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Posted Date: 16 April 2025

doi: 10.20944/preprints202504.1363.v1

Keywords: pleural empyema; chest tube drainage; video-assisted thoracoscopy; thoracic ultrasound

 doi:10.20944/preprints202504.1363.v1

Article

Role of Thoracic Ultrasound in Assessing the Severity of Pleural Empyema in Infants and Children

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Abstract: Background/Objectives In children and infants, thoracic empyema commonly arises as a complication of parapneumonic effusions evolving into purulent collections. With an incidence of 0.6% among pneumonia cases, our study aimed to systematically characterize pediatric empyema by exploring the interplay between clinical, biochemical, and radiological parameters and their influence on patient outcomes. **Materials and Methods:** This is a retrospective single center study comprising patients diagnosed with parapneumonic pleural empyema, treated in the Pulmonology Department of "Grigore Alexandrescu" Emergency Hospital for Children, between January 2021-December 2024. We selected patients who were treated surgically, either with a simple pleural drain or Video-Assisted Thoracic Surgery (VATS). None of the patients received fibrinolytics, due to a lack of experience with their use in our department. Patients were stratified by initial treatment into chest-tube drainage-group or VATS-group. Clinical, laboratory, and radiographic data were extracted from hospital records. **Results:** This study included a final cohort of 33 patients. Median [IQR] age at inclusion was 4 years [3-8]. Median time until initial intervention for the entire cohort was 2 [1-5] days. Fourteen (42.4%) of children undergo VATS as initial intervention, p=0.384, after a median time of 4.5 [2-6.3] days. In 19 children, chest-tube drainage was implemented initially, after a median time of 1[0-3] days with a mean duration of 21.2 ±11.5 days. Median hospitalization length was 27 [21-38.5] days for the overall cohort. A linear regression model identified loculations and septations as significant predictors of hospitalization length. Drainage duration was significantly shorter in the initial VATS group (n=14, median 9.5 days [IQR 7.8–12.5]) compared to the chest tube group (n=19, 19 days [IQR 11–30]; p=0.011). Pleural fluid thickness, septations, and loculations on thoracic ultrasound were not significantly associated with the choice of primary intervention (VATS vs. chest tube drainage). Dyspnea was a strong predictor of intervention type, significantly increasing the likelihood of VATS over chest tube drainage (OR 18.00, 95% CI 1.86–174.21; p= 0.013). Patients were equally divided between early and late VATS intervention groups, each included 11 patients. Early VATS did not significantly reduce hospital stay (29 vs. 31 days; p=0.151), and VATS timing had minimal impact (R^2=0.042; p=0.358). VATS overall did not reduce hospitalization length compared to chest tube drainage alone (24 vs. 28 days; p=0.665). CT was performed in 15 children (45.5%) and revealed complications including bronchopleural fistula (21.2%), empyema necessitans (12.1%), and pyopneumothorax (21.2%), with 15.2% presenting multiple complications. CT imaging was associated with longer hospitalization. **Conclusions** In this cohort, chest-tube drainage represented the primary treatment, with decision-making guided by a combination of clinical features, paraclinical data, and institutional protocols, rather than imaging findings alone. Thoracic ultrasound (TUS) played a key role in assessing effusion complexity and guiding management, yet demonstrated limited prognostic value, similar to biochemical markers. The absence of fibrinolytic use—due to limited institutional experience—resulted in nearly half of the patients requiring escalation to VATS, underscoring the need for standardized symptom-driven algorithms combined with biomarkers and imagistic findings to guide escalation of care

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 doi:10.20944/preprints202504.1363.v1

1. Introduction

Under normal conditions, pleural fluid is regulated at approximately 0.3 ml/kg through balanced production and lymphatic drainage. Infection disrupts this balance by increasing vascular permeability, allowing inflammatory cells and bacteria to enter the pleural space. Cytokine release activates the coagulation system, leading to excessive fibrin production, septations, loculations, and pleural adhesions, which hinder fluid resolution and impair lung function[1].

When pleural effusions are becoming purulent, with significant fibrin formation, they are converting into empyema, most commonly as a complication of parapneumonic effusions [2]. although causes like chest trauma or surgery are also described [3].

