

Impact of the COVID-19 Pandemic on Pediatric Pneumonia Outcomes: A Five-Year Retrospective Cohort Study

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Background: Pneumonia remains a leading cause of pediatric morbidity globally, with *Streptococcus pneumoniae* (SP) as the primary bacterial pathogen. Despite vaccination programs and modern antibiotics, complicated cases requiring surgical intervention present ongoing challenges for healthcare providers. Recent clinical observations suggest an increase in complicated pneumonia cases requiring surgical intervention, particularly in the post-COVID-19 era. This trend warrants systematic investigation to optimize treatment protocols and surgical timing.

Objective: Primary objectives: Examine epidemiological trends in pediatric pneumonia (2019–2023) and evaluate surgical treatment outcomes. Secondary objectives: Analyze demographic and clinical characteristics, assess treatment response patterns and investigate factors associated with complicated disease courses.

Methods: A retrospective, single-center study was conducted at Thomayer University Hospital, Prague, Czech Republic, analysing medical records of children diagnosed with pneumonia in years 2019–2024. Data highly suggestive to *Streptococcus pneumoniae* were assessed for trends in incidence, clinical characteristics, treatment outcomes, surgical interventions, and antibiotic resistance. Statistical analysis using linear regression and Somers' D statistic confirmed an increasing trend in total and complicated pneumonia cases in the years following the onset of the pandemic. Three figures depict severe cases.

Results: We collected a total of 305 pediatric patients with community-acquired pneumonia (CAP). A total of 181 patients out of all CAP patients (59.3%) were suspected from pneumococcal aetiology. About 12.1% were identified as complicated. The statistical models showed significant increases over time ($P < 0.05$), with the complication rate rising by 0.143 per year ($R^2 = 0.804$) and interventions increasing by 0.062 per year ($R^2 = 0.69$).

Conclusion: This study highlights a rising incidence of bacterial pneumonia, mainly pneumococcal, and its severe forms in children, particularly after the emergence of the pandemic. The findings underscore the need for a multidisciplinary approach and the role of minimally invasive surgical techniques in managing complex cases.

Plain Language Summary: Pneumonia is a common and serious lung infection in children. Pneumococcus is one of the main bacteria that causes it. Thanks to vaccines and antibiotics, many cases are mild and can be treated effectively. However, some children develop severe forms of pneumonia, which can lead to complications requiring surgery.

Recent reports suggest that the number of complicated pneumonia cases has increased, especially after the COVID-19 pandemic. To understand this trend, we studied cases of pneumonia in children treated at Thomayer University Hospital in Prague between 2019 and 2024. We analyzed how often Pneumococcus was involved, how severe the cases were, and whether more children needed surgery over time.

We found that out of 305 children with pneumonia, 181 (59.3%) were likely to have pneumococcal pneumonia. About 12% of these children developed severe complications. Our analysis showed a clear increase in the number of complicated cases and surgical

interventions over time, especially after COVID-19. One particularly severe form, necrotizing pneumonia, which destroys lung tissue, was more common in recent years.

These findings suggest that complicated bacterial pneumonia is becoming more frequent in children, and doctors may need to adjust their treatment strategies. Using less invasive surgical techniques and ensuring timely medical care could help improve outcomes for children with severe pneumonia.

Keywords: pneumonia, *Streptococcus pneumoniae*, epidemiology, necrotising pneumonia with cavity formation, surgical management

Introduction

Community acquired pneumonia (CAP) continues to represent a significant cause of morbidity and mortality among children on a global scale. Despite significant advances in medical science and the availability of efficacious vaccines, *Streptococcus pneumoniae* remains the leading cause of bacterial pneumonia in children, with *Mycoplasma pneumoniae* ranking as the secondary cause.^{1,2}

CAP represents a significant burden on healthcare systems, particularly in hospital settings where severe cases require complex and multidisciplinary care, predominantly in children with a complicated course of infection.

Streptococcus pneumoniae (SP) is an important human pathogen, typically a commensal component of the physiological flora in the upper respiratory tract. The bacterium can be isolated from the upper respiratory tract of about 5–10% of healthy adults and 20–40% of children.³ The incidence of SP on mucous membranes and the prevalence of disease in children exhibit a greater correlation with the academic year than in adults, where the incidence of disease is higher during the winter months.^{4–6} The isolation of SP in children with pneumonia represents a prominent challenge.^{7–9}

A significant proportion of children with pneumonia will develop pleuropneumonia with pleural effusion, empyema or necrotising pneumonia with cavity formation.^{10,11} These phenomena can occasionally be attributed to the presence of a virulent microbial agent and additional pathological conditions, such as a coincidental viral infection, delayed diagnosis, malnutrition, prematurity or immunodeficiency.^{10–12} In the management of pleural effusion, the necessity for multi-level invasive procedures must be taken into account. In instances where a substantial pleural effusion is identified, the initial invasive therapeutic strategy is typically a single-stage evacuation of the fluid via an ultrasound-guided needle puncture. A second invasive therapeutic option is the continuous drainage of the intrapleural space via a chest tube. The chest drain may be employed for the purpose of either deriving the fluid itself or applying a fibrinolytic agent, such as r-TPA (recombinant tissue plasminogen activator, also known as alteplase). The injection of alteplase into the pleural space should be considered in cases of empyema and suspected fibrin formation.¹³ In the event that drainage proves ineffective in improving the patient's condition, it may be necessary to consider MITS (Mini Invasive Thoracic Surgery), such as VTS (VideoThoracoscopy) or VATS (Video-Assisted Thoracic Surgery), or open thoracotomy for empyemectomy, abscess drainage, pleural abrasion, fistula closure or other potential procedures, including resection of necrotic tissue.¹⁴

The hypothesis, formulated on the basis of clinical observation, postulated an increase in the number of cases of complicated pneumonia, highly suggestive of SP etiology, requiring surgical intervention. A retrospective study of cases of bacterial pneumonia in paediatric patients at Thomayer University Hospital in Prague was conducted from January 2019 to December 2024, with the objective of optimising treatment protocols, enhancing patient management, and formulating various thoracic surgery strategies at multiple levels and their respective timing.

Materials and Methods

This retrospective observational single-center study was conducted at Thomayer University Hospital, a tertiary hospital in Prague, Czech Republic. The study population comprised children of both biological genders, with no race or ethnicity preference, aged 0–18 years, who had been diagnosed with community acquired pneumonia (CAP) between January 2019 and December 2024. The data were obtained from the medical records of the patients, which were accessible via the hospital information system, thus ensuring accurate diagnosis and consistency across cases.

