Pediatric Empyema Thoracis: A Two-Year Prospective Observational Study of Clinical Profile, Microbiological Spectrum, and Surgical Outcomes at a Tertiary Care Centre in South India.

ABSTRACT:

Background: Empyema thoracis (ET), a severe complication of community-acquired pneumonia (CAP) characterized by pus in the pleural cavity, remains a significant cause of morbidity in children, particularly in resource-limited settings. Optimal management is debated, ranging from intercostal drainage (ICD) and intrapleuralfibrinolytics to surgical interventions. Ultrasonography (USG)-based staging offers a rational, radiation-free, and bedside-accessible framework for guiding treatment.

Objectives: To evaluate the clinical profile, microbiological spectrum, and outcomes of a structured USGguided, stage-based management protocol for pediatric empyema thoracis at a tertiary care centre in South India.

Methods: A prospective observational study was conducted on 35 children under 18 years diagnosed with empyema thoracis over two years. Patients were managed according to a predefined USG-based protocol: Stage 1 (non-loculated) received ICD alone; Stage 2 (loculated) received ICD with intrapleural streptokinase (IPSK); Stage 3 (organized peel) underwent primary surgical intervention (VATS or open decortication). Demographic, clinical, microbiological, and outcome data were analyzed.

Results: The cohort predominantly comprised young, school-aged males (62.9%; mean age 7.84 years) from lower socioeconomic backgrounds (88.6%), with 82.9% presenting chronically (symptoms ≥7 days). USG staging revealed 17.1% Stage 1, 42.9% Stage 2, and 40.0% Stage 3 disease. Culture positivity was 42.9%, with Staphylococcus aureus (20%) as the most prevalent isolate. The overall primary treatment success rate was 88.6% (31/35), escalating to 100% with salvage surgery. ICD+IPSK for Stage 2 achieved an 88.2% success rate, and primary surgery for Stage 3 achieved 100% success. At 3-month follow-up, 82.9% showed complete radiological resolution.

Conclusion: A USG-guided, staged management protocol for pediatric empyema thoracis is highly effective, rational, and reproducible. ICD+IPSK is a successful, surgery-sparing strategy for loculated (Stage 2) disease. Timely surgical intervention with VATS or open decortication for Stage 3 disease achieves definitive outcomes. Routine USG staging should be implemented at every tertiary care centre, as it remains the most practical tool for guiding management in resource-limited settings.

Keywords: *Empyema thoracis; children; parapneumonic effusion; intrapleuralfibrinolytic therapy; intercostal drainage; decortication; ultrasonography staging; Staphylococcus aureus; management protocol; South India.*

1. INTRODUCTION

Community-acquired pneumonia (CAP) remains a formidable challenge to global child health, constituting a leading cause of morbidity and mortality in children under five years of age, particularly in low- and middleincome countries. While the majority of pneumonia episodes resolve with appropriate antibiotic

therapy, a significant subset develops local complications, the most common and serious of which is parapneumonic effusion (PPE)—the accumulation of exudative fluid in the pleural space adjacent to a pneumonic process. A proportion of these effusions progress to become infected, evolving into the more severe condition known as empyema thoracis (ET), characterized by pus in the pleural cavity.

The development of PPE and ET significantly alters the clinical course of pneumonia, leading to prolonged fever, increased hospitalization, greater requirement for invasive interventions, higher healthcare costs, and considerable morbidity. Despite advances in antibiotic therapy and vaccination programmes, the incidence of pediatric pleural empyema has been reported to be increasing in various parts of the world, including India, making it a persistent and evolving clinical problem.

Empyema thoracis progresses through three pathological stages: (1) the exudative stage, characterized by free-flowing sterile exudate; (2) the fibrinopurulent stage, marked by bacterial invasion, fibrin deposition, and loculation; and (3) the organizing stage, wherein fibroblasts migrate into the exudate to form a thick, inelastic pleural peel causing lung entrapment. The clinical challenge lies in accurately identifying the stage to dictate the most appropriate management strategy.

Ultrasonography (USG) has emerged as the single most practical and indispensable bedside tool for staging pleural disease in real time, without radiation exposure. It characterizes the effusion, identifies septations and loculations, and estimates the degree of pleural thickening—information that is clinically superior to chest radiography for guiding treatment decisions. Guidelines from the American Pediatric Surgical Association (APSA) and the British Thoracic Society (BTS) recommend USG as the primary imaging modality for pediatric parapneumonic effusion, with CT reserved for complex cases.

Management options span a hierarchy from least to most invasive: antibiotic therapy alone, ICD, ICD with intrapleuralfibrinolytic therapy (IPFT), video-assisted thoracoscopic surgery (VATS), and open thoracotomy with decortication. The optimal choice is dictated by the USG stage. In resource-limited settings in South India, where the majority of patients present late with advanced disease due to socioeconomic barriers, a structured, USG-guided protocol offers a pragmatic and reproducible framework.

This prospective observational study was designed to: (i) analyze the clinical and microbiological profile of pediatric empyema thoracis; (ii) evaluate outcomes of a structured USG-based staged management protocol; and (iii) highlight the utility of USG staging as the primary decision-making tool in a tertiary care setting in South India.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

A prospective observational study was conducted in the Department of General Surgery at Al-Ameen Medical College Hospital, Vijayapura, Karnataka, India, a tertiary care referral centre serving a predominantly rural and semi-urban population of North Karnataka. The study was conducted over a two-year period and received ethical clearance from the Institutional Ethics Committee.

2.2 Study Population

Thirty-five consecutive children below 18 years of age diagnosed with empyema thoracis were enrolled after obtaining informed consent from parents or guardians. Inclusion criteria were: (a) age <18 years; (b) clinical and radiological diagnosis of empyema thoracis confirmed by USG; and (c) written informed

consent. Exclusion criteria included recurrent empyema, empyema secondary to malignancy, and patients transferred out before completion of treatment.

2.3 USG-Based Staging Protocol

All patients underwent thoracic ultrasonography at the time of admission. The USG staging system adopted was as follows:

Stage 1 (Exudative): Free-flowing, anechoic or minimally echogenic pleural fluid without septations.

Stage 2 (Fibrinopurulent/Loculated): Echogenic pleural fluid with visible fibrin strands, septations, or loculations.

Stage 3 (Organizing): A thick hyperechoic pleural peel with or without lung entrapment; non-moving, collapsed lung parenchyma.

CT thorax was performed selectively in patients with advanced or complex disease and preoperatively in all patients undergoing open decortication. USG was the primary staging tool for all management decisions.

