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Minimally invasive methods of treating diaphragmatic injuries in combat trauma in hemodynamically stable patients

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Abstract

Objective. To evaluate the effectiveness of laparoscopy and video-assisted thoracoscopy in the treatment of diaphragmatic injuries in patients with combined trauma who are hemodynamically stable, and to compare the results with the relevant current literature data.

Materials and methods. A retrospective analysis of surgical tactics was performed in 298 hemodynamically stable patients with thoracoabdominal and abdominal injuries hospitalized in 2023–2025 who underwent minimally invasive procedures (videothoracoscopy and laparoscopy). During minimally invasive revision, diaphragmatic injuries were confirmed in 34 patients. The average time from injury to surgery was (4.5 ± 2.1) hours, and the average length of hospitalization was (5.1 ± 1.3) days.

Results. Computed tomography was not sufficiently sensitive, as 11 (32.4%) diaphragmatic injuries were confirmed only during endoscopic cavity revision. Left-sided diaphragmatic defects more often required laparoscopy, while right-sided defects were mainly treated with videothoracoscopy. Minimally invasive intervention in the abdominal cavity allowed us to identify a wide range of injuries to its internal organs and restore them, including the diaphragm. In all thoracoscopic interventions, damaged lungs were repaired, hemothorax was removed, bleeding was stopped, and fragments were removed from the liver, the abdominal cavity was revised, and the diaphragm was sutured. No diaphragmatic suture failures were recorded during the observation period.

Conclusions. Minimally invasive approaches provide reliable diagnosis and effective treatment of diaphragmatic injuries in combat trauma in hemodynamically stable patients. The choice of access largely depends on the side of the injury (odds ratio 7.48, p=0.031). Laparoscopy may be the method of choice for left-sided diaphragmatic injuries associated with intra-abdominal trauma. Videothoracoscopy provides better access for right-sided diaphragmatic injuries combined with blind liver damage, especially if reconstructive interventions are required for concomitant intrathoracic injuries and hemostasis of the posterior segments of the liver. Minimally invasive interventions should be included in treatment protocols for hemodynamically stable patients with combat trauma.

Keywords: combat trauma; diaphragmatic injury; thoracoabdominal injuries; laparoscopy; videothoracoscopy; minimally invasive surgery.

Traumatic diaphragmatic injuries are quite rare in peacetime, but they are associated with high mortality due to the difficulty of diagnosing these injuries and their frequent combination with severe injuries to the internal organs of the chest and abdominal cavities. According to the classification of the Japanese Association for the Surgery of Trauma (JAST), diaphragmatic injuries are divided into closed and penetrating injuries, with the latter more often associated with stab and gunshot wounds [1].

Full-scale combat operations in Ukraine have led to an increase in the number of thoracoabdominal injuries and an increase in the proportion of diaphragmatic injuries, which has stimulated the active introduction of minimally invasive methods – laparoscopy and video-assisted thoracoscopy [2, 3]. The structure of injuries largely depends on the nature of the combat operations: while high-energy bullet wounds dominated during the Anti-Terrorist Operation, FPV drone strikes, explosive ordnance, and multiple low-energy shrapnel wounds now prevail, forming complex, multi-vector wound channels and increasing the frequency of combined injuries [4]. Wound channels from modern ammunition are characterized by unpredictable trajectories and a high probability of secondary damage to the diaphragm, which is often hidden and remains unnoticed during initial diagnosis [5].

Clinical diagnosis of diaphragmatic injuries is difficult due to the nonspecific nature of the symptoms and the location and function of this organ. The diagnostic value of radiological methods is also limited. According to a

systematic review [3] involving 294 patients, the sensitivity of computed tomography (CT) for diaphragmatic injuries in penetrating trauma was only 74%, and the specificity was 92%. The difficulty of visualizing the diaphragmatic plate, the masking of defects by hematomas, and the absence of obvious signs of diaphragmatic integrity compromise early diagnosis [6].

