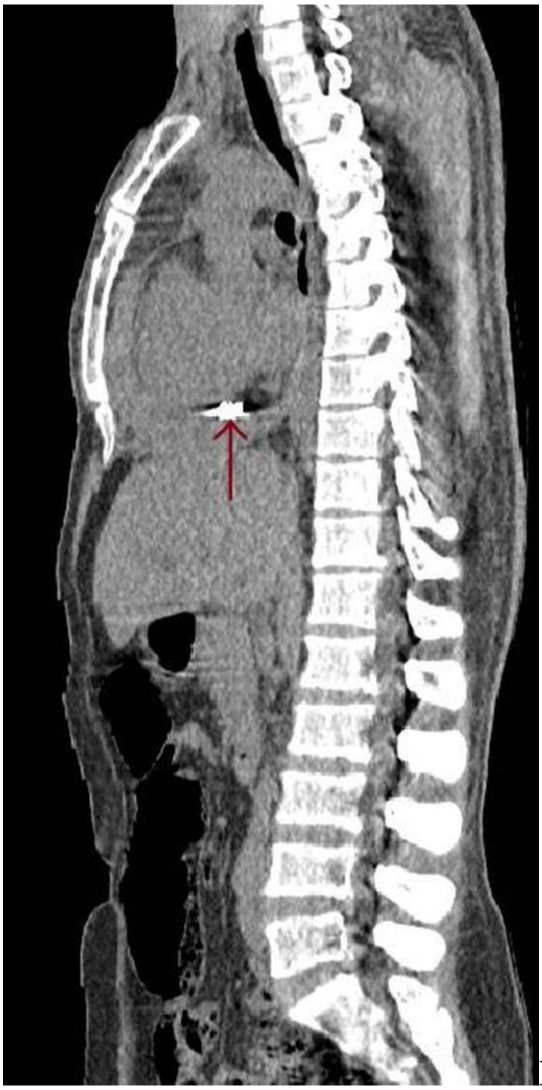

D

Fig. 10. Spiral CT scan of the chest with contrast enhancement: right-sided hemothorax, post-traumatic pulmonitis along the wound canal in the upper lobe of the right lung, a metal fragment in the interatrial septum. A, B, C – oblique projections to visualize the course of the wound channel; G – sagittal plane.

Penetrating cardiac trauma is rarely seen but when present there is a short time lag to keep the patients alive. When a cardiac gunshot injury is suspected computerized tomography, transthoracic echocardiography, and transesophageal echocardiography are suggested for evaluation of cardiac compromise, bullet trajectory, and the localization of the bullet [Kaya A. et al., 2016]. Surgical intervention is gold standard when hemodynamic compromise like pericardial tamponade, hypovolemic shock due to bleeding is present (Fig. 11, 12).



A



B

Fig. 11. Chest CT shows a bullet (hyperdense material) in the pericardial sac with pericardial effusion. A - transverse view; B - sagittal view.

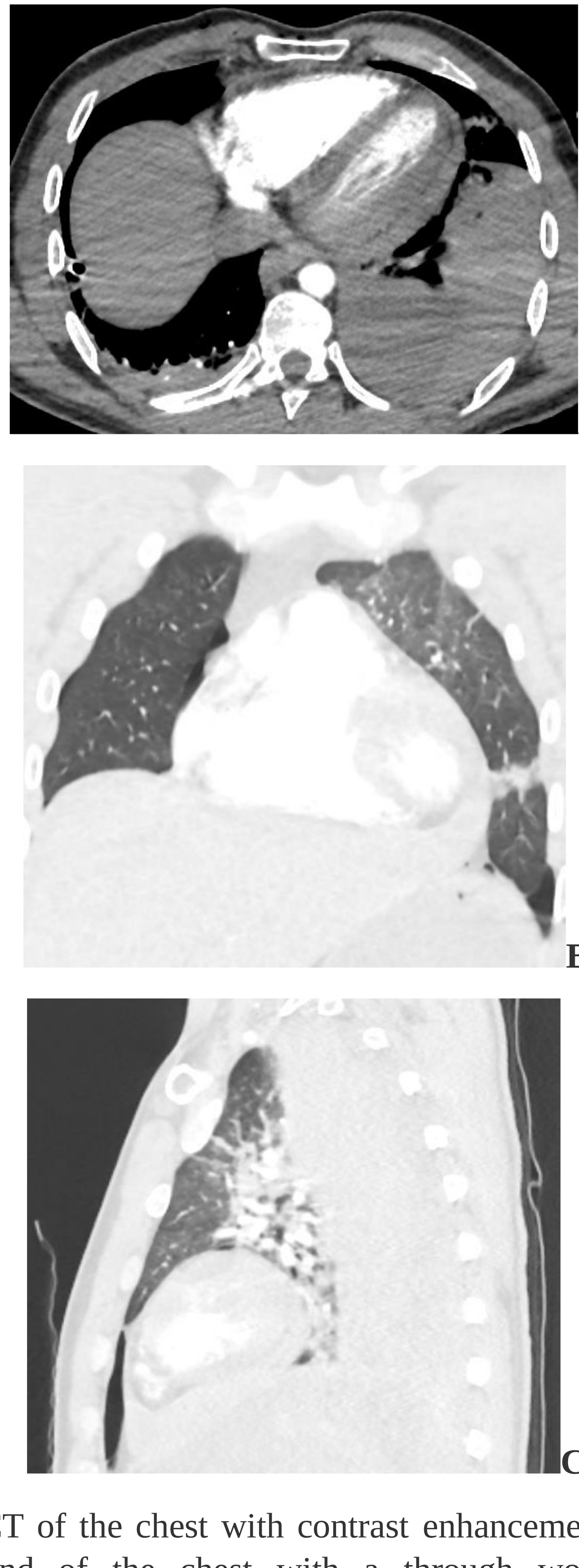



Fig. 12. Spiral CT of the chest with contrast enhancement: a blind gunshot penetrating wound of the chest with a through wound to the heart, hemoperitoneum, bilateral partial pneumothorax, left-sided massive hemothorax, no signs of extravasation were found. A – axial plane; B – coronal plane; B – sagittal plane.

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## Chapter 3.

### Imaging in the treatment of gunshot wounds of the thoracoabdominal region.

*Lurin I., Vorovskiy O., Makarov V., Khoroshun E., Nehoduiko V., Ryzhenko A., Chobey S., Gorobeiko M., Dinets A.*

The ongoing Russia-Ukraine war is associated with critical and severe injuries of military personnel and civilian population due to the frequent application of all possible kinds of high-energy weapons, resulting in severe injuries to military personnel and civilians [Gumeniuk K. et al., 2023; Lurin I. et al., 2023; Rogovskyi VM. et al., 2022; Kazmirchuk A. et al., 2022; Gybalo RV. et al. 2022; Anatoliyovych IL. et al., 2022; Osmanov B. et al., 2024]. Injuries to the thorax and abdomen are on the top among other sites of gunshot traumas in warfare and armed conflicts and are frequently presented as combined thoracoabdominal injuries. The latter is associated with a high rate of lethal outcomes and longer rehabilitation in those, who survived due to injuries of multiple organs and major vessels of the chest and abdomen, bone fractures as well as severe maxillofacial trauma [Kotwal R.S. et al., 2018; Roman P. et al., 2023]. The modern weapon is designed to cause critical and severe damage in multiple organs which is presented by separate injuries to the chest or abdomen, or combined trauma, including abdominal and thoracoabdominal cases [Golovko S. et al., 2023; Tsymbaliuk V. et al., 2023].

Surgical management is envisaged application of damage control surgery, whereas recent studies also suggested damage control resuscitation for severe combat trauma [Quinn J. et al., 2023; Chen S. et al., 2019]. A more specific approach to treating patients with thoracoabdominal injury should also include minimally invasive technologies to reduce surgical trauma for patients in critical and severe conditions, which is frequent in war settings. In the ongoing war in Ukraine, thoracoabdominal injuries constituted 0.5% out of all cases. The possibility of application of minimally invasive technologies (i.e. laparoscopy and thoracoscopy) in the Role 2 hospitals (i.e. deployed military hospital) in the ongoing Russo- Ukrainian war is associated with multiple technical and safety issues, due to high risk of blackouts, problems with supplies for the generators as well as high risk of cruise-missiles or multiple rocket launch rockets attacks on the civil or military medical facilities by russia army [Rogovskyi VM. et al., 2022; Gumeniuk K. et al., 2023; Lurin I. et al., 2024]. The little is known about the application of laparoscopy and thoracoscopy in the Russo-Ukrainian war, indicating need for further evaluation of video-assisted thoracoscopic surgery (VATS) and laparoscopy over the open surgical techniques in patients with severe trauma at Role 2 hospitals.

The authors examined the utility of laparoscopy, video-assisted thoracoscopic surgery and magnetic instrumentation, and demonstrated the feasibility of using a minimally invasive approach (laparoscopy and thoracoscopy) to treat severe abdominal and thoracoabdominal injuries in combat patients injured during the ongoing war in Ukraine and treated at the Role 2 hospital.

A 36 male combat patients were identified for the study during the first 100 days from February, 24 2022. All patients were male with a mean age of 32 years (range 19–54 years). These individuals were diagnosed with thoracoabdominal GSW at the Role 2 hospital of the Armed Forces of Ukraine in Donetsk oblast. The exact number of all injured individuals for the mentioned period can not be shown at the time of manuscript submission because these data are classified. The medical roles system of military care in Ukraine was presented in our previous publications [Gumeniuk K. et al., 2023; Lurin I. et al., 2023; Tsema I.V. et al. 2018; Khomenko I. et al. 2022].

The thoracoabdominal injury was considered severe for cases with an Injury Severity Score (ISS) $\geq$ 16 or for cases presenting with two or more injured body areas, which corresponded to the score $\geq$ 3 according to the Abbreviated Injury Scale (AIS) [Su W.T. et al. 2022]. Upon admission, all injured were evaluated by clinical chemistry blood tests, and ECG. An ultrasound examination was performed according to the extended Focused Assessment with Sonography for Trauma (e-FAST) protocol using a portable ultrasound machine "Sonosite Micromaxx, 2017", equipped with probes having the Doppler and M-mode for the 2D visualizations. Software SonoCalc was used for the ultrasound measurements of the trauma extent. X-ray examination was performed by using the machine "Opera RT20, 2018", which is equipped with modules to have contact with a good focus on the patients in a distance of 150–180 cm, which is specifically important for patients with severe gunshot injury. Digital X-ray surgical device type C-arc was applied as well ("Siemens Siremobil Compact, 2017"). A computed tomography (CT) scan was performed by using the "Planmed Verity, 2019" machine equipped with modules for 3D visualization and patient positioning. All patients underwent catheterizations of the subclavian vein, bladder, and nasogastric intubation. Video-assisted thoracoscopy surgery (VATS) was performed by using the system "Richard Wolf, 2011". Two minimally invasive towers for laparoscopy and VATS were available: one from the civil hospital to be turned into Role 2 hospital and other one from the military medical team, indicating good cooperation approach between civil and military medicine. The indications for the surgery were positive peritoneal signs, free fluid and air in the abdominal cavity, presence of the foreign bodies with a greatest diameter > 1 cm. Thoracotomy was performed in case of continuing bleeding, open hemothorax, clotted hemothorax, air leak. The surgery team were two surgeons, surgery nurse, anesthesiologist and anesthesiology nurse. All patients underwent thoracocentesis with subsequent application of surgical suction drainage to the pleural cavity. Thoracotomy was performed for patients with bleeding over 250 ml/hour or immediate receiving of > 1,200 ml of blood by surgical suction drainage. All patients who did not met above-mentioned criteria were operated by VATS and laparoscopy. The inclusion criterion was performing VATS and laparoscopy, all other patients were excluded from this study. To preserve $CO_2$ in the unsealed abdominal cavity in the conditions of penetrated gunshot injury, we temporarily sutured inlet/ outlet projectiles holes, or use it as a port for the instruments. The gas pressure was considered as sufficient in the abdominal cavity at the level of 12–14 mm of Hg. Gas insufflation is carried out into the abdominal cavity. In case of minimally invasive approach to pleural cavity the gas insufflation was not performed, because of the separate intubation of the lungs. The surgical magnetic tools were designed and manufactured in Ukraine [Negoduyko V. et al., 2019].

The routine protocol for surgical removal of ferromagnetic fragments using VATS and magnetic tools was shown previously [Negoduyko V. et al., 2019; Lurin I. et al., 2023]. In brief, the foreign body (metal fragment) was fixed by a surgical magnetic tool in a lateral position. To reduce the risk of secondary injury to the adjacent fragment tissues while removing a fixed foreign body, the foreign body needed to be located on the same axis as the magnetic tool. The rotation and fixation of the metal foreign body (bullet or shell etc.) was performed with the assistance of the magnetic multifunctional tool for the diagnosis and removal of metal ferromagnetic foreign bodies [Negoduyko V. et al., 2019; Lurin I. et al., 2023].

A perfusion index (PI) was calculated for all patients and PI values were considered in surgical planning. Damage control resuscitation as a part of damage control surgery (DCS) was applied for patients in the case of PI within the range of 2–3%. Management of the shock was performed until the stable hemodynamics. Patients underwent completed surgical interventions in case of achieving normal PI > 4%, which was considered as sufficient result after the DCR. The above-mentioned tactics of DCS with damage control resuscitation were quickly adopted in our routine clinical war surgery settings with the general title of “Damage control reanimation” (DCR). DCR is an emergency method, applied for patients with severe post-traumatic hemorrhagic shock. The patients with such injuries are managed by the simultaneous application of reanimation and surgical operation upon admission to the Role 2 hospital, which resulted in the adoption of the integral conception of DCR/DCS. The concept of DCR/DCS was adopted by Ukrainian military surgeons only for patients in critical conditions in order to do the reanimation measures upon the admission of the patients without delaying the surgical interventions, which resulted in better survival of the patients [Malgras B. et al., 2017; Khomenko I. et al. 2022].

In 32 (89%) of the patients were diagnosed with right-side injuries to the chest and the lift-side in 24 (67%) patients. Analyses of the cohort showed the following injuries in addition to the thoracoabdominal GSW: fractures of ribs in 21 (58%), scapula in 1 (3%) pericardium wounds in 1 (3%) patient. Severity injury of the patients was moderate in 14 (39%) patients (ISS < 16), severe in 33 (92%) patients (ISS 16–25), critical in 9 (25%) patients (ISS > 25), and lethal outcome was in 1 (3%) patient due to. The mean time of surgical operation was 50 ± 5.2 minutes (the time from the incision to the final stich”, excluding intubation and extubating time). The application of endoscopic methods did not increase the duration of the surgery. The “conversion by demand” was performed immediately upon the evaluation of the injury severity and the patient’s condition.

Surgical suction drainage (i.e. Bülau drain) was applied for all 36 (100%) patients within 10±0.5 min upon admission, followed by transporting the patient to the operation room for DCR and surgical management. The FAST protocol was applied for all patients to check for possible hemoperitoneum and hemopericardium, showing effectiveness in 30 (83%) patients, whereas false-positive detection of the fluid was detected in 6 (17%) patients. Out of these 6 patients, the misdiagnosis was detected in 3 (8.3%) patients, presenting with clotted pneumothorax in 2 (6%) cases, and non-diagnosed hemoperitoneum in the lower pelvis in 1 (3%) case. A CT scan was applied in 18 (50%) patients and an X-ray in all 36 (100%).

Hemopneumothorax was diagnosed in 36 (100%) patients. These patients were admitted with previously placed surgical suction drainage, however in 18 (50%) patients we had to replace it. The derange replacement was performed due to unreliable fixation, the insufficient diameter of the tube, and the placement of drainage out of the pleural cavity. The hole created for the thoracentesis was used as a port for thoracoscopy in 10 (28%) patients.

Further data analyses showed that 2 (6%) patients had a massive injury to the liver along with the PI 2–3%, resulting in a two-step approach of simultaneous surgical operation (with limited surgical extent) and application of DCR. The completed surgical operations were performed for these 2 patients after the stabilization of their hemodynamics as well as PI > 4%. Other 34 (96%) patients were presented with PI > 4%, indicating good hemodynamics and possibilities to apply VATS and laparoscopy. Autologous blood transfusion was performed in 17 (47%) patients, other patients were resuscitated using crystalloid fluids infusions.

VATS was performed in all 36 patients. Of these 36 patients, in 10 (28%) patients, VATS was applied to remove the metal foreign body fragments, remove coagulated hemothorax, suturing of the lung wounds as well and apply bipolar electrocautery to the liver wounds using GSW defect in the diaphragm as a port to the abdominal cavity. The diaphragmatic wounds were also sutured under the conditions of VATS.

A typical case of the patient with thoracoabdominal injury is illustrated in Fig. 1. Simultaneously with VATS, the laparoscopy was applied for 32 (89%) patients, presenting with severe liver bleeding, whereas in 4 (11%) patients, the conversion to the laparotomy was performed due to severe continuing bleeding that cannot be stopped by minimally invasive surgery. Of these 32 patients with simultaneous VATS and laparoscopy, in 28 (78%) patients, the bleeding from the liver was stopped by applying bipolar electrocautery, whereas in 4 (11%) patients the wounds were sutured because of the wound defect length of 3 to 5 cm was associated with continuing bleeding. Laparoscopy for right side injuries was performed for 30 (83%) patients as well as for left side injuries in 6 (17%) patients, indicating the right side to be more frequent. The metal fragments from the gunshot projectiles were found in the diaphragm and associated with superficial injury to the liver in 4 (11%) patients and 32 (89%) patients we identified more severe wounds to the liver by metal fragments. The analyses of these 32 patients showed one metal fragment in 28 (78%) patients, two in 3 (8.3%) patients, three in 2 (6%) patients, four in 1 (3%) patient, five in 1 (3%) patient, six in 1 (3%) patient. These metal fragments from the shelling were removed laparoscopically in 13 (36%) patients. The multifunctional magnetic tool was applied to remove foreign bodies from the pleural or abdominal cavity was used in 10 (17.8%) patients, whereas another magnetic tool designed for the video-endoscopic approach was applied in 13 (23.2%) patients. The application of a magnetic tool for the removal of metal fragments was performed in 20 (35.7%) patients under X-ray guidance by using a C-arc device (Fig. 2). The rotation and fixation of the metal fragments were performed laparoscopically in 5 (13.9%) patients. The size of the removed metal fragments varied from 2 × 1.2 cm to 4.3 × 2.8 cm (Fig. 3).

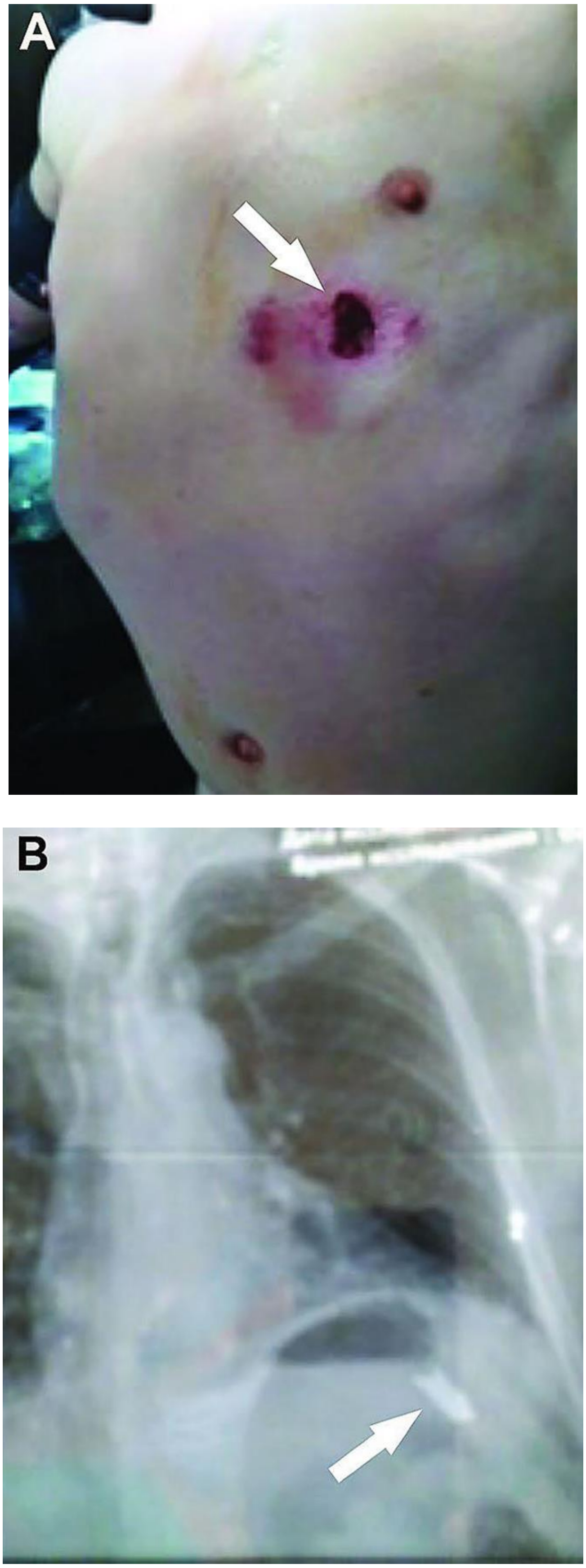
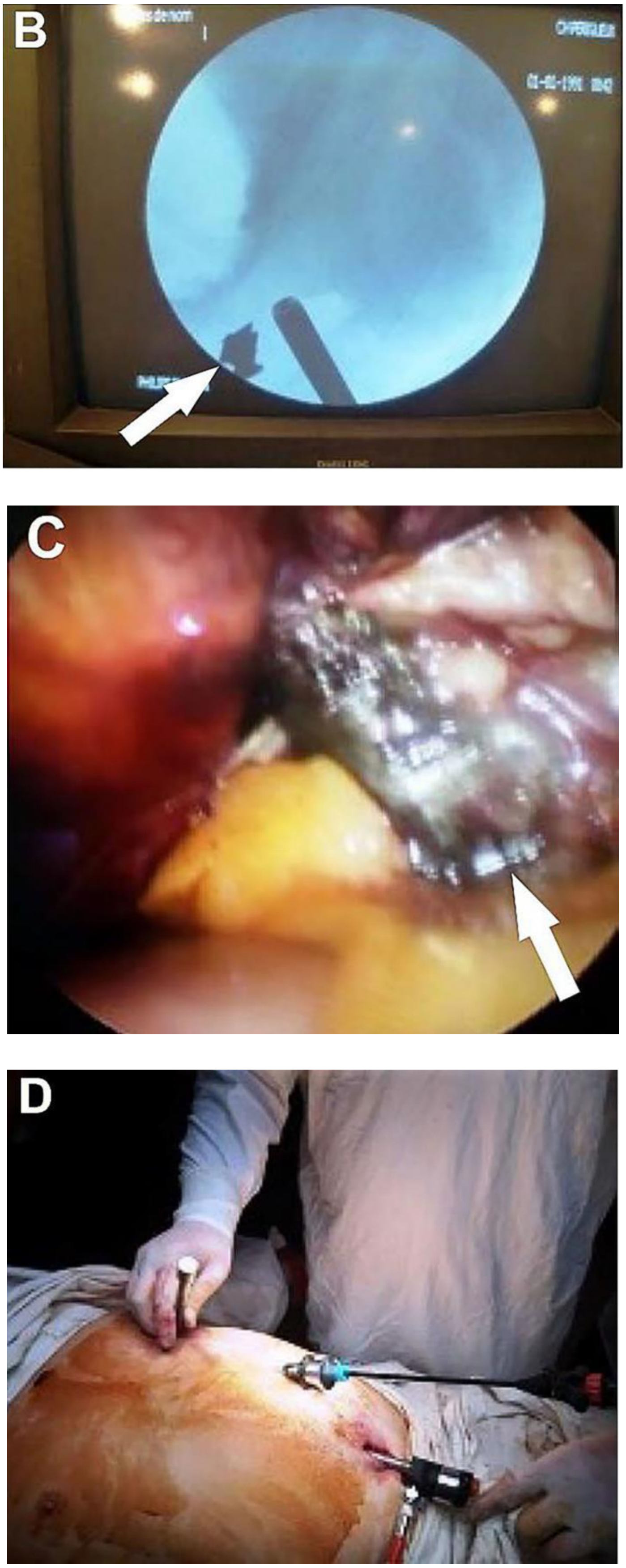