A subsequent analysis was performed on the dataset relating to patients with CAP. The patients were divided into two groups. The first group consisted of children with pneumonia proven or highly suspected *Streptococcus pneumoniae* infection, while the second group consisted of patients with a proven infection other than *Streptococcus pneumoniae* (mainly *Mycoplasma pneumoniae*, *Streptococcus pyogenes* and *Klebsiella pneumoniae*, among others). The primary focus of this study was children with suspected pneumococcal pneumonia (SPP) (Figure 1).

The majority of patients included in the study underwent a range of diagnostic procedures, comprised clinical, laboratory, radiological and microbiological procedures. Children were included in the SPP cohort provided they exhibited a minimum of two of the following clinical symptoms: elevated body temperature (with temperatures frequently exceeding 38°C), cough, dyspnoea (a condition marked by difficulty breathing), and a state of marked fatigue. Inclusion also required specific laboratory markers indicative of infection and inflammation, such as leukocytosis with a left shift (indicating an increased number of immature white blood cells) or leukopenia (a low white blood cell count),

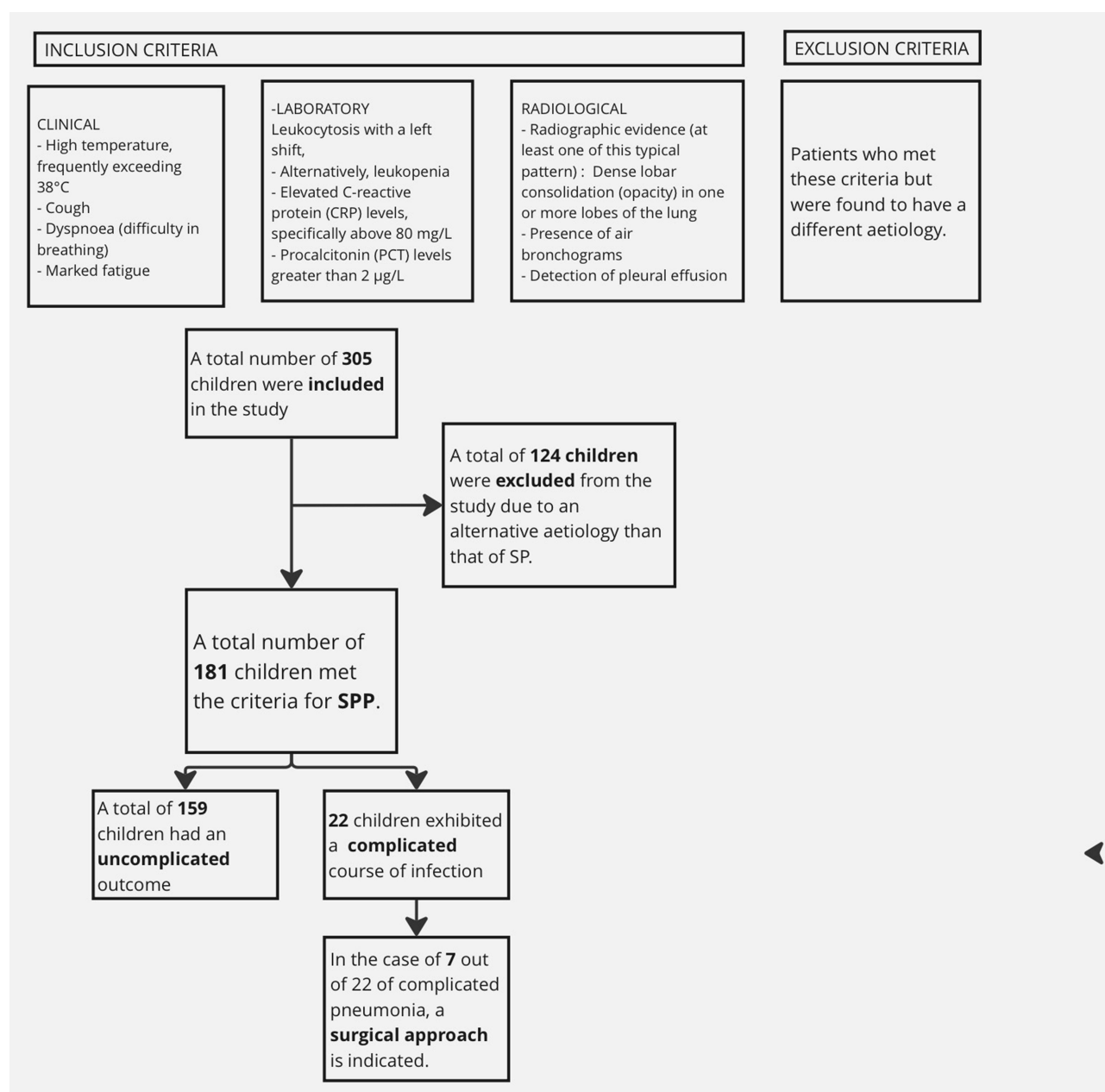


Figure 1 Flow chart of the study enrolment process.

and/or elevated C-reactive protein (CRP) levels above 80 mg/L and procalcitonin (PCT) levels greater than 2 µg/L. The requisite radiological criteria encompassed at least one of the following patterns: dense lobar consolidation (opacity) in one or more lobes of the lung, the presence of air bronchograms, or the detection of pleural effusion. Confirmation by means of microbiological tests for SP (urinary pneumococcal antigen, sputum culture in cooperative older children, nasopharyngeal swab, hemoculture, pleural fluid culture, serology, and bacterial PCR) was requested but did not represent a mandatory inclusion criterion. It is important to consider the variable perspectives on the specificity and sensitivity of urinary pneumococcal antigen given the low detection rate of SP in hemoculture,¹⁵ and the high prevalence of nasopharyngeal carriage, especially among young children.^{16–19}

Complicated pneumonia was defined as a severe illness with at least one of the local complications, such as parapneumonic effusion, empyema, or necrotising pneumonia, which is characterised by the necrosis of lung tissue, which results in the formation of cavities, liquefaction, and the destruction of the lung parenchyma. Such cases are frequently accompanied by the formation of abscesses and/or the development of systemic complications, including sepsis and respiratory insufficiency or failure.¹¹

The study design is consistent with the Strobe protocol.

Statistical Analysis

The analysis examined trends in the average annual complication rate and number of interventions over time using linear regression. A good regression model was determined by overall F-test on model fit and its ability to explain variability (R^2) and the significance of regression coefficients (P-value < 0.05).²⁰

For the complication rate, the model explained 80.2% of the variability ($R^2 = 0.802$) and had a significant P-value of 0.016 of F-test, indicating the observation period (year) plays a statistically significant role. The regression coefficient of 2.0 (statistically significant: $P = 0.016$) shows an annual increase of 2.0 in the number of complications.