2.4 Treatment Protocol

A structured, stage-directed treatment algorithm was applied consistently to all patients:

Stage 1: Intercostal drainage (ICD) alone. Small-bore chest tubes (12–16 French) were inserted under USG guidance, connected to an underwater seal drainage system, and combined with intravenous antibiotics.

Stage 2: ICD with intrapleural streptokinase (IPSK). Streptokinase (25,000–50,000 IU in 30 ml normal saline) was instilled through the ICD tube, clamped for 4 hours, then released. The instillation was repeated daily for 3–5 doses depending on clinical and radiological response.

Stage 3: Primary surgical intervention. Cases with early organizing peel (multiple loculations with early peel) underwent VATS, while cases with thick fibrous peel and lung entrapment underwent open thoracotomy with decortication. Two Stage 3 patients with borderline features were initially trialled on ICD+IPSK; both required salvage decortication.

Empirical intravenous antibiotics were initiated at admission in all patients and de-escalated based on culture and sensitivity results. Antibiotics were continued for a minimum of 10 days after defervescence.

2.5 Outcome Measures

Primary treatment success was defined as complete clinical improvement (resolution of fever, respiratory distress) and radiological clearance without the need for escalation to a more invasive procedure. Secondary outcomes included: need for salvage surgery; complication rates; duration of hospital stay, ICD placement, and IV antibiotic therapy; and radiological outcomes (complete resolution, residual thickening, persistent collapse) at 3-month follow-up.

2.6 Statistical Analysis

Data were analyzed using SPSS version 23.0. Categorical variables were expressed as frequencies and percentages. Association between USG stage and treatment modality was assessed by Fisher's Exact Test. Comparison of continuous variables (hospital stay, ICD duration, antibiotic duration) across treatment groups was performed by one-way ANOVA with Tukey's HSD post hoc test. A p-value <0.05 was considered statistically significant.

3. RESULTS

3.1 Demographic and Socioeconomic Profile

A total of 35 children were enrolled. The cohort was predominantly male (22/35; 62.9%) with a mean age of 7.84 years. The 6–10 years age group was the most commonly affected (42.9%), followed by 1–5 years (31.4%) and 11–16 years (25.7%), yielding a male-to-female ratio of 1.7:1. An overwhelming 88.6% of patients (n=31) belonged to the lower or lower-middle socioeconomic class, with only 11.4% from the uppermiddle class. The majority of patients (82.9%, n=29) presented chronically, with symptom duration of ≥7 days.

Table 1: Age and Gender Distribution of the Cohort (n=35)

Age Group (Years)	Male, n (%)	Female, n (%)	Total, n (%)
1–5	7 (20.0%)	4 (11.4%)	11 (31.4%)
6–10	10 (28.6%)	5 (14.3%)	15 (42.9%)
11–16	5 (14.3%)	4 (11.4%)	9 (25.7%)
Total	22 (62.9%)	13 (37.1%)	35 (100%)

Male predominance was most pronounced in the 6–10 years age group (10 males vs. 5 females).

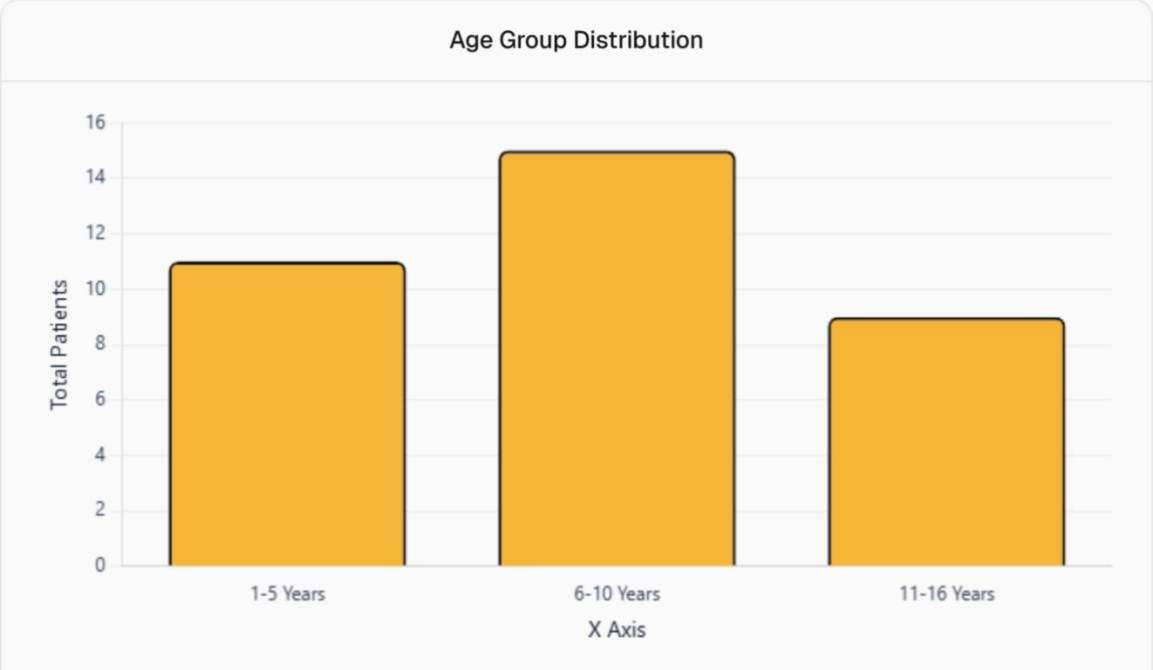

Figure 1a: Age group distribution of pediatric empyema patients (n=35)

