Review

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Diaphragmatic Injury in Multisystem Closed Abdominal Trauma: Features of Diagnosis and Treatment

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INTRODUCTION In connection with the increase in the number of cases of combined and multiple injuries among the population, a proportional increase in the number of cases of diaphragm injury is also observed. In this case, shock is observed, damage to the organs of the chest and abdomen prevails in the absence of strictly specific clinical symptoms of diaphragm rupture, which leads to a large percentage of medical and diagnostic errors and complications. The described difficulties in diagnosing cases of diaphragm injury dictate the need to develop a standardized approach to the management of this category of patients.

AIM OF STUDY Refinement of the treatment and diagnostic approach to the management of patients with concomitant blunt trauma and diaphragm injury from the view of modern diagnostic and surgical technologies.

MATERIAL AND METHODS The literature review presents materials of domestic and foreign publications for the period from January 2015 to December 2020, obtained from electronic databases of medical literature PubMed, Cochrane Library, Scopus, eLibrary using the primary search strategy for the following search queries: diaphragm damage, diaphragm rupture, multisystem injury of the chest and abdomen, tactics of multi-stage surgical treatment, closed abdominal trauma, treatment and diagnostic algorithm, thoracoscopy, thoracotomy, laparoscopy, laparotomy (total 308 publications), with subsequent exclusion of experimental studies, non-full-text articles, publications not in Russian or English, manuscripts on open trauma and post-traumatic diaphragmatic hernia older than 30 days old from the moment of injury. The data extraction method was performed by two researchers independently of each other. The analysis was made of multicenter studies, systematic reviews, large case series, original articles (14 retrospective selective studies from 1994 to 2018; a total of 928 patients with closed diaphragmatic injury) and one meta-analysis (2023 patients).

RESULTS The treatment and diagnostic algorithm for multisystem closed diaphragmatic injury has been standardized based on the hemodynamic status of the patient, the indications for minimally invasive and open interventions in this category of patients have been clarified, and a description of the staged surgical treatment has been given.

CONCLUSION Timely diagnosis, minimally invasive interventions in the treatment of diaphragmatic injuries, as well as their stage-by-stage organization in conditions of severe polytrauma contribute to a decrease in mortality.

Keywords: closed abdominal trauma, multisystem injury, closed diaphragmatic injury, diaphragm rupture, laparoscopy, thoracoscopy, tactics of multi-stage surgical treatment

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AC – abdominal cavity
BPsyst – systolic blood pressure
CI – confidence interval
DR – diaphragmatic rupture
EchoES – echoencephaloscopy
EE – endovascular embolization
FG – free gas
FF – free fluid
HR – heart rate
MRI – magnetic resonance imaging
MSCT – multislice computed tomography
MV – mechanical ventilation
PC – pleural cavity

RH – retroperitoneal hemorrhage
RR – respiratory rate
RS – retroperitoneal space
URT – upper respiratory tract

INTRODUCTION

Diaphragm ruptures occur in 0.46-8.8% of cases of closed multisystem trauma of the chest and abdomen due to a dramatic increase in intra-abdominal pressure during traffic accidents (70-90%), falls from a height (8.3-25%), direct impact, forced lifting of heavy weights [1-6] .

Of all victims, 90–92.2 % are people of working age (average age is 32–34 years [7–9]), predominantly men (2–4 times more often) [4, 7, 10]. In an isolated closed abdominal injury, the diaphragm is damaged 5–6 times more often than in a similar chest injury [1].

DR are diagnosed in 68-90 % of cases on the left, on the right – in 10-25 % of cases, due to the protective role of the liver [1, 4, 11]; at the same time, autopsy data show approximately the same frequency of right and left ruptures. The results obtained are associated with the fact that the right-sided ruptures are often combined with severe trauma of the liver, inferior vena cava, and hepatic veins [11] and are accompanied by high mortality at the prehospital stage [2, 5, 12–14]. Bilateral rupture occurs in 1.5–10 % of cases [5 , 11, 12], cases of such ruptures with damage to the pericardium and displacement of the abdominal organs into the pericardial cavity (0.9%) have been described [1, 15]. The direct closed damage to the muscular part of the diaphragm by fragments of the VII-XII ribs is possible [4]. With a similar area of the diaphragm defect, prolapse of the AC organs into the left pleural cavity is observed 25 times more often than into the right one. In 56.5–73.2 % of cases, the tendon center of the diaphragm is damaged, which is due to its lower plastic properties [2, 4, 5, 16, 17] .