A
B


**Fig. 1.** Illustration of the patient with thoracoabdominal gunshot injury. (**A**) Intraoperative photograph showing inlet projectile hole 3,0×2.5 см in the 5 left intercostal area on midclavicular line. Anterior (**B**) and lateral (**C**) view of the chest X-ray film with signs of metal foreign body in the left subdiaphrag-matic area (marked with arrow)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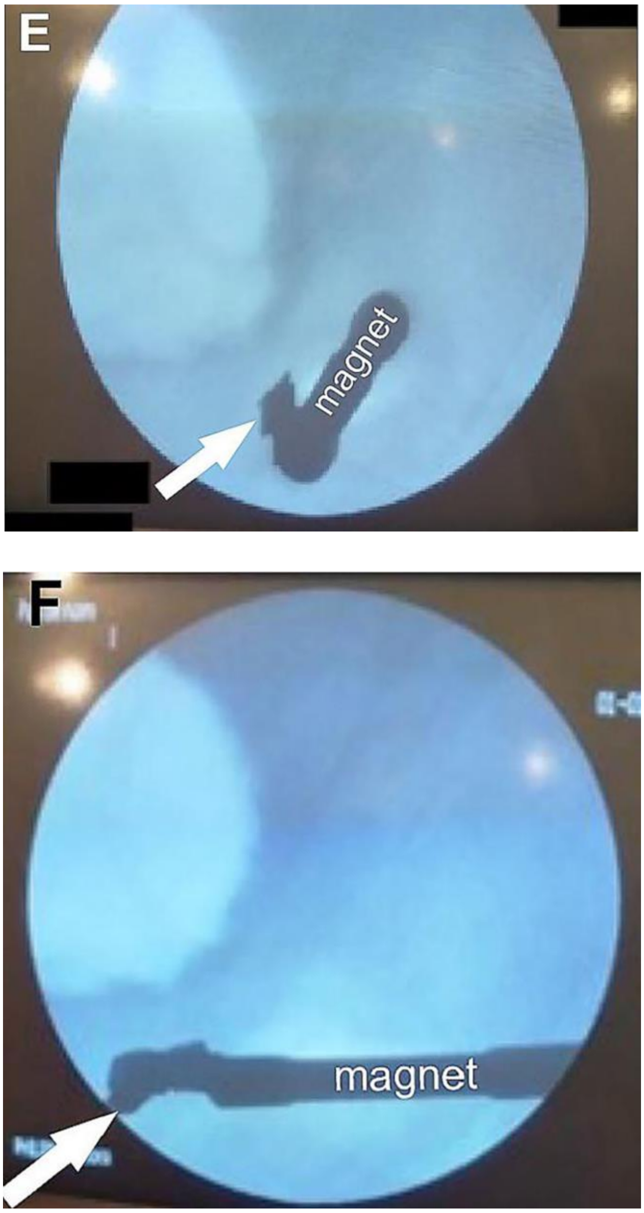


**Fig. 2**. Intraoperative photograph of the video-assisted thoracoscopy (VATS) and laparoscopy procedures. **(A)** A thoracoscope was placed into the thoracic cavity using an inlet hole as a port to perform the revision and revealed no evidence of the metal fragment in the chest. (**B)** Intraoperative X-ray view by C-arc showing the presence of the metal fragment (marked with arrow) in the abdomen. (**C)** Intraoperative laparoscopy image showing metal fragment (marked with an arrow) within the S2 segment of the liver. (**D)** Illustration of the magnetic tool to be inserted into the abdomen (held by the right hand of the surgeon) through the inlet hole in the chest under the laparoscopy guidance as preparation steps to remove the metal fragment from the S2 segment of the liver. (**E)** X-ray view of the fixed metal fragment (marked with an arrow) by the magnetic tool to further perform its rotation. (**F)**X-ray view of the rotated metal fragment (marked with an arrow) to the lateral position by the magnetic tool.

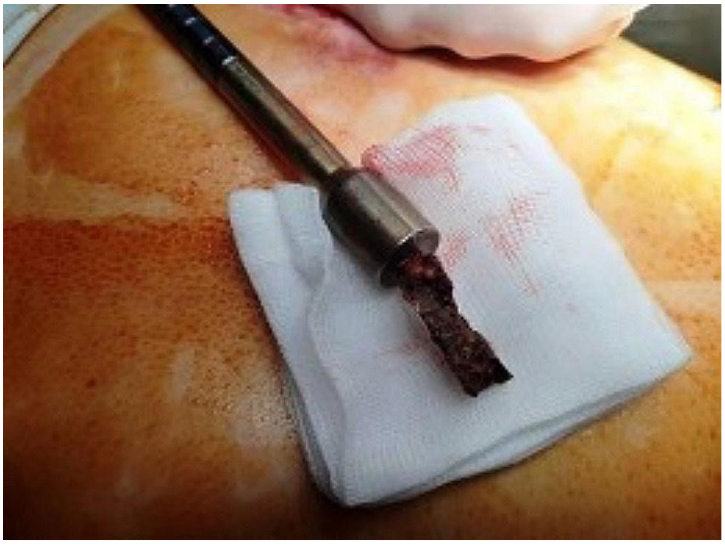

**Fig. 3.** Photograph of metal fragment 3.5×2.3 cm fixed by the magnetic tool after the removal from the abdomen.

The specific feature of the abovementioned operations using advanced surgical features was their application in conditions of the massive admission of injured patients to Role 2 hospitals. The rubber tubes were used to drain chest, left infradiaphragmatic space, abdominal cavity, subheptic space, pelvic space. We usually placed 1 drain to chest, at least 2 drains to left part of abdomen and at least 3 drain tubes to the left part. The exact evaluation of draining approach was not performed for this study. All patients demonstrated both stabile hemodynamics and respiration (usually 2–3 days postoperatively) were transported to higher echelon of medical care to continue treatment, and the follow up data is not available. The time of transportation to the hospital of higher Role depended on the combat situation with a specific consideration of drones attacks, ballistic and artillery strikes by the russian army to the sanitary transport, which is frequent.

The microbial contamination was considered, thus all patients received antimicrobial therapy by broad-spectrum antibiotics at Role 2 hospital.

This study presents the authors' clinical experience in the management of abdominal and thoracoabdominal GSW with the application of such minimally invasive technologies as VATS and laparoscopy at Role 2 hospitals in the ongoing Russo-Ukrainian war. The authors have shown that this approach is contrary to current NATO recommendations for level 2 medical care, which involve the evacuation of critically ill patients to a higher level hospital by helicopter. However, reality of Russo-Ukrainian war to suggest avoid any aircraft using for the medical purposes considering extremely high chances of the shutting down such vehicles by the enemy's stationary missiles. Considering this experience, all patients are transported by the ground and in case the high risk for ground transportation, we have to change the approach for the medical aid, resulting in the decision to bring minimally invasive surgical equipment to the Role 2 hospitals (20–40 km from frontline), despite the risk for the surgical team and this equipment being destroyed by Russian attack, which is frequent to the medical facilities. To our best knowledge, this is the first study reporting a relatively large cohort of combat patients who underwent management of abdominal and thoracoabdominal gunshot wounds by using laparoscopy and VATS with surgical magnetic tools application. Previously, the minimally invasive technologies were presented only as case reports or during the hybrid period of russian aggression [Gumeniuk K. et al., 2023 ]. Another important message from this study is to show the possibility of routine application of the above-mentioned minimally invasive tools under the conditions of the attacks of high-energy weapons like MLRS, drones, and cruise missiles by the russian army. We also consider this study as evidence of the possibility of applying minimally invasive surgery and the surgical magnetic tools at the low echelons of medical care (Role 2 hospital is usually deployed 20–40 km from the battlefield line), which is important, considering the frequent violation of humanitarian law by the russian army as well as under the conditions of limited medical resources in Ukraine [Tertyshnyi SV. et al., 2023, Lurin I. et al., 2023]. Limited medical resources were and remain a common problem for healthcare in Ukraine due to various causes, including bad planning [Dinets A. et al., 2021]. However, military surgeons demonstrated a high ability to make appropriate clinical decisions for patients with a severe thoracoabdominal injury even in unstable combat conditions and available resources at various echelons of medical care, including Role 2 hospitals.

Findings from this study support our hypothesis that VATS and laparoscopy are useful minimally invasive methods for the management of severe thoracoabdominal gunshot injury in war settings. Our results also suggest laparoscopy as an important part of the diagnosis and treatment of severe thoracoabdominal gunshot injury, which is in line with other studies of combat injury [Swiech A. et al., 2021]. It is well known that laparoscopy is associated with lower surgical trauma as compared to open surgery, which is important for patients already having severe injuries. On the other hand, laparoscopy might be considered a routine procedure for combat patients in case of absence of massive admission of the patients to Role 2 hospitals. Other limitations of the laparoscopic interventions are obvious highly traumatic lesions to the abdomen, eversions, and hemodynamically unstable patients. For these patients, we immediately perform laparotomy to stop bleeding, excise necrotic tissues, as well as clean the abdomen from dirt and foreign bodies coming with gunshot shelling or bullets.

Results from this study share some similar features of combat trauma as well as differences as compared with data from case reports, larger series of combat patients, and review papers [Zong Z.W. et al., 2018]. Similar to other researchers, we evaluated the severity of trauma by using various injury scales. This study also confirmed the utility of minimally invasive techniques such as VATS and laparoscopy for patients with severe gunshot injury, which is confirmation of our previously published cases. Our approach to using VATS during the war at Role 2 hospital is in line with Swiech et al., who applied a similar approach in Role 2 hospital in war theaters in Afghanistan and West Africa [Swiech A. et al., 2021].

We have shown lethal outcome in 1 (3%) patient, which is in contrast with Morrison et al. who investigated a cohort of 27 combat patients with thoracoabdominal injury, showing lethal outcomes in 9 (33%) patients, Propper et al. demonstrated 13% and Kotwal et al. 38.5% of lethal cases in large series [Kotwal et al. 2018]. Other studies showed lethal cases in 3% of injured with thoracic penetrating trauma. We consider the lower rate of deaths among injured in our cohort could be related to the “golden hour” policy for transportation to the hospital at Role 2, as we also have shown in our previous study. On the other hand, a higher proportion of force fatalities was shown in a smaller cohort as compared to others, which might affect our results. Still, results from our study indicate the importance of the “golden hour” policy to evacuate patients to the appropriate echelon (Role) of medical care within 1 h immediately after the casualty [Khomenko I. et al., 2018]. Similar to others and using our own experience since 2014, we have also demonstrated the utility of perfusion index for evacuation of hemodynamics, as well as using PI within the measures of damage control surgery and including damage control resuscitation (PI > 4 units were considered for the stable hemodynamics) [Ozakin E. et al., 2020; Menegozzo CAM. et al., 2020]. In this study, we have also demonstrated the utility of combining damage control surgery and damage control resuscitation as an integrated approach for patients in extreme conditions, allowing to avoid delays in surgical treatment and improving survival of the patients, which is also typical for combat patients [Malgras B. et al., 2017; Quinn J. et al. 2023].

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## Chapter 4.

FAST protocol

*Abdullaiev R.Ya., Grechanyk O.I., Nehoduiko V., Makarov V., Khoroshun E., Abdullaiev R.R.*

Injuries to the thorax and abdomen can occur during sports, traffic accidents, and combat operations. Thoracic injuries include lung contusion, hemothorax, heart contusion, pericardial effusion, pneumothorax. Abdominal injuries are focused on internal organ injuries: spleen and liver, kidneys, pancreas and intestines. Blast injuries, concomitant bleeding, and the need for massive blood transfusions increased the wound mortality rate. In order to quickly identify high-risk patients and improve the care of the wounded, it is necessary to use predictive models or scoring systems [Öztürk A. et al., 2022].

The mortality rate of patients with gunshot wounds is very high. Bullets have high velocity and energy, which can cause more internal damage than expected. In thoracoabdominal gunshot wounds, plain x-ray and bedside FAST may be ineffective in detecting the full extent of thoracic and intra-abdominal injuries. Thus, in hemodynamically stable patients, CT of the chest and abdomen should be planned early in order to eliminate the causes of the fatal outcome and make the correct diagnosis in a timely manner [Karaca MA. et al., 2015].

Injuries of the thorax during combat occupy a prominent place and often become the cause of mortality. Radiography and computer tomography play an important role in determining the localization and assessment of the nature of damage to the chest organs. Before the widespread introduction of imaging methods into clinical practice, the mortality rate for chest combat injuries exceeded 50%. Such a high mortality rate was due to the defeat of vital structures. in the chest, including the heart, lungs, and major vessels. Modern body armor can protect the body from high-speed (>300 m/s) shots [Yakovenko V.V. et al., 2020]. According to some researchers, mortality from total chest trauma is 8.6–16%. In gunshot wounds of the chest, pneumothorax and lung contusion are the most common chest injuries [Durso AM. et al., 2015; Edgecombe L. et al., 2022].

Gunshot wounds to the abdomen are a serious combat injury and are considered one of the most difficult areas of military surgery and emergency radiology. In hybrid warfare, they make up 4% of all wounded, of which 33% are penetrating and 67% are non-penetrating. Shrapnel and explosive injuries predominate in the structure of the abdomen of a gunshot wound. Combined damage to the organs of the abdominal cavity is accompanied by an increase in mortality from gunshot wounds to the abdomen [Janak C. J. et al., 2019]. The FAST (Focused Assessment with Sonography for Trauma) protocol plays a role in the sorting of the wounded and the subsequent selection of medical imaging methods [Savatmongkorngul S. et al., 2017; Wongwaisayawan S et al. 2016; Richards JR. et al., 2017]. The use of the FAST protocol allows to reduce the number of diagnostic laparotomy [Matsevych OY. et al., 2018]. The effectiveness of the FAST protocol has been demonstrated in the evaluation of blunt abdominal trauma, but its role in penetrating trauma is less clear. In this case, multidetector computed tomography (MDCT) is the best method of medical visualization of closed abdominal trauma and wounds in hemodynamically stable wounded. However, the FAST protocol remains the preferred visual method for hemodynamically unstable patients [Cardi M. et al., 2019].

FAST (Focused Assessment with Sonography for Trauma) is a targeted study of a trauma patient to detect blood in the pericardium, abdominal and pleural cavities. Introduced in 1997 by the American College of Emergency Physicians and Surgeons as a mandatory study in polytrauma.

***Tasks of ultrasound diagnostics during urgent examinations of the wounded:***

- performance of FAST protocol according to abbreviated or extended methods to determine free fluid in the pericardium, pleural cavity and peritoneum, retroperitoneal space with determination of the volume of internal bleeding;
- diagnosis of pneumothorax (examination in B-mode, M-mode);
- diagnosis of pneumoperitoneum.
- diagnostic puncture of the abdominal cavity to verify "free fluid".
- determination of the damaged organ and the degree of its damage.
- definition of "free liquid", peristalsis.
- diagnosis of fractures of the sternum, ribs, including the cartilaginous part.

The FAST protocol examines 6 standard points:

- In the right upper quadrant, fluid is searched in the hepatorenal pocket and the right pleural cavity.
- In the left upper quadrant, a search is made for fluid in the splenorenal pocket and the left pleural cavity.
- In the suprapubic area, a search for fluid in the small pelvis is conducted.
- In the subcostal area, a search for fluid in the pericardium is conducted.
- A pneumothorax is searched for in the upper part of the chest on the right and left.

***Extended (modified) FAST – 8 view zones***

The execution of FAST involves the sequential location of 8 standard inspection zones. During the examination, fluid is determined in the hepatorenal pocket, under the left lobe of the liver, in the splenorenal pocket, in the pelvic cavity, in the right and left pleural cavity, in the pericardial cavity, the movement of the lungs during breathing and the presence of pneumothorax are determined.

The study can be expanded due to additional areas of examination of the pericardium (apical access, parasternal access) and the peritoneal cavity for pneumoperitoneum (under the front abdominal wall in the epigastric area in the supine position; between the liver and the chest wall, between the spleen and the chest wall in the position on the left and right side, respectively). Display of a fixed picture on the monitor facilitates orientation and diagnostic search (Fig. 1).

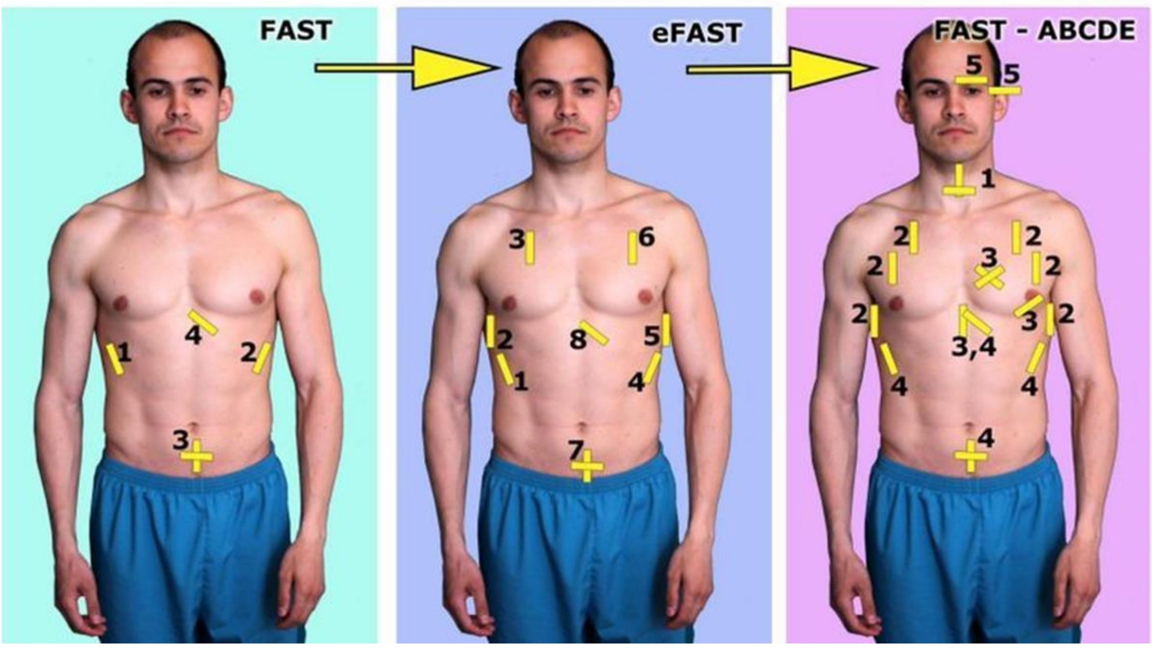
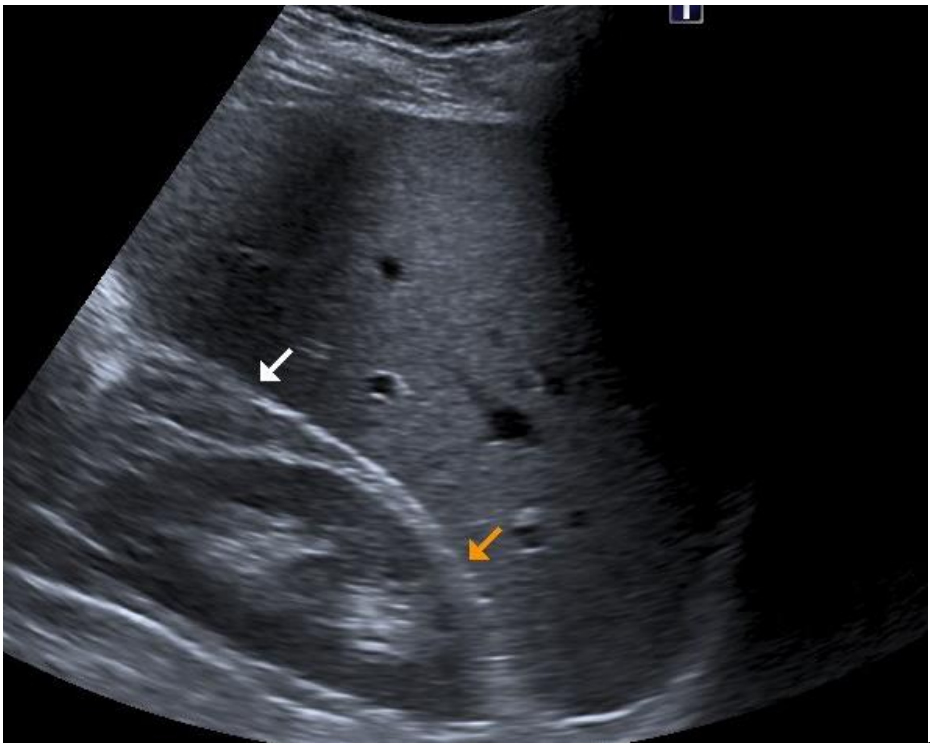



Fig. 1. Evolution of protocols for examination of patients in critical condition: FAST-1995; eFAST-2004; FAST-ABSDE – 2007.

***FAST protocol - the first view zona***

- The probe position is vertically along the front or middle axillary line on the right on the VII-X rib. The examination area includes: the right lobe of the liver, the right kidney, Morison's fossa, the diaphragm, the right pleural sinus, the retroperitoneal tissue (Fig. 2, 3).

Fig. 2. Foto FAST protocol. The first view zona.