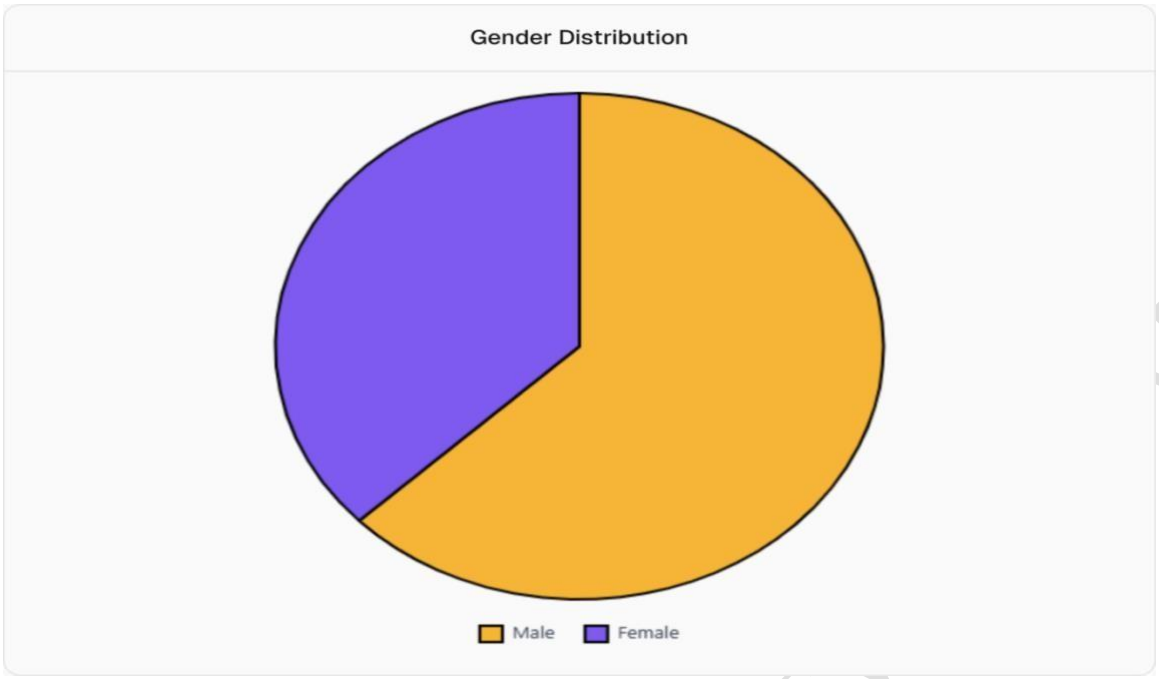

Figure 1b: Gender distribution

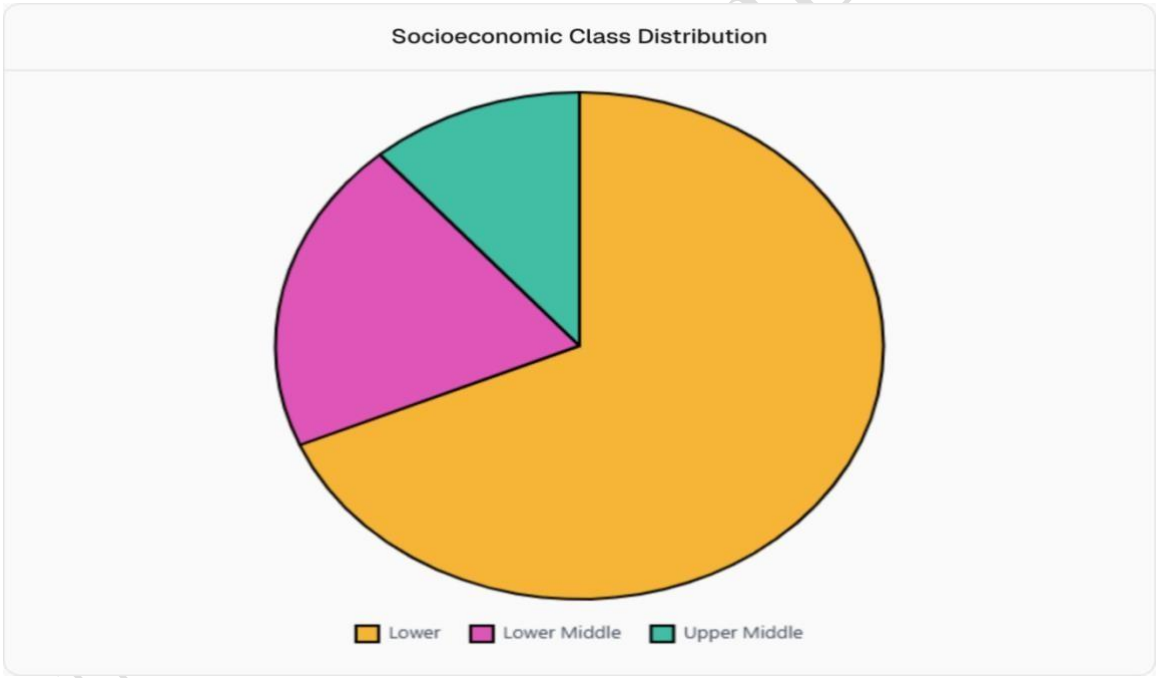

Figure 2: Socioeconomic class distribution

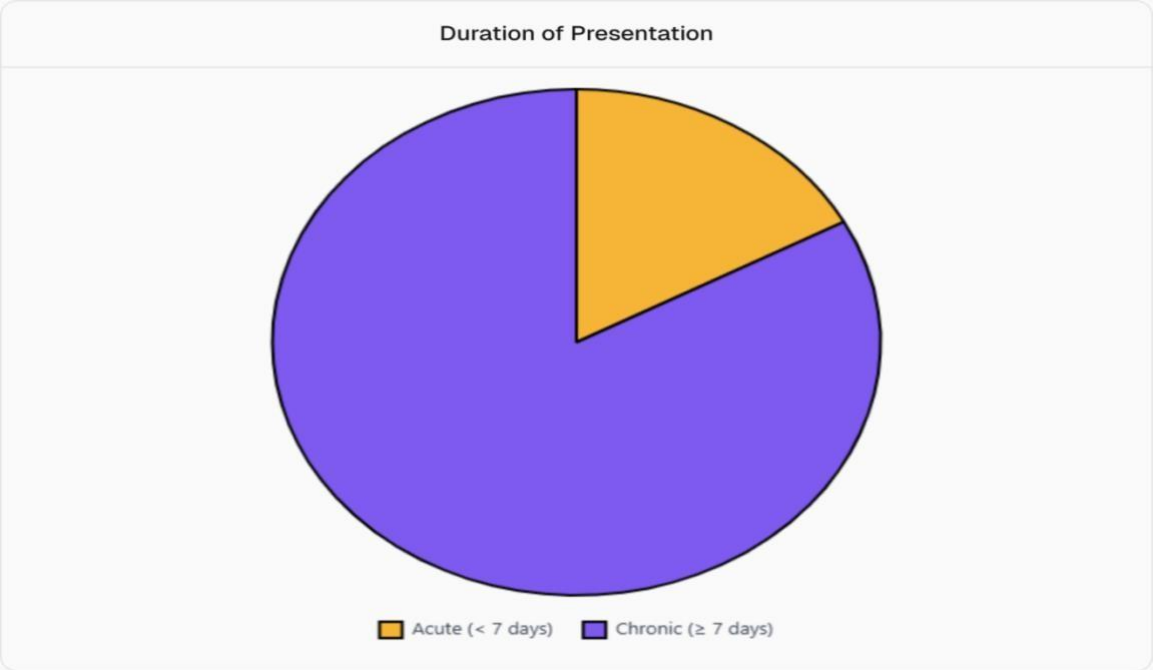

Figure 3: Duration of presentation (acute vs. chronic)

3.2 USG Staging

USG staging revealed a cohort overwhelmingly burdened by advanced disease: 82.9% of patients presented with either Stage 2 (loculated; 42.9%, n=15) or Stage 3 (organized peel; 40.0%, n=14) empyema. Only 17.1% (n=6) had Stage 1 non-loculated disease. This distribution directly reflected the chronicity of presentation and predicted the need for escalated management strategies.