Isolated closed diaphragm injuries are observed in 1.6-6 % of cases. Most often, diaphragmatic ruptures are accompanied by damage to the lungs (18-48.7%), liver (24.1-48%), spleen (17.2-44.8%), small and large intestines (34%) and their mesentery (12.7%), greater omentum, kidneys (16–24.2 %) [1, 4, 8, 18–20] .

The stomach (50–54%) [11, 21], spleen (26%), omentum, loops of the large and small intestine (13%) can move into the pleural cavity through the hole in the diaphragm; liver, gall bladder, right kidney and greater omentum in the right-sided ruptures [1, 5, 6, 12]. The movement of internal organs through a defect in the diaphragm can occur immediately at the time of injury or much later, often even after several months or years after injury [1, 17, 20, 22], including two-stage diaphragm ruptures [1, 12 , 17, 23].

Diagnostic errors in diaphragmatic ruptures are quite common due to the severe condition of the victims (61.1%), the polysymptomatic nature of the clinical picture of combined and multiple injuries, and the absence of signs specific for diaphragm damage [1, 8, 24, 25]. Moreover, this pathology in most cases is not detected in a timely manner, and in almost 50% of cases post-traumatic diaphragmatic hernias are formed [1, 19]. Based on the analysis and systematization of literature sources, an algorithm for diagnostics and tactics in case of combined trauma of the chest and abdomen and suspected damage to the diaphragm was determined, which makes it possible to standardize approaches to the management of such patients (figure) [1, 8, 10, 26, 27].