Hamm and Light described three stages of parapneumonic effusion progression. The exudative phase features clear fluid with low cellularity, often resolving with antibiotics. The fibrinopurulent phase involves fibrin deposition, increased cellularity, and septation, marking the transition to complicated effusion or early empyema requiring drainage. The organizational phase is characterized by fibrous septa and a thick pleural membrane encasing the lung, necessitating surgical intervention such as decortication. This classification underscores the importance of early recognition and management to prevent irreversible complications [4]. Empyema occurs in 0.6% pneumonia cases with an estimated incidence of 3.3 cases per 100 000 children [5]. Despite a decline in the incidence of community-acquired pneumonia following the introduction of pneumococcal vaccines, pleural empyema remains a significant complication due to factors such as bacterial resistance and virulence [6]. The most common causative agents include *Streptococcus pneumoniae, Streptococcus pyogenes*, *Staphylococcus aureus* and *Haemophillus influenzae [7]*.

Chest radiography is the first-line tool for detecting pleural effusion but cannot confirm empyema or differentiate effusion types. Key findings include blunted costophrenic angles, a meniscus sign, or hemithorax opacification, often requiring further imaging (e.g., ultrasound or CT) for diagnosis. Loculated effusions may mimic lung abnormalities, highlighting the need for advanced imaging to guide management [8].

Thoracic ultrasound (TUS) serves as the primary imaging modality for assessing pleural effusions, enabling both detection and volumetric estimation. It effectively visualizes key pathological features such as fibrinous strands, fibrous septations, loculations (non-free-flowing fluid pockets), pleural thickening, and—in advanced stages—impaired lung mobility. Doppler ultrasound further enhances diagnostic utility by identifying parenchymal complications, including lung necrosis. This non-invasive, real-time tool is critical for staging pleural disease and guiding intervention, offering advantages such as portability, lack of ionizing radiation, and dynamic assessment of fluid characteristics [1]. Very recent studies emphasize the role of TUS in neonatal practice in identifying the need for respiratory support or surfactant administration [9]while reducing the radiation exposure in ventilated patients with more than 30% [10].

TUS and/or chest radiography should be performed on a routine basis, both for diagnosis and guided interventions, the former being preferred because of its high sensitivity in assessing the pleural fluid without the burden of irradiation [11]. In addition, thoracic ultrasound allows a rapid evaluation in emergency situations and furthermore, it is a safe tool for thoracocentesis guidance. One of the most important parameters assessed by thoracic ultrasound is the presence of septations, which when numerously, are possible indicators of clinical outcomes [12]. TUS is an essential tool for guiding pleural drainage decisions in parapneumonic effusions. Loculated or echogenic fluid observed on ultrasound strongly supports the need for drainage, as these findings typically indicate complex effusions that are unlikely to resolve spontaneously. Conversely, free anechoic fluid requires further evaluation to avoid inappropriate therapeutic interventions, as it may represent uncomplicated effusion or transudate rather than empyema [13].

CT is not routinely advised for evaluating pleural effusions in children. When utilized, intravenous contrast is critical to enhance pleural visualization. CT may identify features such as pleural thickening/enhancement, increased density of extrapleural fat, and loculated fluid collections. However, it often fails to detect thin fibrinous septations unless air is introduced into the pleural

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space (e.g., via thoracentesis, pneumothorax, or bronchopleural fistula). Despite these limitations, CT plays a key role in distinguishing empyema from lung abscess, diagnosing pyopneumothorax, detecting peripheral bronchopleural fistulae, and guiding interventions such as thoracentesis, chest tube placement, or preoperative planning for VATS [14,15].

TUS is an essential tool for guiding pleural drainage decisions in parapneumonic effusions. Loculated or echogenic fluid observed on ultrasound strongly supports the need for drainage, as these findings typically indicate complex effusions that are unlikely to resolve spontaneously. Conversely, free anechoic fluid requires further evaluation to avoid inappropriate therapeutic interventions, as it may represent uncomplicated effusion or transudate rather than empyema [13].

The management of empyema has evolved significantly over time. Open drainage techniques were first described by Hippocrates around 500 BC. In 1876, Hewett introduced the closed tube drainage method, which laid the foundation for modern thoracic procedures. Later, Eastlander and Schede defined thoracoplasty as a surgical approach to treat refractory empyema, while Kuster and Fowler pioneered decortication techniques aimed at removing fibrous pleural layers to restore lung function [2].

