ОРИГИНАЛЬНАЯ СТАТЬЯ

THE DIAGNOSTIC VALUE OF AIR IN THE ANTERIOR PERICARDIAL LIGAMENTS IN PENETRATING MINE-EXPLOSIVE WOUNDS OF THE CHEST CAVITY

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To substantiate the presence of isolated air collection in the anterior pericardial ligaments as a sign of rupture and pericardial contusion.

Materials and methods. A retrospective analysis of CT scans was performed in 97 wounded patients with diagnosed pericardial contusion and 117 wounded patients without contusion. Inclusion criteria included the presence of penetrating mine-explosive wounds of the chest cavity and a CT scan performed no later than five days after injury. Exclusion criteria included abdominal surgery performed during previous stages of medical evacuation. In all selected cases, CT scans were performed on the day of admission and were performed in the standard "chest cavity" mode. The image reconstruction thickness was 1.5 mm. A repeat analysis of the electronic CT scan records examined the distribution and quantity of air in the mediastinal regions. To quantify the air collection, the concepts of minimal, small, and large volume were introduced.

Results and discussion. It was established that air was present in the mediastinum in 69 cases with pericardial contusions, and in 30 cases without contusion (P = 0.042). In cases without contusion, on the contrary, there was a significant excess of absence of air – 88 versus 27 (P = 0.037). In cases of isolated air accumulation only in the anterior mediastinum and pericardial ligaments, the ratio of the number of observations with air accumulations in pericardial contusion exceeded observations without contusion by more than five times, as 33:6 (P = 0.014). Moreover, large-volume accumulations corresponded to contusion in 14 observations, and in the absence of contusion, cases of large air accumulation were not detected (P < 0.05). Minimal and small air accumulations in contusions were detected in 11 cases versus 2 without contusion (P = 0.019). When air accumulated in the middle and posterior mediastinum, no air was detected in the anterior mediastinal space; the ratio of cases with and without contusion was virtually identical, 5:6. Air accumulation in the pericardial ligaments and in all sections of the mediastinum, both in presence and volume, also showed no significant difference between cases with and without contusion. Thus, a significant predominance of air localization in cases of contusion was observed only with the first distribution pattern, indicating air migration along the following pathway: pleural cavity, anterior pericardial ligaments, indicating their rupture, and the anterior mediastinal space.

Conclusion. Comparison of the presence and volume of air in the pericardial ligaments confirms that direct air entry from the pleural cavity is a consequence of the ligament rupture. Therefore, air within the anterior mediastinum area and pericardial ligaments, in the absence of air in other areas of the mediastinum, indirectly indicates on pericardial contusion.

Keywords: pericardial contusion, rupture of the anterior pericardial ligaments, pneumomediastinum, mediastinal wounds.

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ДИАГНОСТИЧЕСКОЕ ЗНАЧЕНИЕ ВОЗДУХА В ПЕРЕДНИХ СВЯЗКАХ ПЕРИКАРДА ПРИ ПРОНИКАЮЩИХ МИННО-ВЗРЫВНЫХ РАНЕНИЯХ ГРУДНОЙ ПОЛОСТИ

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Цель исследования. Обосновать наличие изолированного скопления воздуха в передних связках перикарда как признака их разрыва и ушиба перикарда.

Материалы и методы. Проведен ретроспективный анализ КТ-исследований 97 раненых с диагностированным ушибом перикарда и 117 раненых без ушиба. Критериями включения служило наличие проникающего минно-взрывного ранения (МВР) грудной полости и выполнение КТ не позднее пяти суток от момента ранения, критерием исключения – наличие проведенных на предыдущих этапах медицинской эвакуации полостных хирургических операций. Во всех отобранных наблюдениях КТ выполнялась в день поступления в стандартном режиме «грудная полость». Толщина реконструкции изображений – 1,5 мм. При повторном анализе электронных записей томограмм изучали распределение и количество воздуха по отделам средостения. Для количественной характеристики скопления воздуха были введены понятия минимального, малого и большого объема.