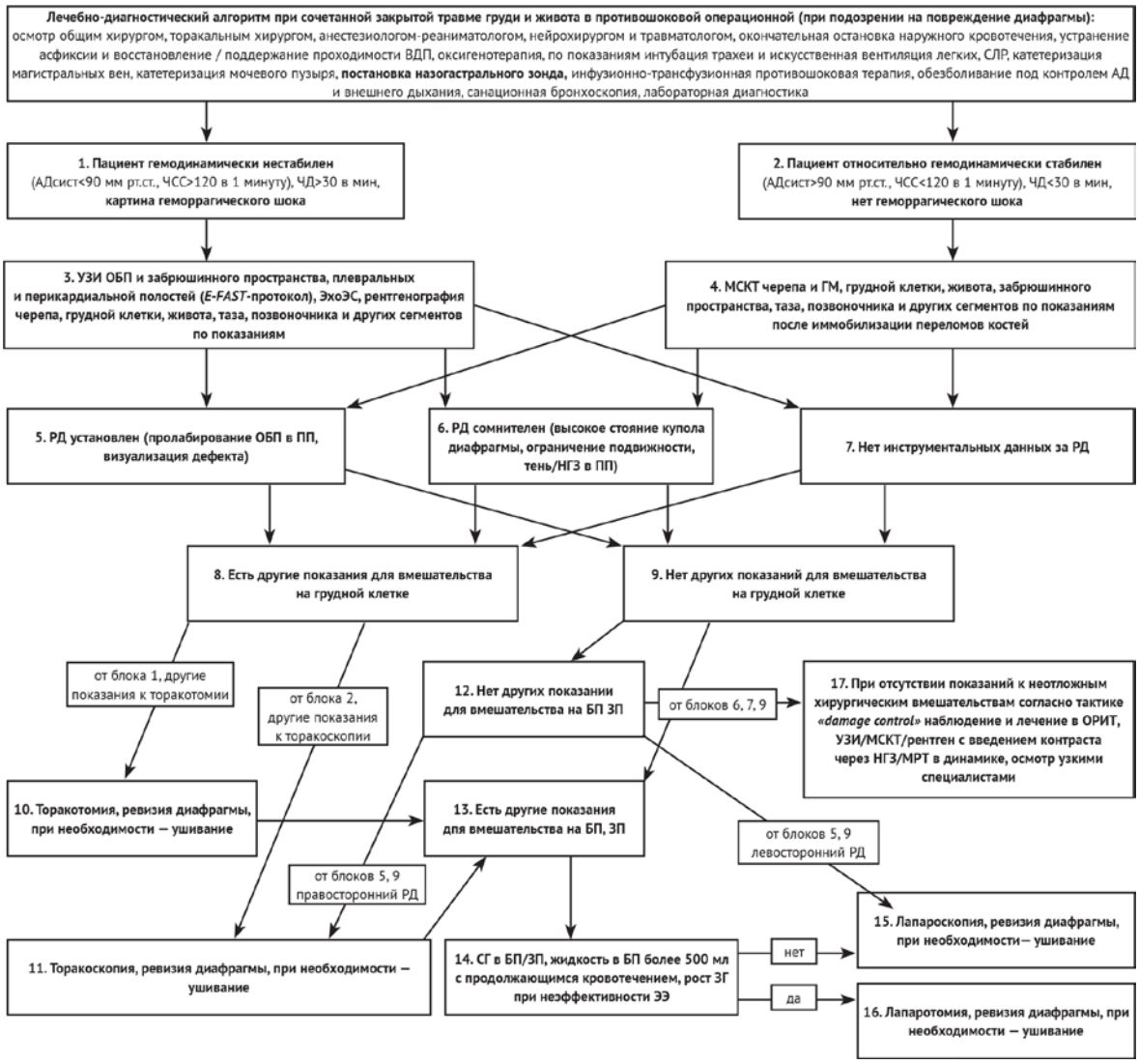

Figure. Therapeutic and diagnostic algorithm for combined blunt abdominal trauma and suspected diaphragmatic injury
АД — blood pressure, АДсист — systolic blood pressure, БП — abdominal cavity, ВДП — upper respiratory tract, ГМ — brain, ЗК — retroperitoneal hemorrhage, ЗП — retroperitoneal space, МСКТ — multispiral computed tomography, МРТ — magnetic resonance imaging, НГЗ — nasogastric tube, ОБП — abdominal organs, ОРИТ — intensive care unit, ПП — pleural cavity, РД — rupture of the diaphragm, СГ — free gas, СЛР — cardiopulmonary reanimation, УЗИ ОБП — ultrasound examination of the abdominal organs, ЧД — respiratory rate, ЧСС — heart rate, ЭхоЭС — echoencephaloscopy

1. **In case of hemodynamic instability of the patient** (BPsyst <90 mmHg, heart rate>120 per minute), respiratory rate>30 per minute, an obvious clinic of hemorrhagic shock (block 1 of the Figure), an ultrasound examinatio is performed in the anti-shock operating room organs of the AC and retroperitoneal space (RS) (level of evidence – A, strength of recommendation – 1; A1 [26]) [4, 7, 27] (if a retroperitoneal hematoma is detected, an ultrasound assessment of the presence of blood flow in the hematoma is performed as a sign of ongoing bleeding), scanning of the pleural and pericardial cavities (E-FAST protocol) to search for free fluid (FF), pneumothorax; perform echoencephaloscopy (EchoES), radiography of the skull, chest, abdomen, pelvis with the capture of the hip joints, spine; other areas if indicated, in parallel with resuscitation (block 3 of the Figure) [26, 27].

Direct ultrasound signs of diaphragm rupture are the presence of abdominal organs in the pleural cavity (12.9%) and a defect in the diaphragm in the form of an oscillating valve leaf (4.7-8.1%); indirect – elevated diaphragm (11.3%) and the absence of its excursion during breathing, the presence of FF above (62.9-100%) or

under (41.9-92.1%) the diaphragm, mediastinal displacement (6.5 %), pneumothorax (44%) [3 – 5, 16]. Diaphragm rupture detection during ultrasound is most informative in the presence of organ dislocation and separation of the pleura with intrapleural fluid (blood) [4, 5, 20].

X-ray: with diaphragm ruptures of more than 4–5 cm and extended detachments from the ribs, the displaced organs of the AC are visualized in the pleural cavity (direct sign; 45.2–60 % [4, 15]) with compression of the lung and dislocation of the mediastinum to the healthy side (indirect signs) [13, 16, 23].

When the diaphragm ruptures on the left and the stomach moves through the defect of the diaphragm into the pleural cavity, a large cavity with a horizontal level of fluid can be determined. Multiple horizontal levels in the pleural cavity indicate the movement of intestinal loops (2.4%) [16]. In a rupture not complicated by organ prolapse, there is a limitation of diaphragm mobility and an its elevation (15.3%) [16, 21].