For the number of interventions, the model explained 69% of the variability ($R^2 = 0.69$) and had a significant P-value of 0.040 of F-test, confirming the significance of the observation period. The regression coefficient of 0.743 (statistically significant: $P = 0.040$) indicates an annual increase of 0.743 in the number of interventions.

Both models demonstrate that time (in years) significantly influences these variables, with upward trends observed. These findings highlight the importance of monitoring trends and exploring factors driving the increases to improve outcomes.

To assess the one-way dependence of the observed phenomenon on time, the non-parametric Somers' D coefficient is used. This coefficient measures the strength and direction of association that exists between an ordinal dependent variable and an ordinal independent variable.²¹ According to the Somers' D coefficient, the one-way dependence of the complication rate is statistically significant ($P = 0.001$) and its value of 0.667 means a moderately strong positive dependence of the complication rate over time. Similarly, the one-way dependence of the intervention rate is verified according to the Somers' D coefficient, which is statistically significant ($P = 0.009$) and the coefficient value of 0.600 means a moderately strong positive dependence of the intervention rate over time.

Results

A total of 305 pediatric patients with community-acquired pneumonia (CAP) were admitted to Thomayer University Hospital (TUH) between January 2019 and December 2024. During the period preceding the pandemic, the hospitalization rate was 14.1% in 2019. In contrast, during the pandemic years of 2020 and 2021, the hospitalization rate was markedly lower, at 2.3% and 5.6%, respectively. In 2024, 35.4% of all diagnosed children with pneumonia were hospitalized. There were no deaths from pneumonia during the study period.

A total of 181 patients out of all CAP patients (59.3%) were identified as suspected pneumococcal pneumonia (SPP). Furthermore, 38 patients (12.5%) were diagnosed with pneumonia caused by *Mycoplasma pneumoniae*. An alternative etiology was identified in 62 cases (20.3%). In the rest of the cases, the etiology remained unclear (Figure 1).

A total of 28 complicated courses of CAP were recorded during the study, representing 9.12% of all cases. Of these, 22 were observed in the SPP group, representing a proportion of 12.1% between SPP. A total of 12 patients (3.93%) required some form of invasive intervention, of whom 7 (3.86%) were in the SPP group. It is noteworthy that in the case

of patients presenting with a bacterial etiology of pneumonia other than that of *Mycoplasma pneumoniae*, namely *Streptococcus pyogenes* (2 cases), non-B *Haemophilus influenzae*, *Staphylococcus aureus*, *Branhamella catarrhalis* and *Enterococcus cobei*, a complex clinical course of the disease and a requirement for invasive interventional procedures were consistently demonstrated.

Of the total number of CAP patients (n = 305), 20 (6.55%) children required admission to Paediatric Intensive Care Unit (PICU) for at least a portion of their stay. This was due to perioperative care, respiratory failure, or both. Of the 181 patients belonging to the SPP subgroup, 10 (5.52%) children required intensive care. A total of 79 patients and 33 patients from the SPP subgroup required oxygen therapy. Nine patients from the entire cohort and 4 from the SPP subgroup required HFNO (high-flow nasal cannula oxygenation) therapy. A total of 4 patients with CAP and 2 patients with SPP were supported by invasive artificial lung ventilation.

The mean age of the SPP patients was 5 years. The median was 4 years. The mode was 4 years. The youngest patient to be hospitalized was 15 days old, while the oldest was 17 years of age.

The maximum average C-reactive protein (CRP) value was observed to be 170 mg/L, with the lowest average recorded in 2020 at 162.33 mg/L and the highest average in 2022 at 204.31 mg/L. The minimum value was recorded in 2020, at 53.82 mg/L, while the highest was observed in 2024, at 484 mg/L.

The mean length of hospitalization was approximately 7 days, with the lowest mean in 2022 at 5.48 days and the highest mean in 2020 at 11.33 days. The shortest period of hospitalization was recorded in 2022, at 1.44 days, while the longest was in 2024, at 37 days. In 2019, 2023, and 2024, the proportion of males with SPP exceeded that of females. In each year, the proportion of children who had not received the pneumococcal vaccine exceeded that of those who had. In all years except 2020, there was a significantly greater proportion of patients who had not been treated with antibiotics prior to hospital admission. The urinary pneumococcal antigen was negative in two-thirds of cases each year. In each of the analyzed years, the vast majority of hemocultures yielded negative results. Coinfection was not verified in a larger number of patients, but it is noteworthy that a higher proportion of cases of complicated pneumonia had an influenza or SARS-CoV-2 coinfection, exactly 7 out of 22 in the group of SPP patients and 9 out of 28 of all CAP complicated patients, respectively. Leukocytosis was recorded in patients in two-thirds of cases each year in the SPP group. A total of 100% of patients received antibiotics. An alteration in antibiotic regimen was deemed in 22 (12.15%) cases classified as complicated (See complementary material, [Table 1](#)).

Table 1 Selected Follow-up Data of Patients with Suspected Pneumococcal Pneumonia During the Study Period

		2019	2020	2021	2022	2023	2024
Number of SPP cases		22	3	12	44	49	50
Average age*		3.98 (4; 0.04–14)	11.33 (7.37; 3–17)	4.16 (2.19; 1.08–9.5)	3.82 (1.33; 0.83–6)	5.82 (3.36; 1.42–17)	4.9 (3.5; 0.67–17)
Average maximum of CRP*		176.65 (105.99; 10.5–419)	162.33 (53.82; 103–208)	169.9 (73.38; 62–271)	204.31 (95.64; 80.1–457)	173.94 (80.01; 3.6–379)	191 (83.26; 79–484)
Average length of stay*		5.73 (2.47; 2–11)	11.33 (4.04; 7–15)	6.33 (2.93; 3–13)	5.48 (1.44; 3–10)	7.06 (4.9; 3–32)	8.08 (5.74; 4–37)
Gender	Man	12 (54.5%)	2 (66.7%)	3 (25%)	21 (47.7%)	27 (55.1%)	28 (56%)
	Woman	10 (45.5%)	0 (0%)	9 (75%)	23 (52.3%)	22 (44.9%)	22 (44%)
	Transgender	0 (0%)	1 (33.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Pneumococcal vaccine	No	18 (81.8%)	3 (100%)	7 (63.6%)	24 (58.5%)	23 (53.5%)	31 (76%)
	Yes	4 (18.2%)	0 (0%)	4 (36.4%)	17 (41.5%)	20 (46.5%)	19 (24%)
Antibiotics prior to hospitalization	No	19 (86.4%)	1 (33.3%)	9 (75%)	34 (77.3%)	46 (93.9%)	38 (76%)
	Yes	3 (13.6%)	2 (66.7%)	3 (25%)	10 (22.7%)	3 (6.1%)	12 (24%)

(Continued)

Table 1 (Continued).