Table 2: Ultrasonographic (USG) Staging of Patients – HIGH YIELD TABLE

USG Stage	Description	No. of Patients (n)	Percentage (%)
Stage 1	Non-loculated (free-flowing)	6	17.1%
Stage 2	Loculated (fibrin septations)	15	42.9%
Stage 3	Organized peel (lung entrapment)	14	40.0%
Total		35	100.0%

82.9% of patients presented with advanced Stage 2 or Stage 3 disease, confirming the pattern of delayed referral at this tertiary centre.

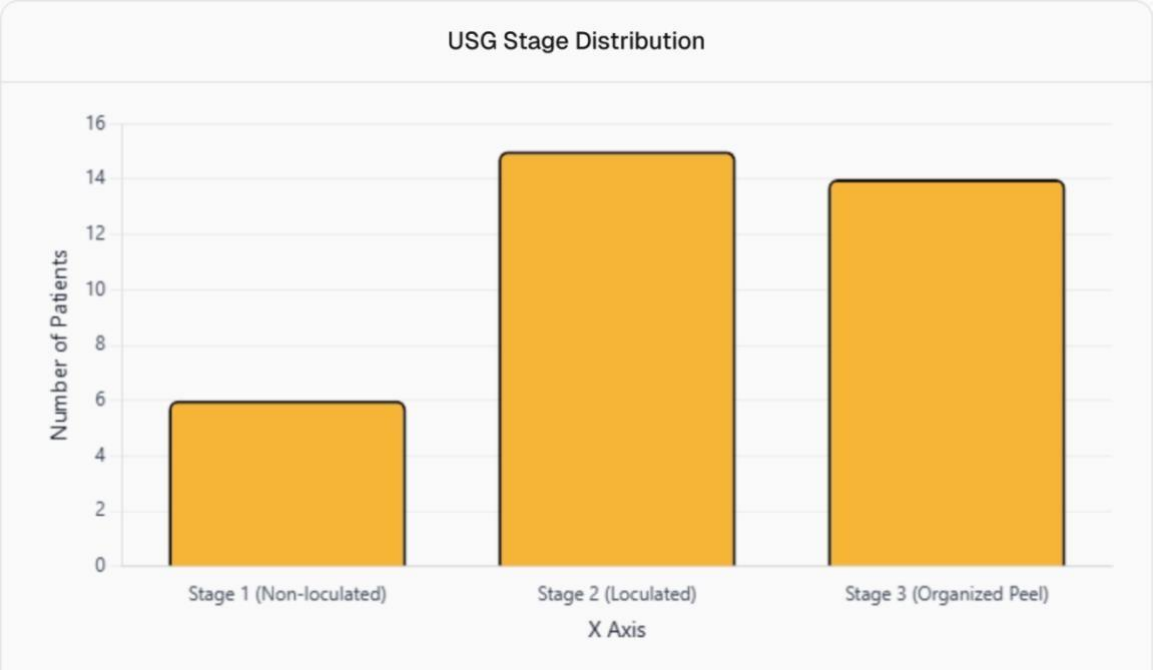

Figure 4: USG stage distribution

3.3 Clinical Features and Laterality

The clinical presentation was dominated by fever (97.1%), cough (94.3%), and dyspnea (71.4%). Chest pain was reported in 28.6% of patients, with its lower prevalence attributable to the younger age demographic and difficulty in localizing pleuritic pain. Right-sided involvement was marginally more common (54.3%) than left-sided (45.7%), with no bilateral cases, consistent with the anatomically more direct right main bronchus.

Table 3: Prevalence of Clinical Features

Clinical Feature	Number of Patients (n)	Percentage (%)
Fever	34	97.1%
Cough	33	94.3%
Dyspnea	25	71.4%
Chest Pain	10	28.6%

