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The Importance of X-Ray in Examination of Lungs in Patients with Inhalation Trauma

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RELEVANCE

Inhalation trauma (IT) is a combined injury of the respiratory tract, lung parenchyma and the central nervous system. Alterations of a mucous membrane during thermochemical airway burn as a result of inhalation of combustion products is most fully described in the literature, while the lesion of pulmonary parenchyma hasn't been studied.

THE AIM OF THE STUDY

To determine the capabilities and significance of the X-ray method in the study of lungs in patients with IT.

MATERIAL AND METHODS

We examined 184 victims with IT, of which 53 patients had airways burn of the 1st degree, 92 patients had airways burn of the 2nd degree, and 39 patients had airways burn of the 3rd degree. Methods used: X-ray, chest X-ray computed tomography, ultrasound of the chest, study of the function of external respiration, morphological examination of lungs, statistical methods.

RESULTS

X-ray studies in patients with IT revealed changes in peripheral parts of both lungs like network deformation of pulmonary pattern to forms resembling "mulberries" or "a bunch of grapes". A study of the function of external respiration revealed signs of decreased lung ventilation and obstructive changes in bronchioles. The X-ray computed tomography of peripheral regions of the lungs in some patients revealed multiple local areas of reduced density with no visible walls corresponding to alveoli holding the air. Histological examination of the peripheral parts of the lungs found round air formations and significantly expanded alveoli. These changes are associated with exhalation disorders due to the constriction of respiratory bronchioles.

CONCLUSION

The X-ray method allows to detect signs of damage to the pulmonary parenchyma in patients with IT. Using a statistical evaluation, we showed that the presence of network deformation of the pulmonary pattern under the conditions of IT is an objective feature, confirmed with Cohen's kappa coefficient (0.6±0.14; 95% CI [0.32–0.88]).

Keywords: isolated inhalation trauma, X-ray of the lungs, X-ray computed tomography, network deformation of pulmonary pattern, airway burn, function of external respiration, morphological examination of the peripheral parts of the lungs

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AB — airway burn
ALV — artificial lung ventilation

b.s. — body surface
CI — confidence interval
COPD— chronic obstructive pulmonary disease
FET — Fisher's exact test
IT — inhalation trauma
IIT — isolated inhalation trauma
NDPP — network deformation of pulmonary pattern
PFT — pulmonary function test
TBT — tracheobronchial tree
X-ray CT— X-ray computed tomography

INTRODUCTION

Inhalation trauma (IT) is one of the complex problems in combustiology. According to various authors, in fires IT receives 20–33% of victims, of which 30–50% die [1-3]. In the USA, more than 20,000 victims with IT are registered annually [4]. In the burn center N.V. Sklifosovsky in 2014–2017 On average, 730 victims were hospitalized annually, of which about 20% were patients with isolated IT (IIT).

In case of fires in enclosed spaces, a complex of physical and chemical factors acts on the victim's body [5]. The concept of IT includes damage to the mucous membrane of the tracheobronchial tree (TBT), which is actually an airway burn (AB), damage to the lung parenchyma and the effects of systemic poisons. The authors note that there is no correlation between the bronchoscopic assessment of the state of TBT, the clinical course, and the outcome of IT [6, 7]. Severe clinical manifestations develop with the destruction of alveolar surfactant and exposure to systemic poisons [5]. The lack of a standard for diagnostic criteria for a comprehensive assessment of the severity of IT is a serious problem in the treatment and prognosis of the disease [8, 9].

In an experiment in sheep with IT, a significant increase in bronchial blood flow, pulmonary edema, obstruction of TBT with solid soot particles, neutrophils, epithelial cells, mucus, were revealed which lead to hypoxia and atelectasis [10].

Inhalation injury can be either isolated or in combination with burns of the skin of various sizes and severity, which mutually aggravates the patient's condition, increasing mortality by 2 times [11].

The main and reliable method for the diagnosis of AB is bronchoscopy. Endoscopic classification of AB, based on the severity of damage to the mucous membrane of the TBT was developed at the Burn Center of N.V. Sklifosovsky Research Institute. It has been used since 1990. The classification distinguishes 4 degrees: 1st degree — catarrhal form, 2nd — erosive, 3rd — ulcerative, 4th — necrotic [12].

Endoscopic and morphological (biopsy material) comparisons of IT of varying severity made it possible to study the course of AB with the traditional method of treatment and endobronchial laser therapy [13].