Результаты и обсуждение. Установлено, что при ушибах перикарда воздух присутствовал в средостении в 69 наблюдениях, а без ушиба – в 30 (P=0,042). В наблюдениях без ушиба, наоборот, имелось существенное превышение отсутствие воздуха – 88 против 27 (P = 0,037). В случаях изолированного скопления воздуха только в переднем отделе средостения (ПОС) и связках перикарда соотношение количества наблюдений со скоплениями воздуха при ушибе перикарда превышали наблюдения без ушиба более чем в пять раз, как 33:6 (P = 0,014). При этом скопления большого объема 14 наблюдениях соответствовали ушибу, а при отсутствии ушиба случаев большого скопления воздуха не обнаружено (P <0,05). Минимальные и малые скопления воздуха при ушибах обнаружены в 11 случаях против 2 без ушиба (P = 0,019). При скоплении воздух в среднем и заднем отделах средостения воздух в ПОС не обнаруживался, соотношение наблюдений с ушибом и без ушиба почти не отличалось, как 5:6. Скопления воздуха в связках перикарда и во всех отделах средостения, как по присутствию, так и по объему, так же не показали достоверного отличия в наблюдениях с ушибом и без ушиба. Таким образом, достоверное превосходство локализации воздуха при ушибах наблюдалось только при первом варианте распределения, что указывает на миграцию воздуха по пути: плевральная полость – передние связки перикарда, что указывало на их разрыв и ПОС.

Заключение. Сопоставление присутствия воздуха и его объема в переднем средостении и связках перикарда подтверждает его прямое поступление из плевральной полости и является следствием разрыва связки. Из этого следует, что воздух в переднем отделе средостения и связках перикарда, при его отсутствии в других отделах средостения, косвенно указывает на ушиб перикарда.

Ключевые слова: ушиб перикарда, разрыв передних связок перикарда, пневмомедиастинум, ранения средостения.

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Visualization of gas accumulation in the mediastinum is a common and easily recognizable sign, the sensitivity of which in the examination of wounded patients by CT approaches 100% [1-4]. Air penetration into tissue occurs quite frequently in penetrating gunshot wounds, and is observed with greater consistency in wounds to the mediastinum, neck, or abdomen [5-10]. The cause of pneumomediastinum is the entry of air from the pleural cavity, in penetrating wounds with damage to the mediastinal pleura or through connective tissue layers along the vessels and bronchi from the damaged lung parenchyma, direct, reverse mechanism, and Macklin C.C. effect [11-14]. Air may enter the mediastinum from the abdominal cavity through the connective tissue running along the natural openings of the diaphragm [15-18]. This is sometimes observed after operations on abdominal organs or the retroperitoneal space, as well as as a result of penetrating wounds: of the esophagus, abdominal cavity and diaphragm [4,10, 16-18]. Air entry into the mediastinum is facilitated by the pressure gradient between the anatomical spaces and the suction action of respiratory movements and cardiac contractions. Air distribution within the mediastinum largely depends on the patient's static position [14]. As a result, air accumulates predominantly in the upper and anterior mediastinum (AMS).

While studying the symptoms of pericardial contusion in penetrating blast wounds (PBL) of the lung, observations were made of air accumulation in the anterior pericardial ligaments (APL) without the presence of air in other parts of the mediastinum [19,20]. This suggested a rupture of the APL and air penetration through the resulting defect. Thus, the hypothesis of "air accumulation in the pericardial ligaments" as an indicator of rupture emerged.

Purpose.

Substantiating the presence of an isolated accumulation of air in the anterior pericardial ligaments as a sign of rupture and contusion of the pericardium.

Material and methods.