Contemporary management of empyema includes both conservatory options represented by antibiotics alone or in combination with thoracocentesis and interventions like chest tube drainage with or without fibrinolytic agents and surgical interventions like video-assisted thoracoscopy (VATS) or open-drainage techniques such as thoracotomy and decortication [16,17].

In a recent meta-analysis of treatment options for empyema in children, the authors reported that when compared with chest-tube drainage alone, chest-tube drainage with fibrinolytics, VATS and thoracotomy were associated with shorter hospitalization time, with no significant differences between the last three treatment modalities [18].

To our knowledge, this is the first Romanian study to systematically characterize pediatric thoracic empyema by examining the relationships between clinical, biochemical, and radiological profiles and their impact on outcomes. By exploring these correlations, the study provides valuable insights into decision-making and contributes to improving the management of empyema in children.

2. Materials and Methods

This is a retrospective single center study comprising patients diagnosed with parapneumonic pleural empyema, treated in the Pulmonology Department of “Grigore Alexandrescu” Emergency Hospital for Children, Bucharest, Romania between January 2021-December 2024. This period represents the post–COVID-19 period, characterized by a notable resurgence in the incidence of empyema cases. We selected patients who were treated surgically, either with a simple pleural drain or Video-Assisted Thoracic Surgery (VATS). None of the patients received fibrinolytics, due to a lack of experience with their use in our department. Patients managed conservatively (systemic antibiotics) were excluded. All clinical, laboratory, and radiological data were extracted from the institutional electronic medical records. Demographic parameters were recorded for all participants.

Patients were stratified by initial treatment into chest-tube drainage-group or VATS-group. Early VATS was defined as intervention performed within 5 days of hospitalization whether as primary or secondary treatment.

Collected clinical and laboratory variables included radiological parameters such as TUS assessment of fluid - maximum thickness (mm), presence of septation (indicator of empyema organization) or loculation (suggesting an advanced evolutive state), anatomic localization (right-/left-sided, bilateral). Clinical symptoms such the presence of respiratory distress, cough and thoracic pain were noted. Documented biochemical parameters were peripheral blood leukocyte count (cells/mm^3), platelet count (cells/mmc), serum C-reactive protein concentration (CRP, mg/dL) and serum procalcitonin (ng/mL).

 doi:10.20944/preprints202504.1363.v1

Additional data included time until intervention (days), prior antibiotics administration, the duration of chest-tube drainage (days) and time (days) to VATS conversion for those treated initially with chest-tube drainage. Also, need for reintervention after an initial VATS and association of complications such as pyopneumothorax, *empyema necesitans* and broncho-pleural fistula were documented, as described on the CT-scan.

Length of hospitalization (days) and in-hospital antibiotic treatment strategies (association of 2,3 or 4 antibiotics) were documented for all patients.

The study was approved by the Ethics Committee of our Institution (reference number #10003/1.04.2025).

3. Results

Initial study population consisted of 36 children; 1 child was excluded due to insufficient data and 2 were excluded because of conservatory (systemic antibiotics) treatment. The final study cohort included 33 patients, 16 (48.5%) boys, p=0.862. Median [IQR] age at inclusion was 4 years [3-8]. Median time until initial intervention for the entire cohort was 2 [1-5] days. Fourteen (42.4%) of children undergo VATS as initial intervention, p=0.384, after a median time of 4.5 [2-6.3] days. In 19 children, chest-tube drainage was implemented initially, after a median time of 1[0-3] days with a mean duration of 21.2± 11.5 days. Median duration of drainage was 12 [9-23.5] days for entire study group, without differences between the medians of the two subgroups, (13 [10-23] days for the only chest-tube drainage group vs. 11.5 [9-26.3] days for the VATS-at-certain-point group, p= 0.836. Median hospitalization length was 27 [21-38.5] days for the overall cohort. A linear regression model (R^2 = 0.159, adjusted R^2 = 0.159, F= 3.02, p= 0.046) identified loculations (B = +14.27, p= 0.010) and septations (B = -12.58, p= 0.020) as significant predictors of hospitalization length. Pleural fluid thickness showed no significant association (p= 0.435). However, adding laboratory values (p= 0.257) and initial intervention type (p= 0.360) reduced the model's validity, leading to a loss of statistical significance. Supplementary, performance of VATS at any point did not significantly change the hospitalization length, 28 [20.8-44.5] days vs. 28 [22-35] days for the chest-tube drainage only group, p=0.665. The duration of drainage differed significantly between the two groups, with the initial VATS group (n = 14) having a median drainage duration of 9.5 days [IQR 7.8–12.5] compared to 19 days [IQR 11–30] in the initial chest tube drainage group (n = 19; p=0.011).