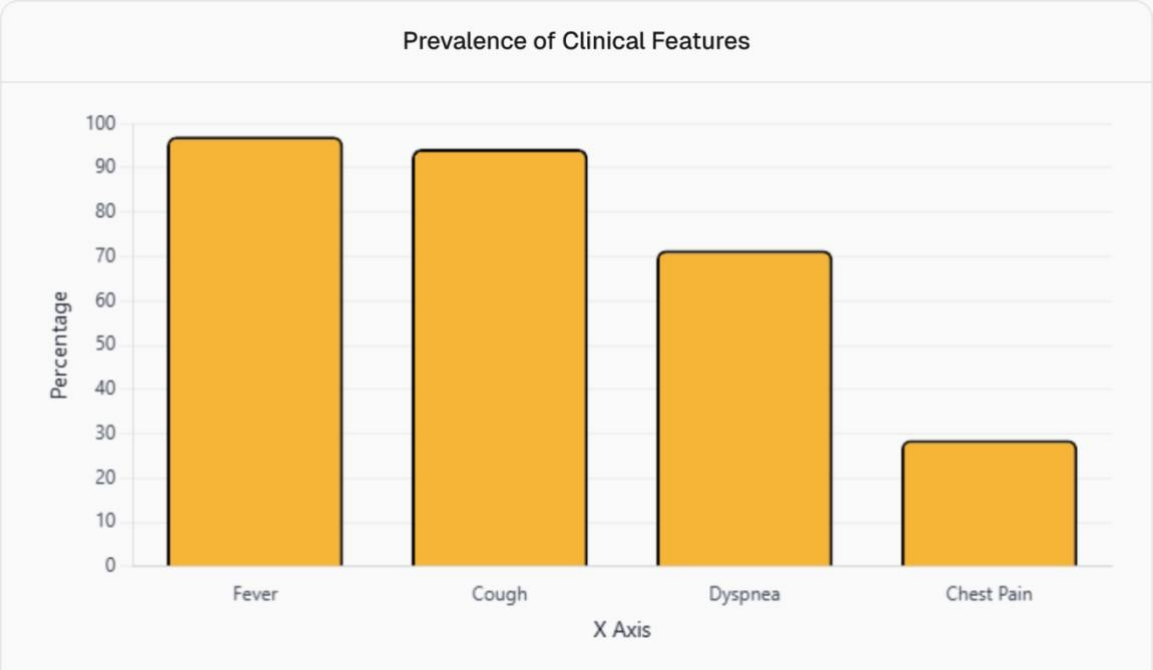

Figure 5: Prevalence of presenting clinical features

3.4 Predisposing Factors

A striking 94.3% of patients had at least one identifiable predisposing factor. Previous pneumonia was the most prevalent (94.3%), underscoring empyema's pathogenesis as a complication of undertreated or virulent CAP. Incomplete vaccination was present in 57.1% and malnutrition in 51.4%, reflecting the socioeconomic vulnerability of the cohort. TB contact was identified in 8.6%. Only 5.7% of patients had no identifiable predisposing factor.

Table 4: Distribution of Predisposing Factors – HIGH YIELD TABLE

Predisposing Factor	Number of Patients (n)	Percentage (%)
Previous Pneumonia	33	94.3%
Incomplete Vaccination	20	57.1%
Malnutrition	18	51.4%
TB Contact	3	8.6%
None	2	5.7%

Note: Patients often had more than one predisposing factor.

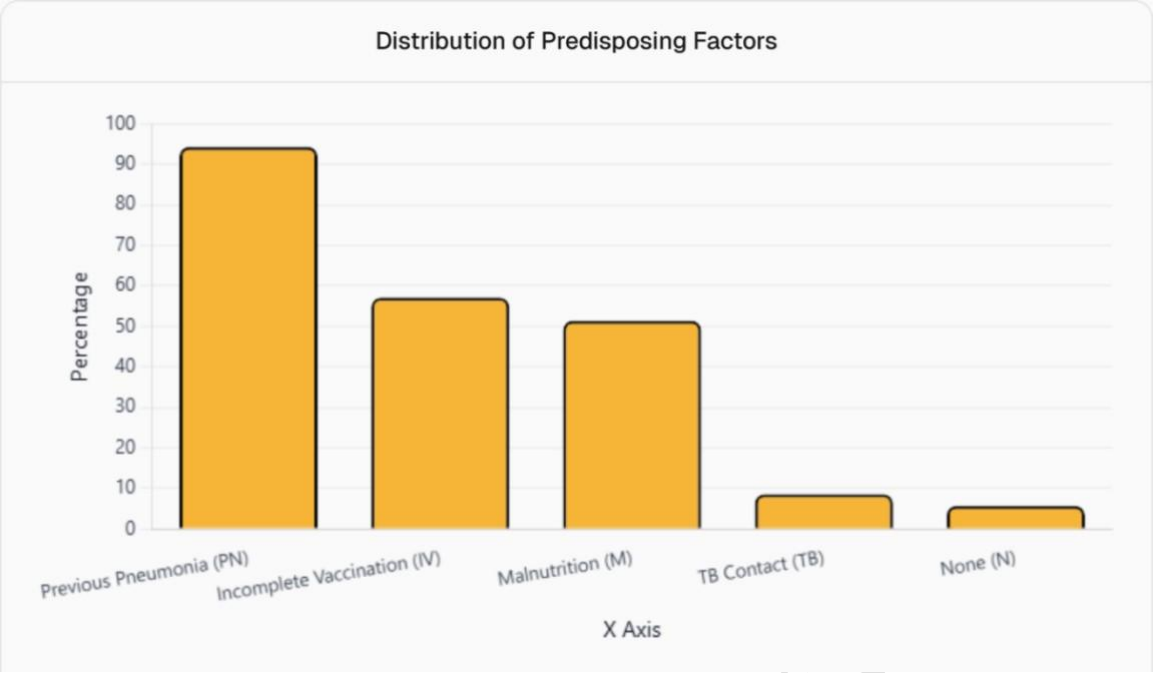

Figure 6: Distribution of predisposing factors

3.5 Microbiological Profile

Pleural fluid culture positivity was 42.9% (n=15). The majority of samples (57.1%, n=20) yielded no growth, a well-documented phenomenon attributable to pre-referral antibiotic administration. Among culture-positive cases, Staphylococcus aureus was the predominant pathogen (20.0%, n=7), followed by Streptococcus pneumoniae (11.4%, n=4), Klebsiellapneumoniae (8.6%, n=3), and Pseudomonas aeruginosa (2.9%, n=1). The high culture-negative rate underscores the necessity for empirical broad-spectrum antibiotic therapy targeting S. aureus and S. pneumoniae.

Table 5: Pleural Fluid Culture Results – HIGH YIELD TABLE

Culture Result	Number of Patients (n)	Percentage (%)
No Growth	20	57.1%
Staphylococcus aureus	7	20.0%
Streptococcus pneumoniae	4	11.4%
Klebsiellapneumoniae	3	8.6%
Pseudomonas aeruginosa	1	2.9%
Total	35	100.0%

Culture positivity rate: 42.9%. S. aureus was the most common isolate, consistent with studies from the Indian subcontinent.