To achieve this goal, a repeat retrospective analysis of 214 cases previously selected to determine the ability of chest CT to detect cardiac contusions during thoracic mine-explosive wounds was conducted. Inclusion criteria included the presence of penetrating thoracic mine-explosive wounds and a CT scan performed no later than five days after injury. Exclusion criteria included abdominal surgery performed during previous stages of medical evacuation. The average age was 35±11 years. In all selected cases, CT scans were performed on the day of admission; the examination was performed in the standard "chest cavity" mode. The vast majority (209 wounded) had mine-explosive wounds; the remaining 5 had gunshot wounds. Chest injuries were characterized by combined damage to the head (32), abdomen (69), and extremities (94). The choice of this group was due to the peculiarities of mine-explosive wounds, in which the shock wave has a strong damaging effect on the lung and pericardium, therefore the risk of ligament damage is maximized. According to the selection conditions, all wounds were penetrating, and the time for the initial CT scan ranged from 2 to 5 days, with an average of 3.6 days. During a repeat analysis of the electronic CT scan records, the distribution and amount of air in the mediastinal sections was studied. To quantify air accumulation, the concepts of minimal, small, and large volume were introduced. With regard to the PSP, the minimal amount of air corresponded to the presence of single bubbles (symbol +). A small accumulation denoted conditions when air was present between the ligament fibers; the superior or inferior ligament was filled with linear accumulations located along the connective tissue layers, while the volume of the PSP did not increase (symbol ++). A large accumulation corresponded to air distribution throughout the entire ligament(s), an increase in their volume, and air spread to the fibrous layer of the pericardium (symbol +++). With regard to the upper mediastinal floor (UMF) and the lower mediastinal floor (LMF), minimal air accumulation corresponded to the presence of single bubbles only in the UMF (symbol x); small air accumulation corresponded to the spread of single air bubbles in the UMF and LMF (symbol xx). Large - air spread over two floors in the form of linear clusters

along the connective tissue layers (designation xxx). The volume of air in the pleural cavity and subcutaneous fat was not taken into account.

Statistical analysis of the data was performed using quantitative distributions and simple percentage ratios. The Shapiro-Wilk Z-test (P value) was used to assess the normality of the distribution of the quantitative variable. The statistical significance of the results was determined based on the P value. Differences were considered statistically significant at a P value of <0.05. To correct for potential error in the analysis of multiple comparisons of contusion detection in groups with different air localizations, the Holm-Bonferroni correction was used. Statistica 10.0 and Medcalc v20.104 software were used for data processing and statistical analysis.

Results and discussion.

As a result of the previously conducted analysis, pericardial contusion in the selected group was diagnosed by CT in 97 (45.2%) of the wounded. Contusion was not detected in 117 (54.8%). Signs of an established contusion included pericardial thickening up to 2-3 mm due to edema and accumulation of blood in the pericardium, indicated by an increase in pericardial thickness of more than 3 mm. Large pneumothorax was detected on CT in 65 (30.4%) of the wounded. In the remaining 149 (69.6%), air in the pleural cavities was localized subpleurally as a thin layer or was not detected at all, which we explained by the presence of pleural drains in all admitted patients and the time interval between the injury and the CT examination. Given the fact of the presence of a penetrating wound, the presence of air in the pleural cavity was assumed to be 100% in all selected observations. Under these conditions, there were theoretically several pathways for air to spread from the pleural cavity to the pulmonary artery:

Pathway 1: lung wound – perivascular connective tissue – mediastinum – pericardial

Table №1. Comparative statistics of air distribution and volume in the mediastinum with and without pericardial contusion (n=214).

Localization of air accumulations in the mediastinal regions	Contusion: there is (n=96) no (n=118)	Air distribution by localization		Air distribution by volume		
		Number of observations	P	Air volume	Number of observations	P
Option 1 Air only in the pericardial sac and pericardial ligaments (n=39)	There is a bruise	33 (15,4%)	0,014	+	11	0,019
				++	8	
				+++	14	
	There is no bruise	6 (2,8%)		+	2	<0,05
				++	4	
				+++	0	
Option 2: Air in the middle and posterior mediastinum (n=11)	There is a bruise	5 (2,3%)	>0,05	x	2	
				xx	3	
				xxx	0	
	There is no bruise	6 (2,8%)		x	1	
				xx	4	
				xxx	1	
Option 3 Air in the pericardial ligaments and in all parts of the mediastinum (n=49)	There is a bruise	31 (14.5%)	0,0744	+ (x)	10	>0,05
				(++) (x)	15	
				(+++) (xx)	4	
				(++) (xxx)	2	
	There is no bruise	18 (8,4%)		(+) (xx)	3	>0,05
				(++) (xx)	9	
				(+) (xxx)	4	
				(++) (xxx)	2	
In total with air in the mediastinum (n=99)	There is a bruise				69 (32.2%)	0,042
	There is no bruise				30 (14.0%)	
Total without air in the mediastinum (n=115)	There is a bruise				27 (12,6%)	0,037
	There is no bruise				88 (41,1%)	

ligaments and pericardial ligaments;