A

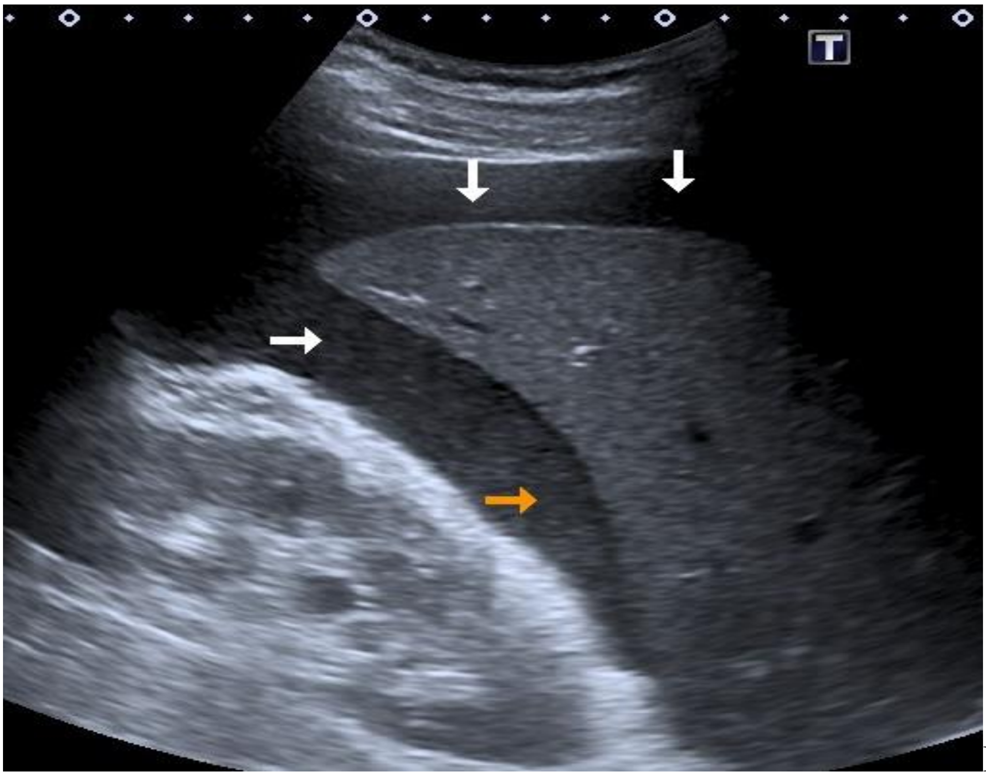



Fig. 3. Foto FAST protocol. The first view zona. Visualization of Morrison's fossa (hepatorenal fossa): A - normal (arrows), B - free fluid (arrows).

***The second view zona***

The prob position is in the VII or VIII intercostal space and is advanced dorsally to the posterior axillary line. The examination area includes the lung, the right lobe of the liver, and the diaphragm. Examination of this zone allows to assess the presence of liquid and gas in the right pleural cavity, as well as to determine the state of the lung and its movement during the act of breathing. If the lung is spread out and there are no pathological changes in the pleural cavity, its movement is unlimited and it freely enters the lower point of the pleural sinus during inhalation (Fig. 4-7).

Fig. 4. Foto FAST protocol. The second view zona.

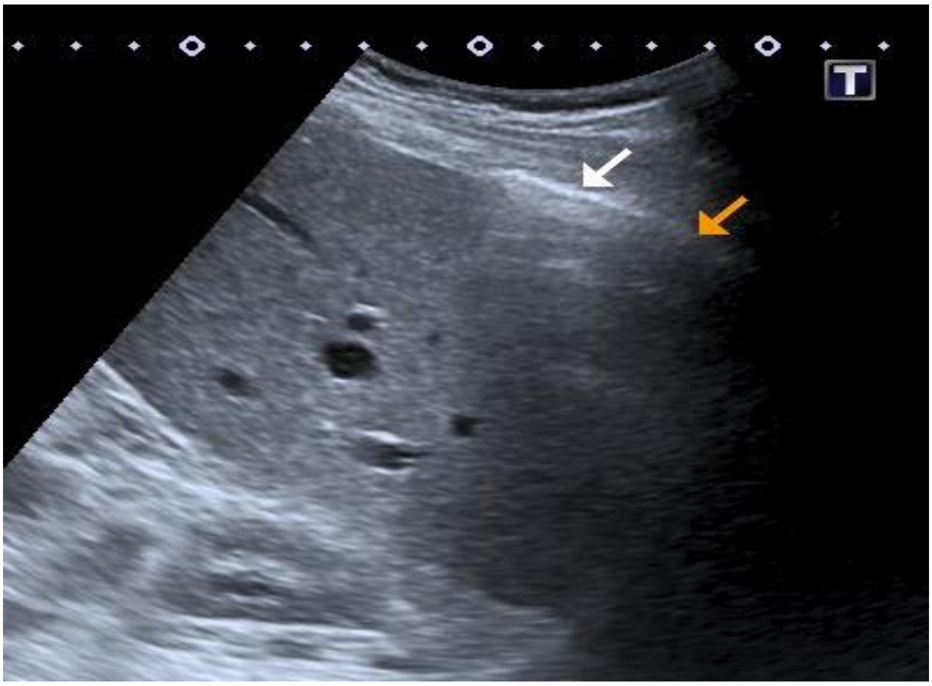


Fig. 5. The second view zona. The arrow shows gas in the right retroperineal area.

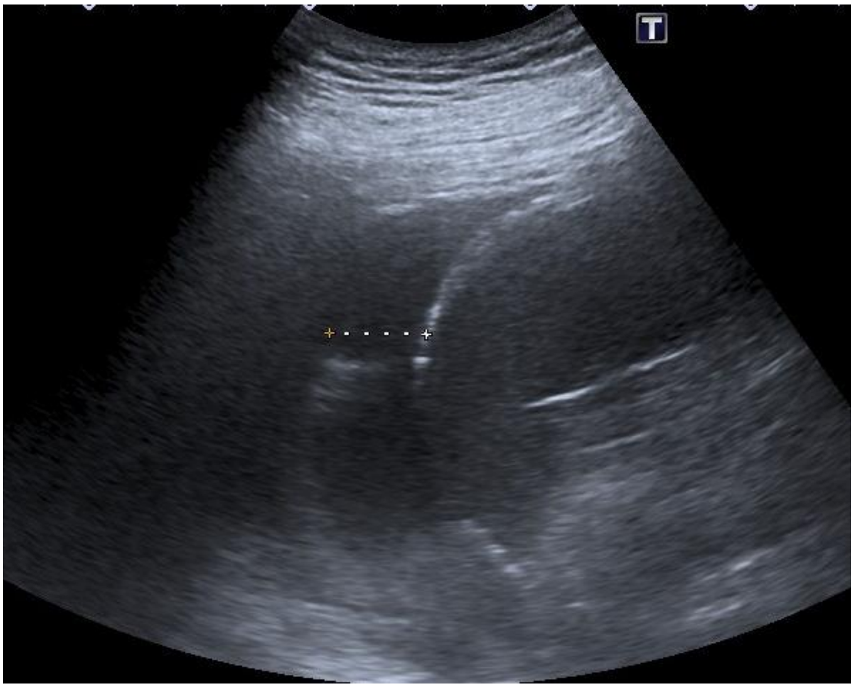


Рис. 6. Друга зона огляду. Помірний випіт у правому плевральному синусі.

Fig. 7. The second view zona. Significant effusion in the right pleural sinus. The arrow shows lung tissue.

*The third view zone*

The probe is positioned in the epigastric area under the xiphoid process with a slight upward tilt. The left lobe of the liver, the subhepatic space, the diaphragm, and the pericardium are visualized. Scanning of this area is aimed at finding free fluid under the liver, under the diaphragm, and in the pericardial cavity (Fig. 8, 9).

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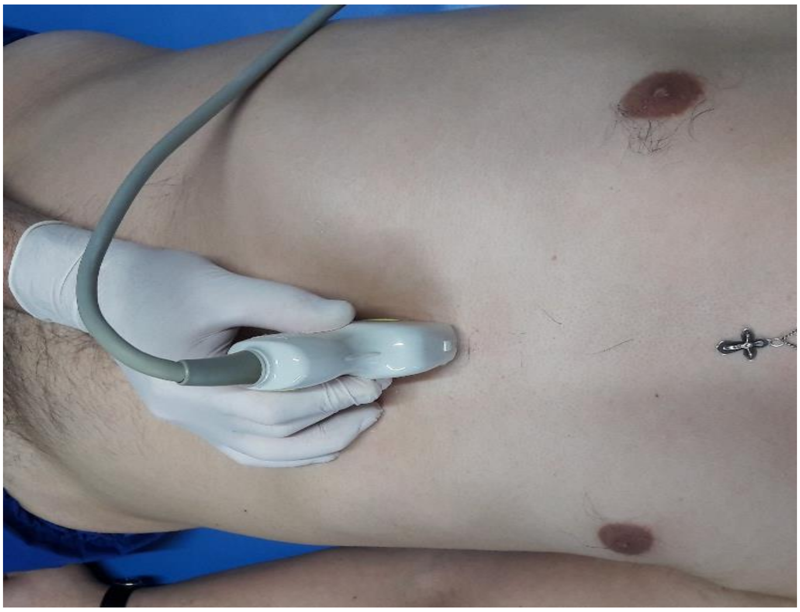


Fig. 8. Foto FAST protocol. The third view zone.

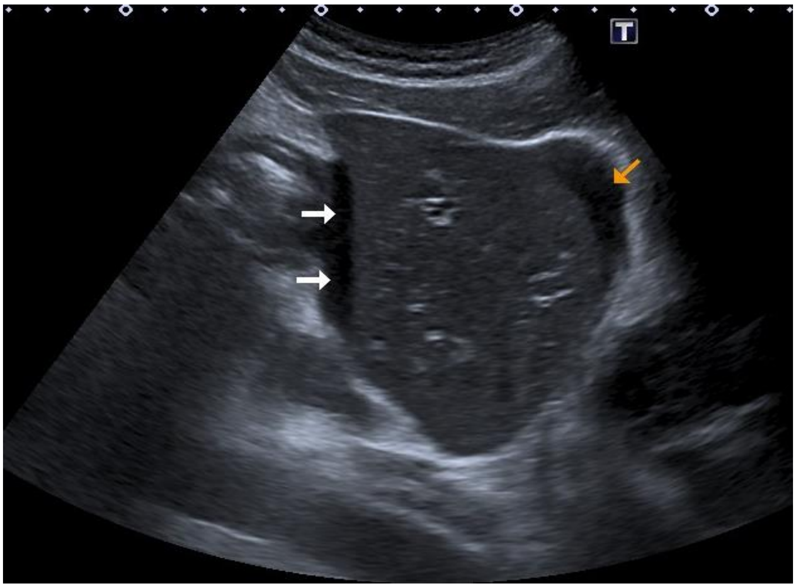


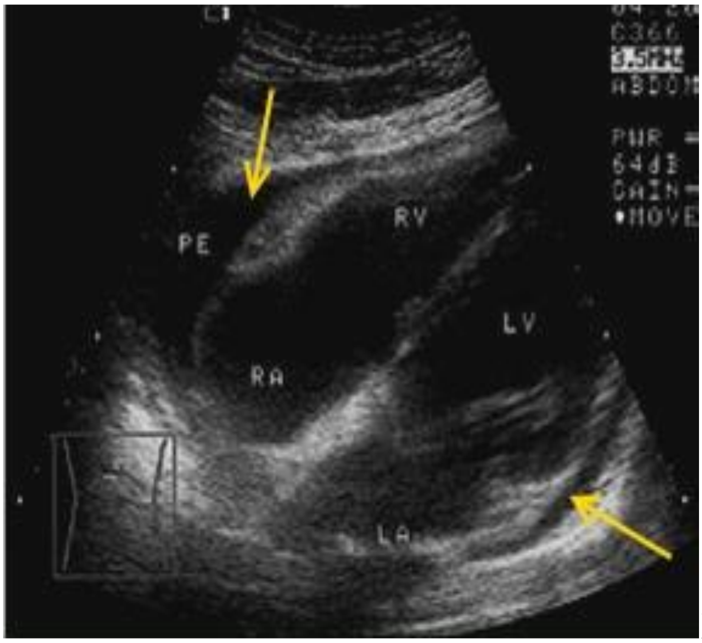
Fig. 9. The third viewi zona. Free fluid in the abdominal cavity (arrows).

*Additional subcostal access to search for hemopericardium*

With poor visualization of the pericardial cavity, it is necessary to use the classic subcostal approach. The prob position is under the xiphoid process and the ultrasound beam is directed in the direction of the left shoulder at an angle of 20-30˚ to the surface of the skin to obtain a four-chamber view of the heart and pericardium (Fig. 10, 11).

А

Fig. 10. Foto FAST protocol. Subcostal access to search for hemopericardium




Б

Fig. 11. Subcostal access – hemopericardium (arrows).

**The fourth view zona.**

The probe position is at the level of the VII-IX ribs vertically or obliquely in the intercostal space along the middle axillary line. The spleen, splenorenal fossa, diaphragm, left pleural sinus are visualized (Fig. 12, 13).

Fig. 12. Foto FAST protocol. The fourth view zona.

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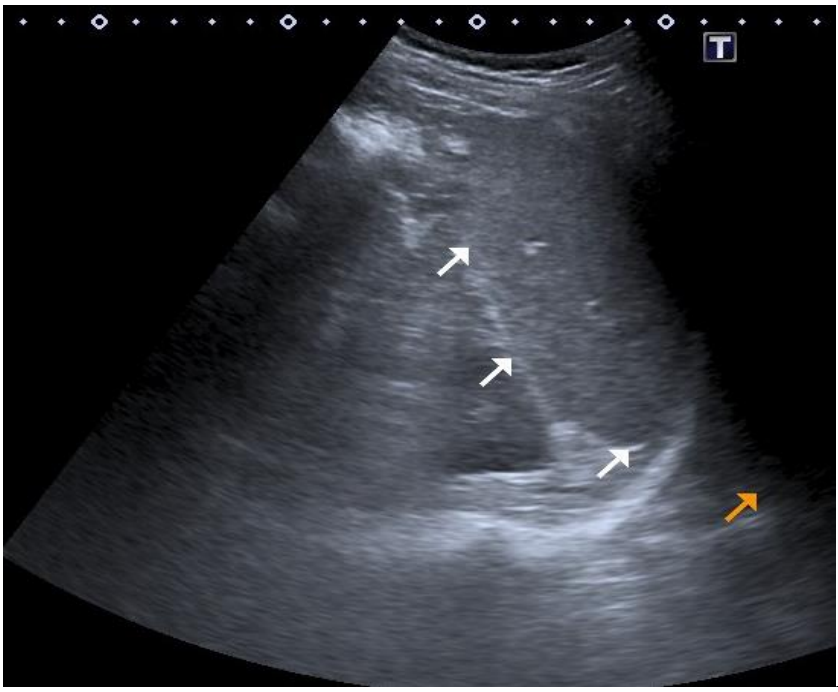

A

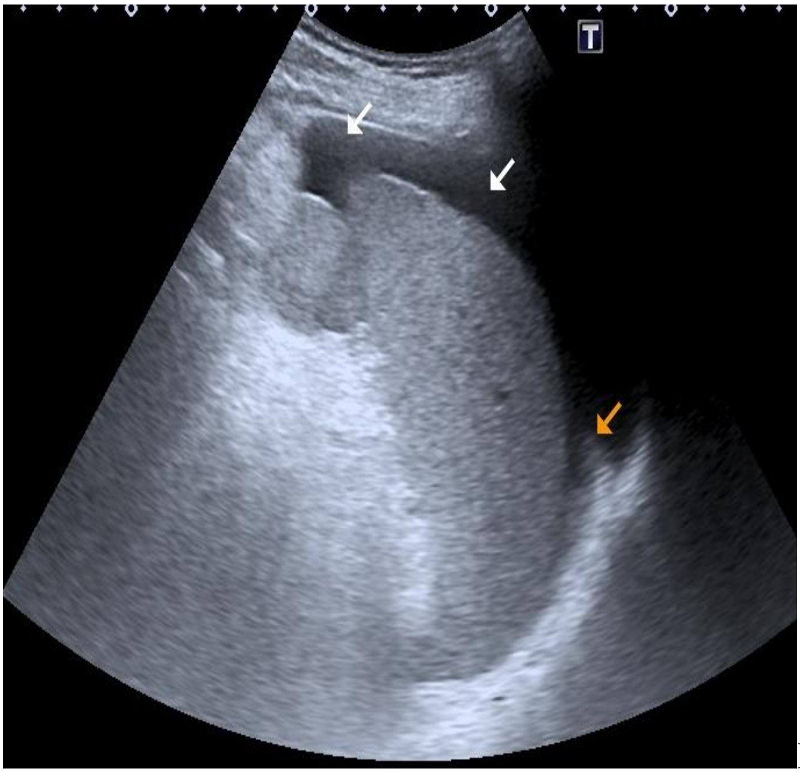
Б

Fig. 13. The fourth view zona. A – normal; B - free fluid in the left pleural sinus (arrows).

**The fifth view zona.**

- The probe position is in the VII-VIII intercostal space and advanced dorsally to the posterior axillary line. At this region the pleural sinus, lungs, diaphragm and spleen are visualized. The examination is aimed at finding free liquid and gas in the pleural cavity, determining the state of the lung and its movement during the act of breathing.
- In the absence of pathological changes, the lung is represented by a hyperechoic zone that freely moves to the lower point of the pleural sinus during inhalation.
- The presence of lung damage changes its structure and echogenicity, significantly limits movement and is accompanied by the presence of free liquid or gas in the pleural cavity (Fig. 14, 15).

Fig. 14. Foto FAST protocol. The fifth view zona.

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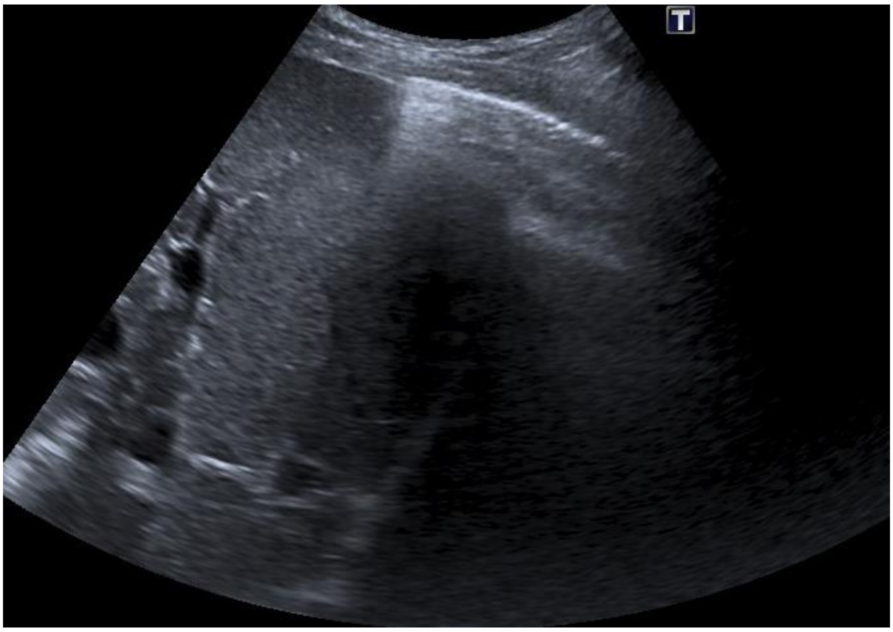


Fig. 15. The fifth view zona. Gas in the left pleural sinus.

**The sixth view zone.**

- The probe is  vertically in the suprapubic area and scans the lowest pockets of the pelvic cavity - the space of Douglas in women or the vesico-rectal space in men. The bladder, uterus, rectum, and pelvic tissue are visualized.
- the search is aimed at detecting free fluid in the pelvic cavity and evaluating the bladder. The transverse position of the sensor allows for a more detailed examination of the bladder (Fig. 16, 17).

Fig. 16. Foto FAST protocol. The sixth view zone.

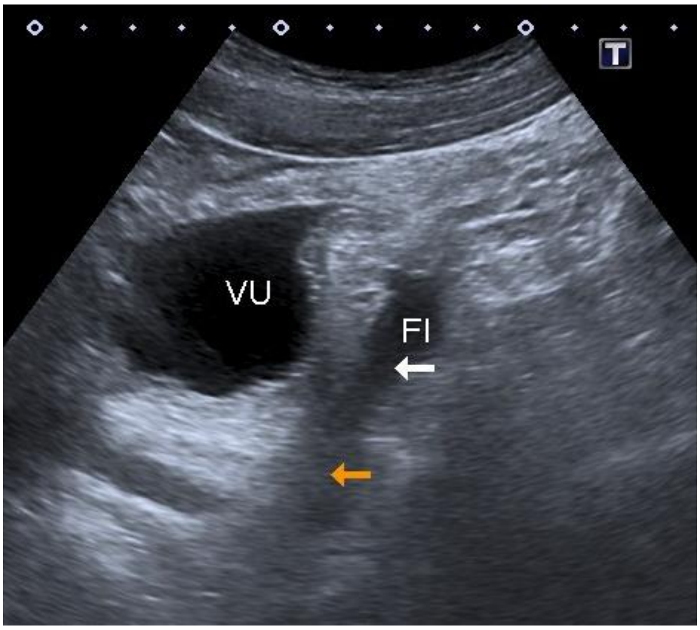


Fig. 17.. The sixth view zone. Free fluid in the pelvis (arrows).

**Seventh and eighth view zonas.**

- used to search for pneumothorax. The sensor position is longitudinal at the level of the III-IV rib along the midclavicular line, or transversely in the intercostal space.

- a convex sensor with a frequency of 3-5 MHz or a linear sensor with a frequency of 7-10 MHz is used. Scanning depth is 5-7 cm.

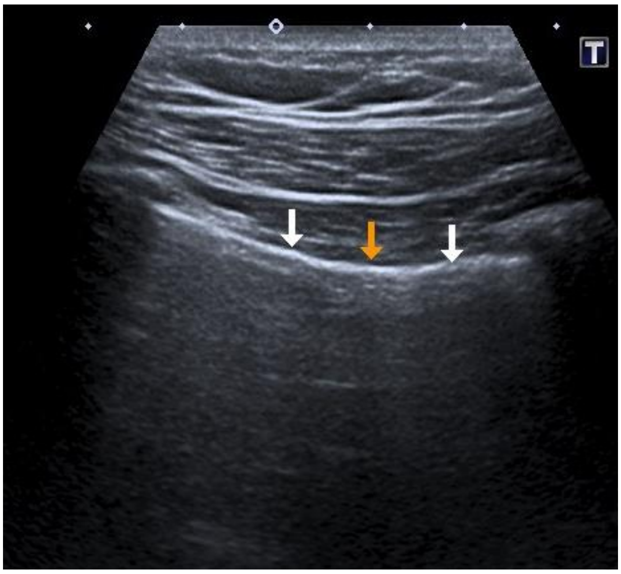
- It is necessary to obtain an image of two ribs, intercostal space, chest muscles, parietal and visceral pleura, lung (Fig. 18, 19).