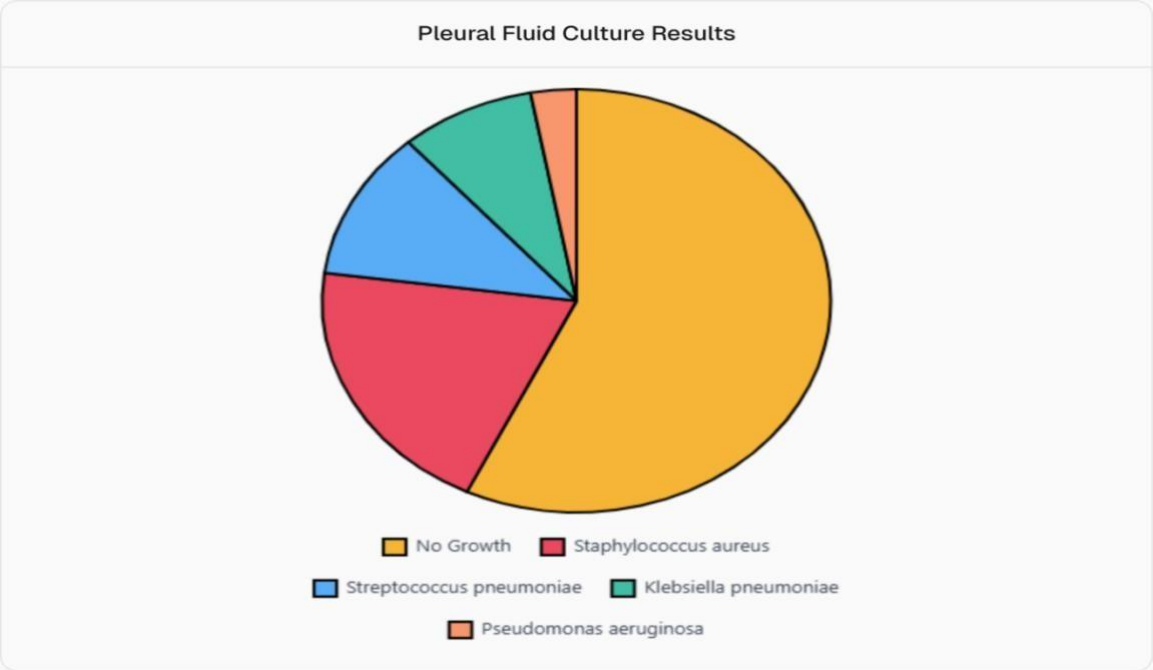

Figure 7: Pleural fluid culture results

Pleural fluid appeared as frank pus in 80.0% (n=28) of patients and as seropurulent fluid in 20.0% (n=7). The overwhelming prevalence of frank pus provided a macroscopic confirmation of advanced, suppurative disease in this cohort.

3.6 Treatment Modalities and Outcomes

Treatment allocation followed the USG staging protocol. The most common intervention was ICD+IPSK (48.6%), followed by VATS (22.9%), ICD alone (17.1%), and open decortication (11.4%). Fisher's Exact Test confirmed a highly statistically significant association between USG staging and treatment modality ($p<0.001$).

Table 6: Primary Treatment Modalities Employed

Primary Treatment	No. of Patients (n)	Percentage (%)
ICD alone	6	17.1%
ICD + Intrapleural Streptokinase (IPSK)	17	48.6%
Video-Assisted Thoracoscopic Surgery (VATS)	8	22.9%
Open Decortication	4	11.4%
Total	35	100.0%

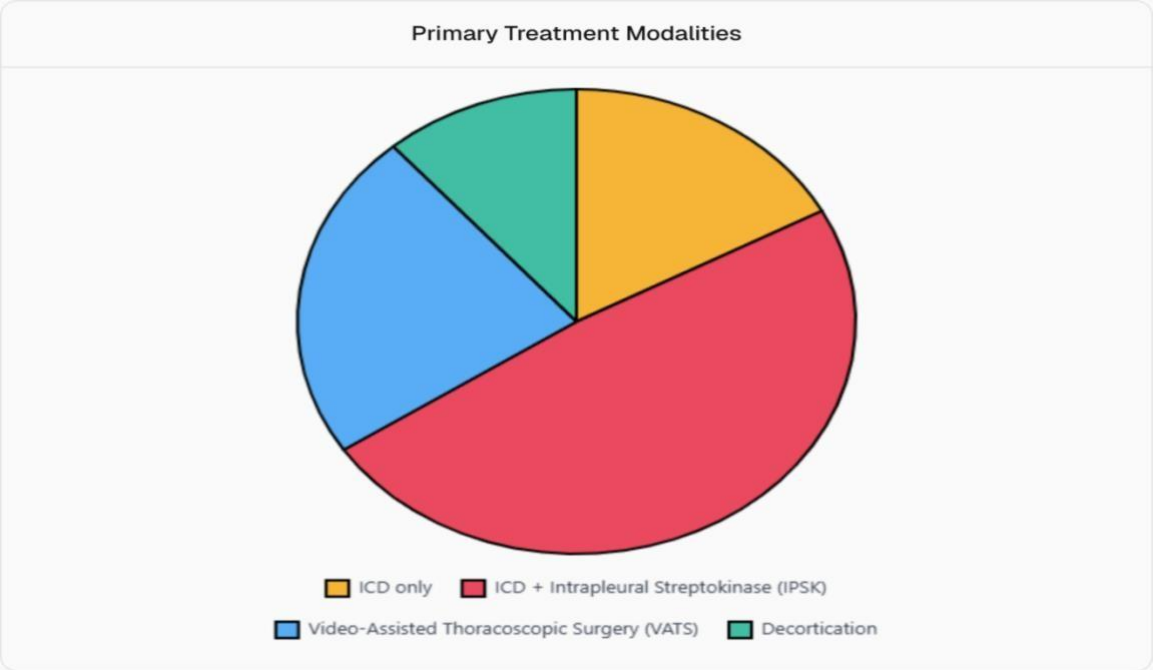

Figure 8: Primary treatment modalities employed

Table 7: Correlation Between USG Stage and Primary Treatment – HIGH YIELD TABLE

USG Stage	ICD only	ICD+IPSK	VATS	Decortication	p-value
Stage 1 (n=6)	6	0	0	0	<0.001
Stage 2 (n=15)	0	15	0	0	<0.001
Stage 3 (n=14)	0	2*	8	4	<0.001

** 2 Stage 3 patients were initially trialled on ICD+IPSK; both required salvage decortication. p-value by Fisher's Exact Test.*

Table 8: Treatment Outcomes and Need for Salvage Surgery – HIGH YIELD TABLE

Primary Treatment	Success (n)	Failure → Salvage	Total (n)	p-value
ICD only	4	2 → VATS	6	0.421
ICD + IPSK	15	2 → Decortication	17	0.421
VATS	8	0	8	—
Decortication	4	0	4	—
Overall	31 (88.6%)	4 (11.4%)	35	—

Overall primary success rate: 88.6%. Final success rate with salvage surgery: 100%. Both primary surgical modalities (VATS and decortication) achieved 100% primary success.

