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Hydro-surgical technologies in the treatment of children with pulmonary-pleural complications of destructive pneumonia

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ABSTRACT

Drainage and endoscopic methods of sanitation of the pleural cavity do not always allow to achieve effective debridement of pathological contents.

Aims — to development and introduction into clinical practice of hydrosurgical technologies for debridement of the pleural cavity.

Material and methods. From 423 children with acute community-acquired pneumonia 88 (20.80%) children destructive pneumonia were diagnosed. Of the 88 patients with destructive pneumonia, 28 patients did not have pleural complications and were excluded from the study. 60 patients were divided into 2 groups depending on the method of surgical treatment. In the first group (n=30), two additional subgroups were formed: IA group (main n=15) — they carried out drainage and washing the pleural cavity with saline; IB group (control n=15) — only drainage of the pleural cavity. The second group (n=30) were also divided into 2 subgroups; Group IIA (main n=15) children operated according to the method of video-assisted thoracoscopic sanitations of the pleural cavity developed by us using hydrosurgical technologies; Group IIB (control n=15) — children are operated on by the method of traditional video-assisted thoracoscopic sanitations of the pleural cavity. A prospective, non-randomized, single-center study was conducted to evaluate the effectiveness of various treatments. The treatment plan was determined on the basis of a combination of anamnesis, clinical and instrumental studies and laboratory parameters.

Results. All studied in the comparison groups were homogeneous by sex, weight and height. The results of applying the Kruskal—Wallis test revealed statistically significant differences between the groups for the periods of relief of the intoxication syndrome ($p<0.001$) and the periods of relief of the pain syndrome ($p=0.012$) in favor of the main group. Summarizing all analyzing the parameters in the comparison groups allowed us to prove the advantage of the proposed treatment methods over the treatment methods used in the control groups.

Conclusion. Hydrosurgical methods of treatment demonstrate obvious clinical and economic efficacy, which leads to the rapid reexpantion of the affected lung.

Keywords: pneumonia, empyema, thoracoscopy, hydrosurgery, children.

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Background

Incidence of acute community-acquired pneumonia is still high among children and one of the main causes of infant mortality in the world [1]. Destructive forms account about 15% of all cases of community-acquired pneumonia [2]. In turn, the percentage of pulmonary-pleural forms of acute destructive pneumonia (ADP) ranges from 26.5 to 60.0% [3, 4]. These forms of pneumonia often require participation of pediatric surgeon in the treatment of these children.

Conventional methods (pleural puncture and drainage) in children with pulmonary-pleural forms of ADP are effective only at the initial stages [8]. A significant percentage (41-45%) of lowly effective treatment through the drainage is due to incomplete pleural debridement in patients with severe inflammation of pulmonary parenchyma and its collapse. These processes ultimately result sacculated cavities, fibrinous pleural adhesions and subsequent lung cortication [9].

Thoracoscopic pleural debridement has been widely introduced over the last decades. This approach became preferable for pleural complications of destructive pneumonia [10]. However, vacuum aspiration and mechanical extraction are not associated with complete debridement of inflamed pleura [11]. Attempts of complete debridement are complicated by air aspiration from the pleural cavity during thoracoscopy, that results lost visualization of surgical field and contamination of optical system. Elimination of these problems prolongs surgery. Moreover, complete removal of abnormal tissues is hampered by suction of aspirator to the affected areas, that causes bleeding and injury of inflamed pulmonary parenchyma [3].

These circumstances forced us to look for other approaches to ensure quality of pleural debridement.

Hydro-surgical methods of sanation of the wounds are successfully used in the treatment of extensive suppurative lesions of skin in combustiology. An advantage of hydrosurgical method is saline solution used in this procedure due to its safety for the patient and no allergic reactions [12]. VERSAJET™ hydrosurgery system is a surgical instrument based on high-speed fluid flow. This system allows an excision of tissues with simultaneous aspiration of detritus and fluid that reduces time and increases efficiency of surgical intervention [13]. High accuracy of fluid flow and shallow tissue cutting (approximately 1 mm) result selective excision of nonviable tissue without injury of deeper intact tissues [14]. The use of this method enhances wound healing due to less bacterial contamination and edema, as well as improved microcirculation in the wound [15]. These features facilitate lung re-expansion in early postoperative period and improve manufacturability of the procedure.