Hemothorax occurs in 80–97 % of cases [15, 16, 18, 25]. In 2-7.5% of cases, pneumomediastinum occurs, in 19.4-23% – intrapulmonary hematoma/pulmonary contusion, in 40.3-48.4% – subcutaneous emphysema, in 50-79.3% – rib fractures, in 24.1-52% – pneumothorax [2-4, 10, 16, 18]. Elevation and limited mobility of the diaphragm, as well as its paradoxical movements, can also occur in traumatic paresis without rupture [1].

The greatest difficulties arise in the differential diagnosis of right-sided clotted hemothorax and rupture of the right cupula of the diaphragm [19]. At the same time, traumatic hemothorax can actually mask damage to the diaphragm, or the shadow of an organ moved into the pleural cavity can be taken for it [1, 8, 19, 25].

The sensitivity of radiography in the diagnosis of diaphragmatic ruptures is 25-54% (up to 63% for left-sided injuries, 17-38 % for right-sided ones), with prolapse of hollow organs into the pleural cavity – 86%, ultrasound – 62-73% [3, 5, 7, 10, 13, 19].

In all cases of combined injury, with simultaneous indications for emergency interventions on the organs of the chest and abdominal cavity, first of all, interventions on the chest are performed as a resuscitation measure and to prevent ventilation disorders during mechanical ventilation (MV), then other urgent surgical interventions (blocks 5, 6, 7→8→10, 11 Fig.). During thoracoscopy/thoracotomy, if a diaphragm rupture is detected, it is sutured (blocks 10, 11 of Fig.) [14, 16, 27].

In the presence of unstable hemodynamics and signs of ongoing intra-abdominal (with FF more than 500 ml)/retroperitoneal bleeding (blood flow in the retroperitoneal hematoma), the presence of free gas (FG) in the AC/RS, or diaphragm rupture, an emergency laparotomy is performed (A1 [26]) [27]/revision of the RS (blocks 13→14→16 Fig.) [4, 7, 9, 16]. If there are no obvious sources of bleeding in the AC during laparotomy, and blood from the pleural cavity enters through the rupture of the diaphragm, it is necessary, without suturing the laparotomy wound, to turn the operating table by 45° and perform anterior-lateral thoracotomy. An attempt to revise the pleural cavity through a rupture of the diaphragm in unstable hemodynamics and massive hemothorax is inappropriate, since it does not provide quick access to the source of bleeding, will lead to loss of time and aggravation of the patient's condition [26].

In case of a smaller volume of hemoperitoneum or uninformative ultrasound with the absence of FG in the AC/RS, or in the absence of FF/FG in the AC/RS, but the “restless” abdomen, the question of laparotomy is resolved after diagnostic peritoneal lavage (A1 [26]) [27].

In the absence of indications for emergency laparo-/thoracotomy, X-ray examination with contrast injection through a nasogastric tube (blocks 6, 7, 9, 12 → 17 Fig.) is possible for differential diagnosis of total hemithorax occlusion syndrome [18, 23].

2. **If the patient is relatively hemodynamically stable** (systolic blood pressure > 90 mm Hg, heart rate <120 per minute), respiratory rate <30 per minute, there are no obvious signs of hemorrhagic shock (block 2 of Fig.), multispiral computer t homography (MSCT) of the skull and brain, chest, abdomen (A1 [2]) [4, 7, 8, 14, 18, 22, 28, 29], pelvis with capture of the hip joints, spine, and other segments-according to indications; in cases of suspected damage to large vessels and parenchymal organs of the chest/abdominal cavity/PC and/or FF in the pleural cavity (PC)/AC and the absence of FG in the AC/RS, the examination is supplemented with angiocontrast to identify the source of possible bleeding and endovascular embolization (EE) (block 4 Fig.) [26, 27].

With the help of MSCT in the acute period, both diaphragmatic rupture (21.1–54.3 % [4, 25, 29]) and dislocation of abdominal organs (32.3% [4, 24]) with the presence of “cuff” symptoms are detected or “hourglass” in case of compression of hollow organs or “hump” symptom in case of compression of the liver in a diaphragm defect [22], signs of liver damage, hemo-/pneumothorax (96%) [12, 14, 18, 28, 29], elevation of the diaphragm [22]. Oral contrasting and three-dimensional reconstruction increase the diagnostic value of the study [22, 29].