Characteristics of the study population are described in Table 1.

Table 1. Characteristics of study population.

	Type of initial intervention		
	VATS (n=14)	Chest-tube drainage (n=19)	*p*-value
Sex [n (%)]			0.393
Male	8 (57.1)	8 (42.1)	
Female	6 (42.9)	11 (57.9)	
Residence [n (%)]			0.024
Urban	10 (71.4)	6 (31.6)	
Rural	4 (28.6)	13 (68.4)	
Median age at inclusion, years [IQR]	4.5 [3.8-8]	4 [2-8]	0.439
Median time until intervention [IQR] (days)	4.5 [2-6.3]	1 [0-3]	0.004

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Mean number of leukocytes ±SD (cells/mm^3)	24317.9 ± 9825	23025.3 ± 8734.1	0.699
Mean number of platelets±SD (cells/mm^3)	346x10^3 [230 x10^3-476x10^3]	362 x10^3 [248 x10^3- 489x10^3]	0.760
Mean serum C-reactive protein level ±SD, (mg/dL)	26.3 ±13	18.7±9.7	0.079
Median serum procalcitonin level*, ng/mL [IQR]	4.8 [0.44-8.5]	1.1 [0.5-4]	0.134
Median thickness of pleural fluid [IQR] (mm)	33 [23.3-50]	31 [18-40]	0.843
Septations			0.095
Yes	10 (71.4)	8 (42.1)	
No	4 (28.6)	11 (57.9)	
Loculations			0.284
Yes	7 (50)	6 (31.6)	
No	7 (50)	13 (68.4)	
Necrosis			0.510
Yes	3 (21.4)	3 (15.8)	
No	11 (78.6)	16 (84.2)	
Median length of hospitalization [IQR], (days)	27 [20-35.5]	24 [22-42]	0.815
Cough			0.676
Yes	13 (92.9)	18 (94.7)	
No	1 (7.1)	1 (5.3)	
Thoracic pain			0.461
Yes	4 (28.6)	15 (78.9)	
No	10 (71.4)	4 (21.1)	
Number of antibiotics [n (%)]			0.883
Two	1 (7.1)	2 (10.5)	
Three	3 (21.4)	3 (15.8)	
Four	10 (71.5)	14 (73.7)	
Dyspnoea [n (%)]			0.005
Yes	7 (50)	18 (94.7)	
No	7 (50)	1 (7.7)	
Anatomic distribution [n (%)]			0.454
Right-sided	6 (42.9)	7 (36.8)	
Left-sided	8 (57.1)	10 (52.6)	
Bilateral	0	2 (10.5)	
Previous antibiotic therapy [n (%)]			0.652

 doi:10.20944/preprints202504.1363.v1

Yes	3 (21.4)	4 (21.1)
No	11 (78.6)	15 (78.9)

*Computed for 30 patients VATS, video-assisted thoracoscopy.

In another 8 (42.1%) patients VATS was performed after initial chest-tube drainage treatment, after a mean time of 11.5± 6.6 days. TUS parameters were not associated with treatment failure, p=0.506 for loculations, p=0.551 for septations; median pleural fluid thickness was similar among the two groups (p=0.492).

Pleural fluid thickness did not correlate with hospitalization length (Spearmen's ϱ =0.278, p=0.118), mean number of leukocytes (ϱ =0.066, p=0.715), platelets (ϱ =-0.040, p=826), C-reactive protein (ϱ =0.267, p=0.154) nor the procalcitonin levels (ϱ = 0.235, p=0.189).