We decided to apply this technology in the treatment of children with pulmonary-pleural forms of ADP considering similar wound surfaces of lung, pleura and skin. It should be noted that we have not found information about the use of thoracoscopic hydrosurgery for pulmonary-pleural forms of ADP in children and adults in the available literature. This research was approved by the local ethical committee of the Speransky Children's Municipal Clinical Hospital № 9 (protocol of meeting No. 10 dated 25.02.2016) and the Pirogov Russian National Research Medical University (extract from the protocol of meeting No. 153 dated 14.03.2016). We acquired the first experience of hydrosurgical debridement in 2016 (patent for invention) [16].

The purpose of the research: development and introduction into clinical practice of hydrosurgical pleural debridement.

Material and methods

Destructive pneumonia was diagnosed in 88 (20.8%) out of 423 children with acute community-acquired pneumonia. Of these, 28 children had not pleural complications and were excluded from the study.

Other 60 patients were divided into 2 groups depending on surgical treatment.

Two subgroups were formed in the first group (N — 30). IA group (main, n = 15) — pleural drainage and lavage with saline; IB group (control, n = 15) — pleural drainage alone.

Similarly, there were 2 subgroups in the second group (N-30). Group II A (main, n = 15) — thoracoscopic pleural debridement using hydro-surgical technology; Group II B (control, n = 15) — conventional thoracoscopic pleural debridement.

A prospective, non-randomized, single-center study was conducted to evaluate the effectiveness of various treatment methods. Treatment strategy was determined considering data of anamnesis, clinical, instrumental and laboratory examination.

Pleural puncture and drainage including fractional lavage

Transthoracic pleural drainage is well known and does not require detailed description. It should be only noted that we used ultrasound-assisted pleural drainage under general anesthesia **(Fig. 1 a)**.

a b

***Fig. 1*: a — US-navigation before pleural drainage; b — fractional pleural lavage.**

Fig. 2: **a — Venturi effect, b — Variants of manipulator handle bending (explanations in the text).**

Video-assisted thoracoscopic pleural sanation

All procedures were performed under general anesthesia with mechanical ventilation. The first 5-mm port was placed over the largest pleural effusion and fibrinous adhesions according to preoperative ultrasound of the pleural cavity. Some patients had not a free pleural cavity. In these cases, we formed the cavity using a telescope tube with sterile saline solution injection up to 2 liters (temperature up to 37 degrees Celsius). Coarse fibrinous adhesions between visceral and parietal pleura were dissected. A significant volume of fibrinous detritus was removed from the pleural cavity using endoscopic manipulator. If endoscopic removal of detritus was technically impossible, we applied a prolonged (up to 1 cm) incision within the placement of the additional trocar.

Hydro-surgical pleural debridement (methodical substantiation)

Patient's position, preoperative selection of surgical approach, deployment of optical equipment and trocars were similar to the previous method. Hydro-surgical pleural debridement was carried out using Versajet hydrosurgery system (Smith & Nephew, England). Duration and power of the flow was determined by the stage of pleural empyema (6—8 power mode for suppurative-fibrinous stage, 7—10 power mode for organization stage). Lower power modes (5—8) were used in younger children. The working handle of the device has insufficient length for debridement of the entire pleural cavity. So, we dismantled plastic handle of manipulator. This measure made it possible to hold metal guidewire of the handle throughout entire pleural cavity. Diameter of the manipulator of hydrosurgery system was 5 mm. There are 2 variants of manipulator handle with various inclination angles (15 or 45 degrees, respectively) **(Fig. 2 a, b)**. In any case, it was impossible to pass manipulator through the trocar. So, we did not use trocar for insertion of manipulator handle. A contact mechanical effect was applied to the affected pleura.

Fibrinous-suppurative masses were eliminated due to Venturi effect (local vacuum at a high fluid flow rate from 665 to 1628 km/h). Cutting of pathological tissues took place with simultaneous elimination of detritus by an aspiration system integrated into the manipulator of the hydrosurgery system **(Fig. 2 a)**. Dissection of coarse adhesions between parietal and visceral pleura was followed by lung decortication. Debridement of inflammatory pleural surfaces was carried out until hemorrhage by diapedesis occurred (dew drops) on the visceral and costal surfaces of the pleura. This sign indicated complete removal of fibrinous detritus from inflammatory surfaces. Surgery was also completed by pleural drainage through inferior thoracoscopic orifice under optic control. Drainage tube was withdrawn into the Bobrov's jar with active aspiration.