The study of *W.Y. Lin et al.* in 1997 with 99^{m}Tc-*DTPA* pulmonary scintigraphy showed that a nonuniform distribution of the drug consistent with a more severe failure. The authors concluded that this method provided an objective assessment of the severity of inhalation damage to the lungs [14].

X-ray computed tomography (CT) of the chest organs has been used along with bronchoscopy to diagnose AB. Studies have shown a correlation between an increase (>3 mm) in the thickness of the bronchus wall (measured at a distance of 2 cm from the bifurcation of the trachea), the development of pneumonia, and the time spent on mechanical ventilation (ALV). The authors proved the high sensitivity and specificity of the X-ray CT method for inhalation damage, revealing that a thickening of the bronchial wall leads to a decrease in air flow [15, 16].

Thus, early intravital diagnosis of lung parenchyma injuries is an urgent scientific and clinical problem. Some authors describe the radiological signs of pulmonary changes in IT as compaction of the bronchial wall, submaryngeal edema, and pulmonary edema, as a "spotty heterogeneous structure" [17–19]. It has been suggested that the X-ray method for examining lungs with IT has low-sensitivity, since almost half of patients requiring mechanical ventilation have normal lung radiographs [14, 20]. This conservative approach explains almost complete absence of domestic and foreign publications on X-ray examination of the lungs in IT.

In 2013, Professor E.A. Beresneva first drew attention to the presence of characteristic changes in radiographs of most patients with IIT in the form of network deformation of the pulmonary pattern (NDPP). The detected changes were the basis of this study.

Aim of study: to determine the capabilities and significance of the X-ray method in the study of lungs in patients with IT.

MATERIAL AND METHODS

A retrospective analysis of case histories of 184 patients with IT who were treated in the Burn Center of the N.V. Sklifosovsky Research Institute from 2014 to 2017. The criterion for including patients in the study was IT. The diagnosis of IT was made clinically on the basis of an anamnesis and examination (being in a smoky room, smoked mouth and nasal passages, coughing and sore throat, diffuse wheezing in the lungs, shortness of breath). The severity of AB was determined in primarybronchoscopy upon admission.

Statistical analysis of the data was performed using the *Statistica* 13 software package (*StatSoft, Inc.*, USA). Descriptive statistics of quantitative characteristics are presented by medians and quartiles in the format Me (LQ; UQ). Independent groups were compared using Fisher's exact test (FET). The threshold significance level *p* was taken equal to 0.05. In order to confirm the newly detected symptom of NDPP, two radiologists (experts) performed an independent assessment of the X-ray scans. Each expert confirmed or denied the presence of NDPP on the scan. The results were statistically evaluated using the Cohen's kappa coefficient with the calculation of the standard error and 95% confidence interval (CI), which makes it possible to judge the random or nonrandom coincidence of conclusions [21].

Among 184 patients, 1st degree AB was detected in 53 patients, 2nd degree trauma was diagnosed in 92 patients, 3rd degree trauma was revealed in 39 patients. In 49 patients (26.6%), there were superficial burns of the skin of the first degree (according to ICD-10) in the area from 0.1 to 10% of the body surface (b.s.), median 4.0 (2.0; 5 0)% b.s. 38 patients died.

The age of patients ranged from 16 to 95 years. Table 1 shows the medians of the age of patients with varying severity of AB.

Table 1

Characterization of patients by age with varying degrees of airways burn

Degree of AB	The number of observations	Indicators of age, years		
		Me (LQ; UQ)*	Minimum	Maximum
1	53	42 (30; 67)	20	85
2	92	57.5 (40; 72.5)	21	95
3	39	58 (41; 80)	16	90
Total:	184	54 (35; 73)	16	95

Note: * Median (25; 75 quartiles)

The distribution of patients by gender with varying degrees of severity of AB is given in Table 2.

Table 2

Characteristics of patients by gender in the presence of varying degrees of airways burns

Gender	Degree of airways burn		
	1	2	3
Women	23 (43.4%)	46 (50.0%)	16 (41.0%)
Men	30 (56.6%)	46 (50.0%)	23 (59.0%)
Total	53	92	39

Poisoning by products of incomplete combustion of various materials, including carbon monoxide, was diagnosed in 112 patients (60.9%) which is reflected in the Table 3. Clinically, this was manifested by a violation of consciousness (up to a coma). In some patients, an elevated blood carboxyhemoglobin content in the blood was determined from 8 to 27%, and the median was 21 (16.2; 24.9)%.