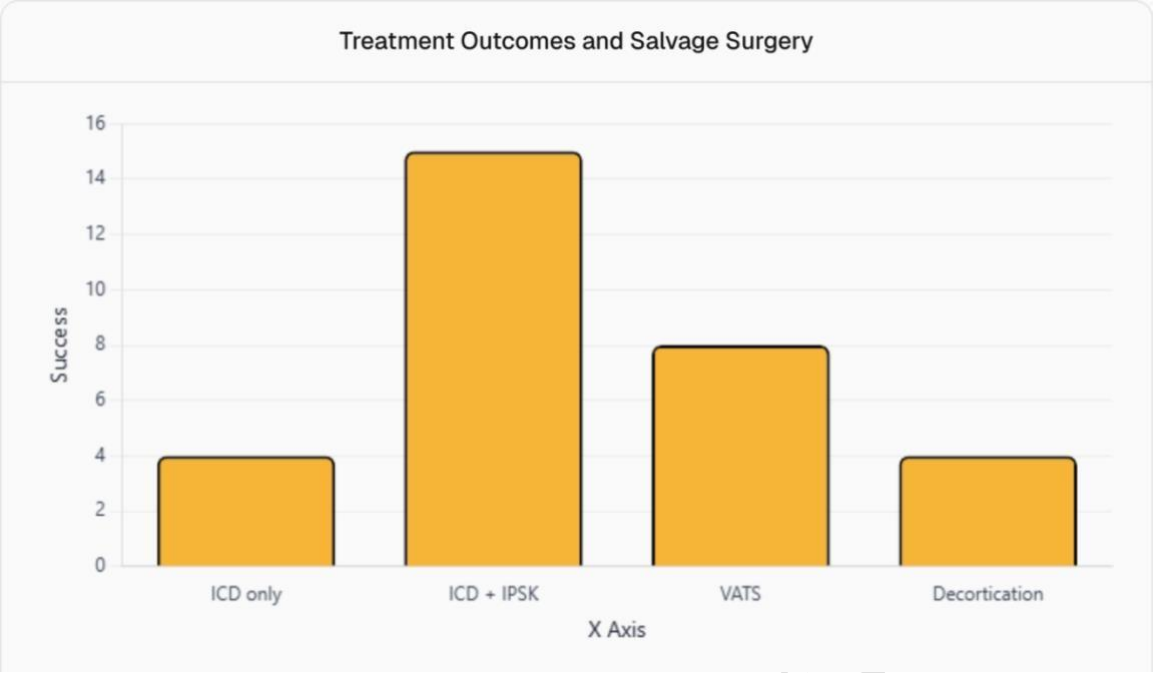

Figure 9: Treatment outcomes and need for salvage surgery

3.7 Complications

The majority of patients (77.1%, n=27) had an uncomplicated clinical course. Tube blockage occurred in 3 patients (ICD-only group). Subcutaneous emphysema was noted in 3 patients (ICD+IPSK: 2, ICD: 1). The two most significant complications — persistent air leak and surgical site infection — each occurred in one patient from the open decortication group, reflecting the higher invasiveness of that procedure. No complications were noted in the VATS group.

Table 9: Complications Encountered

Complication	No. of Episodes (n)	Associated Treatment
Tube Blockage	3	ICD only
Subcutaneous Emphysema	3	ICD+IPSK (2), ICD only (1)
Persistent Air Leak	1	Decortication (1)
Surgical Site Infection	1	Decortication (1)
None	27	—

3.8 Duration of Hospital Stay and IV Antibiotic Therapy

A clear gradient was observed across treatment groups: the VATS group had the shortest mean hospital stay (8.5 days), followed by ICD+IPSK (11.8 days), Decortication (14.5 days), and ICD alone (16.2 days). Oneway ANOVA revealed a statistically significant difference in mean hospital stay across treatment groups ($p=0.018$). Post hoc analysis (Tukey's HSD) demonstrated that the VATS group had a significantly shorter hospital stay compared to the ICD-only group ($p=0.018$) and ICD+IPSK group ($p=0.042$). These findings

confirm that timely and definitive surgical source control — as achieved by VATS — facilitates the most rapid recovery.

Table 10: Duration of Hospital Stay and Treatment by Modality – HIGH YIELD TABLE

Primary Treatment	Mean Hospital Stay (Days)	Mean ICD Duration (Days)	Mean IV Antibiotics (Days)	p-value*
ICD only	16.2	13.2	15.8	0.023
ICD + IPSK	11.8	8.9	11.4	0.042
VATS	8.5	6.8	11.3	0.018
Decortication	14.5	9.5	13.6	0.216
Overall Mean	11.9	9.2	12.8	0.018

**p-values derived from one-way ANOVA; VATS demonstrated significantly shorter hospital stay vs ICD-only (p=0.018) and ICD+IPSK (p=0.042) groups.*

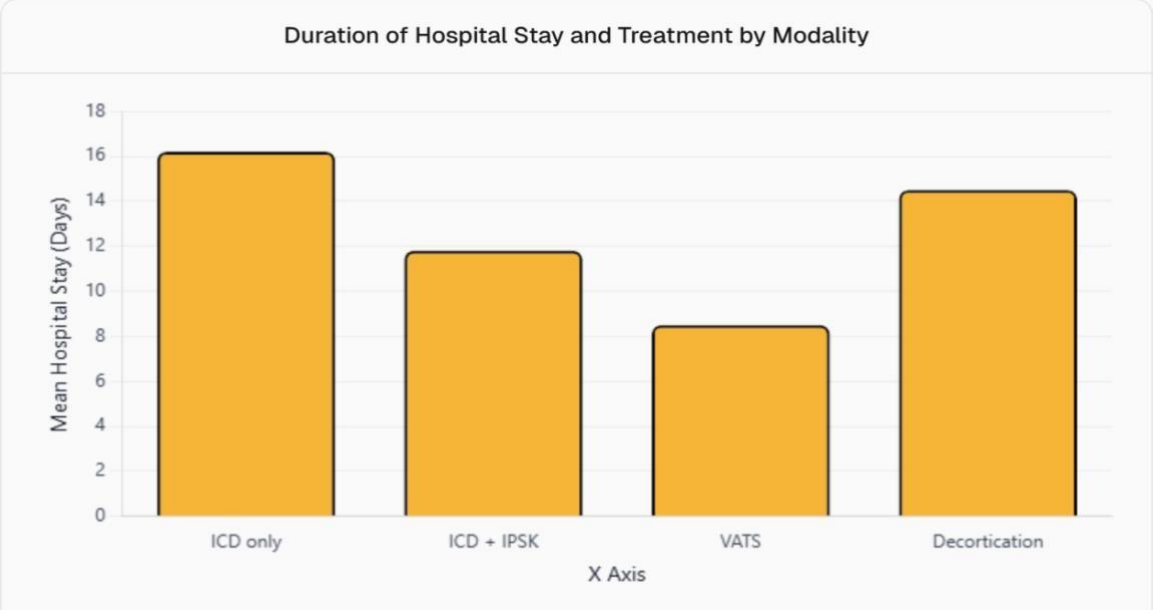

Figure 10: Mean duration of hospital stay and treatment by modality

3.9 Follow-up Radiological Outcomes at 3 Months

At the 3-month follow-up, 82.9% (n=29) of patients achieved complete radiological resolution. Residual pleural thickening was noted in 14.3% (n=5), and persistent collapse in 2.8% (n=1). Critically, all residual sequelae were concentrated in the open decortication group, reflecting the severity of the initial disease burden in those patients rather than a failure of the surgical procedure. Patients managed with ICD alone, ICD+IPSK, and VATS all achieved complete radiological resolution.