		2019	2020	2021	2022	2023	2024
Pneumococcal urinary antigen test	Negative	14 (63.6%)	2 (66.7%)	8 (66.7%)	29 (65.9%)	31 (63.3%)	29 (58%)
	Positive	1 (4.5%)	0 (0%)	2 (16.7%)	9 (20.5%)	12 (24.5%)	12 (24%)
	Not done	7 (31.8%)	1 (33.3%)	2 (16.7%)	6 (13.6%)	6 (12.2%)	9 (18%)
Blood culture	Negative	12 (54.5%)	1 (33.3%)	8 (66.7%)	33 (75%)	24 (49%)	32 (64%)
	Contamination	1 (4.5%)	0 (0%)	0 (0%)	3 (6.8%)	1 (2%)	1 (2%)
	Not done	9 (40.9%)	2 (66.7%)	4 (33.3%)	8 (18.2%)	24 (49%)	17 (34%)
Coinfection	No	19 (86.4%)	3 (100%)	8 (66.7%)	30 (68.2%)	38 (77.6%)	39 (78%)
	Yes	3 (13.6%)	0 (0%)	4 (33.3%)	14 (31.8%)	11 (22.4%)	11 (22%)
Leukocyte level	Normal	7 (31.8%)	0 (0%)	3 (25%)	14 (31.8%)	16 (32.7%)	18 (36%)
	Leucocytosis	14 (63.6%)	3 (100%)	8 (66.7%)	29 (65.9%)	32 (65.3%)	31 (62%)
	Leucopenia	1 (4.5%)	0 (0%)	1 (8.3%)	1 (2.3%)	1 (2%)	1 (2%)
Respiratory support	No	21 (95.5%)	1 (33.3%)	8 (66.7%)	36 (81.8%)	42 (85.7%)	35 (71.4%)
	Yes	1 (4.5%)	2 (66.7%)	4 (33.3%)	8 (18.2%)	7 (14.3%)	15 (28.6%)
Antibiotic therapy	No	0 (0%)	0 (0%)	0 (0%)	1 (2.3%)	0 (0%)	0 (0%)
	Yes	22 (100%)	3 (100%)	12 (100%)	43 (97.7%)	49 (100%)	50 (100%)
Necessary change in antibiotic treatment	No	22 (100%)	3 (100%)	10 (83.3%)	43 (97.7%)	39 (83%)	38 (86.4%)
	Yes	0 (0%)	0 (0%)	2 (16.7%)	1 (2.3%)	8 (17%)	6 (13.6%)
Complications	No	22 (100%)	3 (100%)	10 (83.3%)	43 (97.7%)	42 (85.7%)	41 (81%)
	Yes	0 (0%)	0 (0%)	2 (16.7%)	1 (2.3%)	7 (14.3%)	9 (19%)
The need for invasive intervention	No	22 (100%)	3 (100%)	12 (100%)	44 (100%)	47 (95.9%)	46 (92%)
	Yes	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (4.1%)	4 (8%)

Note: *Average, Standard deviation (min, max).

As the previously outlined regression analysis methodology has demonstrated, the number of complicated courses has also increased, notably rising to 7 cases by 2023 and 10 cases by 2024. Similarly, an increase in the number of interventions is evident. In 2022, interventions were not required at all. In 2023, they were needed in 2 cases, and in 2024, they were needed in 4 cases (See Figure 2).

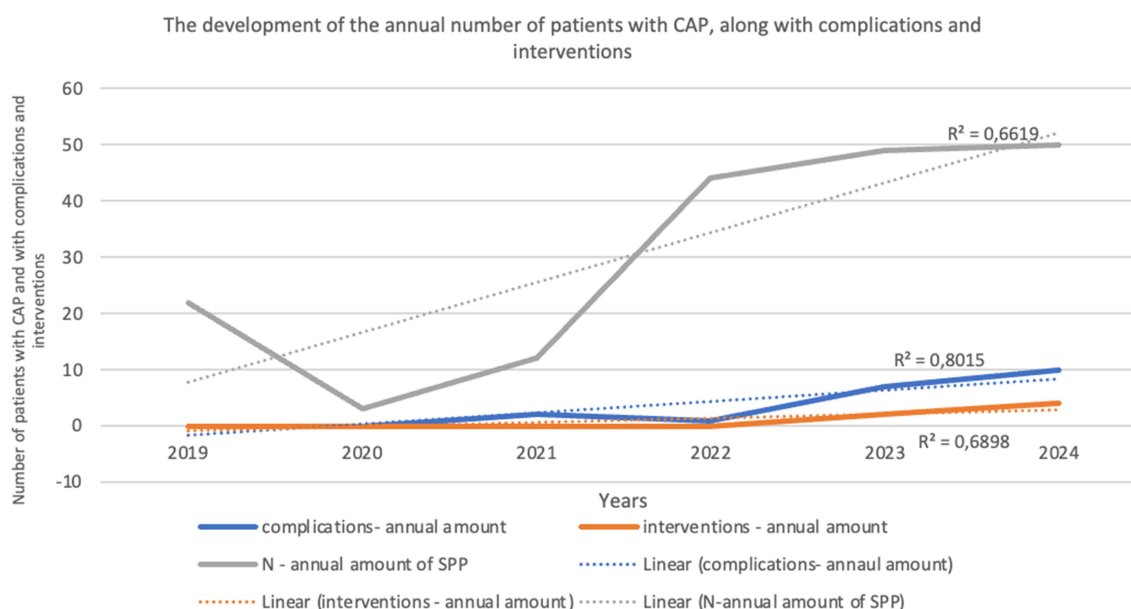


Figure 2 Graphical representation of the trend of complicated SPP cases and the need for invasive interventions during the study period.

To provide a comprehensive overview, the proportion of complications and interventions from the total number of SPP patients in a given year (N) is presented. This share is sensitive to the small base total (occurred in 2021, where there was a noticeable fluctuation in the form of a high share given by only two cases). However, in subsequent years, a larger number of patients indicate an increasing trend in the share of complications in SPP patients, rising from 2.3% in 2022, through 14.3% in 2023, to 20.0% in 2024. Similarly, the share of interventions in SPP patients increased from 0% in 2022, through 4.1% in 2023, to 8.0% in 2024 (See Figure 3).

Over the final two years of the study period, there was a notable increase in the number of cases of patients with SPP who developed complications such as effusion or even empyema. In 2023, 2 cases were identified, while in 2024, there were 5 cases. All patients required a stay in the PICU and some form of invasive intervention. In only one case was a single, ultrasound-guided puncture evacuation of the effusion deemed sufficient; all other patients required continuous chest drainage, with the potential for alteplase application. Four cases ultimately necessitated an MITS procedure for empyemectomy, decortication and surgical treatment of abscesses and chronic fistulas (Figures 4–6). All children were primarily healthy, with no known immunodeficiency. The age of these patients ranged between 1 and 17 years. None of the patients required segmental or even lobar resection, and all of these patients appear to have made a full recovery with months of follow-up. Three complex figures with a short case report are presented to illustrate the complexity of the disease (Figures 4–6).