Table 3

Distribution of patients with airways burns depending on poisoning by combustion products

Combustion poisoning	Degree of airways burns			Total
	1	2	3	
Yes	25 (47.2%)	61 (66.3%)	26 (66.7%)	112 (60.9%)
No	28 (52.8%)	31 (33.7%)	13 (33.3%)	72 (39.1%)
Total	53	92	39	184

Among 184 patients, 121 (65.8%) did not have symptoms of respiratory failure, and 63 (34.2%) required mechanical ventilation due to respiratory failure (Table 4).

Table 4

Distribution of patients with AB, depending on the type of breathing

Type of breath	Degree of airways burns			Total
	1	2	3	
Independent	51 (96.2%)	63 (68.5%)	7 (17.9%)	121 (65.8%)
ALV	2 (3.8%)	29 (31.5%)	32 (82.1%)	63 (34.2%)
Total	53	92	39	184

All victims underwent an X-ray examination of the chest organs to study the condition of the lungs on the first day of admission to the Burn Center. For this, mobile x-ray machines were used, direct back pictures were taken.

Ten patients underwent CT studies on a *Toshiba Aquilion Prime* (80/0.5) spiral computed tomography scanner. The scanning area started from the level of the jugular notch to the lower sections of the costal phrenic sinuses, the field width involved soft tissues, the collimation of the layer was 0.5–1 mm, the reconstruction interval was 1-3 mm. Voltage 120 kW, exposure 120–140 mA (used the automatic adjustment function). A preliminary analysis of the results of spiral X-ray CT was performed on the working console. The obtained images were subjected to qualitative (position, shape, contours, structure) and quantitative analysis (dimensions in mm, volume in cm^3 , density in Hounsfield units (units N)). Then, post-processor image processing with the construction of multi-plane reformation was carried out at the workstation.

The respiratore function rest (RFT) was determined by spirometry. The study was performed on 25 patients with IIT and included measuring the vital capacity of the lungs and respiratory rate. For research, we used a computer digital spirometer, consisting of an air flow sensor and an electronic device that converts the sensor readings into digital form.

Ultrasound of the pleural cavities and lung was performed upon admission and in the dynamics on *Logiq P*6 devices using a 2–5 MHz convex sensor and a 7 MHz linear sensor. The study was performed according to the standard method described by B.E. Shakhov, D.V. Safonov [22] in a sitting position and with a modification in the patient's supine position (if possible, on his side) [23], depending on the severity of the victim's condition. On examination, the dissociation of the pleural leaves, the presence and nature of the contents of the pleural cavity, the thickness of the pleura, and the lung parenchyma from all available points along the intercostal space were assessed. Each patient underwent from 2 to 4 ultrasound of the pleural cavity.

A histological examination of autopsy material from the peripheral parts of the lungs was performed in 35 of 38 deaths. Well-known methods were used: staining with hematoxylin and eosin, picrofuchsin according to Van Gieson. Fibrin was examined using *MSB* stain .

RESULTS

When analyzing X-ray scans of patients with IT upon admission, network changes in the pulmonary pattern of varying degrees, attracted attention. These changes consisted in the disappearance of a clear vascular pattern and the appearance of either multiple round-shaped areas of enlightenment of almost equal sizes (0.3–0.4 cm) closely spaced, resembling a bunch of grapes (Fig. 1), or occupying the entire pulmonary field, as in upper and lower sections. In the peripheral parts of the lungs, more to the right, it looked like "bunch of grapes". The roots of the lungs were unchanged. The diaphragm was determined in the usual position, there were no signs of free fluid in the pleural cavities. When other changes in the lungs were detected (venous congestion, hypoventilation, pneumonia, etc.), NDPP manifested more clearly.