Biochemical parameters, including leukocyte and platelet counts, as well as inflammatory markers such CRP and procalcitonin, were comparable across the categories defined by TUS parameters (Table 2).

Table 2. Biochemical profile stratified by thoracic ultrasound parameters.

	Parameter			
TUS categories	Leucocytes (cells/mmc), mean ±SD	Platelets (cells/mmc) Median [IQR]	CRP (mg/dL) mean ±SD	Procalcitonin* (mg/mL) Median [IQR]
Loculations				
Yes (n=20)	24421.5 ± 8782.5	351x10^3 [218x10^3-798x10 ^{3}]	23.4 ± 13.3	2.5 [0.4-7]
No (n=20)	23022.5 ± 9460.4	363.5x10^3 [278.5x10^3-454.8x10 ^{3}]	21 ± 10.7	0.2 [0.5-4.8]
p value	0.668	1	0.585	0.350
Septations				
Yes (n=18)	25601.7 ± 10067.3	374.5x10^3 [245.8x10^3-557.25x10 ^{3}]	21.9 ± 11.5	1.1 [0.4-7.9]
No (n=15)	21140 ± 7346.8	299x10^3 [248x10^3-420x10 ^{3}]	22 ± 12.3	3.4 [0.6-4.8]
p value	0.164	0.585	0.977	0.509
Pleural fluid thickness				
>25 mm (n=22)	24451.4 ± 10113	356x10^3 [226.8x10^3-468x10 ^{3}]	24.2 ± 9.8	2 [0.4-6.7]
<25 mm (n=11)	21818.2 ± 6655.2	362x10^3 [299x10^3-597x10 ^{3}]	17.5± 14.2	2 [-.5-4.7]
p value	0.379	0.462	0.172	0.756

CRP, C-reactive protein; IQR, interquartile range; SD, standard deviation. *Computed for n=30 patients

Biochemical markers, including leukocyte count, platelet count, CRP, and procalcitonin levels, showed no significant correlation with hospitalization length (Spearman's ϱ = -0.170, p= 0.344 for

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platelets; ϱ = -0.119, p= 0.511 for leukocytes; ϱ = 0.178, p= 0.321 for CRP; ϱ = 0.062, p= 0.744 for procalcitonin.

We evaluated thoracic ultrasound (TUS) parameters for their ability to predict the primary intervention type (VATS vs. chest tube drainage). None of the TUS parameters—pleural fluid thickness (OR 1.00, 95% CI 0.966–1.051; p= 0.734), septations (OR 3.49, 95% CI 0.548–22.189; p= 0.186), or loculations (OR 1.06, 95% CI 0.176–6.433; p= 0.947)—demonstrated statistically significant associations with intervention choice. CRP exhibited a marginal inverse association with surgical intervention (OR 0.92, 95% CI 0.85–1.00; p=0.041). The presence of dyspnea emerged as a robust predictor, accounting for 33% of the variance in intervention selection (Nagelkerke R^2 = 0.33). Dyspnea increased the likelihood of VATS by 18-fold compared to chest tube drainage (OR 18.00, 95% CI 1.86–174.21; p= 0.013)

Patients were equally divided between early and late VATS intervention groups, each comprising 11 children (50%). Early VATS intervention did not significantly reduce median hospitalization length, with the early VATS group demonstrating 29 days [IQR 20–29] versus 31 days [IQR 27–49] in the late VATS group (p= 0.151). A linear regression model incorporating VATS timing explained minimal variance in hospitalization duration (R^2 = 0.042), with no statistically significant association observed between VATS timing and length of stay (coefficient B= -5.6, p= 0.358). Additionally, VATS performed at any time did not reduce hospitalization length compared to chest-tube drainage alone (24 days [IQR 22–35] vs. 28 days [IQR 20.8–44.5], p = 0.665.

Type of initial intervention was not significantly associated with the occurrence of complications (p=0.275). Additionally, within the VATS-at-any-point group, intervention timing showed no significant association with the occurrence of any complication (p=0.38).

Septation identified on TUS were significantly associated with early intervention (p=0.04) whereas loculations were not predictive of VATS within the first 5 days of hospitalization (p=0.087).