Minimally invasive methods (laparoscopy and videothoracoscopy) play a key role in the diagnosis of hidden diaphragmatic defects in hemodynamically stable patients. Back in 1997, J. A. Murray and co-authors [7] demonstrated that up to a third of diaphragmatic injuries can only be detected by minimally invasive revision, despite the absence of data on the defect in conventional imaging. Recent studies confirm these observations and, accordingly, the importance of minimally invasive methods in trauma [2, 3, 8, 9].

Diaphragmatic injuries are dangerous both in the early stages of trauma and in the long term. Bleeding from blood vessels, pinching of the wall of a hollow organ in a small defect, displacement of abdominal organs through a large defect are accompanied by respiratory disorders of varying degrees [9]. Given the risk of serious long-term complications (late diaphragmatic hernias with the risk of organ entrapment and respiratory disorders, cardiac dysfunction), timely detection and repair of diaphragmatic defects is critically important [10]. In addition, timely separation of serous cavities prevents the spread of inflammatory complications and microflora. Given the current challenges, especially in wartime, there is an urgent need to optimize algorithms for the diagnosis and treatment of thoracoabdominal injuries using standardized minimally invasive approaches.

The aim of the study: to evaluate the effectiveness of laparoscopy and videothoracoscopy in the treatment of diaphragmatic injuries in combat trauma in hemodynamically stable patients and to compare the results with current literature data.

Materials and methods

A retrospective, single-center cohort study was based on an analysis of the surgical treatment tactics of 1,829 patients with thoracoabdominal and abdominal combat injuries between March 2023 and October 2025. The study covered both the results of diagnostic examinations of patients and a description of the intraoperative field with photo and video recording.

Criteria for inclusion of patients in the study: hemodynamic stability at the time of hospitalization; thoracoabdominal combat injury with diaphragmatic damage; laparoscopy or thoracoscopy performed; availability of complete data from imaging methods (CT, video recording and photos of thoracoscopy and laparoscopy), surgical protocols, and other data from medical records.

Fig. 1.
Frontal reconstruction of a computed tomography image: disruption of the integrity of the diaphragmatic plate on the left and signs of displacement of the abdominal organs into the left pleural cavity, compression of the left lung and displacement of the mediastinum.

Criteria for exclusion of patients from the study: hemodynamic instability requiring immediate laparotomy or thoracotomy; massive concomitant injuries and urgent conditions that made minimally invasive intervention impossible; lack of complete medical documentation.

According to data on the treatment of 1,829 wounded patients, open (standard) surgical approaches were used in 1,255 cases (thoracotomy in 298 cases, laparotomy in 957 cases, including 723 cases using damage control surgery tactics); video endoscopic interventions – in 298, among which 34 were diagnosed with diaphragmatic damage. In addition, selective non-surgical management tactics were used in 276 wounded patients.

At the initial examination stage, all thoracoabdominal injuries were considered potentially critical, which is in line with current protocols for providing care to trauma patients – Advanced Trauma Life Support (ATLS).

CT was used in all patients as the basic method of primary imaging. Given the large flow of wounded in wartime conditions, scanning was mainly performed in native mode (without contrast) to speed up the examination and decision-making process (*Fig. 1*).

At the same time, given the limited sensitivity of CT in detecting small or hidden defects of the diaphragm, the final diagnosis was made based on the results of a minimally invasive examination of the corresponding cavity with an emphasis on the surface of the diaphragm. In particular, in 11 (32.4%) patients (95% confidence

Супутні ушкодження, виявлені при лапароскопії, та додаткові втручання

Супутнє ушкодження	Кількість пацієнтів		Доступ / характер втручання
	абс.	%	
Поранення			
печінки	14	41,2	Лапароскопія/коагуляційний гемостаз
шлунка	4	11,8	Лапароскопія/зашивання дефекту
селезінки	3	8,8	Лапароскопія/коагуляційний гемостаз; 1 спленектомія
товстої кишки	2	5,9	Лапароскопія/сегментарна резекція з апаратним анастомозом, зашивання товстої кишки
Забій чи поранення легені	10	29,4	Торакоскопія/ревізія, гемостаз
Гемоторакс	12	35,3	Торакоскопія/видалення у 100% пацієнтів
Наявність сторонніх тіл (металевих осколків)	11	32,4	Лапаро– або торакоскопічне видалення

interval – CI 19.6 – 48.5%), the diagnosis of diaphragmatic injury was established de novo only intraoperatively, although the preoperative CT data were negative or inconclusive. Surgical access was chosen based on the location of the injury: laparoscopy was preferred for left-sided injuries, while right-sided defects more often required a thoracoscopic approach, since the possibilities for examining the diaphragm from the abdominal cavity were limited by the location of the liver.