А

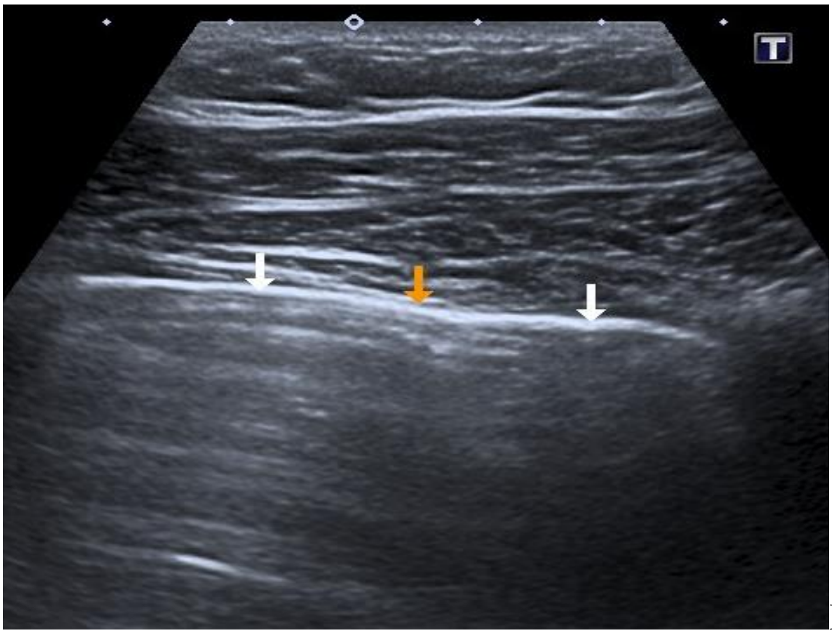
Б

Fig. 18. Foto FAST protocol. Seventh and eighth view zonas.

А – longitudinal view of the probe with visualization of two ribs; В – transverse view of the probe with visualization of the intercostal space.



А



Б

Рис. 19. Ехограми: А - поздовжнє положення датчика з перетином двох ребр (стрілки); Б - поперечне положення датчика між ребрами (стрілки).
Fig. 19. A – longitudinal view of the probe with visualization of two ribs (arrows); B – transverse view of the probe with visualization of the intercostal space.

The diagnosis of pneumothorax is based on the detection of the "bar code" symptom, which is formed by the absence of sliding of the visceral pleura during the inhalation of the patient. The appearance of this symptom is based on the effect of reverberation (Fig. 20).

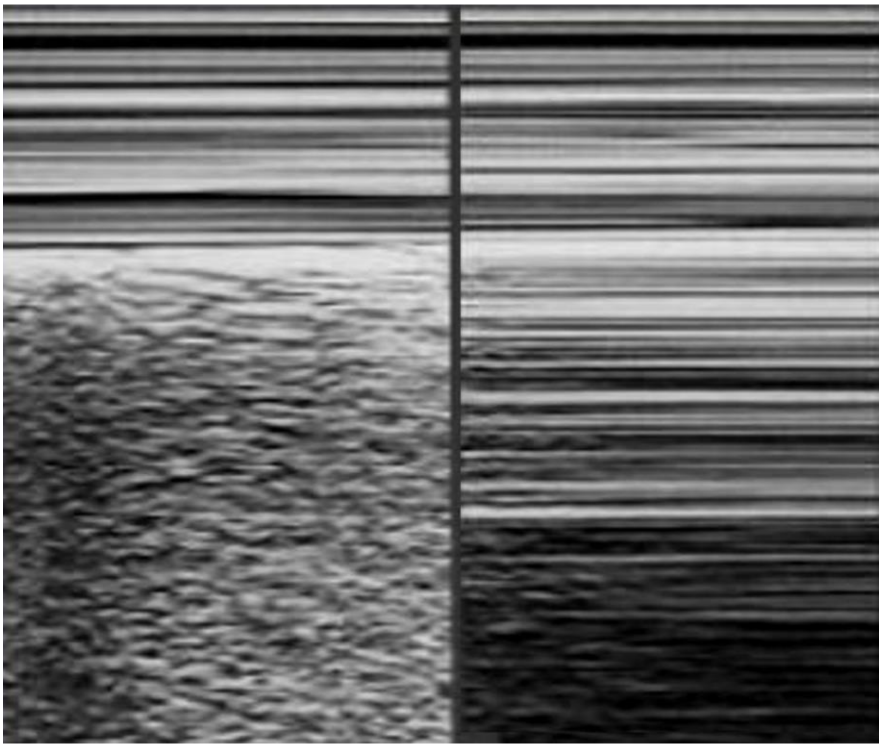


Fig. 20. Ultrasound diagnosis of pneumothorax in M-mode. On the left side of the echogram, the ultrasound symptom of the seashore (indicating a normal pleura) is registered, on the right side is the bar code symptom, which is formed at point M during inspiration and indicates the absence of sliding of the visceral pleura in the pneumothorax area.

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## Chupter 5.

### X-ray and ultrasound diagnostics of  pneumothorax

*Abdullaiev R.R.*

Combat injuries of the chest occupy a prominent place and often become the cause of mortality. X-ray and computer tomography play an important role in determining the localization and assessment of the nature of damage to the chest organs. Before the widespread introduction of imaging methods into clinical practice, the mortality rate for chest combat injuries exceeded 50% [Singleton J.A. et al., 2013]. Such a high mortality rate was due to the defeat of vital structures. in the chest, including the heart, lungs, and major vessels. Modern body armor can protect the body from high-speed (>300 m/s) shots [Yakovenko V.V. et al., 2020]. According to some researchers, mortality from general chest trauma is 8.6–16% [Durso A.M. et al., 2015; Edgecombe L. et al., 2022].

Pneumothorax is one of the most common causes of acute dyspnea. In patients under general anesthesia, the symptoms may not be obvious, which may delay diagnosis and treatment. Computed tomography is the gold standard for the diagnosis of pneumothorax, but is not suitable for rapid diagnosis of this complication. In contrast, lung ultrasonography can provide rapid diagnosis and treatment of pneumothorax [Zhang G.,  2021]. During the battle, potential penetrating wounds are transformed into blunt injuries thanks to the improved body armor [Lichtenberger J.P. et al., 2018; Klausner M.J. et al., 2021]. Pneumothorax is one of the most common complications of any chest injury and usually occurs in the emergency department with a frequency of 40–50% [Kong V.Y. et al. 2015]. Thoracic trauma alone accounts for approximately 25% of all trauma-related deaths, and of these cases, pneumothorax occurs in nearly 50% of patients [Tran J. et al. 2021].

Pneumothorax is recognized as the second most important cause of death on the battlefield after blood loss [Daurat A. et al. 2016].

Rapid and accurate diagnosis of the nature of pneumothorax in penetrating chest trauma is of particular importance in the early stages due to the urgency of the condition of the fighters. Chest radiography is a method of initial assessment of chest trauma, it allows identifying unexploded radiopaque fragments of ammunition, diagnosing tension pneumothorax, large hemothorax, determining the position of tubes during thoracotomy [Tataroglu O. et al., 2018]. Although plain chest radiography is the traditional method for assessing pneumothorax, some studies suggest low sensitivity of radiography in detecting intrapleural air in trauma patients, especially in the supine position [Abdulrahman Y. et al., 2015].

Chest computed tomography (CT) is the primary imaging modality for trauma assessment. CT can exclude imminent injuries in hemodynamically stable patients with suspected multiple injuries that are not detected by conventional radiography. One study showed that CT detected abnormalities not detected by conventional radiography in 71% of patients with blunt chest trauma. Of these patients, 37.5% required life-saving surgery [Langdorf MI. et al., 2015]. CT is superior in detecting pulmonary contusions, pneumothorax, rib fractures, and major vessel injuries, providing 38-81% additional diagnoses compared to chest radiography [Moussavi N. et al., 2015].

In recent years, chest ultrasonography has found its way into emergency and intensive care settings and is currently gaining momentum in the evaluation of acute emergencies, including pneumothorax. Numerous recent clinical studies have shown that pneumothorax can be diagnosed using ultrasound with high sensitivity and specificity [Soult M.C. et al., 2015]. Focused assessment with sonography in trauma (FAST) has been extensively utilized and studied in blunt and penetrating trauma [Richards JR. et al., 2017].

The results of radiography and ultrasonography were compared in 76 patients with tension pneumothorax resulting from blunt combat chest trauma. The diagnosis was established using multidetector computed tomography, which is considered the gold standard for chest examination. X-ray was performed in the anterior and lateral projections, with patients in vertical and horizontal positions. Ultrasonography was performed using a linear transducer in the frequency mode of 5-10 MHz, a convex transducer with a frequency of 2-5 MHz in B and M modes.

The pneumothorax was right-sided in 41 (53.9%) cases, and left-sided in 35 (46.1%) cases. Explosive trauma was the most frequent cause of pneumothorax and was noted in 59 (77.6%) cases. Rib fractures were recorded in 24 (31.6%) cases. Among the clinical symptoms observed in patients with pneumothorax, pain in the chest was noted more often - in 29 (38.2%) cases, then rapid heartbeat - in 25 (32.9%), rapid breathing - in 12 (15.8 %), hypotension with a blood pressure level of less than 90 mmHg. – in 6 (7.9%) cases, respectively.

X-ray of the chest was carried out in the sitting and horizontal position of the patients. When X-rays were performed with patients lying on their backs in the diagnosis of pneumothorax, the results of the method were true positive in 25 cases, false negative in 18 cases, true negative in 24 cases, and false positive in 9 cases. The sensitivity of the method was 58.1%, specificity - 72.7%, accuracy - 64.5%, positive predictive value - 73.5%, negative predictive value - 57.1%, respectively (Table 1).

**Table 1. X-ray results in the diagnosis of pneumothorax in the supine position of the patient.**

| Pneumothorax diagnosed by CT (n=76) | | | |
|---|---|---|---|
| Yes - 43 | | No – 33 | |
| TP | FN | TN | FP |
| 25 | 18 | 24 | 9 |
| Sensitivity | | 58,1% | |
| Specificity | | 72,7% | |
| Accuracy | | 64,5% | |
| Positive predictive value | | 73,5% | |
| Negative predictive value | | 57,1% | |

When X-rays were performed in the sitting position of patients in the diagnosis of pneumothorax, the results of the method were true positive in 41 cases, false-negative in 16 cases, true-negative in 17 cases, and false-positive in 2 cases. The sensitivity of the method was 71.9%, specificity - 89.5%, accuracy - 76.3%, positive predictive value - 95.3%, negative predictive value - 51.5%, respectively (Table 2).

**Table 2. X-ray results in the diagnosis of pneumothorax in the sitting position of the patient.**

| Pneumothorax diagnosed by CT (n=76) | | | |
|---|---|---|---|
| Yes - 43 | | No – 33 | |
| TP | FN | TN | FP |
| 41 | 16 | 17 | 2 |
| Sensitivity | | 71,9% | |
| Specificity | | 89,5% | |
| Accuracy | | 76,3% | |
| Positive predictive value | | 95,3% | |
| Negative predictive value | | 51,5% | |

On X-ray, moderate to extensive pneumothorax is determined by the appearance of a vertical thin line, which is formed by eliminating the visceral edge of the pleura (Fig. 1, 2).

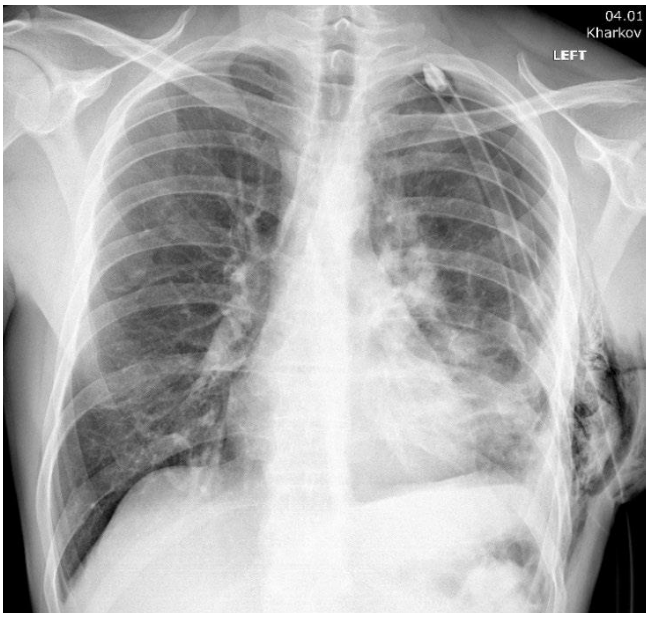


Fig. 1. X-ray examination: a bruise of the left lung of the I degree, a pneumothorax of the I degree, local emphysema of soft tissues in the axillary region is determined.

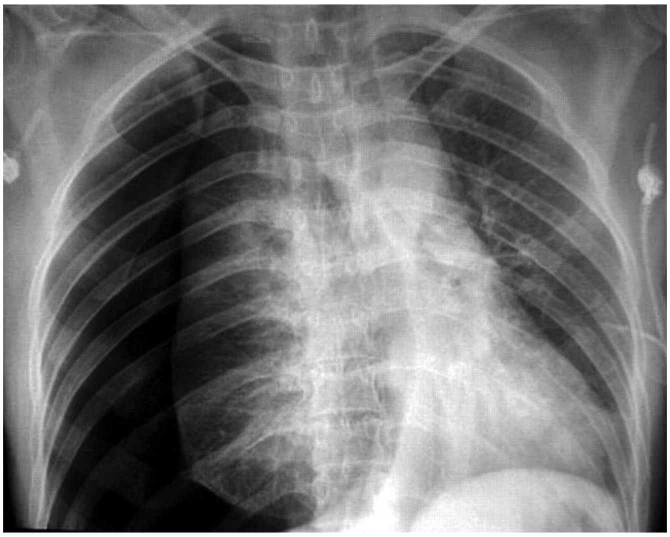

Fig. 2. Chest X-ray, anterior projection. A right-sided large pneumothorax is determined by the appearance of a vertical line corresponding to the image of the visceral pleura pushed back due to pneumothorax.

Ultrasound diagnosis of pneumothorax was carried out using linear or convex sensors in B and M modes. Preference is given to the patient's sitting position with the arm raised above the head on the side of the pneumothorax, which allows for the expansion of the intercostal space. In patients in serious condition, the examination is performed in the supine position or on the side opposite to the pneumothorax.

The examination is performed in the longitudinal and transverse positions of the sensor. In the longitudinal position of the sensor, the image of the pleura is limited by the ribs. In the absence of pneumothorax, the visceral pleura shifts (slides) in the caudal direction during inhalation and a fine-point image is formed on the screen, which is called the "beach sign". Diagnosis of pneumothorax is based on the detection of the "barcode" ("parallel lines sign") symptom, which is formed by the absence of sliding of the visceral pleura during the patient's inhalation. The appearance of this symptom is based on the reverberation effect.

**Table 3. Ultrasound results in the diagnosis of pneumothorax in B-mode**

| Pneumothorax diagnosed by CT (n=76) | | | |
|---|---|---|---|
| Yes - 65 | | No – 11 | |
| TP | FN | TN | FP |
| 59 | 6 | 9 | 2 |
| Sensitivity | | 90,8% | |
| Specificity | | 81,8% | |
| Accuracy | | 89,5% | |
| Positive predictive value | | 96,7% | |
| Negative predictive value | | 60,0% | |

With B-mode ultrasonography in the diagnosis of pneumothorax, the results of the method were true positive in 59 cases, fals-negative in 6 cases, true-negative in 9 cases, and fals-positive in 2 cases. The sensitivity of the method was 90.8%, specificity – 81.8%, accuracy – 89.5%, positive value transfer – 96.7%, negative transfer value – 60.0%, consistent (Table 3).

The combined use of B and M modes of ultrasonography contributed to the improvement of the diagnostic indicators of the method. In 63 cases, the US results were true positive, in 4 cases false negative, in 8 cases true negative, in 1 case false positive. The sensitivity of US was 94.0%, specificity - 88.9%, accuracy - 93.4%, positive expected value - 98.4%, negative expected value - 66.7%, respectively (Table 4). In the B-mode, the absence of comet tail artifacts, the so-called B-lines, is determined. In the M-mode, the "barcode" symptom is recorded (Fig. 3).

**Table 4. Ultrasound results in the diagnosis of pneumothorax in B+M modes.**

| Pneumothorax diagnosed by CT (n=76) | | | |
|---|---|---|---|
| Yes - 65 | | No – 11 | |
| TP | FN | TP | FN |
| 63 | 4 | 8 | 1 |
| Sensitivity | | 94,0% | |
| Specificity | | 88,9% | |
| Accuracy | | 93,4% | |
| Positive predictive value | | 98,4% | |
| Negative predictive value | | 66,7% | |

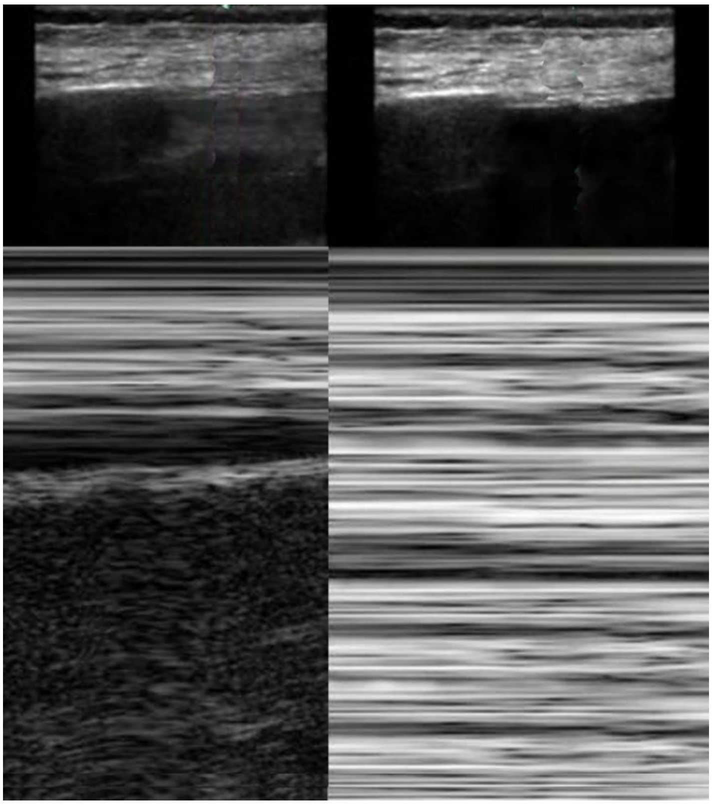

Fig. 3. On the left side of the echogram in B and M modes, the "beach sign" symptom is determined, indicating a normal pleura, on the right side - the "barcode" symptom, which is formed at point M during inhalation and indicates the absence of sliding of the visceral pleura in the zone pneumothorax.

Small pneumothorax becomes less visible on chest X-ray in the supine position, since free air rises to the anterior chest wall, the area increases, and the degree of separation of the parietal and visceral pleura decreases significantly, thereby making their demarcation clearer. This makes the X-ray results questionable. In this case, polypositional ultrasonography can detect a small pneumothorax (Fig. 4, 5).

Fig. 4. On the digital X-ray, it is noted on the left in the 3-4 intercostal space, darkening without a clear contour of increased intensity is determined. In the lower third of the lung on the left, parasternally, the absence of a pulmonary pattern with increased pneumatization and unclear visualization of the visceral pleura is determined. On the left, a fracture of the lateral sections of the 5-8 ribs. On the left, along the entire length, a shadow from the drainage is noted tubes.

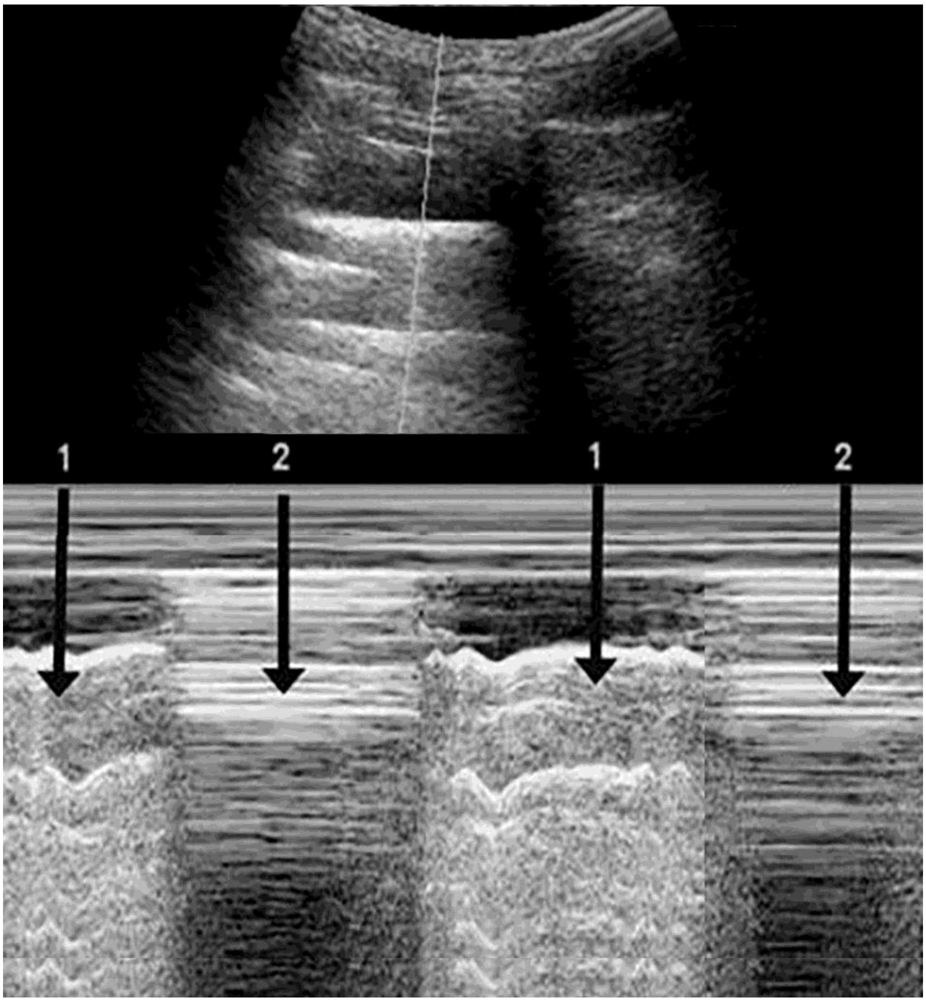


Fig. 5. Combined B and M mode. At the border of the normal part of the lung (1) and pneumothorax (2), the "beach sign" symptom (1) is determined, which alternates with the “bar code” symptom (2) as the patient inhales.

In 32 (42.1%) cases, pneumothorax was assessed as extensive, since radiographically the visceral line on the side of the pneumothorax was displaced up to the midclavicular line. In 30 cases, the radiography results were true positive, in 1 case false negative, in 1 case true negative. The sensitivity of radiography was 96.8%, specificity was 100.0%, accuracy was 96.9%, positive predicted value was 100.0%, and negative predicted value was 50.0%, respectively. In 29 cases, the results of USG were true positive, in 1 case false negative, in 2 cases – true negative. The sensitivity of USG was 96.7%, specificity – 100.0%, accuracy – 96.9%, positive expected value – 100.0%, negative expected value – 66.7%, respectively (Table 5).