In case of ineffective EE, detection of diaphragmatic rupture and SF in the BP more than 500 ml, growth of retroperitoneal hematoma, signs of damage to a hollow organ, a clear clinical signs of peritonitis, laparotomy is urgently performed (blocks 4 → 5, 6, 7 → 8, 10, 11 / 9→13, 14, 16 Fig.) [4, 7, 9, 16, 27, 30]. In case of ineffective EE, the presence of diaphragmatic rupture and the amount of FF in the abdominal cavity is less than 500 ml, laparoscopy is performed (blocks 4→5, 6, 7→8, 10, 11/9→13, 14, 15 Fig.) (after drainage of the pleural cavity; for video-assisted laparoscopy, dosed insufflation of the gas mixture is necessary!) to stop bleeding, suturing the diaphragm, sanitation and drainage of the AC [4, 27]. It is also indicated in cases of larger amount of FF, but in the case of arrested bleeding (effective EE) or the absence of extravasation of a contrast agent (rupture of a hollow organ/spontaneously ceased bleeding?), suspected diaphragmatic rupture (with carboxyperitoneum up to 600 ml with an initial examination of the diaphragm) for diagnostics, sanitation and drainage of the abdominal cavity. With an unexplained source of ongoing bleeding or ineffective hemostasis, access conversion is performed [9, 16, 21, 27, 29].

MSCT sensitivity for diaphragmatic rupture on the left is 78-100 %, on the right is 50% , specificity is 100% on the left and 83% on the right [6, 12, 13, 19-21 , 30]; general sensitivity of MSCT according to V.A. Leung et al. (2015) [31] was 66.7% (95% CI 46.7-82.0%), specificity – 100% (95% CI 94.1-100%), positive predictive value – 100% (95% CI 80.6-100%), negative predictive value – 88.4% (95% CI 78.8-94.0%), accuracy – 90.6% (95% CI 82.5-95.2%). The sensitivity of thoracoscopy is 100% [24, 29, 30], laparoscopy for left-sided injuries is 95.2–100 %, for right -sided injuries is 74 % (difficulty in revision of the posterior inferior sections), specificity is 100%, predictive efficiency is 96.8% [1, 4, 8, 9, 16].

TREATMENT

In contusions (AAST I) and small right-sided diaphragm defects (AAST II, ⩽ 2 cm), non-operative management is possible due to the rare occurrence of hernias, while at the same time, there are no studies in the world literature devoted to long-term results [7, 8, 32].

After establishing the diagnosis of a closed rupture of the diaphragm, an emergency operation is indicated [2, 8, 20, 33, 34], which purpose is to eliminate the compression syndrome (return of the abdominal organs to their natural anatomical conditions), remove devitalized tissues and eliminate the diaphragm defect, and during relaxation – moving its cupula to its previous position. In a meta-analysis by G.P. Silva et al. (2018) [9], which included 68 studies and 2023 patients, showed that in the acute period of diaphragm rupture, laparotomy access is used in 75% (95% CI 71–78 %) [11, 25, 30, 32], providing the possibility of a full revision of the AC organs and elimination of detected injuries, since in 94-100 % of cases with diaphragm injuries there are concomitant injuries [7, 9, 19, 20, 34], thoracotomy – in 12% (95% CI 10-14 %) of cases. In case of isolated left-sided diaphragmatic rupture (especially in the first 10–14 days), laparotomy is considered to be the optimal surgical approach [13, 19, 24, 32]. To eliminate traumatic diaphragmatic hernias resulting from ruptures that were not repaired in a timely manner, to separate adhesions between the displaced organs of the

AC and intrathoracic structures, as well as for isolated right-sided ruptures of the diaphragm, thoracotomy access is used in the VII-VIII intercostal space [2, 13, 16, 21, 34]. In all cases, the defect is sutured with a non-absorbable interrupted stitch (II (diaphragm rupture ⩽2 cm)-part III (diaphragm rupture 2–5 cm) AAST) [2 , 15, 23, 28, 32] or 8/U-shaped [7, 13, 18, 32] sutures covering at least 1 cm of the defect edge and forming a duplication (part III (diaphragm rupture 5–10 cm)-IV (diaphragm rupture >10 cm with tissue loss <25 cm^2) AAST) [19, 20 , 25, 32], sometimes (5.3-26.7%) – using a polypropylene mesh (V AAST – ruptures with tissue loss > 25 cm^2) in the absence of contamination with the contents of hollow organs [3, 8, 10, 15]. When the diaphragm is torn off, it is fixed by wrapping the corresponding ribs with a ligature [1, 19, 29].