Pathway 2: pleural cavity – mediastinum – pericardial ligaments and pericardial ligaments;

Pathway 3: pleural cavity – pericardial ligaments and pericardial ligaments.

It was possible that air could migrate in several directions, but this scenario was not considered due to its unprovability. Therefore, air distribution in the mediastinum was analyzed using the three proposed approaches. The goal of the analysis was to identify reliable differences between patterns of air accumulation in various mediastinal regions with and without pericardial contusion. It was also assumed that air accumulation in the pericardial septum should be an indicator of its rupture. The results of comparative statistics for air distribution and its volume in various mediastinal regions with and without contusion are shown in Table 1. For ease of presentation, air accumulation in the anatomical regions of the mediastinum is conventionally divided into patterns, designated by numbers.

Table №2. Association of the "Air Accumulation in the Mediastinum" Symptom with Pericardial Contusion.

Localization of air in the mediastinal compartments	Presence of a bruise	Test result		Ch	S	R
All departments (3rd option)	There is a bruise (n = 96)	TP = 69	FP = 30	0,72	0,74	0,45
	No bruise (n = 118)	FN = 27	TN = 88			
PSP only (Option 1)	There is a bruise n = 33	TP = 33	FP = 6	-	-	-
	No bruise (n = 6)	FN = 0	TN = 0			

The table shows that with pericardial contusions, air penetrated into the mediastinum in 69 observations, and without contusion in 30 (P = 0.042). In the absence of contusion, on the contrary, there was a significant excess of the absence of air over its presence – 88 versus 27 (P = 0.037). In the first variant of distribution, the ratio of the number of observations with air accumulations in pericardial contusion exceeded observations without contusion by more than five times, as 33:6 (P = 0.014). In the second variant of distribution, in which air was not detected in the POS, a similar ratio differed little, as 5:6. In the third variant of distribution, the differences in the localization of air in pericardial contusions and without this did not show a significant difference (P = 0.74). Thus, a statistically significant advantage in air localization in bruises was observed only with the first distribution option, which indicates in favor of the third route of air migration. A comparison of the volume of incoming air in the first distribution pattern revealed that a large volume of air in 14 cases corresponded to a contusion, while no significant air accumulations were detected in the absence of a contusion. These findings further support a third route for air entry, as a large air volume in the cerebrospinal fluid (CSF), formed via the first or second pathways, inevitably predetermines a similar accumulation in the mediastinum, which should leave at least a minimal trace along its migration. Equally, this trace could not completely disappear through diffusion, as the average time to perform a CT scan after injury was 3.6 ± 1 day. Air accumulations in the mediastinum do not disappear within this time period. Minimal and small air accumulations in the first pattern were detected in 11 cases with contusions versus 2 without contusions (P = 0.019). In the third distribution variant, large air accumulations in the pericardial ligament with contusions were detected in only four out of 31 observations. It should be noted that in these four observations, the mediastinal air accumulations corresponded to small volumes, which is more indicative of retrograde air migration from the ligament. However, overall, the third volume distribution variant also did not reveal a significant difference between observations with and without contusions (P>0.05). A comparison of the association between mediastinal air localization and pericardial contusion is shown in Table №2.

The table's data confirm that in cases of mediastinal air distribution according to the third scenario, the probability of a rupture of the posterior ventricle is extremely low (O = 0.72). In the absence of air in the mediastinum, the probability of a lack of rupture is also inconclusive (C = 0.74). Therefore, air accumulation according to the third scenario has no diagnostic value. When air is distributed according to the first scenario, it is impossible to correctly calculate sensitivity and specificity, since the conditions for selecting the LO and LP result in zero cases. Nevertheless, a 100% PI rate of air accumulation observations according to the first scenario indicates a high probability of a rupture of the posterior ventricle.