**Table 5. Results of X-ray and ultrasound in diagnosis of large pneumothorax**

| Large pneumothorax diagnosed by CT (n=32) | | | | | | | |
|---|---|---|---|---|---|---|---|
| X-ray | | | | US (B + M mode) | | | |
| Yes | | No | | Yes | | No | |
| 31 | | 1 | | 30 | | 2 | |
| TP | FN | TP | FN | TP | FN | TP | FN |
| 30 | 1 | 1 | 0 | 29 | 1 | 2 | 0 |
| Sensitivity | | 96,8% | | Sensitivity | | 96,7% | |
| Specificity | | 100,0% | | Specificity | | 100,0% | |
| Accuracy | | 96,9% | | Accuracy | | 96,9% | |
| Positive predictive value | | 100,0% | | Positive predictive value | | 100,0% | |
| Negative predictive value | | 50,0% | | Negative predictive value | | 66,7% | |

Pneumothorax can be suspected and diagnosed based on a combination of physical examination findings. The most common clinical symptoms are chest pain and a creaking sound, usually caused by a rib fracture, shortness of breath, and increased heart rate [Ekpe EE., 2016]. Tympanic sound may be recorded over the pneumothorax upon percussion. It should be noted that physical examination methods have low sensitivity and specificity in diagnosing pneumothorax. In penetrating trauma, the presence of pneumothorax can be assumed based on the appearance of pulmonary dysfunction with rapid progression to respiratory arrest and hypotension against the background of penetrating injury [Roberts D.J. et al., 2015].

Sabri Y.Y. et al. (2018) analyzed the ultrasound results of 28 patients in whom pneumothorax was diagnosed by CT. According to the authors, the sensitivity of ultrasound was 60.71%, the specificity was 97.47%; accuracy – 88%, positive predictive value – 89.47%, negative predictive value – 87.50%, respectively [Sabri Y.Y. et al., 2018].

Abdalla W. et al. (2016) conducted a comparative analysis of the results of ultrasound and radiography in 36 patients in whom pneumothorax was diagnosed using CT, which is considered the gold standard for the diagnosis of chest pathologies. According to the authors, the sensitivity of ultrasound was 86.1%, radiography - 52.7%, specificity - 97.4% and 99.4%; accuracy – 95.3% and 90.1% [Abdalla W. et al., 2016].

In the diagnosis of pneumothorax, when comparing the results of ultrasound and radiography, Attia Y.Z. et al. (2023) obtained opposite data. The sensitivity of ultrasound was 100.0%, specificity - 13.3%, accuracy - 48.0%, and radiography, on the contrary - 15.0%, 93.3% and 62.0%, respectively [Attia Y.Z. et al., 2023]. When using only B-mode, according to data of Grechanik O.I. and Abdullaiev R.R. (2024) , the sensitivity of ultrasound was 90.8%, specificity 81.8%, accuracy 89.5% [Grechanik O.I., Abdullaiev R.R. et al., 2024].

Avila J. et al. (2018) compared the results of B+M modes with B-mode. The authors found that combinations of the two modes compared with B-mode had the following diagnostic indicators: sensitivity of 93.1% and 93.2%, specificity of 96.0% and 89.8%, and accuracy of 91.5% and 94.5%, respectively. According to the authors, the sensitivity of the methods did not change, and the specificity of the two modes compared with one mode improved by 6%, and the accuracy decreased by 3% [Avila J. et al., 2018]. According to Grechanik O.I., Abdullaiev R.R. et al. (2024), with the combined use of B and M modes, the sensitivity of ultrasound in the diagnosis of pneumothorax improved by 3.2%, specificity - by 7.1%, accuracy 3.9%, respectively [Grechanik O.I., Abdullaiev R.R. et al., 2024].

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## **Chapter 6**.

## Imaging of damage to large abdominal arteries in combat injuries.

*Tsymbaliuk V.I., Lazoryshynets V.V., Usenko O.Y.,*

*Lurin I.A., Abdullaiev R.Ya. .*

Gunshot wounds are the second most common cause of traumatic injuries leading to death [Naghavi M. et al., 2018]. The mechanisms of vascular injury in polytrauma can be blunt, penetrating, or combined [Ntola V.C., et al., 2023]. Vascular injuries in modern armed conflicts occur five times more often than in previous wars. According to American surgeons, the incidence of vascular injury during the Iraq War was 12%, which was 1-3% higher than during the Korean and Vietnam Wars [Cannon J. W. et al., 2020]. Victims with injuries to the vessels of the chest and neck often die from blood loss and shock in the coming hours. With injuries to the vessels of the abdominal cavity, the survival rate is comparatively higher [Grechanyk O.I. et al., 202].

The determining factor for the successful outcome of surgical treatment is the timely evacuation of the wounded to specialized vascular departments, and this should be preceded by high-quality and rational radiological diagnostics. It is one of the complex areas of modern military surgery and angiology in combat injuries to the main vessels [Barnard E.B.G. et al., 2015].

Ultrasound examination of the abdomen, pelvis, FAST protocol allows to accurately determine clinically significant intra-abdominal bleeding in patients with severe pelvic fractures [Dammers D. et al., 2017]. Previously published works have shown the clinical use of ultrasound to identify injuries to the abdominal aorta and its large branches, to perform ultrasound-guided catheterization, as well as to assess hemodynamic parameters, angioarchitecture of internal organs in case of injuries [Navsaria P.H. et al., 2015; Penn-Barwell J. G. et al., 2015; Abdullaiev R.Ya. et al., 2022].

Experience with the results of radiographic examinations of wounded patients who died as a result of blood loss and shock in NATO hospitals has shown their low diagnostic efficiency. Currently, among the numerous imaging methods, the most effective with high throughput is computed tomography with contrast. [Mabbott A. et al., 2020; Dreizin D. et al., 2015].

In combat injuries of internal organs and vessels, damage by explosive fragments or bone fragments causes bleeding, hemorrhage in the abdominal cavity and the risk of fragment embolization, which has an unfavorable prognosis. For this reason, contrast-enhanced CT is the "gold standard" for identifying emboli and vascular injury [Pinto A. and Romano L., 2016]. Due to the detailed interpretation of the most common vascular injuries, multidetector contrast-enhanced CT is an invaluable method for assessing the severity of injury [Gopireddy D.R. et al., 2023].

In the visual assessment of vascular injury to the abdominal cavity and pelvis, the effectiveness of emergency ultrasound has been proven in blunt abdominal trauma, but the role of the FAST protocol in penetrating abdominal and pelvic trauma is controversial [Richards J.R. et al., 2017].

The analysis of ultrasound results in diagnostics of damages of large arterial vessels of the abdominal cavity in 43 wounded during combat operations diagnosed by CT contrast was performed. The types of vascular damages were established on the basis of CT angiography results, which is currently the main method of assessing the condition of the vessels of the abdominal organs. The presence and type of damage to large abdominal vessels was determined based on CT with contrast. In this case, damage to parenchymatous and hollow organs was simultaneously determined, and fragments were visualized (Fig. 1).

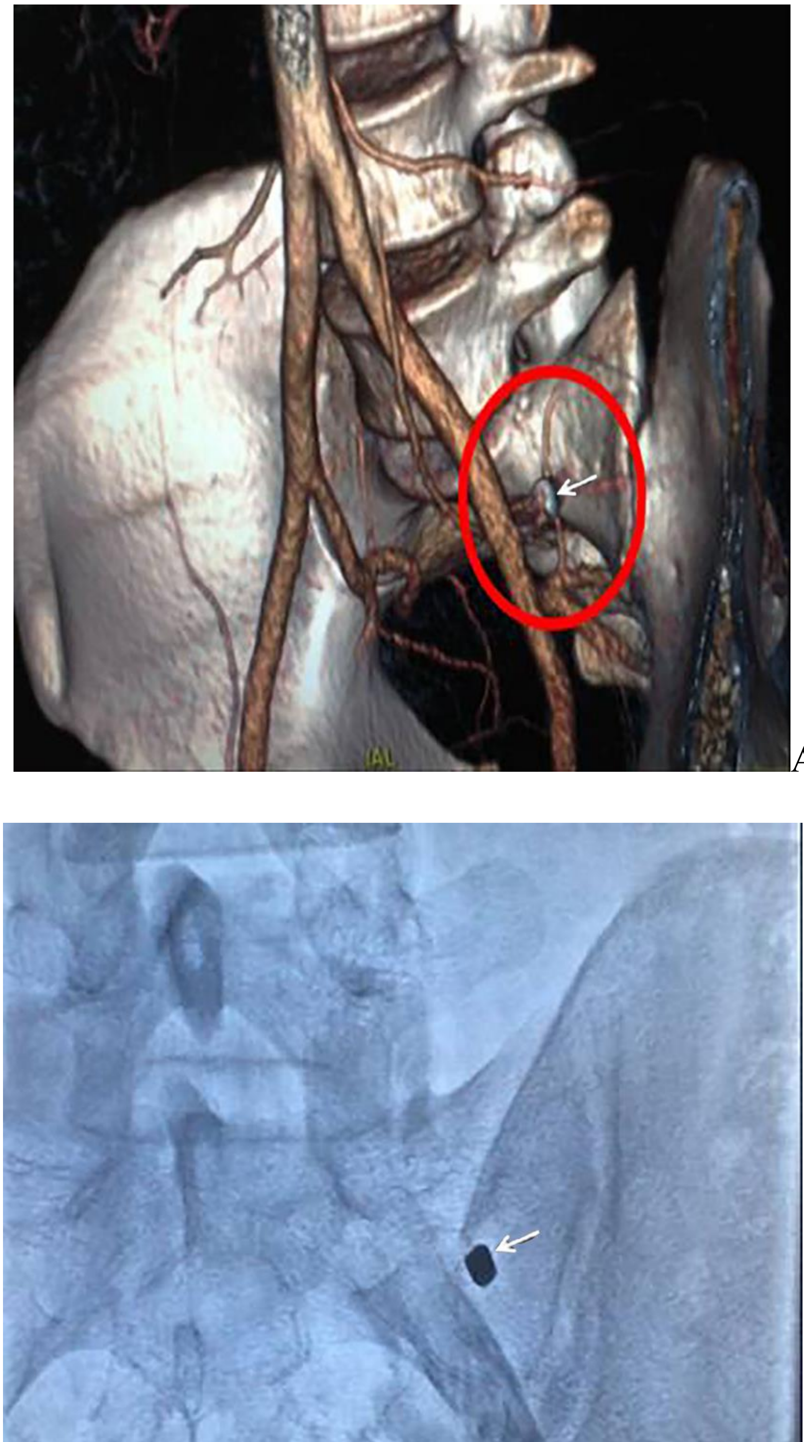



Fig. 1. Penetrating gunshot wound to the abdomen, CT angiography (A) and X-ray angiography (B) demonstrate a metallic fragment (arrow) at the bifurcation of the left common iliac vein.

As can be seen from Table 1, according to the results of CT with contrast, aortic damage was recorded in 29 cases (67.4±7.1%), renal arteries – in 6 cases (14.0±5.3%), iliac arteries – in 8 cases (18.6±5.9%). The following types of damage were identified: intimal flap, dissection, pseudoaneurysm formation. In CT, among all 43 cases, intimal flap was recorded in 8 cases (18.6±5.9%), dissection – in 16 cases (37.2±7.4%), pseudoaneurysm – in 19 cases (44.2±7.6%), respectively. As can be seen from the table, intimal flap was registered significantly less frequently than dissection ($P<0.05$) and pseudoaneurysm ($P<0.01$). In addition, damage to the abdominal aorta was registered significantly more frequently than renal ($P^{*}<0.001$) and iliac ($P^{**}<0.001$) arteries.

**Table 1.** Types of combat injuries to the abdominal aorta, renal and iliac arteries in combat trauma.

| Major abdominal arteries | Type of Injury | | | Total |
|---|---|---|---|---|
| | Intimal flap | Dissection | Pseudoaneurysm | |
| Abdominal aorta | 6 (14,0±5,3%) | 9 (20,9±6,2%) | 14 (32,6±7,1%) P<0,05 | 29 (67,4±7,1%) $P^{*}<0,001$ $P^{**}<0,001$ |
| Renal artery | 1 (2,3±2,3%) | 3 (7,0±3,9%) | 2 (4,6±3,2%) | 6 (14,0±5,3%) |
| Iliac artery | 1 (2,3±2,3%) | 4 (9,3±4,4%) | 3 (7,0±3,9%) | 8 (18,6±5,9%) |
| Total | 8 (18,6±5,9%) | 16 (37,2±7,4%) P<0,05 | 19 (44,2±7,6%) P<0,01 | 43 |

**Note:** US: Ultrasound, CT: Computed tomography; P – comparison with intimal flap; $P^{*}$ - comparison of abdominal aorta with renal arteries; $P^{**}$ - comparison of abdominal aorta with iliac arteries.

Table 2 presents the results of USG in diagnostics of damages of large abdominal arteries, which were revealed by CT with contrast. In 38 cases the results of USG were true positive (TP), in 4 cases false negative (FN), in 3 cases true negative (TN), in 2 cases false positive (FP). The sensitivity of USG was 89.5%, specificity - 60.0%, accuracy - 86.0%, respectively (Tab.2).

**Table 2. Results of USG in diagnosing injuries of large abdominal vessels.**

| Trauma of major abdominal arterial vessels diagnosed by contrast-enhanced CT (n=43) | | | |
|---|---|---|---|
| Yes | | No | |
| 38 | | 5 | |
| TP | FN | TN | FP |
| 34 | 4 | 3 | 2 |
| Sensitivity | | 89,5% | |
| Specificity | | 60,0% | |
| Accuracy | | 86,0% | |

**Note:** TP – true positive, FN – false negative, TN – true negative, FP – false positive.

The diagnosis of arterial damage by the intimal flap type was based on the visualization of a thin hyperechoic linear structure floating (dangling) with its distal end in the lumen of the vessel. It can cause turbulence or uneven flow in color Doppler examination, as well as thrombosis in the form of a hyperechoic mass in the lumen of the vessel with the absence of color signals (Fig. 2).

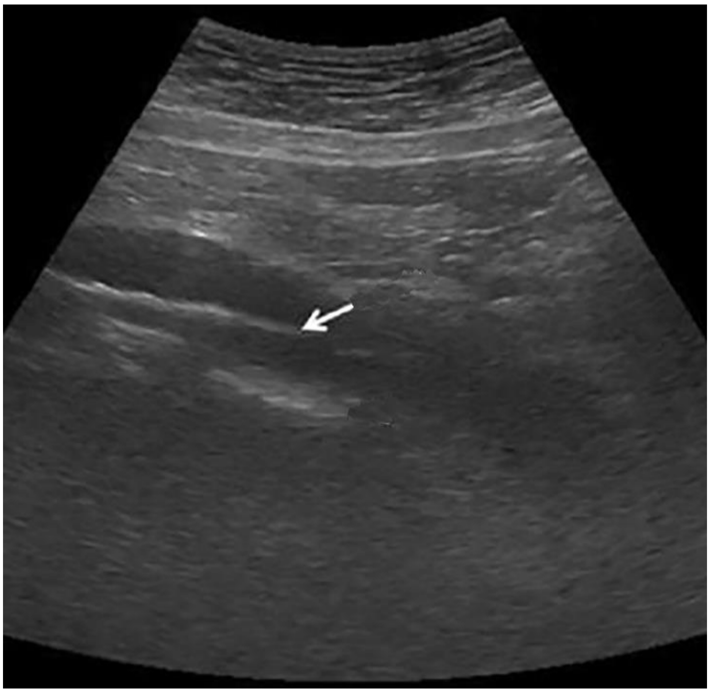


Fig. 2. Echogram of the abdominal aorta in a patient with combat trauma. The arrow shows the intimal flap – the distal segment of the torn intima.

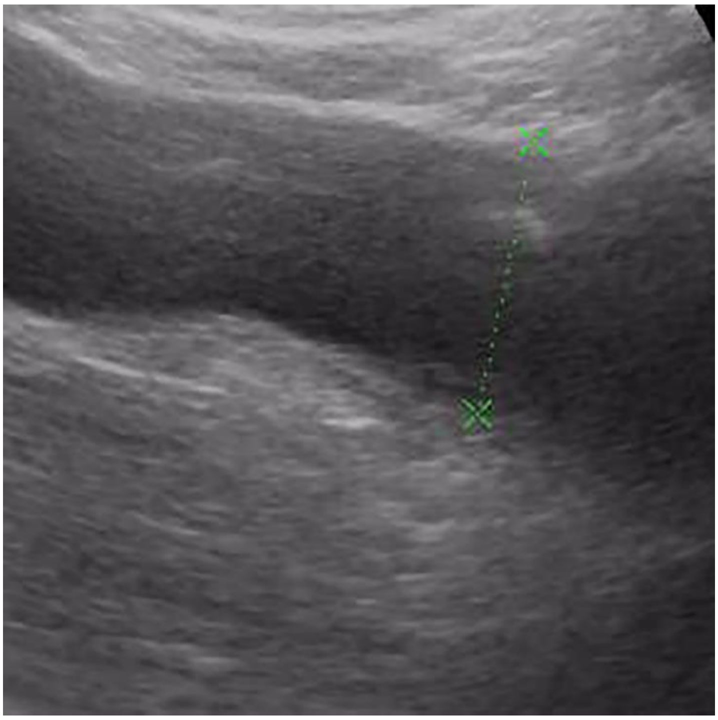
Table 3 presents the results of USG in diagnostics of abdominal aortic injuries, which were revealed by CT with contrast. In 25 cases the results of USG were true positive (TP), in 1 case false negative (FN), in 2 cases true negative (TN), in 1 case false positive (FP). The sensitivity of USG was 96.2%, specificity - 65.7%, accuracy - 93.1%, respectively (Table 3).

**Table 3. Results of USG in diagnosing injuries of abdominal aorta.**

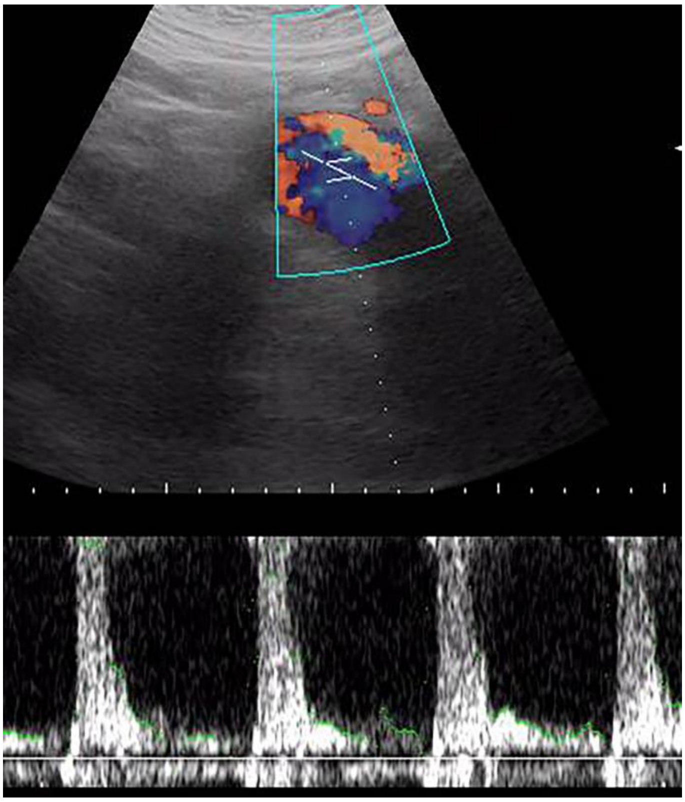
| Trauma of abdominal aorta diagnosed by contrast-enhanced CT (n=29) | | | |
|---|---|---|---|
| Yes | | NO | |
| 26 | | 3 | |
| TP | FN | TN | FP |
| 25 | 1 | 2 | 1 |
| Sensitivity | | 96,2% | |
| Specificity | | 66,7% | |
| Accuracy | | 93,1% | |

Note: TP – true positive, FN – false negative, TN – true negative, FP – false positive.

Dissection of the arterial wall is determined by ultrasonography as a hyperechoic mobile segment of the intima, dividing the vessel into true and false lumens. The true lumen expands during the systolic phase and contracts during the diastolic phase of blood flow. The false lumen, on the contrary, decreases during systole and expands during diastole. The blood flow velocity in the true lumen is higher than in the false lumen (Fig. 3).



A



B

Fig. 3. Echogram of the abdominal aorta in a patient with a combat injury. A – in B mode, dissection of the anterior wall of the aorta is determined. B – in triplex mode, the false channel of the abdominal aorta is colored red, the true channel is colored blue. The control volume is located in the true channel and three-phase blood flow is recorded.

Pseudoaneurysm is defined by B-mode ultrasonography as a localized bulge without involvement of the inner layer of the vessel wall. In color Doppler mode, vortex motion of the wall can be observed during systole (Fig. 4).

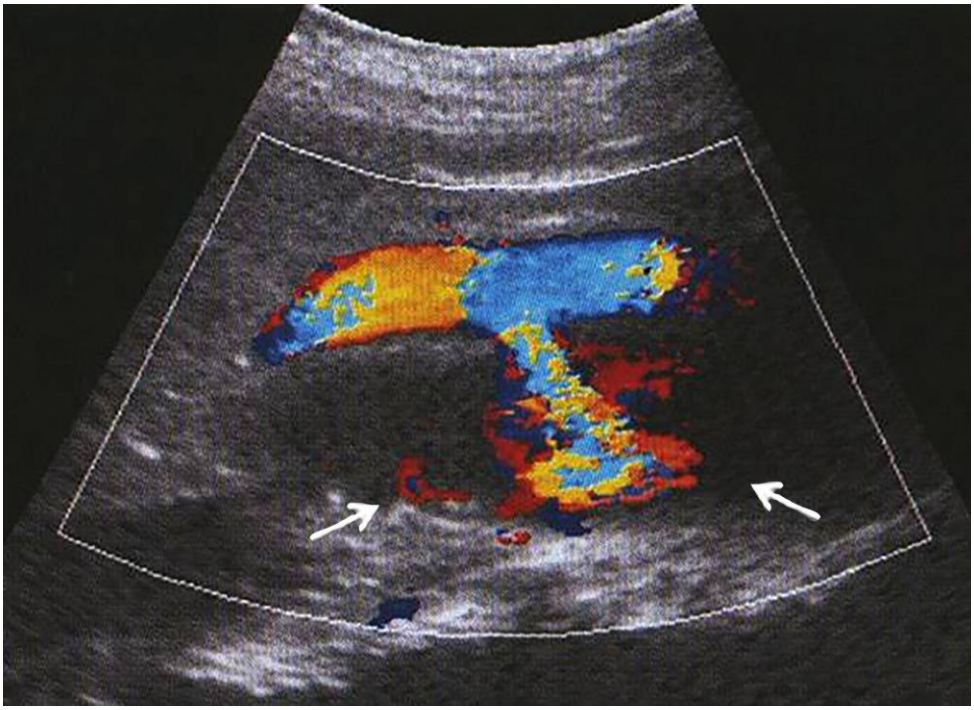


Fig. 4. Large pseudoaneurysm of the posterior wall of the abdominal aorta (arrows). Blood enters the false channel through the intimal defect and bulges the posterior wall of the aorta.