Case 1

(Figure 4) A previously healthy 6-year-old boy was admitted with a febrile illness, elevated CRP, and left lung infiltrate, meeting criteria for suspected SPP with a positive urine test for SP. Initial antibiotics (G-penicillin, then cefotaxime and clindamycin) had limited effect, and his condition worsened, requiring escalation to linezolid and PICU transfer. Imaging showed progressive cavitary disease and effusion, prompting chest puncture and further antibiotic escalation to meropenem/linezolid. On day 14, VATS with decortication and chest drain insertion was performed. The patient improved and was discharged on day 23 with oral antibiotics and favorable follow-up imaging.

Case 2

Figure 5 illustrates a 4-year-old boy with consolidation in the left lower lobe (urine test SP positive, throat culture positive for SP, PCR evidence of influenza A). Following the therapy with G-penicillin, oseltamivir and corticosteroids, a rapid improvement was observed. But shortly after his condition worsened due to a left-sided empyema and pneumothorax, requiring chest tube drainage, intensified antibiotics (cefotaxime, linezolid), and a left-sided video-assisted thoracoscopy, which resulted in the evacuation of the empyema and the demonstration of a fistula with air leak in the lower lobe at the site

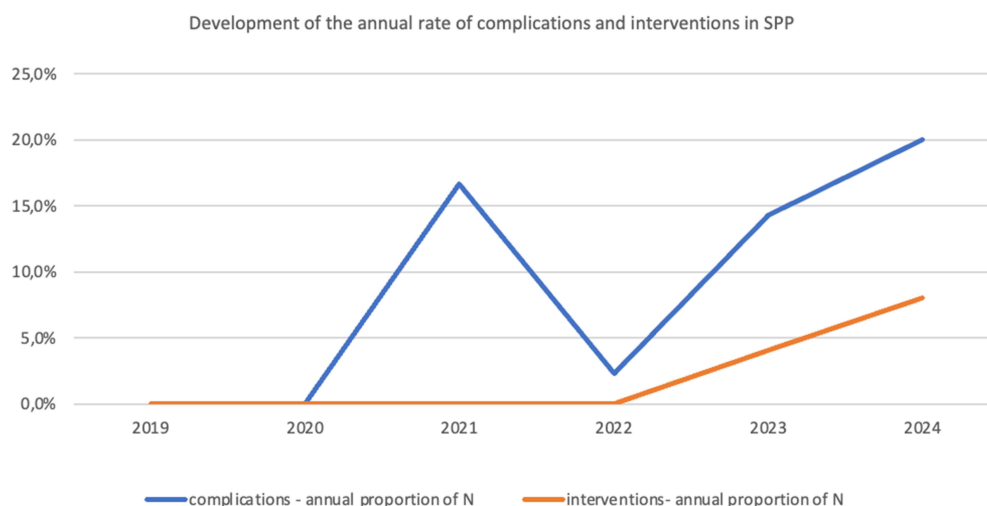


Figure 3 Graphical representation of the trend of complicated SPP rate and the rate of need for invasive interventions during the study period.

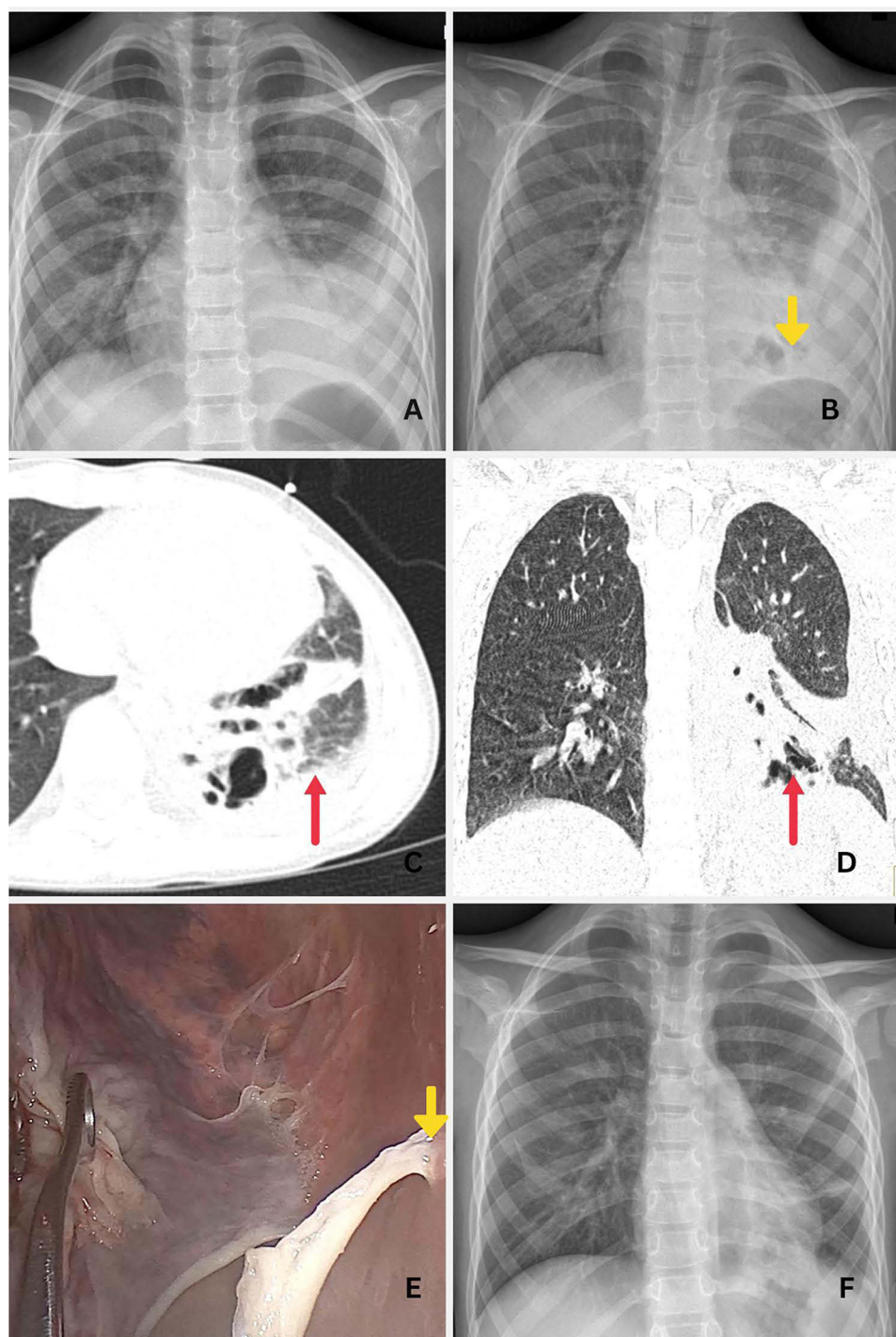


Figure 4 Complex imaging series of a complicated SPP with chest drainage and VATS empyemectomy and fistula surgical treatment ((A) - Initial CXR with left pleural effusion. (B)- CXR: worsening of pleural effusion, cavities within consolidation. (C and D) – CT necrotizing pneumonia (E) – VATS, fibrin adhesion to the chest wall. (F) – CXR resolution of pulmonary infiltrates.).

of a prolapsed lung abscess. The fistula was surgically repaired and two new tubular drains were placed in the pleural cavity. After gradual recovery, he was discharged on day 37 with favorable clinical and radiological outcomes.