The surgical technique was standardized in accordance with existing descriptions of the standardization of diagnostic and therapeutic laparoscopy for trauma [6, 11]. Laparoscopy was performed with the patient lying on their back using 3–4 trocars. For better visualization of the left dome of the diaphragm, a moderate Trendelenburg position and a right tilt of the operating table were used. The pressure for carboxyperitoneum was maintained at 12–14 mm Hg. Thoracoscopy required the patient to lie on the healthy side and selective intubation for lung collapse on the side of the injury. Revision was performed through 2–3 ports. Diaphragmatic defects were sutured using barbed suture material, namely V–Loc™ 180 (polydioxanone, which is slowly absorbed), which greatly facilitated the formation of a uniform suture and reduced the duration of the intervention in conditions of limited operating space. During the procedure, the damaged area was revised and concomitant injuries were treated: hemostasis, suturing of hollow organs, lungs, removal of foreign bodies and hemothorax, sanitation and drainage of the pleural and abdominal cavities.

The statistical analysis was descriptive and aimed to assess the frequency of diaphragmatic injuries, their distribution depending on the location and type of access, as well as associated injuries. Quantitative indicators with normal distribution (in particular, the time from injury to surgery and the duration of hospitalization) are expressed

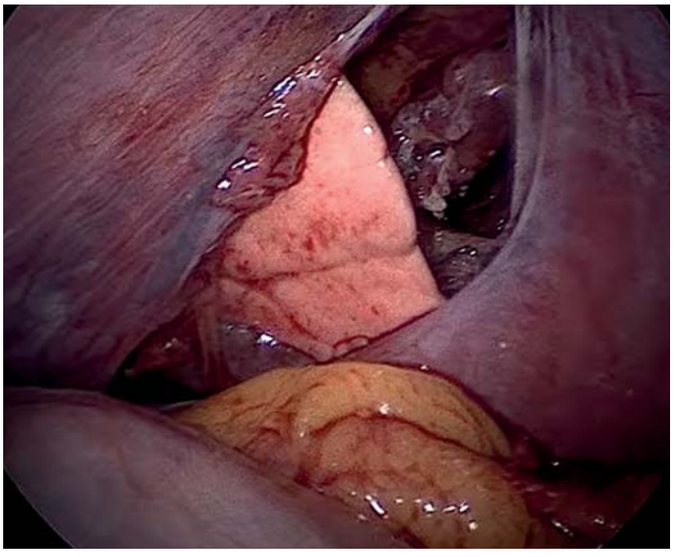

Fig. 2.
Intraoperative photo.
Significant defect (injury) of the left dome of the diaphragm, detected during laparoscopy.

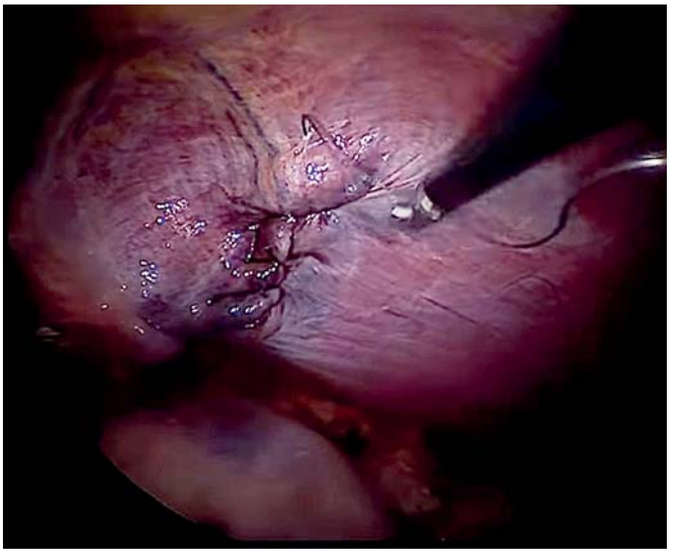

Fig. 3.
Intraoperative photo.
Appearance of the defect in the left dome of the diaphragm after suturing with V-Loc™ suture material.