**Table 4. Results of USG in diagnosing injuries of renal and iliac arteries.**

| Renal and iliac artery injury diagnosed by CT (n=14) | | | |
|---|---|---|---|
| Yes | | No | |
| 12 | | 2 | |
| TP | FN | TN | FP |
| 9 | 3 | 1 | 1 |
| Sensitivity | | 75,0% | |
| Specificity | | 50,0% | |
| Accuracy | | 71,4% | |

**Note:** TP – true positive, FN – false negative, TN – true negative, FP – false positive.

Table 4 presents the results of USG in diagnostics of injuries of the branches of the abdominal aorta – renal and iliac arteries. In 9 cases the results of USG were true positive (TP), in 3 cases false negative (FN), in 1 case – true negative (TN), in 1 case – false positive (FP). The sensitivity of USG was 75.0%, specificity –50.0%, accuracy – 71.4%, respectively (Tab/4).

Gunshot wounds are the second most common cause of fatal traumatic injuries. In modern warfare, a significant proportion of large vessel damage occurs due to shrapnel and blast wounds [Naeem M. et al. 2021]. In the vast majority of cases, damage to the abdominal aorta occurs due to penetrating trauma. In blunt trauma, the incidence of aortic injury does not exceed 1%. The close proximity of the abdominal aorta increases the risk of its damage during fractures of the lumbar vertebral bodies. Most often, with traumatic injury to the abdominal aorta, the infrarenal (67%) and adrenal (33%) sections are affected. In 25% of cases, damage to the thoracic aorta extends to the lower thoracic region [Wu Q. et al. 2021].

Currently, CT with contrast is the main method of non-invasive diagnostics of injuries to abdominal organs, large trunk and visceral vessels [Speelman E. S. et al., 2020]. The effectiveness of ultrasound using the FAST protocol is a generally recognized method for the primary diagnosis of free blood in the abdominal cavity as a result of rupture of internal organs. We studied the possibility of the method in diagnosing injuries to large vessels of the abdominal cavity. As is known, in case of injuries to arterial vessels, the following types of changes are distinguished: rupture of the intima with the appearance of a flap, dissection with the formation of an intramural hematoma, rupture with a transverse incision and the formation of an arteriovenous fistula [Tsai R. et al., 2018].

Ultrasonography using Doppler modes allows visualization of the vessel lumen and recording numerous flow parameters in different phases of the cardiac cycle [Abdullaiev R.Ya. et al. 2023]. Among the various types of vascular wall damage, intimal rupture with flap formation is very rare [Usman R. et al., 2019]. The results of our studies showed that dissection of wall layers and pseudoaneurysms in combat trauma were significantly more common than intimal flap formation. In addition, aortic injuries were also recorded significantly more often than renal and iliac arteries.

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## Chapter 7.

Imaging of damage to abdominal organs in combat injuries.

*Usenko O.Y., Lurin I.A., Abdullaiev R.Ya., Grechanik E.İ., Korol S.A.*

Gunshot wounds to the abdomen are difficult to choose an adequate surgical tactic. They also create certain difficulties for the effectiveness of diagnostic methods of medical imaging [Zarutskyi Ya L. et al., 2018; Herasymenko O.S., 2021; Janak C. J. et al., 2019]. Gunshot wounds to the abdomen are characterized by the development of combined functional disorders and various complications, which lead to increased mortality [Ministrini S. et al., 2015]. The results of treatment of gunshot wounds of the abdomen closely correlate with the timing of the start of surgical care, its quality, the timing and type of medical evacuation from different levels of medical care and the ability of forces and means to provide medical care [Ball C.G., 2014].

In the diagnosis of gunshot wounds to the abdomen, medical imaging methods are of great importance, including ultrasound, digital radiography, and multidetector computed tomography. These methods allow us to assess the nature of the damage, its localization, which makes it possible to refuse unnecessary laparotomy and conduct dynamic observation [Cazes N. et al., 2013].

Minimally invasive interventions under ultrasound navigation control are actively used in the diagnosis of gunshot wounds to the abdomen. Gunshot wounds to the abdomen are often combined with chest wounds, and thoracoabdominal wounds account for about 5% of all wounds, while the mortality rate fluctuates between 28-31%. The use of videothoracoscopy and laser visualization increases the efficiency of diaphragm gunshot wound diagnosis. In this category of victims, the use of the FAST protocol (Focused Assessment with Sonography for Trauma) has reduced the duration of preoperative diagnostics and reduced the number of diagnostic errors. FAST protocols allow for rapid triage of the wounded to select tactics for further highly qualified diagnostics using more expensive methods in a clinical setting [Savatmongkorngul S. et al., 2017; Ianniello S. et al., 2014; Wongwaisayawan S. et al., 2016; Richards JR. et al., 2017; Mohammad A. et al., 2014]

The use of FAST protocols is particularly effective in the evaluation of blunt abdominal trauma, and its role in penetrating trauma is somewhat limited. Multidetector computed tomography (MDCT) is considered the best imaging method for the evaluation of penetrating abdominal trauma in hemodynamically stable patients. However, FAST remains the preferred imaging method in the study of hemodynamically unstable patients [Janak C. J. et al., 2019]. In recent publications, the authors highlighted the role of laparoscopy in the surgical treatment of gunshot wounds, especially in cases where the clinical picture is unclear and there are no signs of damage to a hollow or parenchymal organ according to radiological examination methods [Navsaria P. H. et al., 2015; Di Saverio S. et al., 2015].

Due to its high sensitivity, specificity in determining the trajectory of wound channels, localization and severity of damage to parenchymatous and hollow organs, detection of foreign bodies, hemorrhages, MDCT plays an important role in sorting and choosing the tactics of treating the wounded. In general, MDCT allows identifying more than 50% of injuries to the head, neck, chest, abdomen, pelvis, which cannot be provided by other methods of medical imaging [Cardi M. et al., 2019].

IIn addition to clinical assessment of the severity of the wound in the context of trauma, it is necessary to improve medical imaging methods, since the complexity of diagnosis is due to the large number of combined and multiple injuries. Given the multifactorial nature of gunshot wounds to the abdomen, when performing MDCT, it is necessary to scan the head, spinal cord, chest and pelvis, and, if necessary, perform a study with contrast enhancement [Saher S. et al., 2016].

The results of a comprehensive study of 65 wounded patients with complex combat injuries to the abdomen in combination with other body parts were analyzed. All patients underwent X-ray, ultrasonography, and MSCT. The mechanism of injury and the nature of the wound channel were taken into account when analyzing the results. According to the mechanism of injury, 17 (26.2±5.4%) of the patients had bullet injuries, 29 (44.6±6.2%) had shrapnel injuries, and 19 (29.2±5.6%) had explosive injuries (Table 1). Shrapnel wounds were statistically significantly more common than bullet wounds.

Table 1. Distribution of patients by injury mechanism

| Bullet wounds | Shrapnel wounds | Blast wounds |
|---|---|---|
| 17 | 29 | 19 |
| 26,2 ± 5,4% | 44,6 ± 6,2%<br>$P<0,05$ | 29,2 ± 5,6% |

The wound channel in 23 (35.4±5.9%) patients was through, blind in 24 (36.9±5.8%), and combined in 18 (27.7±5.6%) patients (Table 2). No significant differences were found between the frequency of occurrence of different types of wound channel.

Table 2. Distribution of patients by the nature of the wound channel

| Through wound channel | Blind wound channel | Combined wound channel |
|---|---|---|
| 23 | 24 | 18 |
| 35,4 ± 5,9% | 36,9 ± 5,8% | 27,7 ± 5,6% |

Table 3 presents the data on the frequency of abdominal organ injuries taking into account the trauma factor. There were 104 internal organ injuries in total: 32 of them were bullet injuries (30.8±4.5%), 43 were shrapnel injuries (41.3±4.8%), and 29 were explosive injuries (27.9±4.4%). The number of small intestine injuries in all types of injuries was the greatest, amounting to 43 (41.3±4.8%): of these, 11 were bullet injuries (10.6±3.0%), 18 were shrapnel injuries (17.3±3.7%), and 14 were explosive injuries (13.5±3.4%). The next place in terms of the number of injuries was occupied by the large intestine, with 28 (26.9±4.3%) cases. The greatest number of large intestine injuries were shrapnel injuries, with 12 (11.5±3.1%) cases.

Table 3. Distribution of abdominal organ injuries by mechanism of injury.

| Localization | | Bullet wounds | Shrapnel wounds | Blast wounds | Total |
|---|---|---|---|---|---|
| 1 | Small intestine | 11 (10,6± 3,0%) | 18 (17,3± 3,7%) | 14 (13,5± 3,4%) | 43 (41,3 ± 4,8%) P 1-2<0,05 P 1-3<0,001 |
| 2 | Large intestine | 7 (6,7± 2,5%) | 12 (11,5± 3,1%) | 9 (8,7± 2,8%) | 28 (26,9 ± 4,3%) P 2-3<0,01 P 2-4<0,01 P 2-5<0,001 |
| 3 | Liver | 5 (4,8± 2,1%) | 5 (4,8± 2,1%) | 3 (2,9± 1,6%) | 13 (12,5 ± 3,2%) P 3-6<0,05 |
| 4 | Stomach | 4 (3,8± 1,9%) | 4 (3,8± 1,9%) | 1 (1,0± 1,0%) | 9 (8,7 ± 2,8%) P 4-7<0,05 |
| 5 | Kidneys | 2 (1,9± 1,3%) | 1 (1,0± 1,0%) | 1 (1,0± 1,0%) | 5 (4,8 ± 2,1%) |
| 6 | Spleen | 2 (1,9± 1,9%) | 2 (1,9± 1,9%) | 1 (1,0± 1,0%) | 4 (3,8 ± 1,9%) |
| 7 | Bladder | 1 (1,0± 1,0%) | 1 (1,0± 1,0%) | - | 2 (1,9 ± 1,3%) |
| | Total | 32 (30,8±4,5%) | 43 (41,3±4,8%) | 29 (27,9 ± 4,4%) | 104 |

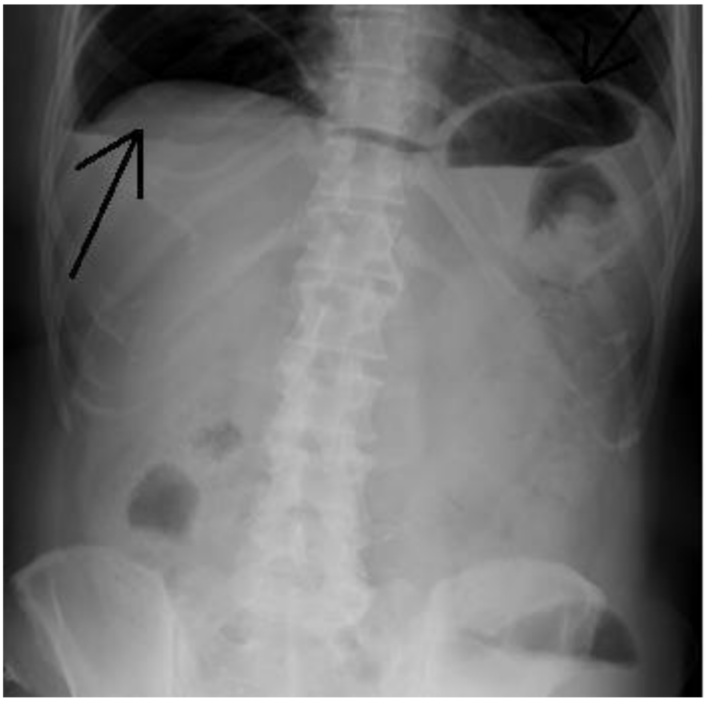
Small intestine injuries were registered significantly (P<0.05) more often than large intestine injuries (41.3±4.8% versus 26.9±4.3%). In both groups, no significant differences were found either within individual injury factors or between each other. Gunshot wounds to the liver were observed in 13 (12.5±3.2%), stomach – in 9 (8.7±2.8%), kidneys – in 5 (4.8±2.1%), spleen – in 4 (3.8±1.9%), and bladder – in 2 (1.9±1.3%) cases, respectively. Liver injuries were significantly more common than spleen and bladder injuries (P<0.05), and stomach injuries were more common than bladder injuries (P<0.05).

Indirect signs of damage to the abdominal organs were the appearance of free gas and fluid in the abdominal cavity and retroperitoneal space . In the first hours of injury in wounded with damage to the abdominal organs, the absence of free gas or fluid in the abdominal cavity and retroperitoneal space did not exclude their damage. Free gas can enter the abdomen cavity and retroperitoneal space either from a damaged hollow organ or through an entrance/exit wound opening. Like any gas, it always accumulates in the highest parts of the abdominal cavity (relative to the position of the body). X-ray can carry out studies in the vertical position of the injured or in the position on the right or left side - there is enough space for the gas to "accumulate" and manifest itself. During the CT examination, only the supine position is possible. In this position, the gas is determined under the front abdominal wall — between it and the intestinal loops with the greatest accumulation in the navel area. In addition, gas in the form of individual bubbles can be visualized in the retroperitoneal space - in the case of injuries of the duodenum, ascending and descending colon, in the mesentery of the small, transverse colon and sigmoid colon.

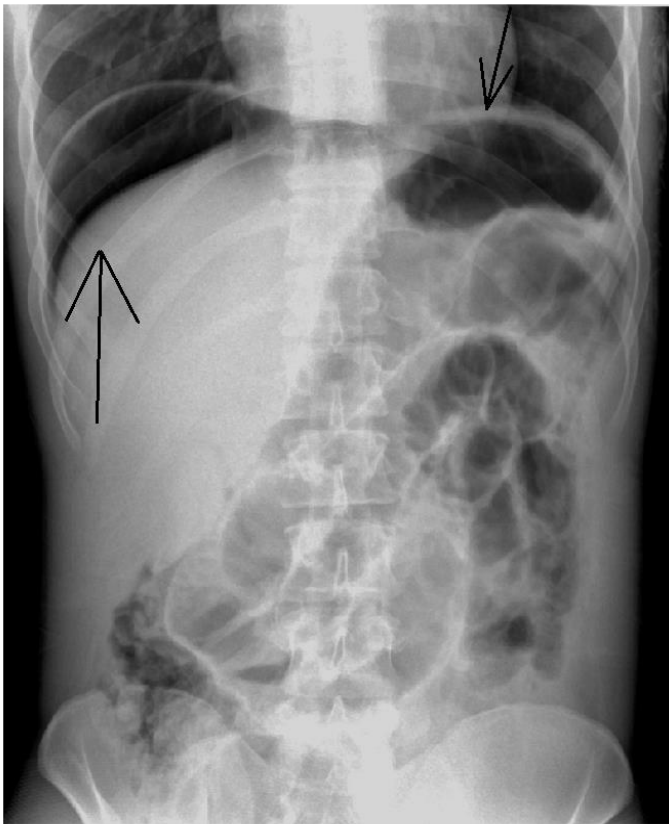
The amount of free gas does not always indicate the severity of damage to the hollow organ or the size of the defect in its wall. There are several main points: filling the organ with gas at the time of injury, closing the hole with a blood clot,  a nearby loop of intestine, etc. In the same way, the largest accumulation of gas that is detected does not indicate the place of damage (excluding partially located retroperitoneal sections of the intestine) - the gas tends upwards from its source (Fig. 1-11).

Fig. 1. Gunshot shrapnel blind penetrating wound of the abdomen with damage to the mesentery of the small intestine. X-ray shows free gas is detected in the subhepatic space.

Fig. 2. Gunshot wound to the abdomen with damage to the right side of the liver. X-ray shows hemoperitoneum.

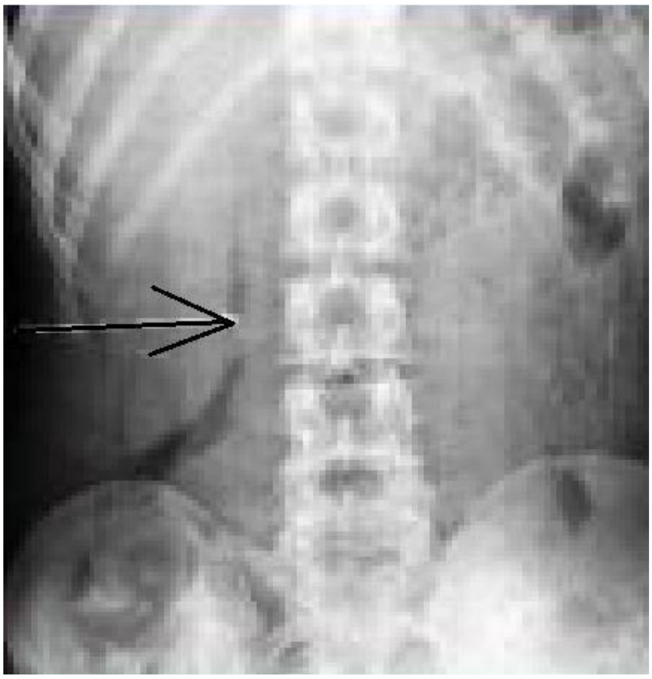


A



B

Fig. 3. Overview direct X-ray of the abdominal cavity (A – vertical position). Free gas under the dome of the diaphragm (arrows) is a sign of closed damage to the hollow organ (B)



A

B

Fig. 4. An overview direct X-ray of the abdomen (lying on the back). The presence of free gas in the retroperitoneal space is determined; in the case of contrast, the exit of the contrast material beyond the duodenum into the retroperitoneal space (arrow).

Fig. 5. Targeted direct X-ray of the right half of the abdomen with a closed injury of the liver. Gas is detected in the intrahepatic bile ducts, projections of the gallbladder (arrows)

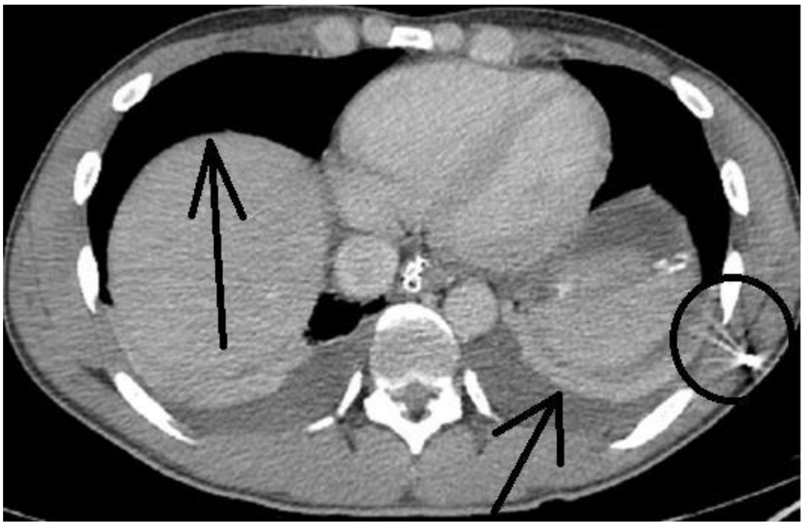


Fig. 6. CT scan of abdominal organs, axial projection. Free gas (upper arrow) and fluid (lower arrow) in the abdomen, foreign body (bullet) in the soft tissues of the abdomen on the left (circle).

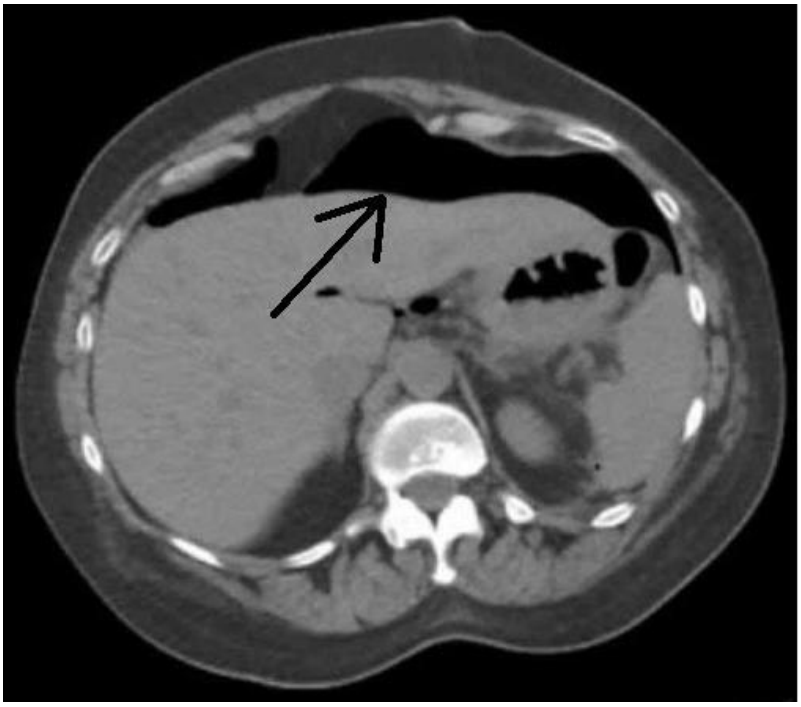


Fig. 7. CT scan of the abdominal organs, axial projection. Free gas (arrow) in the abdominal cavity of a wounded man in the abdomen.

Fig. 8. CT scan of the abdominal organs, axial projection. Free gas in the abdominal cavity and retroperitoneum (arrows) during abdominal gunshot wounds

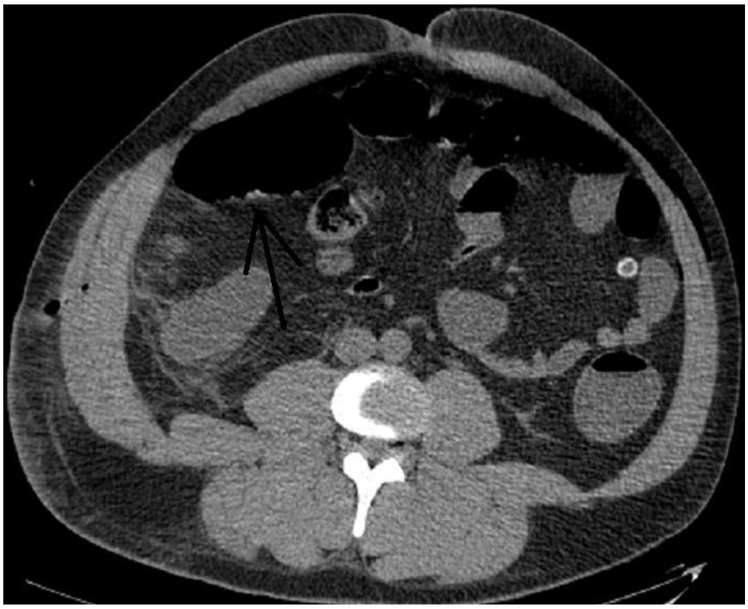


Fig. 9. CT scan of the abdominal organs, axial projection. Free gas in the abdominal cavity and retroperitoneum (arrows).