Various variants of air accumulation due to rupture of the ligament along the third air migration path are shown in Fig. 1-4; along the first path – in Fig. 5.

Thus, comparing the presence and volume of air in the pericardial ligament confirms

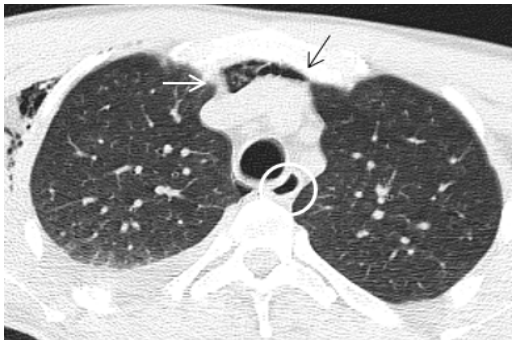

Fig. 1 a (Рис. 1 а)

Fig. 1 b (Рис. 1 б)

Fig. 1. CT scan of the chest, axial plane, native examination.

a - mine-explosive blind shrapnel thoracoabdominal wound. CT scan reveals contusion of the lower lobes of the lungs and pericardium, rupture of the superior anterior pericardial ligament with air penetration forming an upper horizontal border with blood (black arrow), and a hematoma along the right edge of the ligament (white arrow). Air is present in the lumen of the esophagus (circled).

b - no air accumulations are present in other areas of the mediastinum.

Рис. 1. КТ органов грудной полости, аксиальная плоскость, нативное исследование.

а – минно-взрывное слепое осколочное торакоабдоминальное ранение. Определяется ушиб нижних долей легких, перикарда, разрыв верхней передней связки перикарда с проникновением воздуха, формирующим верхнюю горизонтальную границу с кровью (черная стрелка), гематома по правому краю связки (белая стрелка). Воздух в просвете пищевода (обозначен кругом).

б – отсутствие скопления воздуха в других отделах средостения.

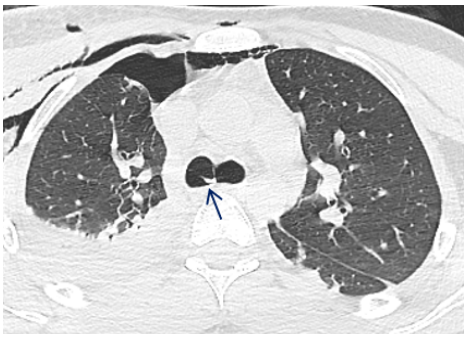

Fig. 2 a (Рис. 2 а)

Fig. 2 b (Рис. 2 б)

Fig. 2. CT scan of the chest, axial plane, native examination.

a - level of tracheal bifurcation.

b - upper chest.

Second day after penetrating pulmonary injury to the right lung. Right-sided pneumothorax, bilateral pulmonary contusion, tracheal contusion, mucosal detachment in the left main bronchus (arrow), air penetration into the superior pericardial ligament. Air is present in the esophageal lumen (dashed arrow). No air is present in other parts of the mediastinum.

Рис. 2. КТ органов грудной полости, аксиальная плоскость, нативное исследование.

а – уровень бифуркации трахеи.

б – верхние отделы.

Вторые сутки после минно-взрывного проникающего ранения правого легкого. Правосторонний пневмоторакс, двусторонний ушиб легких, трахеи, отслойка слизистой в левом главном бронхе (стрелка), проникновение воздуха в верхнюю связку перикарда. Воздух в просвете пищевода (пунктирная стрелка). Отсутствие воздуха в других отделах средостения.