In the VATS cohort (n=22), reintervention was necessary in 22.7% (n=5) of children. Septations were not significantly associated with reintervention risk (OR 2.75, 95% CI 0.36–21.1; p= 0.333). Similarly, loculations were not predictive of reintervention (OR 0.47, 95% CI 0.06–3.5; p= 0.46), nor was pleural fluid thickness (OR 1.005, 95% CI 0.94–1.07; p= 0.89). Furthermore, VATS timing did not significantly influence reintervention risk (OR 0.59, 95% CI 0.08–4.5; p= 0.613).

CT was performed in 15 children (45.5%). Complications such as bronchopleural fistula, empyema necessitans, and pyopneumothorax were observed in 7 (21.2%), 4 (12.1%), and 7 (21.2%) children, respectively, with 5 children (15.2%) experiencing more than one complication. CT imaging was associated with a significantly prolonged median hospitalization duration (35 days [IQR 25–49] in the CT group vs. 24.6 days [IQR 20–27.8] in the non-CT group; p=0.001). Complications occurrence was irrespective of type of initial treatment (28.6% for VATS group and 47.4% in the simple drainage group, p=0.233).

A linear regression model (R^2 = 0.357, adjusted R^2 = 0.143, F= 2.918, p= 0.051) identified loculations (B= +16.02, p= 0.014) and septations (B = -14.9, p= 0.014) as significant predictors of drainage duration while pleural fluid thickness (B = +0.148, p= 0.228) showed no significant association with drainage duration into entire cohort. A separate regression model evaluating biochemical parameters, including leukocyte count, platelet count, CRP, and procalcitonin, showed no predictive value for drainage duration (R^2 = 0.287, adjusted R^2 = 0.082, F= 0.562, p = 0.692), with individual p-values as follows: leukocytes (p= 0.504), platelets (p= 0.496), CRP (p= 0.856), and procalcitonin (p=0.259).

Statistical analysis identified platelet count (B=+8073×10^{-6}, p=0.003) and CRP levels (B=0.179, p=0.009) as significant predictors of time to primary intervention, though the model explained only 37.7% of variance (adjusted R^2=0.233, F=2.619, p=0.04). Leukocyte count (p=0.400) and thoracic ultrasound (TUS) parameters—fluid thickness (p=0.501), septations (p=0.109), and loculations (p=0.105)—showed no significant links. Introducing procalcitonin rendered the model statistically non-significant.

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4. Discussion

TUS is a key-investigation necessary in assessing the characteristics of pleural fluid and drainage guidance, without the burden of radiation.

Our findings align with Long et al.'s "less may be best" approach, with chest tube drainage as the initial intervention in >50% of cases [19].

While Shirota et al. demonstrated comparable efficacy between drainage + fibrinolytics and VATS [20], our protocol omitted fibrinolytics, resulting in 42.1% requiring escalation to VATS—a disparity likely attributable to this therapeutic difference but also, as stated by Goldin et al., it is common for a child to undergo both interventions, based on disease progression [21]. Consistent with Haggie et al., thoracic ultrasound (TUS) parameters like septations and loculations lacked predictive value for treatment failure. Hyperchogenicity was excluded from TUS analysis due to inconsistent data [22].

Empyema is associated with increased length of hospitalization [23]. We observed a longer hospitalization duration compared to findings from other studies. Jeniebi et al. report shorter hospital stays following the implementation of pediatric pleural empyema guidelines from 15 [5-32] days to 11 [6-27] days [24]. Comparable (although shorter) to our study, Marhueda et al. reported similar median hospital stay of 14 respectively 13 days for the VATS group and chest-tube drainage with urokinase group; moreover, median post-operative stay and mean febrile duration were similar between the two groups [25]. Longer hospital length in our hospital may be explained first by study population profile, etiology of pleural infection, the choice of antibiotics regimens, conservative management practices in our Pulmonology Department and delayed escalations to VATS. Furthermore, in our study, VATS performed at any stage of management did not reduce hospitalization length, conflicting with the conclusions of Redden et al. whose meta-analysis supported surgical intervention for shortening hospital stays in pleural empyema [26]. On the contrary, Schultz et al., report that VATS treatment reduced the hospitalization length and the number of days with fever [27]. In a systematic review of literature, Avansino et al., [28] indicate a lower hospitalization length associated with primary VATS intervention. However, the same authors [28] report shorter tube thoracostomy time for primary operative group (4.4 vs. 10.6 days), similar to our study. More recent data is also indicative of shorter hospitalization time for VATS treated patients [11,18,29]. In our population study, hospitalization length was not associated with TUS parameters as supported by other authors [30].