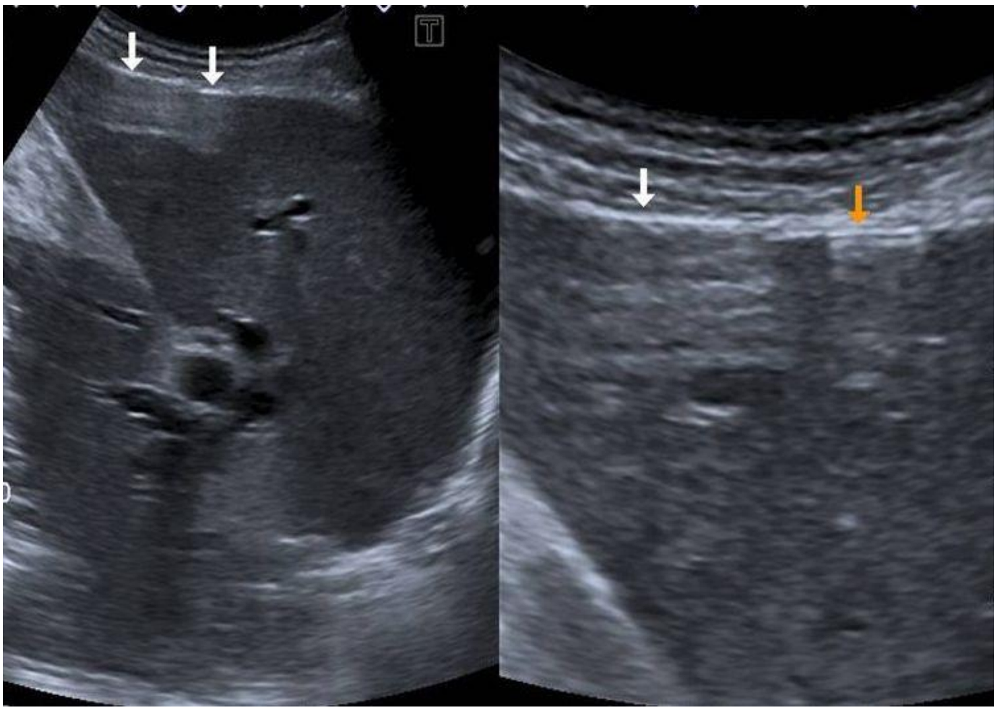


Fig. 10. Gunshot wound to the abdomen. Gas (pneumoperitoneum) is detected in the abdominal cavity in the form of light linear structures in the upper part of the echogram (arrows).

A

B

Fig. 11. Echograms of hyperechoic loci in combat trauma victims. A - gas in the liver wound channel (white arrows). B - enlarged image of gas (comet tail reverberation) in the liver wound channel.

***Fluid*** in the abdominal cavity and retroperitoneal space has different origins, different nature - blood, intestinal contents, urine, bile, exudate. This is an important sign of injury to both parenchymatous and hollow organs. Any destruction of them is accompanied by bleeding, and blood can flow either into the abdominal cavity or into the retroperitoneal space. If gas tends to go up, then any free fluid, on the contrary, goes down. It occupies all the flat places - in the subdiaphragmatic space, the pelvic cavity, in the right and left lateral fossa, between the loops of the small intestine. In the retroperitoneal space, it soaks the cellulose or accumulates as a hematoma. When performing CT, another important sign of the presence of fluid appears - it reduces, smoothes or eliminates the normal, clear image of the internal organs, especially the kidneys (Fig. 12 – 14).

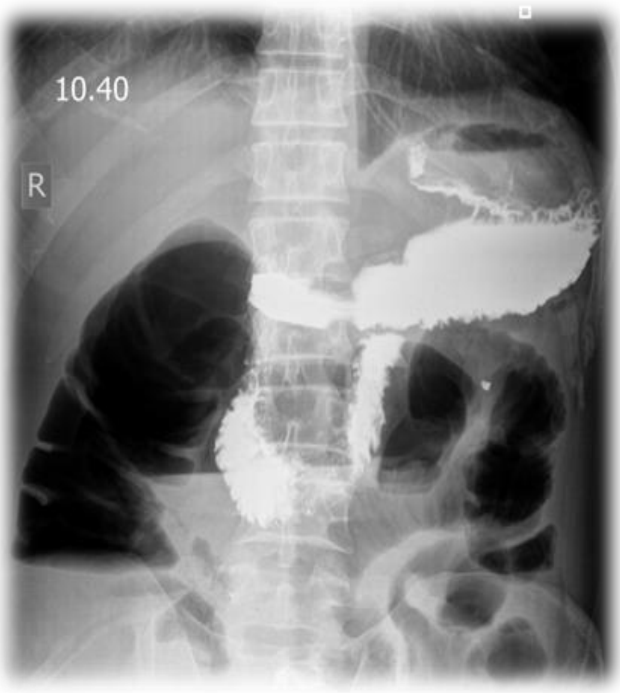



Fig. 12. Gunshot wound to the abdomen. X-ray examination reveals fluid in the central abdominal cavity and pneumatosis of the small intestine.

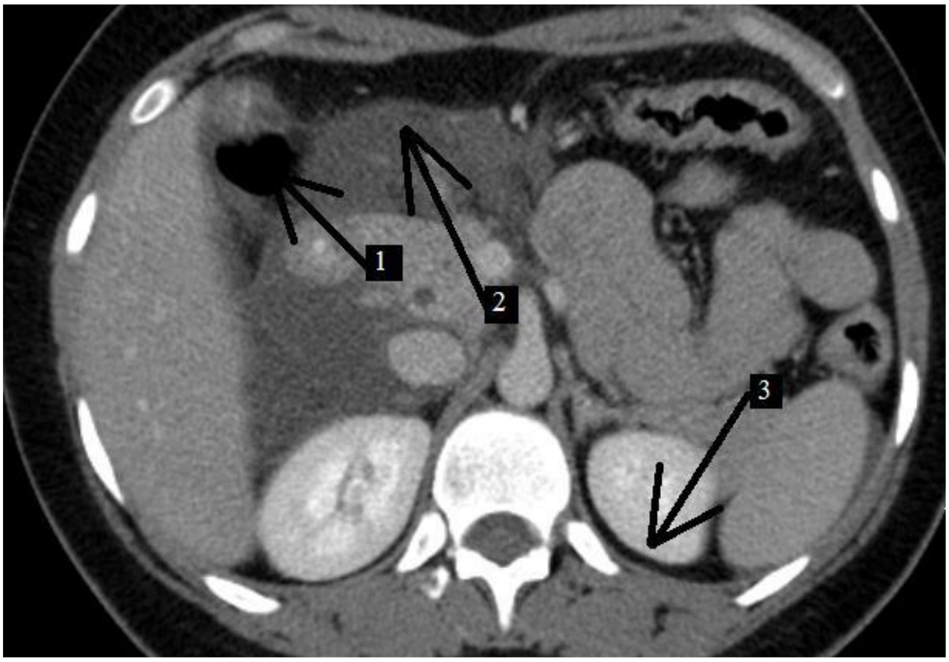



Fig. 13. CT scan of the abdominal organs, axial projection. Free gas (1) and liquid (2) in the abdominal cavity and retroperitoneum, paranephric (3) in a patient with a gunshot wound to the abdomen

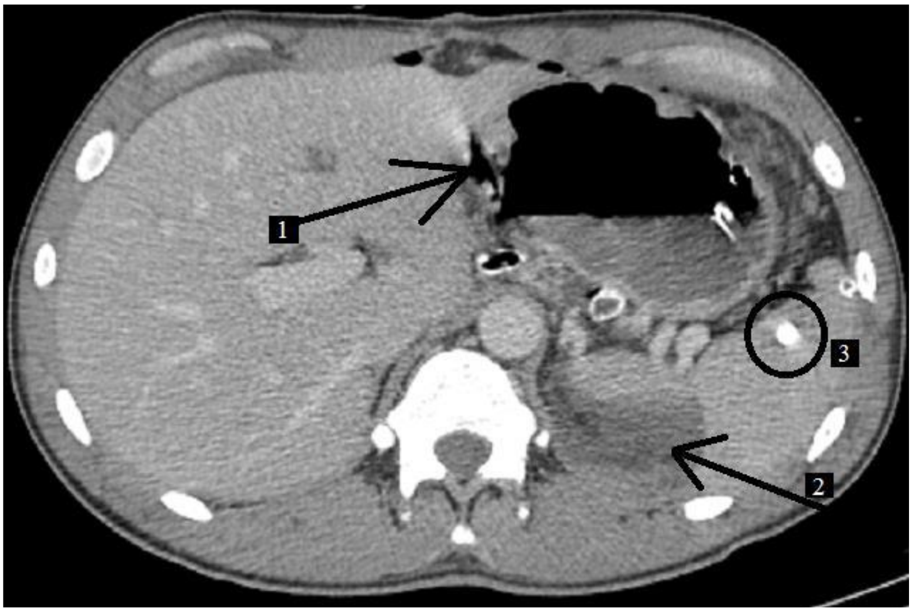



Fig. 14. CT scan of abdominal organs, axial projection. Free gas (1) and fluid (2) in the abdominal cavity in the case of a penetrating gunshot wound to the abdomen, the foreign body (bullet) (3) is in the spleen.

***The liver*** is an important parenchymatous organ, quite “difficult” to diagnose its damage. During the passage of a projectile near the liver, without damaging its capsule and parenchyma, but with damage to adjacent organs, the main sign is hemorrhage foci - diffuse or formed in the form of hematomas. They look like accumulations of fluid or clots, with a density of 20 to 80 HU. “Favorite” places for fluid accumulation in the abdominal cavity are the hepatorenal fossa (Morison's pouch), lateral flanks of the abdomen, and the pelvic cavity. If the blood is predominantly visualized retroperitoneally, then the places of fluid accumulation will be the paranephric space, the tissue along the lumbar muscles (the contours of which are enhanced by intravenous contrast). Hemorrhages can be located under the capsule, they have a sickle-shaped form (repeating the line of the capsule), adjoin it and have a density of 30 to 50 HU. White hematomas can also be located in the parenchyma of an organ; they look like homogeneous, relatively low-density masses of various shapes - from round to irregular. Intrahepatic ruptures look like cracks, often along vessels and straits. They are visible as sharply defined lines (often branched) of reduced density. If the liver is damaged by a projectile (ball, fragments), the visualized wound channel is filled with blood, detritus, and air bubbles. In case of a blind wound, at the end of the wound channel the wounding projectile or its fragments (fragments in different segments of the liver) are usually clearly visible. In the case of penetrating injury to the liver, foci of hemorrhage outside the organ are also determined (Fig. 15 – 21).

Fig. 15. CT scan of abdominal organs, axial projection. Penetrating gunshot wound of the abdominal cavity (bullet), wounding projectile in the gate of the liver.

Fig. 16. CT scan of abdominal organs, axial projection. Penetrating gunshot wound to the abdominal cavity, injury to the right lobe of the liver, hemopneumoperitoneum (arrows).

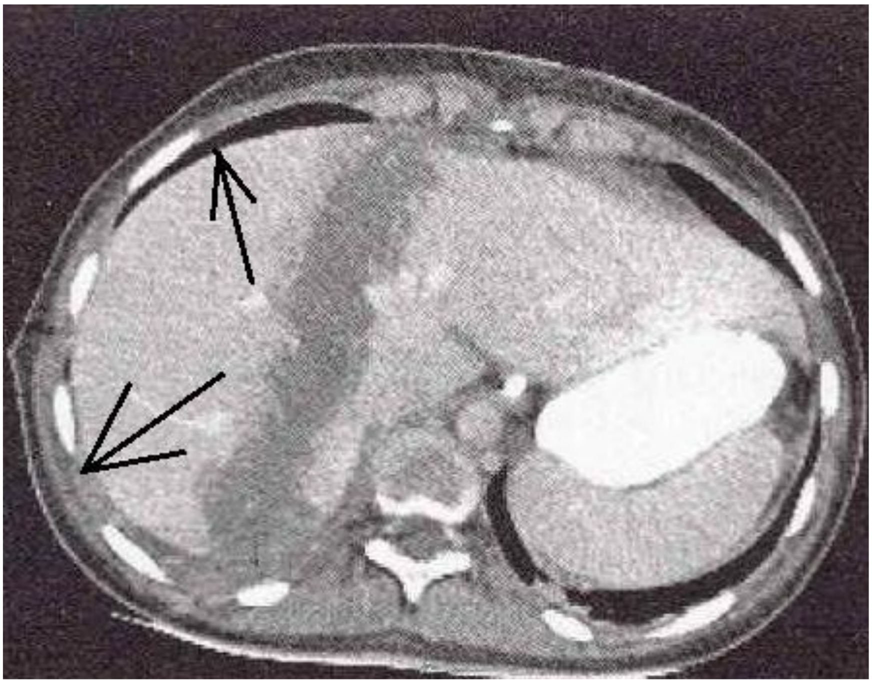


Fig. 17. CT scan of abdominal organs, axial projection. Penetrating gunshot wound to the abdominal cavity, hemopneumoperitoneum (arrows).

Fig. 18. CT scan of abdominal organs, axial projection. Penetrating gunshot wound to the abdominal cavity, injury to the right lobe of the liver, hemopneumoperitoneum (arrow).

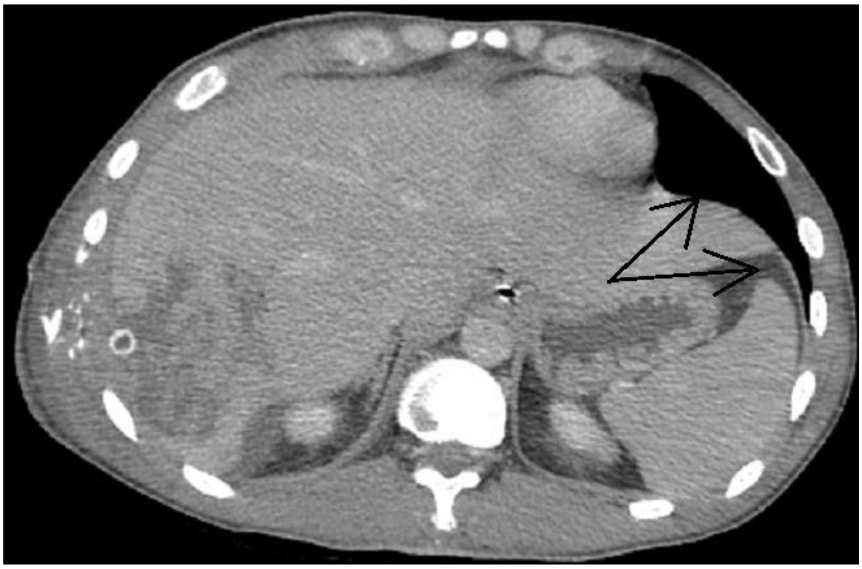


Fig. 19. CT scan of abdominal organs, axial projection. Penetrating gunshot (shrapnel) injury to the abdominal cavity, injury to the right lobe of the liver, hemopneumoperitoneum (arrows).

Fig. 20. CT scan of abdominal organs, axial projection. Penetrating gunshot (shrapnel) injury to the abdominal cavity, injury to the right lobe of the liver

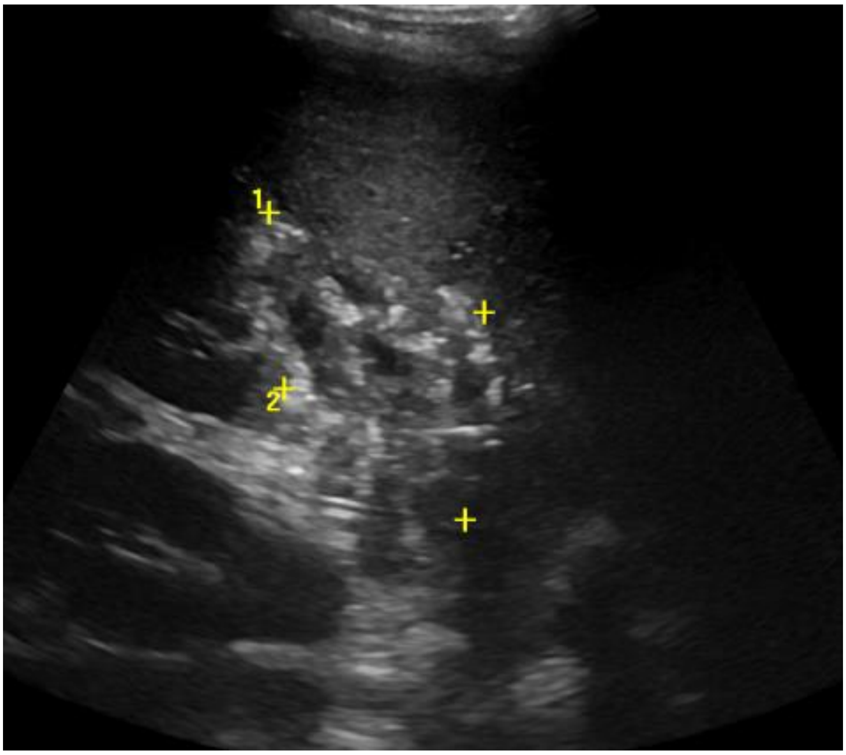
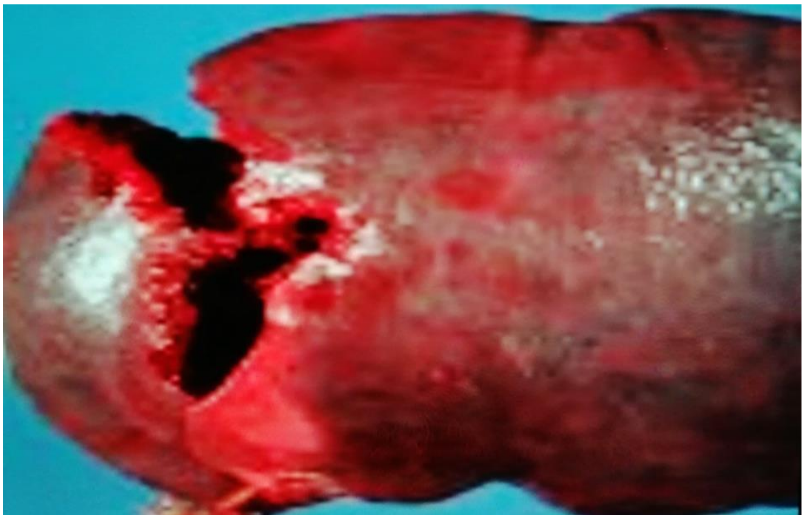



Fig. 21. Blind shrapnel thoracoabdominal wound. Ultrasound reveals local disruption of the architecture of the right lobe of the liver.

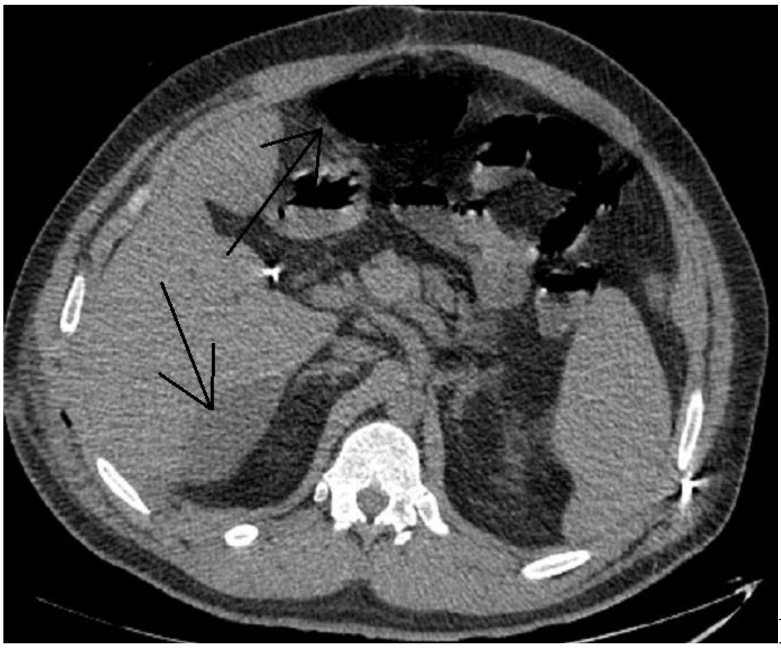
*Damage to the spleen*

The spleen is the organ that is most often damaged in the case of a closed abdominal injury. Its main symptom is severe intraperitoneal bleeding. This happens when the organ ruptures with damage to the capsule and parenchyma. With a preserved capsule, there may be no bleeding at all or it may develop at the second stage of the traumatic period — a two-stage rupture. In case of a complete rupture of the organ in the abdomen, a liquid is determined on the X-ray examination - blood without gas. In addition, it is necessary to pay attention to the high position of the left half of the dome of the diaphragm, the enlargement and blurring of the contours of the spleen, the displacement of the greater curvature and the bottom of the stomach (together with the gas bladder) to the right, and the splenic angle of the colon to the bottom, the indistinctness of the contour of the left kidney. In the case of subcapsular ruptures and the formation of an intra-organ hematoma, the picture is different: a significant increase in the contours of the spleen with preservation of their integrity is determined (Fig. 22 – 27).



A

Fig. 22. Foto of the spleen. Penetrating gunshot wound.



B

Fig. 23. CT scan of abdominal organs, axial projection. Penetrating gunshot (shrapnel) wound of the abdominal cavity, wound of the spleen, hemopneumoperitoneum (arrows).