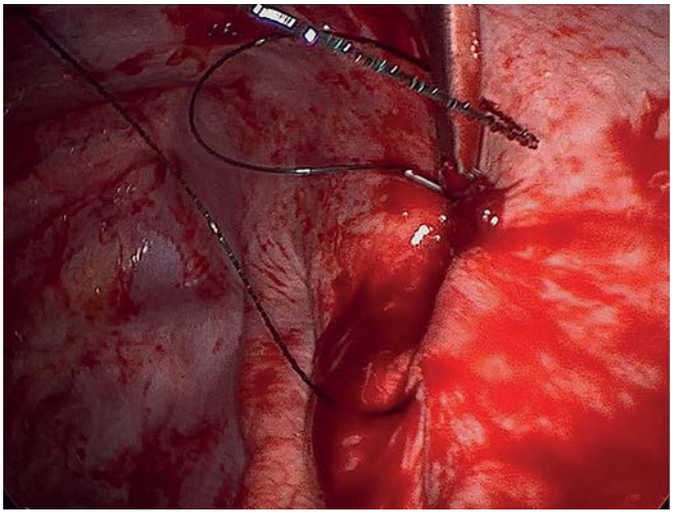

Fig. 4.
Intraoperative photo.
Thoracoscopic access (left pleural cavity):
the defect was sutured using V-Loc™ suture material
after removal of the collapsed hemothorax.

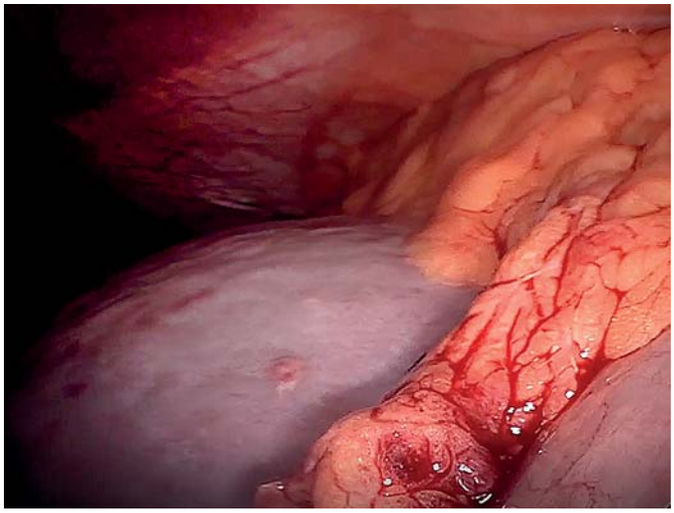

Fig. 5.
Intraoperative photo.
Thoracoscopic access:
through the defect of the left dome of the diaphragm,
the spleen was examined.

as the arithmetic mean and standard deviation, categorical variables – as absolute values and proportions with a 95% CI calculated using the Wilson method. To compare quantitative continuous variables, we used an independent t-test or Mann-Whitney U-test, depending on the nature of the distribution. Differences were considered statistically significant if the p-value was less than 0.05.

Results

Diaphragmatic injuries were diagnosed and confirmed during surgery in 34 (11.4%) of 298 hemodynamically stable patients with combat thoracoabdominal and abdominal injuries. The choice of surgical approach clearly depended on the side of the injury. The choice of method was also influenced by the approximate trajectory of the shrapnel and the probable predominance of injuries in the chest or abdominal cavity.