Case 3

(Figure 6) shows a 20-month-old boy with left-sided pneumonia (urine test SP positive) and right-sided otitis media who was admitted and initially treated with penicillin, later escalated to piperacillin/tazobactam and clindamycin due to

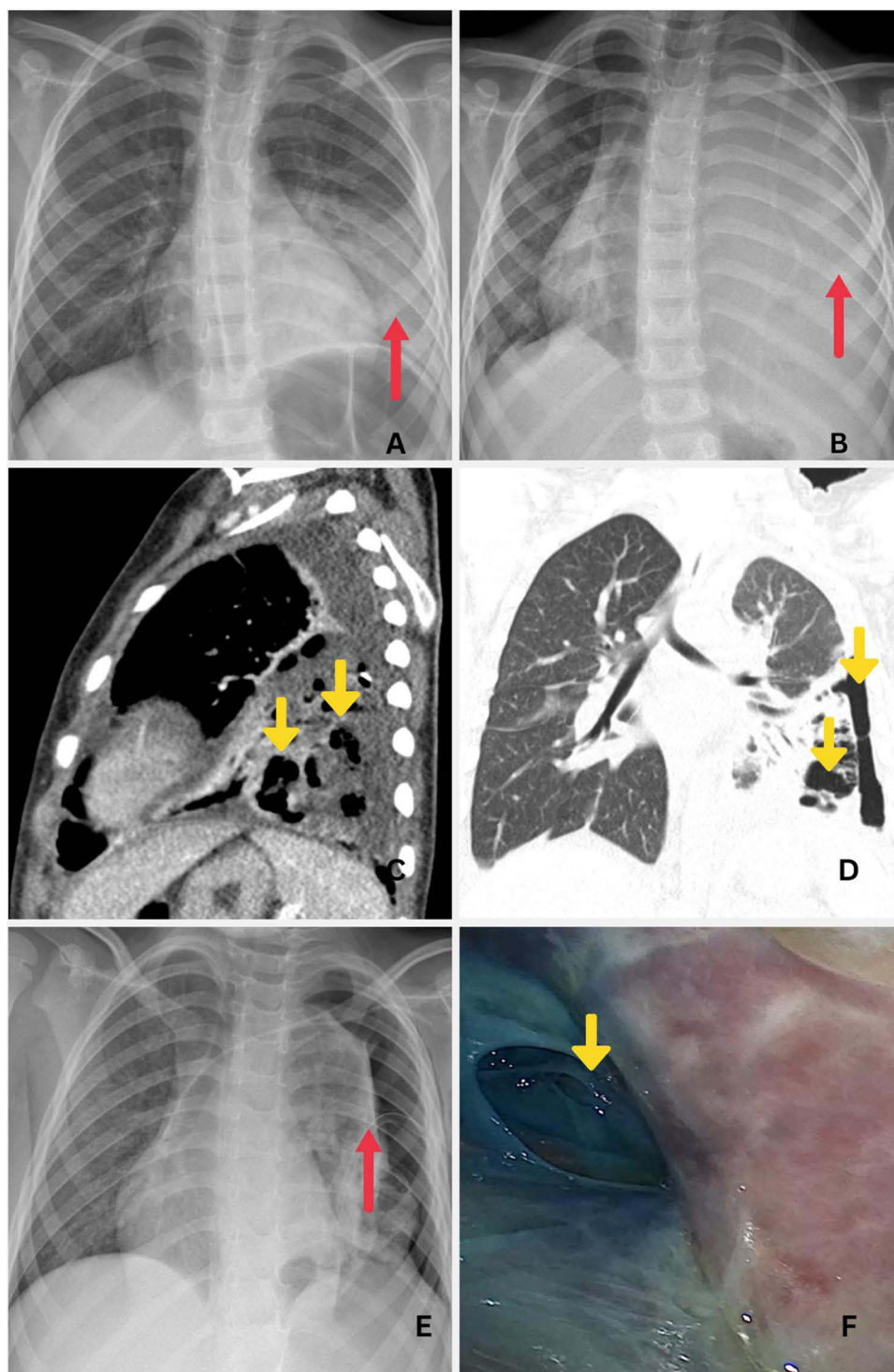


Figure 5 Complex imaging series of a complicated SPP in 4 years old boy with chest drainage and VATS fibrin adhesions removal ((A) - CXR consolidation (red arrow) with air bronchograms. (B) - CXR massive left-sided pleural effusion (red arrow) with contralateral mediastinal shift. (C and D) - CT scan after chest tube insertion in the left hemithorax showed left hydropneumothorax and collapsed lower left lobe with multiple cavities present (yellow arrows). (E) - CXR worsening of left pneumothorax (red arrow) with lung collapse. (F) – VATS: Adhesions (yellow arrow) between visceral and parietal pleura (chest wall) and noticeable incipient fibrin coating on the left lower lobe).

worsening CT findings, including pleural collection and lung cavity disintegration. Chest drainage and alteplase therapy led to effective effusion evacuation, but a massive pneumothorax on day 10 required re-drainage. Persistent pneumothorax and empyema prompted surgical intervention (VATS) with decortication, fistula sealing, and chest drain