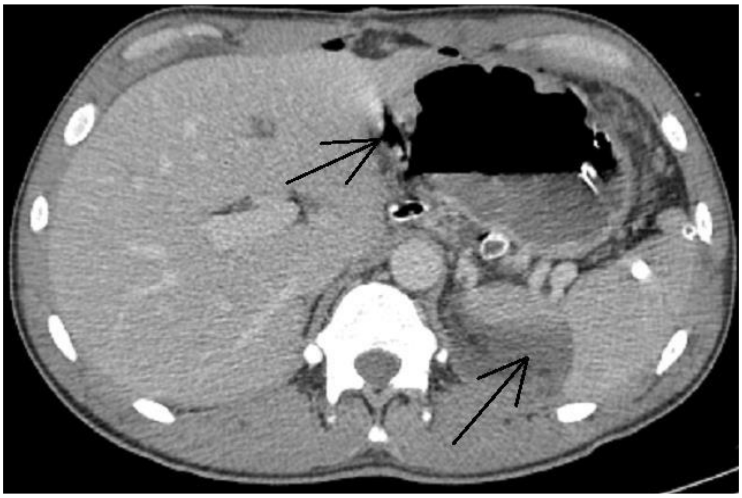
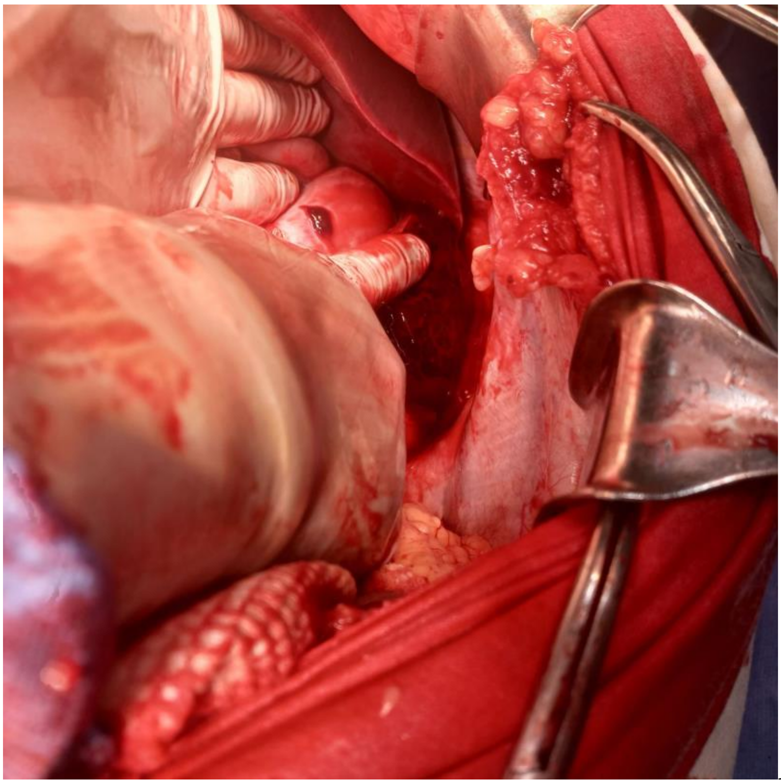
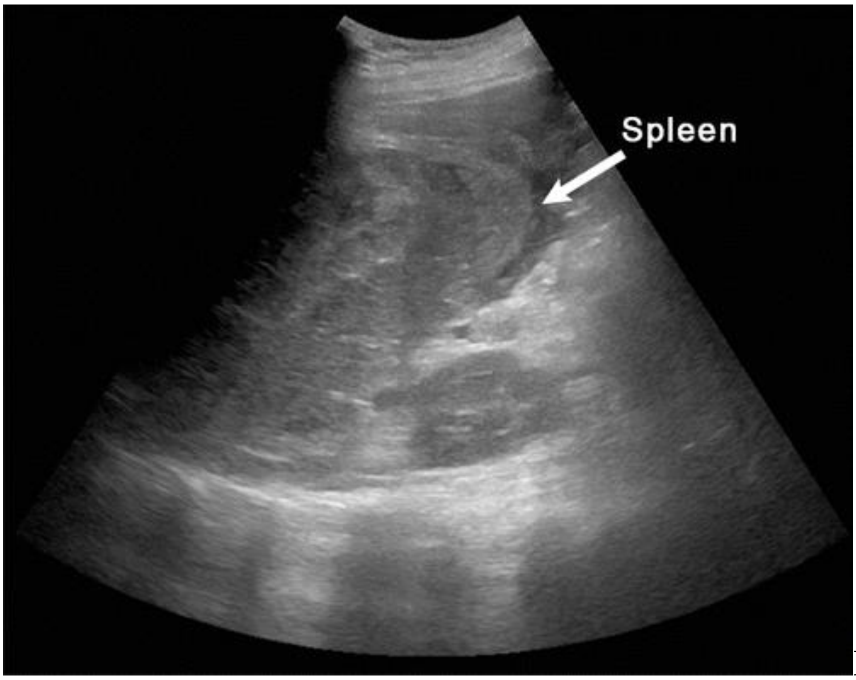


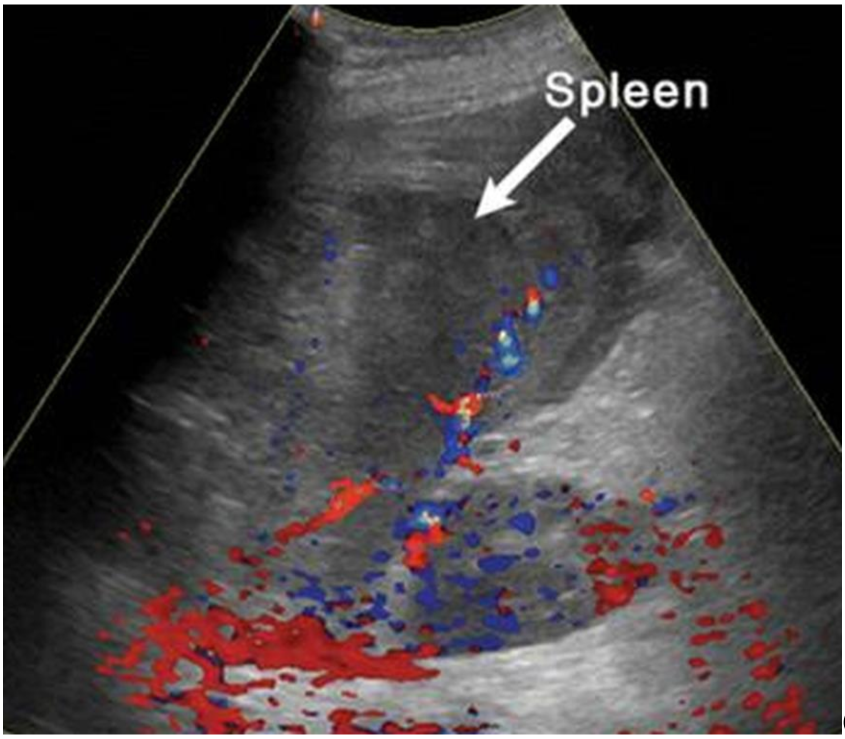
Fig. 24. CT scan of abdominal organs, axial projection. Penetrating abdominal gunshot (bullet), splensc rupture, hemopneumoperitoneum (arrows).



A



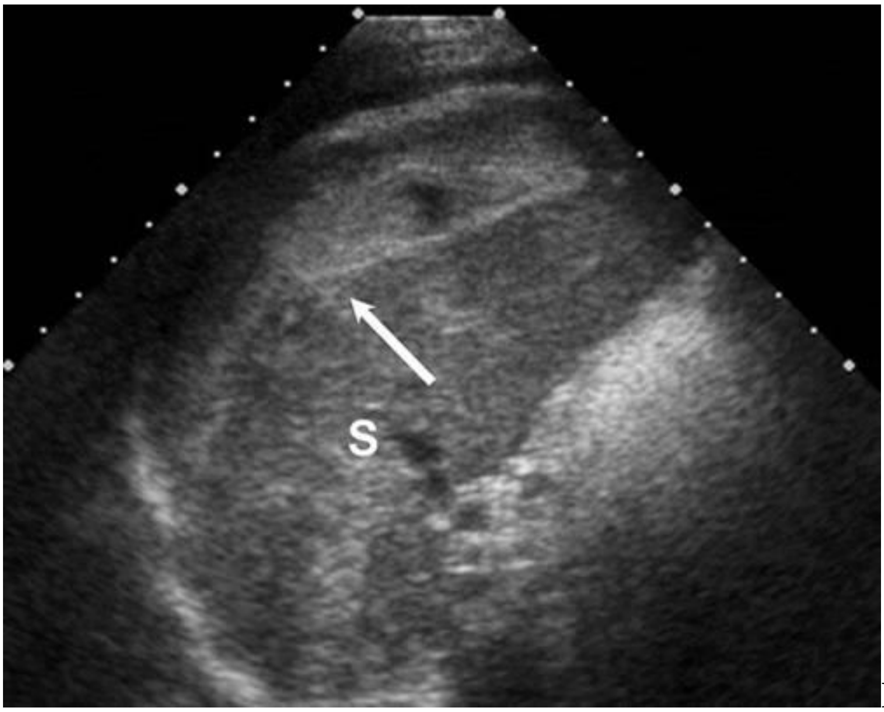

B




C

Fig. 25. Penetrating abdominal gunshot (bullet) wound. A-Foto of splenic rupture; B - ultrasound view of the splensc rupture, hemoperitoneum (arrow) in B mode; B - Color doppler view of the splensc rupture, hemoperitoneum (arrow).

A




B

Fig. 26. Abdominal gunshot wound. Splensc rupture, hemoperitoneum (arrow). A – CT scan; B – ultrasound view.

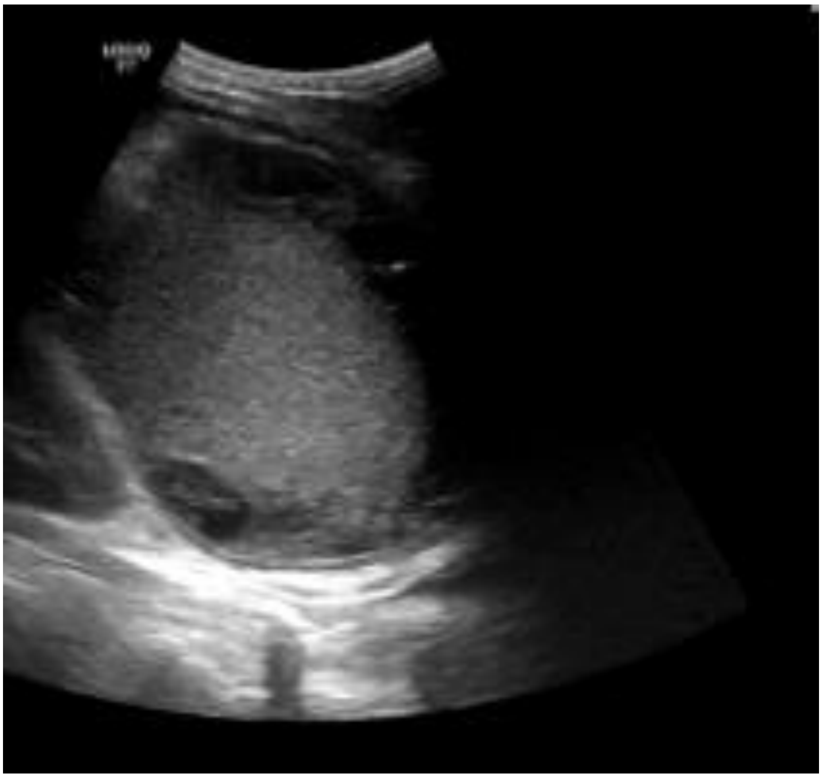


Fig. 27. Gunshot wounds to the spleen. A large crescent-shaped hematoma is seen along the lateral edge of the spleen.

Foreign bodies (balls, metal fragments, bone fragments, etc.) were most often found in the liver and lungs. Metal fragments were found in 2/3 of those injured as a result of ammunition explosions in unprotected areas of the body. During the X-ray examination of the wounded with injuries to the gastrointestinal tract, it is also necessary to determine the condition of the diaphragm and organs of the chest cavity. Also, given the multiple and combined nature of injuries in the wounded with injuries to the esophagus, stomach, small and colon, it was necessary to conduct an X-ray examination of the chest, abdominal cavity. Free gas and liquid were often found in patients with abdominal injuries (Fig. 28-33).

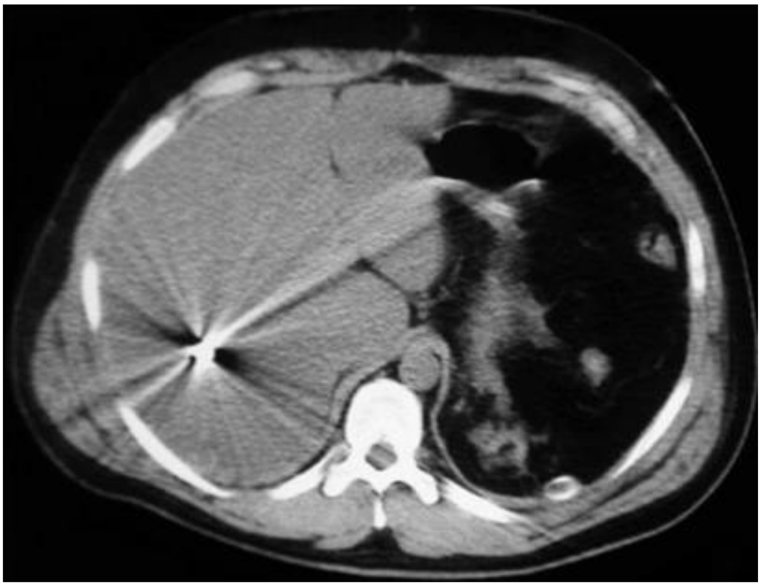


Fig. 28. CT of abdominal organs, axial projection. Penetrating gunshot wound of the abdominal cavity (ball), wounding projectile in the right lobe of the liver.

Fig. 29. Ultrasound visualization of a bullet in the right part of the liver in the form of a hyperechoic linear formation with an acoustic shadow (arrow).

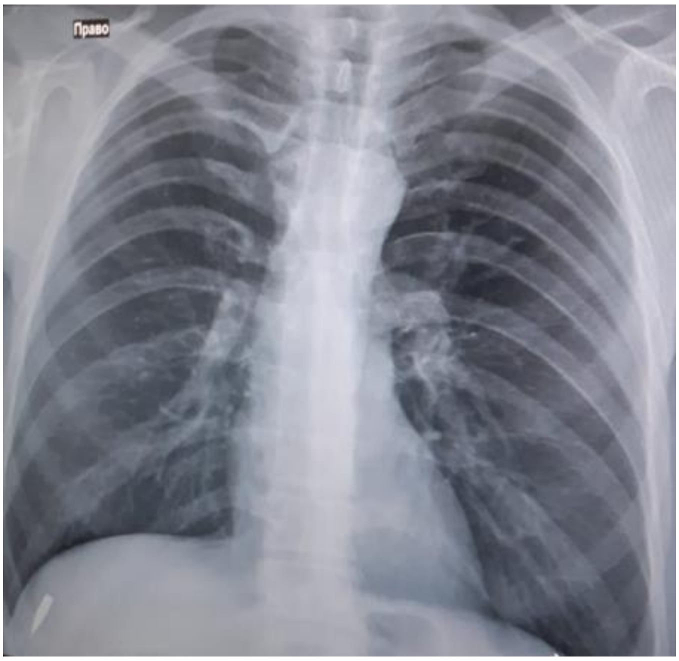



Fig. 30. The same case. Anterior projection of the chest (X-ray). In the projection of the right lobe of the liver, a light linear formation is determined - a bullet.

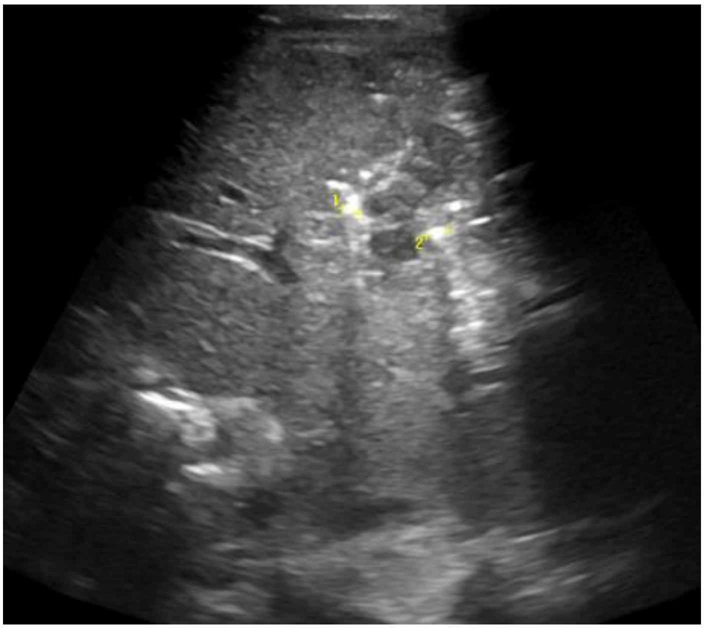


Fig. 31. Shrapnel wounds of the liver. On ultrasound, fragments in the liver are visible as luminous inclusions with the acoustic phenomenon of a “comet tail”.

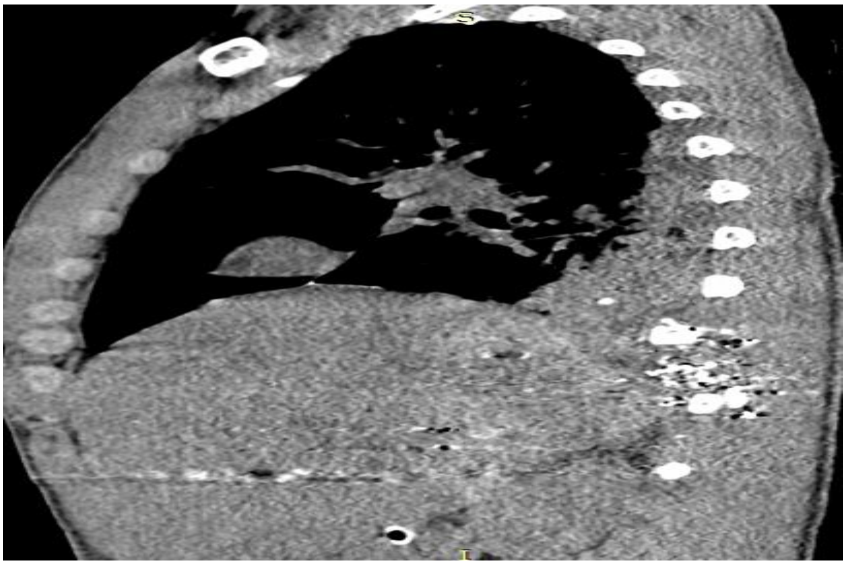
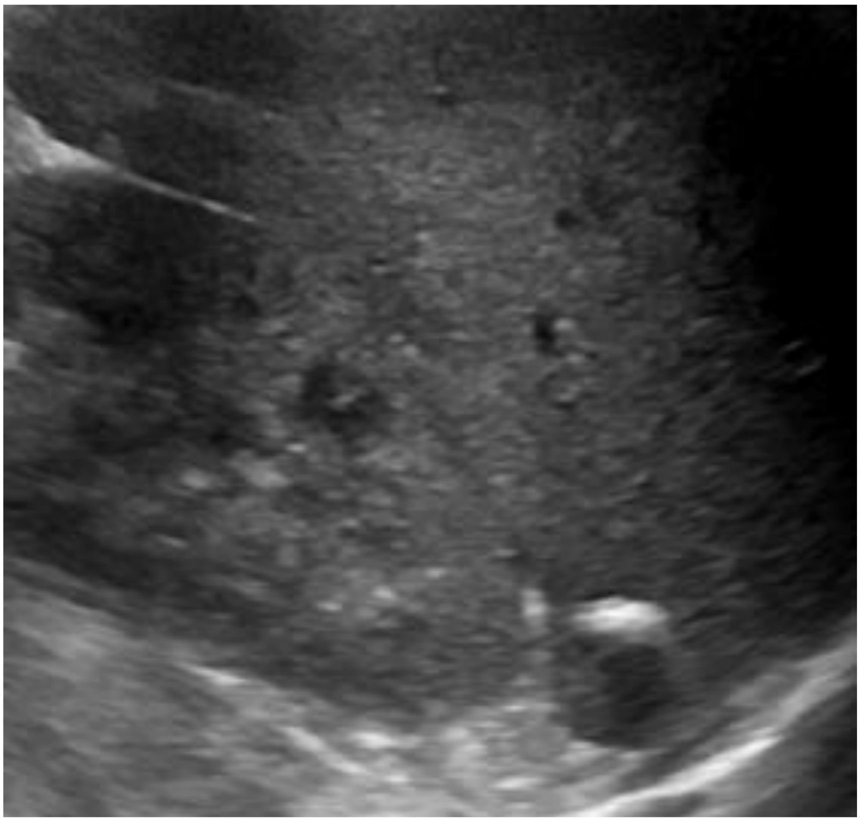
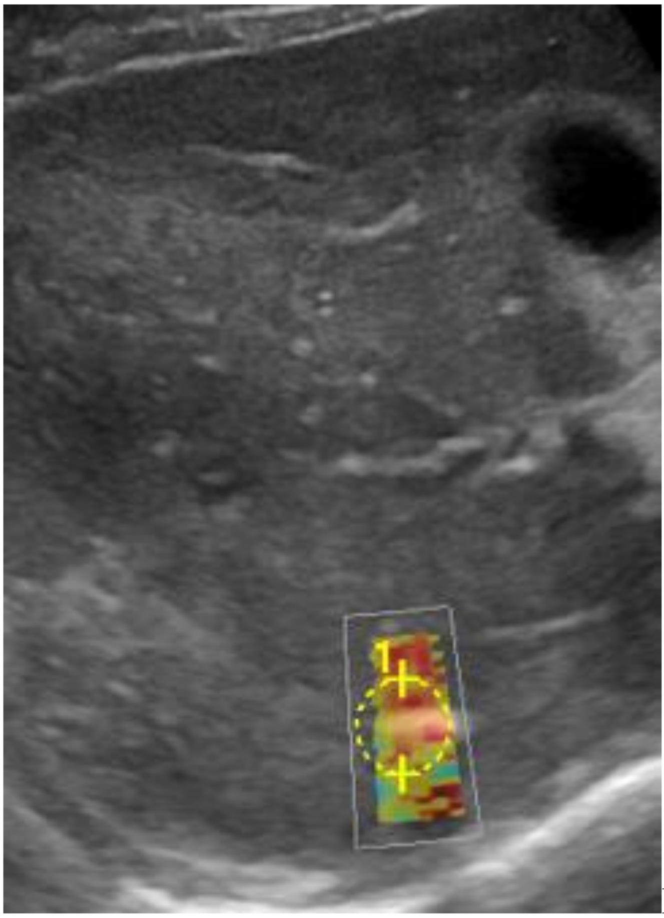


Fig. 32. Gunshot wound to the abdomen. CT images show multiple metal fragments in the form of luminous structures from 6 to 9 mm.



A



B

C

Fig. 33. Fig. Metal splinter in the oven. A – gray scale mode; B – shear elastography – 44.8 kPa. C – MDCT. Axial view. The fragment is in the oven, the thickness is 3071 HU.

***Pancreas***

In the case of pancreatic injuries caused by hydrodynamic impact, swelling of the gland, the appearance of local pathological formations in the parenchyma, and peripancreatic fluid accumulations are determined. When destroyed by a wounding projectile, a violation of the integrity of the organ parenchyma with massive peri-organ hemorrhages is determined (Fig. 34),

Fig. 34. CT scan of the abdominal cavity, axial projection in the case of a penetrating gunshot wound to the abdomen with damage to the pancreas

The current stage of optimization and improvement of the system of providing surgical care to victims with gunshot wounds to the abdomen is characterized by the introduction of advanced medical technologies [Herasymenko O.S. 2021]. It is important to effectively use visualization methods, taking into account their information content and appropriateness in specific situations. Ultrasound was used primarily to detect free fluid and gas in the early stages of combat trauma. In a hospital setting, patients with combined injuries underwent CT and MRI [Navsaria P.H. et al., 2015; Di Saverio S., et al., 2015]. The effectiveness of MDCT was especially evident in combined wounds of the abdominal cavity and chest with shrapnel wounds, which were the most common [Saher S. et al., 2016].

In our studies, intestinal injury was predominant, which was often accompanied by the appearance of free gas both in the abdominal cavity and in the chest. In such cases, the role of radiography was especially increased. Ultrasound was especially effectively used to perform the FAST protocol at the early stages of injury for triage of the wounded and in hospital settings for diagnosing damage to parenchymatous organs, as well as large abdominal vessels.

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# IMAGING of THORACOABDOMINAL GUNSHOT WOUNDS

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