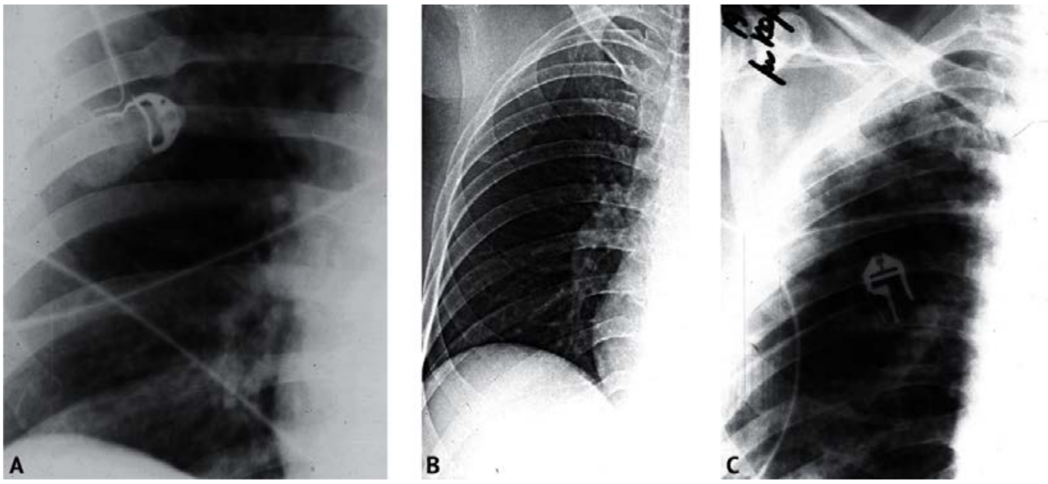

Fig. 1. X-ray images of patients with varying severity of IT. The network deformation of the pulmonary pattern is clearly defined. A — AB of 1 degree; B — AB of 2 degree; C — AB of 3 degree

X-ray scans of 184 patients were evaluated by two radiologists. The first expert revealed the presence of NUCLR in 179, and its absence in 5 patients. The second expert revealed the presence of NDPP in 171, and its absence in 13 patients. The total number of agreed independent diagnostic reports of experts was: positive - 171, negative - 5. In order to exclude accidental coincidence of the doctors' conclusions, we calculated the Cohen kappa coefficient, which was 0.6 ± 0.14 (95% CI [0.32–0.88]). The obtained result indicated that the coincidence of the conclusions of two independent medical experts was objective.

In order to exclude the effect of limited superficial skin burns on the occurrence of NDPP during IT, we compared the frequency of its detection in patients with IIT and patients with IT and limited superficial skin burns. NDPP was detected in all 49 patients with IT and skin burns and in 130 patients out of 135 with IIT. Statistical analysis did not reveal a significant difference between them (p=0.327; FET).

A pairwise statistical analysis of the frequency of detecting NDPP in patients with varying degrees of severity of AB (Table 5) showed that there was no statistically significant difference in the frequency of detection of network deformation between the groups (p=0.757, p=0.615 and p=0.443, respectively, FET).

Table 5

Comparison of network deformation of pulmonary pattern in AB of varying degrees of severity

Comparable degrees of AB	p (FET)
1 and 2	0.757
1 and 3	0.615
2 and 3	0.443

FET – Fisher's exact test

We have shown that the severity of NDPP in the presence of AB of varying severity was different, which is presented in Table 6.

Table 6

The degree of severity of network deformation of the pulmonary pattern in the presence of AB of varying severity

Degree of AB	The number of patients	The degree of severity of network deformation					
		Well-marked		Mild		Absent	
		n	%	n	%	n	%
1	53	34	64.1	18	34.0	1	1.9
2	92	68	73.9	20	21.7	4	4.4
3	39	36	92.3	3	7.7	0	0
Total	184	138	75.0	41	22.3	5	2.7

As seen in Table 6, in patients with AB of the 1st degree, well-marked deformation was detected in 34 out of 53 patients (64.1%), in patients with AB of the 2nd degree it was revealed in 68 out of 92 patients (73.9%), and in patients with AB of 3rd degree it was found in 36 of 39 patients (92.3%).

Thus, the study showed that there was a direct correlation between the severity of damage to the mucous membrane of TBT and parenchymal damage to the lung tissue, which manifested itself as NDPP (Fig. 2).