Statistical analysis

Statistical analysis of data was performed using a personal computer, STATISTICA 13.0 software package (StatSoft, USA) and russified statistical calculation environment (v.3.3.2). Certain variables generally accepted in evidence-based medicine were studied in order to characterize effectiveness of treatment. In-hospital, 1-, 3-, 6-month, 1-, 2- and 3-year follow-up data were analyzed (in some patients).

Results and discussion

Overall characteristics of patients are presented in **Table 1**. There was similar age, sex, weight and height of children.

There were more sick children aged 4—7 years old (n=27, 45.01%).

Patients with pulmonary-pleural forms of ADP had similar clinical symptoms with predominant respiratory, cardiovascular failure and toxic shock.

Various diagnostic methods regarding pathogen verification gave positive results only in 46 patients (76.68%).

***Table 1*. Overall characteristics of patients.**

Variable	Group 1 (N – 30)	Group 2 (N – 30)
Age, years	6.2±4.58	6.0±4.5
Sex, boys/girls	16/14	15/15
Weight, kg	25.5±16.1	28±18.17
Height, cm	118±27	118±27

***Table 2*. Blood counts in both studied groups.**

Variable	Group 1	Group 2
Leukocytes, thousands/µl	19.16±2.47	20.17±2.55
Hemoglobin, g/l	101.5±10.05	106±8.99
Platelets, /мм^3	574.5±109.68	508.9±80.11
ESR, mm/h	95.2±13.02	86.1±20.03
C-reactive protein, mg/l	171.55±72.41	464.7±120.99

In other cases, we were unable to identify the causative agent of infection. Streptococcus pneumonia was found in 34 children (56.67%), Streptococcus pyogenus — in 6 (10%) patients, Chlamydia pneumonia — in 3 (5%) cases, Staphylococcus aureus — in 2 (3.34%) patients, Streptococcus constellatus — in 1 (1.67%) patient.

Laboratory examinations were performed at admission and throughout the treatment in all patients in order to determine optimal medication. Severe inflammation was noted in both groups **(Table 2)**.

X-ray examination revealed pyothorax in 43 (71.6%) patients, pyopneumothorax — in 17 (28.4%) children.

Ultrasound examination of the pleural cavities was performed in all children with pulmonary-pleural forms of ADP at admission and throughout subsequent treatment. Pleural empyema stage was evaluated considering ultrasound data **(Table 3)**. Children with the most severe stage 3 prevailed in the main group. They underwent hydro-surgical pleural debridement.

Choice of strategy and terms of treatment

Intensive preoperative pathogenetic and symptomatic therapy aimed at stabilizing children's condition was applied. In extremely severe cases, mechanical ventilation was used to ensure efficient gas exchange with controlled selection of ventilation settings.

Pleural drainage was performed in case of pleural effusion followed by lung collapse and intrathoracic tension syndrome. There were 91 procedures in 60 children with pulmonary-pleural forms of ADP **(Fig. 3)**.

There were 59 procedures of pleural puncture and drainage. These manipulations were carried out in isolated manner in 30 children. In 24 children, these procedures were made prior to endoscopic treatment in order to relief intrathoracic tension. Repeated pleural drainage due to lowly effective drainage system was required in 5 cases. Redo thoracoscopy with hydro-surgical debridement was applied in 2 cases. These patients deserve special attention and were earlier described by us [17, 18].

Thoracoscopy was used in 17 cases, video-assisted thoracoscopy with hydro-surgical debridement — in 15 cases.

Comparative analysis of the outcomes

Clinical efficacy of all approaches was compared considering terms of relieving pain syndrome, intoxication syndrome, respiratory failure, re-expansion of lung and duration of antibiotic therapy **(Table 4)**.

Kruskal-Wallis test revealed significant between-group differences regarding elimination of intoxication syndrome ($p < 0.001$) and pain syndrome ($p = 0.012$) **(Table 4)**.

Earlier regression of respiratory failure was observed in groups IA and IIA compared with control groups IB and IIB. Hydrosurgery resulted recovery of respiratory failure on the 5th postoperative day as a rule: 12 (80%) patients in group IA and 10 (66.67%) patients in group IIA. Conventional treatment and thoracoscopy were followed by recovery of respiratory failure after 7 days — 7 (46.67%) and 9 (60%) patients, respectively. Therefore, more favorable results were obtained in the main groups compared with the control groups.

Duration of pleural drainage was similar in all groups (mean — 5 days).