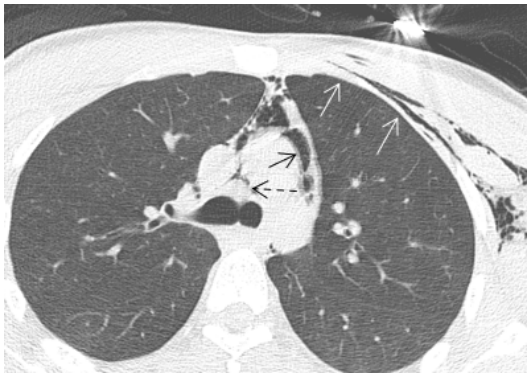

Fig. 3 a (Рис. 3 а)

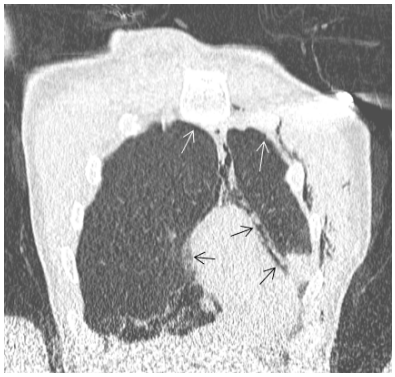

Fig. 3 b (Рис. 3 б)

Fig. 3. CT scan of the chest, axial plane, native examination.

a - mine-explosive penetrating shrapnel wound of the left lung, blind shrapnel wound of the heart, pulmonary and pericardial contusion, rupture of the inferior anterior pericardial ligament. CT scan performed on the fourth day.

b - air is determined in the anterior pericardial ligaments, which spreads to the fibrous layers of the pericardium, the volume of the inferior anterior ligament is enlarged, the ligament is deformed, there is a large volume of air in the ligament.

Legend: air accumulations in the pericardium (black arrows); pneumothorax (white arrows); air in the pericardial folds (dashed arrows).

Рис. 3. КТ органов грудной полости, аксиальная плоскость, нативное исследование.

а – минно-взрывное сквозное осколочное ранение левого легкого, слепое осколочное ранение сердца, ушиб легких и перикарда, разрыв нижней передней связки перикарда. КТ выполнена на четвертые сутки.

б – в передних связках перикарда определяется воздух, который распространяется на фиброзные листки перикарда, объем нижней передней связки увеличен, связка деформирована, большой объем воздуха в связке. Обозначения: скопления воздуха в перикарде – черные стрелки; пневмоторакс – белые стрелки; воздух в заворотах перикарда – пунктирные стрелки.

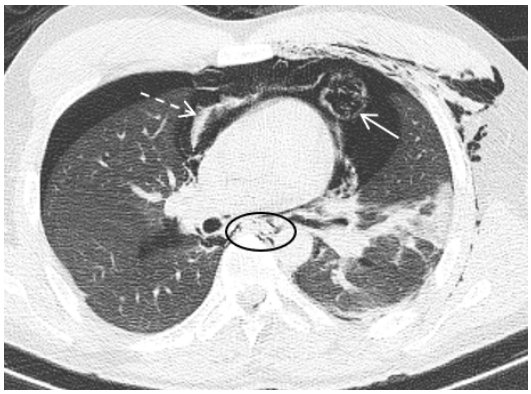

Fig. 4 (Рис. 4)

Рис. 4. КТ органов грудной полости, аксиальная плоскость, нативное исследование.

Penetrating mine-explosive wound to the left side of the chest. Contusion of the lower lobes of the lungs, bilateral pneumothorax, cardiac contusion, and rupture of the anterior pericardial ligament. CT scan shows a rupture of the inferior anterior pericardial ligament. The ligament is deformed and filled with air, with large amounts of air penetrating the fibrous layer of the pericardium (arrow), and blood collections are visible (dashed arrow). Minimal air collections are visible in the posterior visceral ligaments of the mediastinum (indicated by the oval).

Fig. 4. CT scan of the chest, axial plane, native examination.

Минно-взрывное проникающее ранение левой половины грудной полости. Ушиб нижних долей легких, двусторонний пневмоторакс, ушиб сердца, разрыв передней связки перикарда. Определяется разрыв нижней передней связки перикарда. Связка деформирована, заполнена воздухом, воздух в большом количестве проникает в фиброзный листок перикарда (стрелка), видны скопления крови (пунктирная стрелка). Минимальные скопления воздуха видны в задних висцеральных связках средостения (обозначено овалом).