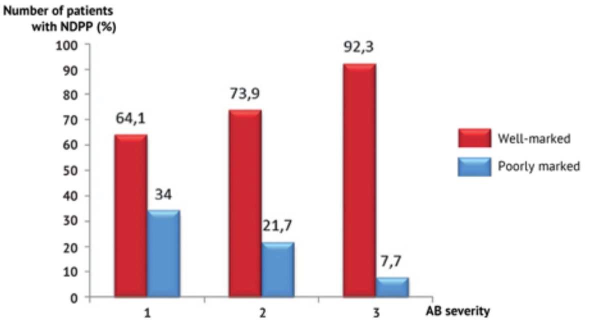

Fig. 2. The dependence of the AB severity and the significance of network deformation of pulmonary pattern

A morphological study of the lungs of 35 deceased revealed changes confirming clinical and radiological data indicating impaired expiration and accumulation of air in the alveoli (M.V. Barinova). Morphological studies of the peripheral parts of the lungs revealed a lesion of respiratory bronchioles in the form of desquamative bronchiolitis with narrowing of the lumen and significantly stretched walls of the alveoli (Fig. 3). These air formations differed from air cysts in multiplicity, close arrangement, lack of lining or capsule. There were no such changes in a morphological study of the central sections of the lungs.

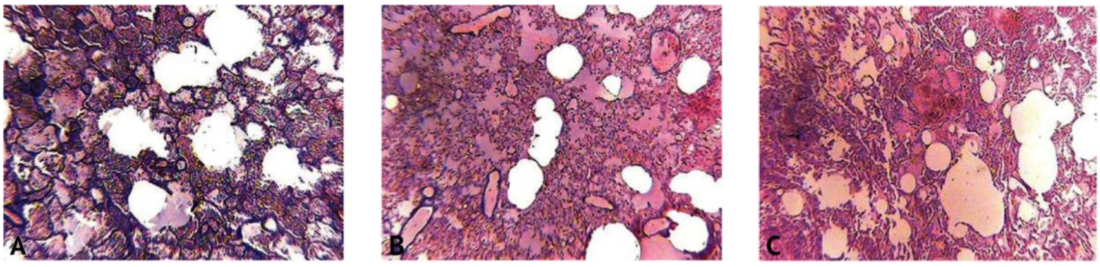

Fig. 3. The morphological changes in the lung. Against the background of inflammatory infiltration, multiple overinflated alveoli are determined as a sign of exhalation disturbance. A — AB of 1 degree. The marked white blood cells reaction with overinflated alveoli. Hematoxylin and eosin stain, magnification x200; B — AB of 2 degree. White blood cells exudate and areas of edema with overinflated alveoli. Hematoxylin and eosin stain, magnification x120; C — AB of 3 degree. Multiple overinflated alveoli of various sizes in the lung tissue. Stained with hematoxylin and eosin, magnification x100

When studying PFT in 25 patients with IIT and the 1st degree of AB, there were no functional disorders of the respiratory system; at the 2nd-3rd degree of AB, a decrease in lung ventilation, signs of obstruction of the bronchioles in combination with restrictive disorders were noted.

Ultrasound of the peripheral sections of the lungs in 4 patients with IT and severe NDPP revealed B-lines that are not specific and are determined for other diseases (pulmonary embolism, pulmonary edema, and also during mechanical ventilation). A moderate heterogeneity of the deeper layers of the pulmonary parenchyma (3-5–7 cm) was found.

When analyzing CT in 10 patients with IT, significant changes were found in one patient, mainly in the upper lobes of both lungs, as centrilobular emphysema (Fig. 4A) with changes around the terminal bronchioles, in the centers of the secondary pulmonary lobes, in the form of multiple local areas of reduced densities clearly distinguished from unchanged lung tissue. It should be noted that the patient had no history of a smoker, did not suffer from chronic obstructive pulmonary disease (COPD). In the same patient, as well as in 4 other patients, signs of thickening of the walls of large and medium bronchi were revealed, leading to a decrease in air flow (Fig. 4B, C).

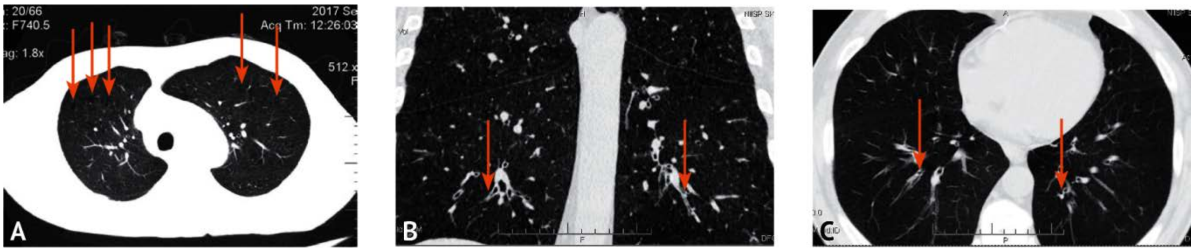

Fig. 4. CT of the chest. A — Centrilobular emphysema in a patient with inhalation trauma; B — Frontal reconstruction. Multiple local areas of reduced density without visible walls are defined, clearly delimited from the unchanged pulmonary parenchyma in both lungs, mainly in the upper lobes, in the center of the secondary pulmonary lobules. The number of vessels and their diameter in these areas are reduced. Arrows indicate the thickened walls of the segmental bronchi; C — Axial slice. Computed tomography of the chest. Arrows indicate the thickened walls of the segmental bronchi