Laparoscopy was more commonly performed for left-sided defects, while a significant proportion of right-sided defects required thoracoscopy due to limited exposure associated with the liver mass. Of the 22 patients with left-sided injuries, 17 underwent laparoscopic surgery and only 5 underwent thoracoscopic surgery; in contrast, for right-sided injuries, the trend was almost the opposite—thoracoscopy was preferred and performed in 9 patients, while laparoscopy was performed in 3 patients. Statistical analysis of the association between the side of the injury and the choice of access showed a significant relationship: according to Fisher's test, p = 0.031, the odds ratio (OR) for the frequency of laparoscopy in left-sided defects was 7.48 (95% CI 1.39–40.2). Thus, the probability that a left-sided diaphragmatic defect would be repaired laparoscopically was almost 7 times higher than the probability of laparoscopy being performed for right-sided defects.

During laparoscopy, concomitant damage to the abdominal organs was often detected (*see table*).

In the vast majority of patients, minimally invasive revision allowed the detection of injuries that were not diagnosed by CT or were nonspecific in nature. Most often, these were liver injuries – in 14 (41.2%) patients (95% CI 26.7–57.8%). In 11 (32.4%) patients (95% CI 19.2–48.9%), foreign bodies (metal fragments) were identified intraoperatively, most often located in the subdiaphragmatic spaces. Hemothorax of varying degrees was detected in 12 (35.3%) patients (95% CI 21.5–52.1%), confirming the high frequency of combined pleural lesions requiring surgical intervention in thoracoabdominal injuries. Injuries or contusions of the lung parenchyma were diagnosed in 10 (29.4%) patients (95% CI 17.0–45.6%), stomach injuries in 4 (11.8%) patients (95% CI 4.7–26.5%), the spleen in 3 (8.8%) patients (95% CI 3.0–23.0%), and the colon in 2 (5.9%) patients (95% CI 1.6–19.1%). All identified concomitant injuries required surgical intervention and appropriate treatment tactics: hemostasis, suturing of defects, resection of intestinal segments, or removal of foreign bodies (*Figs. 2, 3*).

The results of thoracoscopic interventions were particularly revealing: in all 12 patients who underwent thoracoscopy, hemothorax was detected and evacuated, and complete sanitation of clots and liquid blood from the pleural cavity was performed, the diaphragmatic defect was sutured, and drainage was installed (*Fig. 4*). The accessible part of the abdominal cavity was also examined (*Fig. 5*).

These data confirm that thoracoscopy allows not only to accurately visualize the diaphragmatic defect, but also to treat concomitant injuries that are inaccessible from

the abdominal access and to perform a revision of the abdominal cavity.

In most patients, diaphragm reconstruction was performed using pointed suture material, which facilitated manipulation and ensured even tension distribution in conditions of limited operating space. The postoperative course was favorable: there were no significant complications requiring repeat surgical interventions. No diaphragmatic suture failure was observed. The average time from injury to surgery was (4.5 ± 2.1) hours, reflecting the effectiveness of triage and stabilization of patients in the acute phase of trauma. The average length of hospital stay for patients after successful minimally invasive surgery was (5.1 ± 1.3) days. The favorable postoperative course and minimal complications, which are characteristic of minimally invasive surgery, enabled rapid further evacuation of patients. Patients who did not require further evacuation were given a 30-day leave of absence.

Thus, the results of the study confirm that minimally invasive methods of diagnosis and treatment provide high accuracy in detecting diaphragmatic injuries in hemodynamically stable patients with combat- d thoracoabdominal trauma, and also allow for timely and complete correction of injuries in adjacent cavities that may remain undetected by CT performed before surgery.