Contrary to the findings of Di Mitri et al. early VATS in our cohort did not demonstrate improved outcomes, particularly regarding hospitalization length and occurrence of complications [6]

Historically, the presence of loculated pleural fluid was considered a key indicator for thoracotomy, as proposed by Shankar et al. over two decades ago by [31]In our study, TUS parameters - pleural fluid thickness, septation and loculations showed no statistically significant associations with the intervention type (VATS vs. chest-tube drainage) according to the logistic regression model. Counterintuitive, CRP demonstrated marginal inverse association with surgical intervention. In contrast, dyspnea significantly predicted VATS use. These results highlight the prioritization of clinical symptoms over imaging and inflammatory biomarkers in guiding intervention decisions. While septations alone are not associated with clinically significant outcomes, they do play a role in influencing initial treatment decisions, often favoring surgical intervention [32], contrary to our findings. Similarly, Stevic et al. report that in predominantly septated effusions, open thoracotomy and decortications are more frequently used [33]. In our study, septations were not associated with type of primary intervention but with early VATS suggesting that this pattern is an indicator of disease progression rather than a direct determinant of intervention choice. Their association with early VATS reflects a proactive approach of advanced stages of empyema, while lack of influence on primary intervention type highlights the multifactorial process of decision-making, when along with clinical and paraclinical indicators, institutional- and surgeon-related factors may intervene. This underscores the need for risk stratification tools including imaging, biomarkers and

 doi:10.20944/preprints202504.1363.v1

clinical parameters to standardize the type of intervention and intervention timing. Reintervention rates in our study were higher than previously reported by et al., who found reintervention in 12% of patients. In their study, VATS was the initial procedure, imposed by the presence of septations in the pleural fluid [34].

The British Thoracic Society (BTS) guidelines for pediatric pleural infection management in children, emphasize that while TUS cannot reliably determine the stage of pleural infection, it is effective for estimating effusion size, distinguishing free from loculated fluid and assessing fluid echogenity [35]. CT is reserved for exceptional circumstances and not recommended as a routine diagnostic tool [1]. Furthermore, CT becomes essential when surgical intervention, such as VATS is indicated [30]. In our study, nearly half of the patients required CT-scan examination, primarily due to the severity of the disease and concerns about potential complications, supporting literature data.

The predictive capacity of platelet count for time to intervention may be attributed to platelets' role in promoting pleural fibrin deposition through the release of thrombospondin-1 (a platelet-derived glycoprotein that stabilizes fibrin matrices) and plasminogen activator inhibitor-1 (PAI-1), which inhibits fibrinolysis, thereby accelerating pleural organization [32]. Procalcitonin reducing the predictive model for time until intervention might reflect multicollinearity (most probably with CRP).

The lack of significant correlations between laboratory values (CRP, leukocyte/platelet counts) and hospitalization length aligns with evidence showing these markers poorly predict clinical outcomes in empyema management. Our findings align with those of Medeiros et al. supporting the fact that perioperative CRP levels did not correlate with clinical outcomes [36]. Additionally, the lack of correlation between loculations, septations and pleural fluid thickness observed on TUS and paraclinical parameters, including leukocytosis, thrombocytosis, and elevated CRP levels, suggests that the severity of systemic inflammation does not necessarily align with the ultrasonographic characteristics of pleural fluid, suggesting a potential lack of concordance between systemic inflammatory responses and localized pleural pathologic processes.