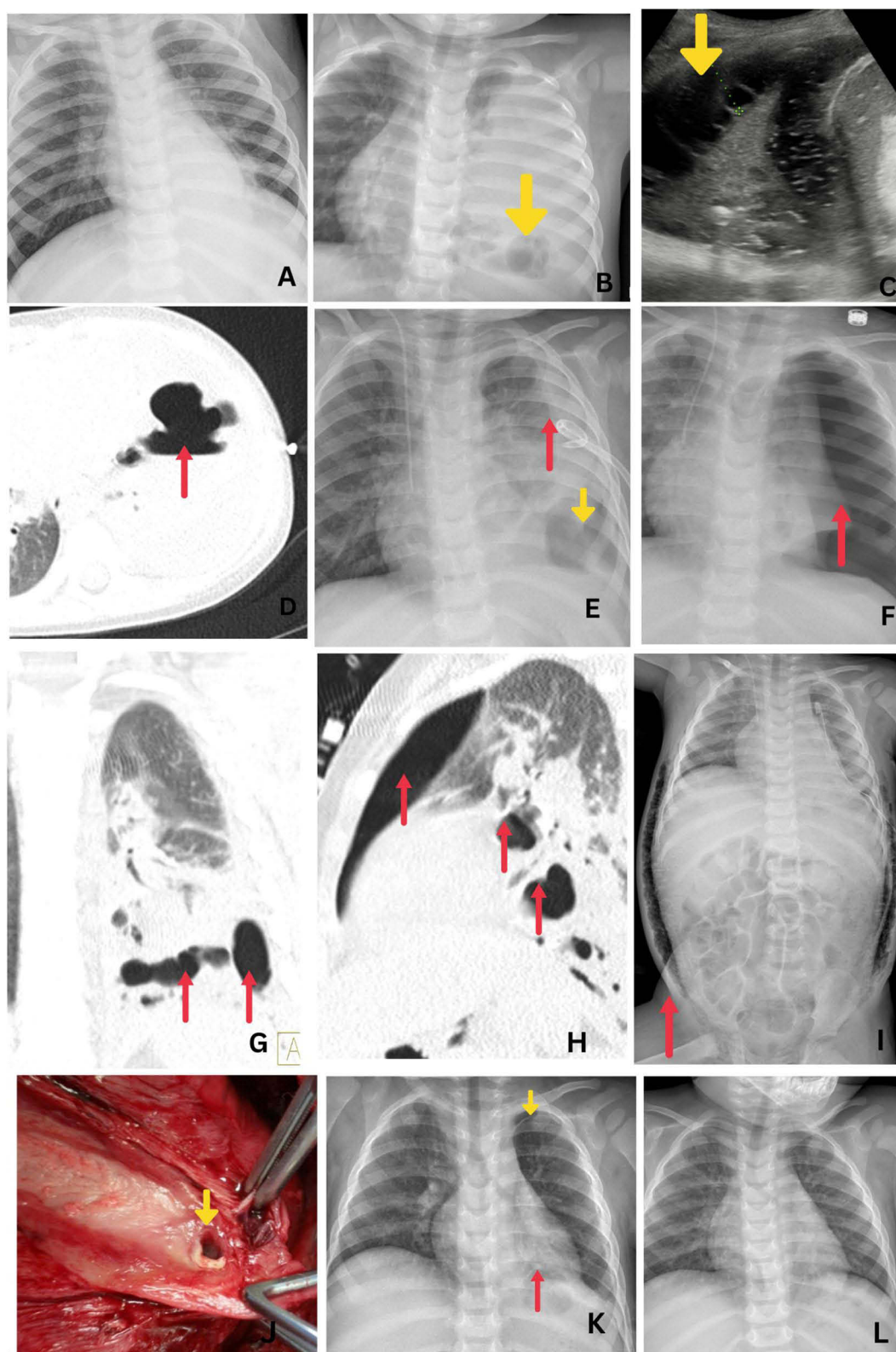


Figure 6 Complex imaging series of a complicated SPP in 20 month old boy with chest drainage, alteplase injection, VATS targeted drainage, decortication and filling of the abscess cavity with a sponge sealant patch ((A) – CXR consolidation in left lower lobe with air bronchogram. (B) – CXR massive pleural effusion in the left lung with contralateral mediastinal shift, cavities (yellow arrow) suspected from necrotizing pneumonia. (C) - Chest sonography: septated pleural empyema (yellow arrow) (D) - CT scan with left pleural effusion, parenchymal consolidation and large cavity (red arrow)(E) - After chest tube insertion improvement in the pleural effusion CXR (red arrow). Persistent consolidation and large gas collection in the left lower zone (yellow arrow). (F) - CXR left-sided tension pneumothorax with left lung collapse (red arrow)(G and H) Multiple cavities (red arrows) (I) - X-ray of the chest and abdomen extensive subcutaneous emphysema of chest wall, abdominal wall and groin (red arrow). (J) - VATS Bronchopleural fistula (marked with yellow arrow) (K) – CXR residual pneumatocele (red arrow) and small apical pneumothorax (yellow arrow) (L) - Complete resolution 10 weeks after initiated therapy).

reinsertion. Temporary subcutaneous emphysema developed due to air leakage but resolved spontaneously. The chest drain was removed on day 29, and the patient was discharged in good condition on day 35.

Discussion

In the context of pediatrics, SP, in conjunction with viruses and *Mycoplasma pneumoniae*, represents a significant aetiological agent in the development of pediatric CAP. Less frequently, *Streptococcus pyogenes* and *Staphylococcus aureus* cause pneumonias, which have a typically very complicated outcome necessitating surgical intervention. Antibiotics are generally an effective treatment, although in rare cases the healing process may be prolonged and complications may occur. In instances where all conservative treatment options have been exhausted, surgical intervention may be a reasonable course of action with generally good results. A growing number of authors have reported an increase in the number of complicated pneumonias requiring an operation.^{22–24}

Based on our study of 305 pediatric patients with community-acquired pneumonia (CAP) from January 2019 to December 2024, we observed a significant decline in hospitalization rates during the pandemic years (2020 and 2021), followed by a sharp increase in 2024. Among the 181 suspected pneumococcal pneumonia (SPP) cases, 28 developed complications, with 12 requiring invasive interventions. Notably, the prevalence of children needing thoracic surgery has risen substantially in recent years compared to earlier periods. This increase in complicated pneumonia cases has prompted us to explore several potential explanations for this shift.

Increased pathogen virulence may explain observed trends.²⁵ Data from the Czech National Surveillance Register show a shift in *Streptococcus pneumoniae* aggressiveness pre- and post-Covid.²⁶ In 2020, the Covid-19 pandemic led to 236 fewer reported invasive pneumococcal infections, underscoring its significant impact.