Discussion

Diaphragmatic injuries in combat thoracoabdominal trauma remain one of the most diagnostically challenging categories of injuries. Due to the nonspecific nature of clinical symptoms, the frequent predominance of other life-threatening conditions, and the anatomical features of the diaphragm, there is a high risk of missing defects at an early stage. According to recent reviews, even in highly specialized centers, the frequency of initially unrecognized diaphragmatic injuries is significant [2, 13]. A meta-analysis by A. Hassankhani et al. [3] showed that the sensitivity of CT in penetrating diaphragmatic trauma was only 74%, and it was possible to detect small or hidden defects in less than 60% of patients. Our data confirm these observations: in 32.4% of patients, diaphragmatic defects were detected only intraoperatively, despite CT scans. Combat injuries further complicate the interpretation of tomograms: multivector wound channels formed by shrapnel or secondary injurious elements from FPV drones form paradiaphragmatic hematomas and artifacts that mask the defect. Modern ammunition creates complex damage patterns that only partially correspond to the trajectory of the channel from a foreign body [4].

Laparoscopy and video-assisted thoracoscopy should become standard diagnostic procedures for hemodynamically stable patients [2, 5]. It should be noted that minimally invasive repair was used for diaphragmatic injuries of grades II–III according to the AAST classification. Laparoscopy proved to be particularly useful for left-sided injuries, which is consistent with the classic works of Mjoli et al. Koto et al., and data from a number of studies conducted in South Africa, Europe, and the United States, according to which left-sided defects accounted for 70–80% of clinically verified diaphragmatic injuries [5, 6, 8]. The anatomical accessibility of the left dome of the diaphragm and the absence of bulky organs ensure higher diagnostic accuracy of laparoscopy and allow for simultaneous treatment of concomitant injuries to the stomach, spleen, or colon [6, 8]. Our data are fully consistent with these observations: laparoscopic access was used in 17 of 22 patients with left-sided defects, which was statistically significantly different from the corresponding indicator for right-sided injuries—laparoscopy was performed in 3 of 12 patients.

Right-sided diaphragmatic injuries are difficult for laparoscopy due to limited exposure caused by the liver mass. That is why videothoracoscopy remains the optimal access for revision of the entire right dome, as it provides direct visualization of the diaphragm, pleural cavity, and paravertebral areas. In our study, thoracoscopic interventions were performed in 12 patients, and in all of them, they allowed not only to identify the defect but also to eliminate concomitant injuries in the pleural cavity, perform sanitation and , and establish drainage. Similar data are contained in recent reviews on the role of videothoracoscopy in combat surgery [5].

Concomitant injuries to the chest and abdominal organs largely determine the treatment tactics for patients with thoracoabdominal injuries. Liver injuries in this type of trauma occur in more than half of the victims, while stomach and colon injuries occur in 15–25% [2, 5, 6, 8, 11]. This combination of injuries not only increases the complexity of the initial diagnosis, but also increases the risk of missing diaphragmatic defects, as the surgeon's attention is naturally focused on controlling bleeding and eliminating life-threatening injuries to parenchymal and hollow organs. In the wounded patients we studied, liver injuries also dominated (41.2%), confirming the need for careful sequential revision of the diaphragm during laparoscopic surgery, even in the presence of obvious abdominal injuries. Injuries or contusions of the pulmonary parenchyma and hemothorax, found in 29.4% and 35.3% of patients, respectively, reflect the characteristic pattern of combined thoracoabdominal injuries and correlate with the corresponding data from the study by D. Gillaspie et al. [2]. The presence of these concomitant injuries in combat trauma further complicates the interpretation of CT scans, as they can mask diaphragmatic defects due to lung collapse, the presence of clots, and diaphragmatic movements. This highlights the importance of minimally invasive

surgical revision as a method that not only allows for the treatment of associated injuries, but also reliably excludes or confirms the presence of diaphragmatic defects.

An important aspect that deserves attention is the technical execution of a surgical maneuver such as diaphragmatic suturing. Under conditions of limited visualization, particularly in minimally invasive surgical approaches, the use of barbed suture materials such as V-Loc™, which take up to 180 days to dissolve, greatly simplifies the surgeon's work and promotes the formation of a uniform suture line. The advantages of V-Loc™ in diaphragm reconstruction are well known [13]. We used this material in 100% of patients, and no suture failure was recorded during the observation period.