Endovideosurgery is promising in the treatment of multisystem closed injuries of the chest and abdomen with diaphragmatic rupture [8, 14, 24, 32], as it is possible to suture linear diaphragmatic ruptures more than 10 cm long and stellate ruptures up to 10 cm long (III-IV AAST) with thread or staples [1, 20, 32, 34], a 2-fold decrease in the frequency of specific postoperative complications (from 30–68 % to 12–32 %; failure of the diaphragm sutures, its partial paralysis due to damage to the phrenic nerve, subphrenic abscesses, etc.), nonspecific (pneumonia, pulmonary embolism, shock, acute myocardial infarction, etc.) – 4.8-7-fold [4], 2-fold reduction of the terms of medical rehabilitation [8].

Endovideosurgical technologies for trauma make it possible to perform interventions on the diaphragm and organs of the chest/abdominal cavity in 34.1–38.7% of the victims or, as one of the stages, on the organs of the chest or abdomen in 20–41.5 % of patients [3, 14, 16, 28]. The need for thoraco- and laparotomy occurs

in 18% of cases [1, 8, 20]. With extensive ruptures or detachment from the chest wall, the best results are observed when the rupture is repaired with a mesh allograft with its fixation with a stapler or suturing. The use of implants with one-sided adhesion is optimal to prevent complications associated with the development of adhesions in the subdiaphragmatic space. In 2020, an article was published on successful robot-assisted transthoracic closure of a right-sided diaphragmatic rupture of 9 × 11 cm in the acute period of injury in a hemodynamically stable patient [33]. Limitations for the use of minimally invasive techniques are a pronounced adhesive process, the general condition of the patient, which prevents the operation from being performed under conditions of increased intra-abdominal pressure, and hemodynamic instability [32, 33, 34].

In patients with hemorrhagic shock (with unstable hemodynamics requiring inotropic support (BP system <70 mmHg for more than 2 hours)), combined (C1 [26]) and multiorgan damage, ongoing bleeding (the need for blood transfusion of more than 10 doses of erythrocyte weight), leading to metabolic acidosis (pH<7.2; serum lactate>5 mmol/l (B1 [26]); base deficiency<-10-15 mmol/l), hypothermia (<34°C) and coagulopathy (activated partial thromboplastin time (APTT) > 60 sec., thrombocytopenia <90x10 9 l) (B1 [26]), with a total severity score of more than 21 on the APACHE- II scale, it is recommended to use staged treatment in accordance with the principles of "damage control" (DC) (B1 [26]) [8, 20, 25, 34]:

1st stage-primary emergency operation in a reduced volume: laparo-/thoracotomy, temporary or final stop of bleeding. When bleeding from diaphragmatic ruptures, they are sutured. In the absence of bleeding from them and the movement of the abdominal organs into the pleural cavity, no interventions on the diaphragm are performed during the primary laparotomy [8, 20, 25, 32, 34].

2nd stage-Intensive therapy to stabilize the vital functions of the body. At this time, angiography can be performed to detect secondary bleeding with embolization [25, 32, 34].

3rd stage – re-planned surgery 24–96 hours after the first operation (B1 [26]): a thorough revision with suturing of the defects, the solution of the issue of plasty with a mesh allograft [8, 20, 25, 32, 34].

Mortality in diaphragmatic ruptures is 15.6-66.7%, and directly correlates with the severity of concomitant injuries; hospital mortality is 20–40 % [1, 3, 5, 11, 17, 18]. S. Kaya et al. (2020) [35], LF Cardoso et al. (2017) [30], KH Lim et al. (2018) [10] named right-sided diaphragmatic ruptures with concomitant liver injury (p = 0.020), unperformed surgical treatment (p = 0.003) and the severity of the patient's condition according to ISS more than 24 points (p = 0.003), preoperative shock as independent predictors of death . When using DC tactics , it is possible to reduce mortality to 10–15 % [8, 13, 20, 25, 34].

CONCLUSION

A standardized treatment and diagnostic algorithm for combined blunt trauma of the chest and abdomen contributes to the timely diagnosis of diaphragm injuries and the choice of the optimal access and treatment method based on the patient's hemodynamic status and damage localization. The use of minimally invasive interventions for diaphragm injuries, as well as their phased treatment in conditions of severe polytrauma, contributes to a decrease in mortality.

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