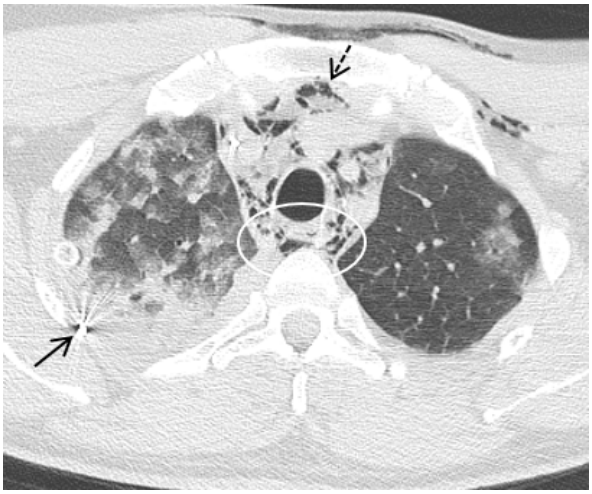

Fig. 5 a (Рис. 5 а)

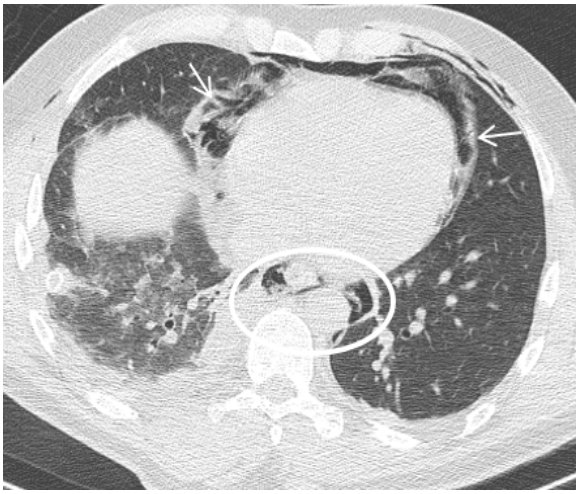

Fig. 5 b (Рис. 5 б)

Fig. 5. **CT scan of the chest, axial plane, native examination.**

a - the upper chest.

b - the lower chest.

Mine-explosive injury. Penetrating shrapnel wound to the right lung, pulmonary contusion, and pericardial contusion. Air accumulates in the deformed pericardial septum (dashed arrow), in the visceral ligaments of the posterior mediastinum (circled), and in other parts of the mediastinum, and also spreads through the fibrous layer of the pericardium (white arrows). The shrapnel (black arrow) and contusions of the right and left lungs are clearly visible.

Рис. 5. **КТ органов грудной полости, аксиальная плоскость, нативное исследование.**

а – верхние отделы.

б – нижние отделы.

Минно-взрывное ранение, проникающее осколочное ранение правого легкого, ушиб легких, перикарда. Воздух скапливается в деформированной передней связке перикарда (пунктирная стрелка), в висцеральных связках заднего отдела средостения (обведены овалами) и в других отделах средостения, а также распространяется по фиброзному листку перикарда (белые стрелки). Хорошо виден осколок (черная стрелка), ушибы правого и левого легкого.

its direct entry from the pleural cavity due to a ligament rupture. Therefore, air in the pericardial ligament and pericardial ligaments, in the absence of air in other areas of the mediastinum, is a sign of a pericardial ligament rupture and indirectly indicates a pericardial contusion.

Conclusions.

1. The sign of “Isolated air accumulation in the anterior pericardial ligaments” on CT scans performed no later than 5 days after mine-explosive injury, with a high probability indicates their rupture and should be considered a marker of pericardial contusion.
2. Low prevalence of the symptom – 46.3%; in its absence, pericardial contusion does not ex clude.
3. Air accumulations in the pericardial ligaments and in other parts of the mediastinum did not confirm the diagnostic value of a ligament rupture, since they could equally be a consequence of tissue diffusion or direct air entry through the wound channel.

Source of funding and conflict of interest.

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Compliance with ethical standards.

The authors confirm that the rights of people who participated in the study were respected, including obtaining informed consent where necessary.

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