Data in Table 4 confirm the advantages of hydro-surgical pleural debridement due to excision of abnormal tissues with their simultaneous elimination. Video-assisted thoracoscopic pleural debridement as independent method of treatment is less effective for elimination of detritus due to coarse pleural adhesions. The use of a vacuum aspirator for video-assisted thoracoscopic debridement is limited by a tube diameter of 5 mm. Fibrinous and purulent detritus with greater diameter cannot be extracted through this aspirator. On the other hand, a 10-mm aspirator can result trauma of intercostal neurovascular bun-

***Table 3*. Distribution of patients regarding pleural empyema stage in accordance with the classification of the American Society of Thoracic Surgeons (1962).**

Stage	Group 1 (n-30)		Group 2(n-30)		In all
	Main group (IA) – pleural drainage and lavage	Control group (IB) – pleural drainge	Main group (IIA) – Thoracoscopic hydro-surgical debridement	Control group (IIB) – Thoracoscopic debridement	
I (exudative)	4 (6,66%)	6 (10%)	-	-	10 (16,66%)
II (fibrinopurulent)	6 (10%)	6 (10%)	3 (5%)	9 (15%)	24 (40%)
III (fibrin organizing)	5 (8,34%)	3 (5%)	12 (20%)	6 (10%)	26 (43,34%)
In all	15 (25%)	15 (25%)	15 (25%)	15 (25%)	60 (100%)

***Fig. 3*. Overall number and types of surgical procedures in both groups.**

***Table 4*. Comparison of clinical features in both groups.**

Duration, days	Main group IA	Control group IB	Main group IIA	Control group IIB	Kruskal-Wallis test [H]
Elimination of respiratory failure	4±0,59	4,86±0,69	4,73±0,5	4,6±0,57	2,868679*
Pleural effusion output	3,73±0,72	4,46±0,76	4,33±0,81	5,4±0,79	3,821506*
Lung re-expansion	7,73±2,06	9,06±2,27	5±1,59	9,13±1,83	4,072583*
Elimination of pain syndrome	3,6±0,49	4,8±0,57	4,2±0,47	5,4±0,59	10,895112**
Elimination of intoxication syndrome	5,13±2,1	12,6±2,95	6,13±1,32	10,06±2,18	23,212568**
Antibiotic therapy	20,4±1,39	22,73±1,58	17,26±1,51	20,26±1,12	15,435988**
Hospital-stay	22,6±1,47	24,8±2,27	20,4±2,02	23,86±1,49	15,065421**

* — no significant differences.
** — significant differences were found in dispersion complex.

dle, especially in younger children. This complication is followed by long-term pain syndrome. Moreover, large aspirator with high underpressure leads to additional injury of inflamed pleural surfaces, lung parenchyma and bleeding. In these cases, we use a prolonged (up to 1 cm) incision within a trocar placement point to extract fibrinopurulent detritus. However, this technique is possible in empyema stage 2, when fibrinopurulent detritus may be separated from the pleura and removed. Above-mentioned approach is ineffective in patients with stage 3 of empyema and hydro-surgical system is essential to excise abnormal tissues in these cases.

Thus, the indications for hydrosurgery were determined. This technique demonstrated obvious advantages in the 3rd stage of empyema with lung cortication **(Fig. 3 a, b)**.

It should be noted that the most severe forms of destructive pneumonia (stage 3) were concentrated in group IIA. However, even these circumstances did not impair outcomes in these patients. Moreover, the outcomes were slightly better than in the control groups **(Table 4)**.

Regarding postoperative lung re-expansion, we observed the advantages of hydro-surgical pleural debridement in pleural empyema stage II and III and pleural lavage with saline solution in stage I. According to the data in **Table 4**, we can conclude that pleural drainage and lavage with saline solution in group IA and hydro-surgical debridement in group IIA resulted earlier lung re-expansion compared with the control groups. This aspect is one of the most significant in assessing the effectiveness of treatment, since it creates prerequisites for fast rehabilitation.