Furthermore, the implementation of quarantine measures to control the spread of the SARS-CoV-2 virus also had an impact on the number of cases reported worldwide in 2021.^{27,28} Our study is concordant with this trend. The eased restrictions on anti-epidemic measures resulted in a notable surge in respiratory morbidity in the subsequent years. This was evidenced by a markedly elevated incidence of respiratory syncytial virus (RSV) infections, a particularly severe outbreak of influenza, and a notable rise in cases of invasive bacterial infections, such as bacterial pneumonias. These findings are not exclusive to respiratory diseases; for example, there has been a notable surge in group A *Streptococcus* invasive infections frequency and severity from 2022 in European countries,^{29–32} or a sharp increase in meningococcal meningitis in France.³³ A number of authors have proposed that these phenomena may be explained by what has been termed an “immune debt”. They suggest that the wearing of masks and the isolation of individuals for a period of approximately two years may be a significant contributing factor.^{34–36}

Another potential explanation for the severe and more complicated outcome for pneumococcal pneumonia is the introduction of voluntary, insurance-covered vaccination against SP and the phenomenon of “serotype replacement”, which is commonly observed in this pathogen.^{37,38} The implementation of universal immunization programmes has resulted in a notable reduction in the incidence of infections caused by vaccine-included serotypes. However, serotype 3 continues to represent a significant cause of pneumococcal disease, with serotype 19A also being a notable contributor.^{38,39} The distinct capsular synthase mechanism, profuse production of a thick capsule, and its unique interaction with the bacterial surface are considered the mechanism of vaccine escape of serotype 3. Furthermore, serotype 3 has been demonstrated to be linked to more severe clinical manifestations and an elevated fatality rate in comparison to other serotypes.⁴⁰ Unfortunately, serotyping was only available in a few cases in our study. However, according to data from the National Institute of Public Health of the Czech Republic, serotype 3 caused almost 800 cases of invasive pneumococcal disease (IPD) from 2011 to 2022, which was twice as many as the next most frequent serotype (19A).⁴¹

A key objective of this discussion is an evaluation of the efficacy of antibiotic therapies in managing SPP cases. The level of resistance to penicillin among SP in the Czech Republic is relatively low 25. Consequently, high-dose G-penicillin remains the preferred initial treatment for SPP in hospital settings in TUH.⁴² Despite the favourable results observed in the majority of cases, the use of Penicillin G may occasionally have certain inherent limitations (in our study 17 complicated cases requiring escalation of antibiotics). One explanation is that commensal mucosal bacteria, though not primarily pathogenic, can worsen disease progression through their virulence factors, while beta-lactamase production—commonly seen in *Branhamella* or *Haemophilus*—may reduce antibiotic efficacy and contribute to treatment

failure despite *Streptococcus pneumoniae* sensitivity.⁴³ Another theoretical explanation, devoid of empirical evidence, pertains to the shortage of oral penicillin antibiotics in the Czech Republic during the 2022–2023 season, which impacted access and contributed to inappropriate use, potentially driving antimicrobial resistance and exacerbating the issue due to the bacterium's unique biological characteristics.^{44,45}

The present study focused more intensively on the subject of complicated pneumonia, with an examination of its prevalence and the various surgical techniques employed in its treatment. Another significant outcome of our research is the ability to reflect on the appropriate indications, timing, and extent of surgical intervention. Over the course of the five-year study period, surgical intervention was indicated in 11 cases of CAP, of which 6 was from SPP subgroups, with the majority of these occurring in the final year. Nevertheless, the optimal surgical treatment for acute necrotizing pneumonia and the optimal timing for its implementation remain subjects of contention within the pediatric surgical community. A study by Lai et al concludes that some investigators recommend a formal lobectomy for the majority of cases,^{22,46} whereas others suggest that lobectomy is rarely necessary and prefer to perform decortication to preserve lung parenchyma.^{14,47,48} In the cohort of patients studied by Lai et al,²² the aggressive surgical management involving lung resection in cases of complicated and devastating necrotising pneumonia was associated with a reduction in postoperative morbidity. In view of the findings of our study, we put forward the suggestion of a less invasive surgical approach. When provided with sufficient time, patients benefit from the full effect of supportive therapy and their intrinsic capacity to heal and recuperate from damage caused by severe disease.^{11,49} We believe that even a longer hospital stay is a good price to pay for the preservation of all five lobes of the lung, especially in terms of childhood and later life.

Strength and Limitations

Strengths of this study include a five-year observation period encompassing the epidemiological impact of the SARS-CoV-2 pandemic, a large cohort of complicated patients treated across Prague and surrounding regions, and a multidisciplinary approach involving experts from various medical fields. However, a key limitation is the reliance on suspected *Streptococcus pneumoniae* etiology, which was not microbiologically confirmed in all cases. Additionally, the study's single-center design and potential biases from retrospective data collection are notable limitations.

Conclusion

The results of this longitudinal analysis demonstrate that following a two-season hiatus due to the implementation of restrictions associated with the global pandemic of SARS-CoV-2, the incidence of pneumonia highly suspected for SP aetiology has once again become apparent in our region. Moreover, over the past two years, there has been a notable increase in the number of cases where first-line antibiotic therapy has failed to achieve the desired outcome in its entirety. Additionally, there has been a rise in the frequency of complicated pneumonia cases, including those with pleural effusion, empyema, and necrotising pneumonia with cavity formation. These cases often require more complex treatment, including surgical intervention, compared to those seen prior to the pandemic. Despite these developments, there is still a need to identify optimal diagnostic and treatment strategies for all levels of severity of pediatric pneumococcal pneumonias, with a particular focus on the timing and choice of potential surgical intervention. In the context of our study, it is recommended that minimally invasive surgical procedures be prioritized, compared to lobectomy, in pediatric cases.

Abbreviations

ATBs, Antibiotics; CAP, Community Acquired Pneumonia; COVID19, Coronavirus Disease 2019; CRP, C-reactive protein; CT, Computed Tomography; CXR, Chest X-Ray; HFNO, High Flow Nasal cannula Oxygenation; MITS, Mini Invasive Thoracic Surgery; PCR, Polymerase Chain Reaction; PCT, Procalcitonin; PICU, Pediatric Intensive Care Unit; r-TPA, Recombinant Tissue Plasminogen Activator (eg Alteplase); SARS-CoV-2, Severe acute respiratory syndrome-related coronavirus 2; SP, *Streptococcus pneumoniae*; SPP, Suspected Pneumococcal Pneumonia; TUH, Thomayer University Hospital; VATS, Video-Assisted Thoracic Surgery; VTS, VideoThoracoScopy.

Ethics Approval

The ethical considerations were rigorously adhered to, ensuring that the patient data was anonymised and securely stored. This study was approved by the Ethics Committee with multicenter competence of the Institute for Clinical and Experimental Medicine and Thomayer University Hospital under the code 30292/24. The study protocol complies with the Declaration of Helsinki.

Consent to Participate

The nature of the study was a retrospective analysis of data in the information system. Therefore, informed consent could not be applied.

Consent to Publish

The authors affirm that pictures used for the figures were published with the consent of patients' parents. Human research participants provided informed consent for publication of the images in [Figures 3–5](#).

Use of AI

AI was used with the translation into English with DeepL, otherwise AI was not used in preparation of this article.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors have no relevant financial or non-financial interests to disclose in this work.

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