DISCUSSION

The problem of diagnosing and treating mucosal lesions of TBT in IT has been studied in an experiment and in a clinic [5, 10, 24]. However, significant difficulties are presented by the diagnosis of damage to the final structural and functional unit of the lungs (acinus) in IT. Despite the fact that many authors consider the X-ray method for evaluating lungs with IT to be low-sensitive [15, 20], our comprehensive diagnostic study of the lungs showed that IT is accompanied by significant radiological changes in the peripheral parts of the lungs. These changes are characterized by the appearance of NDPP with the formation of a multitude of air cavities that are closely located, which are detected in the peripheral parts of all pulmonary fields in patients with IT. The close arrangement of air cavities in some cases is created by figures resembling a "bunch of grapes" or "mulberry". We did not meet in either domestic or foreign literature the results of x-ray studies in IT, which indicate air retention in the swollen alveoli as a result of expiratory disturbance. We have identified a direct correlation between the severity of AB and NDPP.

The study of the parameters of respiratory mechanics using graphical monitoring of the ventilator made it possible to identify an increase in airway resistance (*PEEP*=16±3 cm water column). Using the “exhalation delay” maneuver, signs of an “air trap” or *autoPEEP* (8 ± 3 cm water column were detected. The obtained data confirmed the alleged violation of exhalation and air retention in the swollen alveoli, which is the basis of NDPP with the formation of "clusters of grapes" or "mulberry" [25].

Our studies have shown that the informative method for the diagnosis of respiratory disorders in patients in spontaneous breathing is to determine the parameters of the RFT. The method revealed signs of obstructive and restrictive disorders that create conditions for air retention in the alveoli, which also confirmed the results of an X-ray examination. We did not find such information in literature sources. *F.W. Endorf* and *R.L. Gamelli* reported two groups of patients with IT of 0-1-th degree and 2-3-4-th degree with the definition of the following parameters: mode of ventilation, tidal volume, peak inspiratory pressure, the average pressure in airways and compliance. The study results show only digital compliance data that are not statistically different in the two groups being compared, as well as other indicators where values are not given [26].

We have not received convincing data on the deformation of the pulmonary pattern in lung CT, which may be associated with a limited number of observations and requires further research. In some patients, thickening of the walls of large bronchi was found, leading to a decrease in air flow, and the appearance of sections of centrilobular emphysema. Our data are consistent with the results of foreign studies [15, 16].

A study of pulmonary echosemiotics in individual patients with IT did not reveal signs of lung parenchyma damage, which also requires further research [22].

Histological studies of the peripheral sections of the lungs of the deceased with IT confirmed X-ray findings: the presence of a round-shaped aerial balloon, which can be regarded as swollen alveoli due to air retention due to bronchioles obstruction. Histologically similar air cyst-like structures have been described in acute poisoning with psychotropic drugs in the elderly and senile patients [27], which is why it is not possible to assert the specificity of NDPP in IIT.

CONCLUSION

Using a statistical assessment, we showed that the detection of network deformation of the pulmonary pattern during inhalation injury is not accidental, this is confirmed by the Cohen kappa coefficient (0.6 ± 0.14; 95% CI [0.32–0.88]). An X-ray method for examining the lungs reveals the network deformation of the pulmonary pattern of varying severity in most patients with inhalation injury. The incidence of cellular deformity in patients with inhalation injury was not affected by the presence of superficial skin burns with an area of up to 10% of the body surface. Cellular deformation is associated with parenchymal damage to the lungs and is caused by the development of desquamative bronchiolitis with air retention and ovevstretching of the alveoli as a result of exhalation disturbance. In the presented study, the network deformation of the lung parenchyma and the associated respiratory failure are confirmed by the results of studying the function of external respiration and autopsy material of the peripheral parts of the lungs. A direct dependence between the severity of a burn of the respiratory tract and damage to the lung parenchyma was revealed.

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