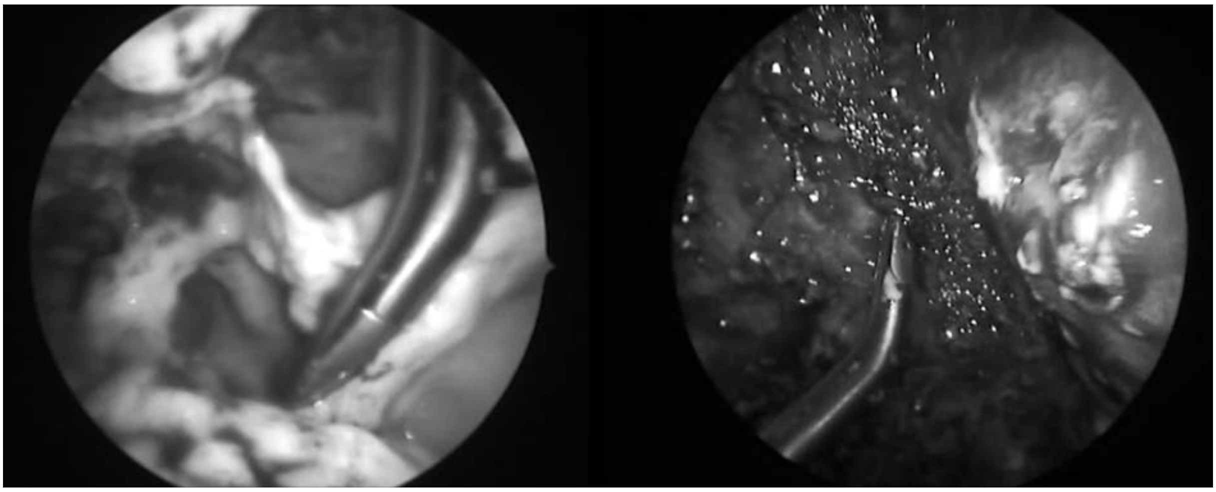

Fig. 4. **Intraoperative image — hydrosurgical debridement using «Versajet» apparatus in the 3rd stage of pleural empyema.**
a — the beginning of the operation; b — complete pleural debridement at the end of surgery.

The greatest mean duration of antibiotic treatment was observed in the IB group. Nine (60%) patients required antimicrobial treatment during 20—24 days, 3 (20%) patients — over 25 days. At the same time, only 1 (6.67%) patient received antibiotic drugs during 26 days in group IA, 9 (60%) children — during 20 days. Thoracoscopic debridement (group IIB) was followed by medication during 26 days in 1 (6.67%) patient, but the majority of patients received antibacterial treatment within 20-25 days (n=9, 60%). Endoscopic hydro-surgical debridement (group IIA) was followed by antibiotic treatment within 20 days in 13 (86.66%) children, 2 children (13.34%) received medication during 21 and 26 days, respectively. These data also confirm the effectiveness of hydrosurgery in comparison with the control groups. Economic feasibility of these methods is obvious due to reduced duration of antibiotic therapy.

Hydro-surgical pleural debridement resulted less hospital-stay **(Table 4)**. These results demonstrate clinical and economic effectiveness of hydrosurgery for pulmonary-pleural forms of ADP once again.

There were 7 redo surgeries. Repeated pleural drainage was required in 1 case in groups IA, IIA, IIB and in 2 cases in group IB. Repeated thoracoscopic hydro-surgical debridement was performed in 2 cases in group IIB.

Early postoperative complications occurred in all groups. Long-standing bronchopleural fistula was diagnosed in one case in groups IB and IIB. The greatest number of complications associated with intrapleural blocked effusions was found in groups IA and IB (2 and 4 cases, respectively). Lung injury followed by bleeding or bronchopleural fistula was found only after thoracoscopic treatment (by 3 cases in groups IIA and IIB). PlasmaJet Surgery System was successfully used for intraoperative hemo- and aerostasis. We have previously described technical aspects of manipulations with argon plasma coagulator [18].

There were no delayed complications within 6 months and later in any group.

Conclusion

In conclusion, we would like to note that proposed methods of treatment are associated with various obvious advantages in comparison with conventional approaches. Clinical and economic advantages of hydro-surgical pleural debridement in the 3rd stage of inflammation were confirmed. All other approaches are characterized by lower efficacy.

Hydrosurgery system with unique characteristics result qualitative debridement by high-speed fluid flow with excision and elimination of abnormal tissues. However, it is not accompanied by excessive “flooding” of the wound. Contact vacuuming of the wound surface improves perfusion of inflammatory surfaces near non-viable tissues.

Another advantage of hydrosurgery is potential application of this technique in minimally invasive version using video-assisted thoracoscopy. In case of conversion (advanced pleural adhesions and other circumstances), hydrosurgery system may be used for thoracotomy even more successfully than in endoscopic version. Moreover, all above-mentioned advantages of debridement by a water jet will be preserved. In our opinion, this technique is preferable in patients with pulmonary-pleural complications of destructive pneumonia.

Conflict of interests.
No conflict of interests to declare.

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