Our results also confirm the effectiveness of the concept of "forward surgical minimal invasiveness," which is being actively implemented in NATO military medical units and adapted in Ukraine. Research by I. Lurin and co-authors [5] has shown that laparoscopy and thoracoscopy can be safely integrated into Role 2 medical care, which will significantly reduce the number of negative laparotomies and missed diaphragmatic injuries. Our data provide grounds for extending this statement to Role 3 medical care conditions.

Surgical repair of the diaphragm (closure of the defect) prevents transdiaphragmatic passage of fluid and pathogens, thereby reducing the risk of pleural complications (e.g., empyema) and spread of inflammation from the abdominal cavity to the chest cavity. A retrospective analysis involving 192 patients with penetrating diaphragmatic injuries [14] found that after surgical repair of the injury, post-traumatic empyema developed in 5.7% of patients, and identified the main independent risk factors for this complication : a significant degree of severity of concomitant chest trauma and the presence of severe contamination of the abdominal cavity during injury increased the likelihood of transdiaphragmatic spread of infection.

Remote complications in cases of missed or untimely diagnosed diaphragmatic injuries require special attention. Late diaphragmatic hernias, as one of the most dangerous consequences of unnoticed defects, can manifest months or even years after the initial injury, often in the form of acute intestinal obstruction, necrosis of strangulated organs, or severe respiratory disorders [11]. In military conditions, these risks increase significantly, as patients often undergo several stages of evacuation, have limited access to highly specialized medical care after discharge and continuation of military service (especially in frontline units), while changes in intra-abdominal pressure, physical exertion, and recurrent traumatic influences can contribute to the progression of even minor defects. Up to 20–30% of diaphragmatic hernias after trauma are already detected at the stage of complicated course, which significantly worsens the prognosis and requires open reconstructive interventions [2, 10, 14]. Early minimally invasive revision with suturing of even small and, at first glance, clinically insignificant defects allows for the almost complete prevention of such hernias. Our results confirm the feasibility of this approach, as routine minimally invasive revision allowed us to identify missed defects that, if not treated in a timely manner, could have led to the long-term consequences described above.

Thus, early surgical repair of the diaphragm should be considered not only as a treatment method but also as a key preventive measure that directly affects long-term outcomes in patients with combat thoracoabdominal trauma.

Despite the significance of the results obtained, the study has certain limitations: retrospective design, relatively small sample size, and lack of long-term follow-up for some patients. However, even with these limitations, the data obtained allow us to conclude that minimally invasive methods of diagnosis and treatment should become the basis for the management of hemodynamically stable patients with combat thoracoabdominal injuries in a Role 3 military hospital.

Conclusions

1. Laparoscopy is the optimal approach for detecting and repairing left-sided diaphragmatic injuries, whereas right-sided defects more often require thoracoscopy due to anatomical limitations caused by the location of the liver. Statistical analysis confirmed a significant association between the side of the injury and the choice of access (OR 7.48; 95% CI 1.39–40.2; p=0.031).

2. Thoracoscopy has high therapeutic value because it allows not only effective repair of the diaphragmatic defect but also complete pleural cavity sanitation ( ): in all patients who underwent thoracoscopic defect repair, hemothorax was evacuated and the pleural cavity was drained. In our study, 9 (75%) of 12 right-sided injuries were repaired using thoracoscopy.

3. CT does not provide sufficient diagnostic sensitivity for small or hidden diaphragmatic defects. In particular, in 11 (32.4%) patients, the diagnosis of injury was established *de novo* during minimally invasive revision. This confirms the need to use laparoscopy and thoracoscopy as the definitive diagnostic standard.

4. The use of minimally invasive approaches is technically feasible, safe, and highly effective in a Role 3 military hospital. This conclusion is based on minimal postoperative complications and rapid patient recovery.

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Conflict of interest. The authors have declared that they have no conflict of interest. None of the authors received any financial or non-financial benefits that could directly or indirectly influence the content of the study.

Consent to publish. All authors have read and approved the final version of the manuscript and consented to its publication.

Ethical considerations. All procedures performed in the study involving patients complied with ethical standards of clinical practice and the 1964 Declaration of Helsinki, as amended.

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