Total duration of drainage was shorter for the primary VATS group, comparative with the observations of Ratta et al., who report reduced drainage duration in VATS group [37], although shorter than the ones in our study. Loculations were associated with prolonged drainage duration, likely indicative of complex effusions necessitating extended therapeutic management. Conversely, septations correlated with shorter drainage duration, potentially reflecting earlier intervention practices as observed in our cohort. Inflammatory markers, such as CRP and procalcitonin, likely reflect systemic disease severity rather than localized pleural fluid organization. Variables such as antibiotic selection, prior antibiotic use, and biomarker trends over time (e.g., rising/falling CRP) may hold greater prognostic value than isolated admission values. This last finding is supported by the observations of Tsurono et al. which indicated that the utility of CRP measured in the 3rd day of hospitalization may predict the need for surgical intervention in adult patients with empyema [38]. Moreover, Carboni et al., reported that CRP and procalcitonin exhibit specific pre- and postoperatively patterns, with peak values in day 2. Undoubtedly, additional clinical and therapeutic factors influence outcomes, necessitating validation in larger, prospective cohorts. In our study, baseline CRP measurement was made on the first day of admission [39].

Consistent with the findings of Marhuenda et al., our study demonstrated that the duration of chest tube placement was significantly shorter in patients who underwent initial VATS compared to those managed with chest tube drainage alone, despite the overall drainage duration being lower across both groups [25]. The shorter drainage duration in the VATS group likely reflects the mechanical advantages of VATS over passive drainage and suggests that standardized protocols for early VATS in select cases (e.g., septated effusions) may optimize outcomes.

To our knowledge, this is the first study that comprehensively assess the utility of TUS in predicting the evolution of pleural empyema in children, in Romania. Although it makes an important contribution to the specialized literature, our study has several limitations. First, the retrospective data collection may have introduced variability due to the non-uniform nature of the data sources from medical records. Second, the absence of specific guidelines to standardize clinical

 doi:10.20944/preprints202504.1363.v1

practice, has led each physician to adopt a personal-approach to therapeutical and diagnostics decision-making, influenced by individual experience and the availability of certain interventions at the time of patient admission. Moreover, personal-approach to therapeutic management, particularly antibiotic regimens, may have impacted patient outcomes. Finally, the lack of standardized ultrasound evaluation criteria and operator dependency could have led to subjective and non-uniform interpretations of TUS findings. As a statistical limitation, we mention the relatively small sample size.

Given that septations are associated with early-VATS, platelet count and CRP correlate with reduced time-to-intervention, and CRP and dyspnea are associated with type of intervention, namely VATS, future perspectives may be represented by development of a scoring system by integrating clinical, radiological and laboratory parameters to guide interventions decision-making.

5. Conclusions

Simple drainage without fibrinolytic agents served as the principal primary treatment approach in this cohort, reflecting limited institutional experience with fibrinolytic therapy. Considering this strategy, nearly half of patients required VATS escalation. Therapeutic intervention type—whether initial drainage or primary VATS—showed no statistically significant association with hospitalization duration or complication rates. Notably, chest tube in place time was shorter in patients undergoing primary VATS. While TUS remains indispensable for empyema diagnosis, its prognostic utility—like that of biochemical markers —proved limited in predicting clinical trajectories. These findings underscore the need for standardized symptom-driven algorithms combined with biomarkers and imagistic findings to guide escalation of care, prioritizing clinical response over isolated imaging or laboratory parameters.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, A.-I.U.; methodology, A.I.U., E.R.M..; software, E.R.M..; validation, A.-I.U., A.U., E.R.M.; formal analysis, A.-I.U., A.U., E.R.M..; investigation A.-I.U., E.R.M.; resources, A.-I.U., A.U., E.R.M.; data curation, A.-I.U, A.U.,E.R.M.; writing—original draft preparation, A.-I.U.,E.R.M.; writing—review and editing, A.-I.U., A.U., E.R.M.; visualization, A.-I.U..; supervision, A.-I.U.; project administration, A.-I.U.; funding acquisition, A.U. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of "Grigore Alexandrescu" Emergency Hospital for Children, Bucharest, Romania, with approval number #1003/01.04.2025

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

Data Availability Statement: Data are contained within the article.

Acknowledgments: Publication of this paper was supported by the University of Medicine andPharmacy "Carol Davila" through the institutional program Publish not Perish.

Conflicts of Interest: The authors declare no conflicts of interest

Abbreviations

The following abbreviations are used in this manuscript:

BC	Before Christ
CT	Computed tomography
CRP	C-reactive protein
IQR	Interquartile range
SD	Standard deviation

 doi:10.20944/preprints202504.1363.v1

TUS	Thoracic ultrasound
VATS	Video-assisted thoracoscopy

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