Table 11: Follow-up Radiological Outcomes at 3 Months – HIGH YIELD TABLE

Treatment	Complete Resolution (CR)	Residual Thickening (RT)	Persistent Collapse (PC)	Total
ICD only	6	0	0	6
ICD + IPSK	15	2	0	17
VATS	8	0	0	8
Decortication	0	3	1	4
Total	29 (82.9%)	5 (14.3%)	1 (2.8%)	35

All residual radiological sequelae (RT and PC) were confined exclusively to the decortication group, confirming that this represents the most severe initial disease burden.

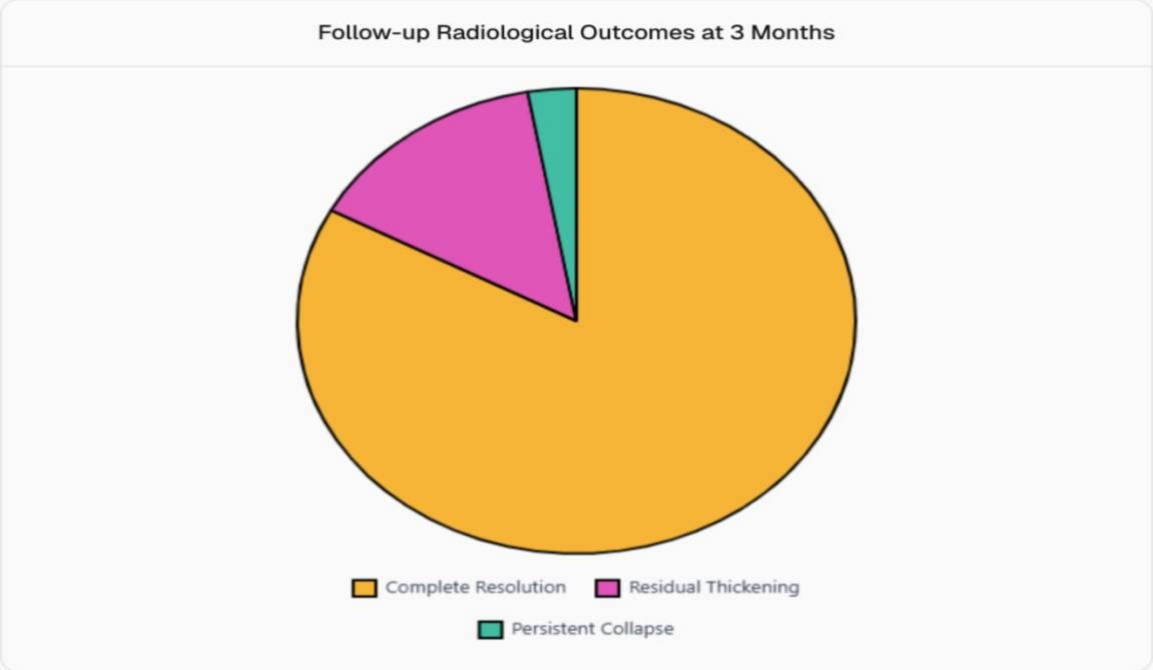

Figure 11: Follow-up radiological outcomes at 3 months

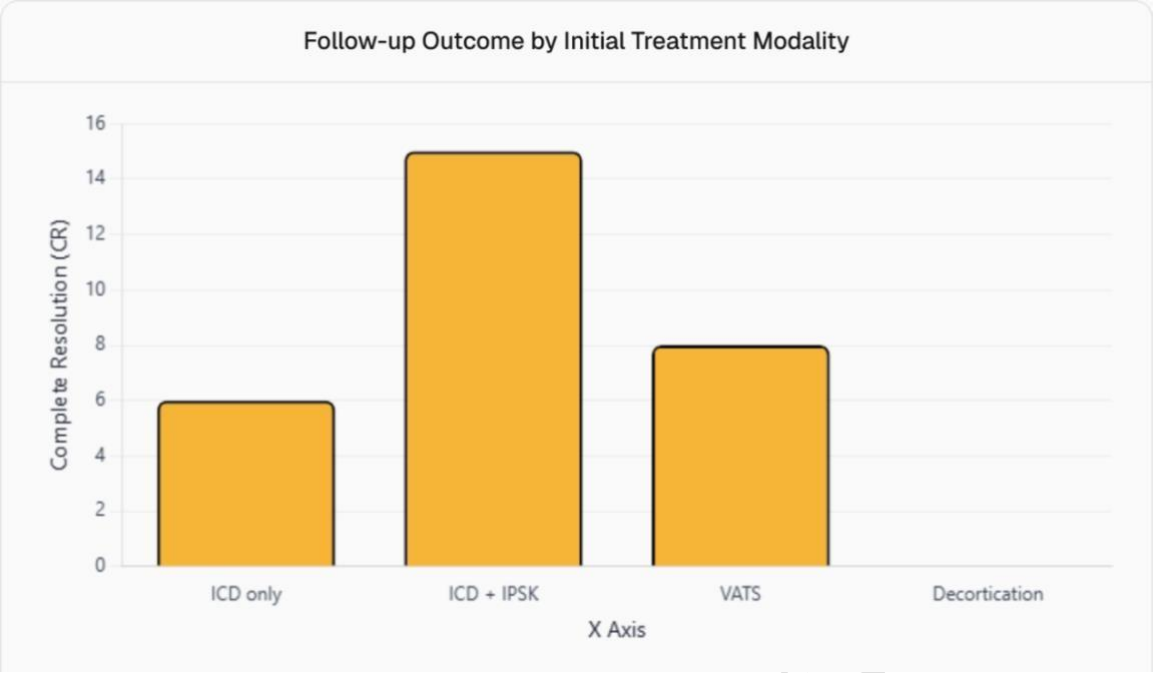

Figure 12: Follow-up outcome stratified by initial treatment modality

4. DISCUSSION

The findings of this prospective study provide robust institutional validation for a structured, USG-guided, stage-directed management protocol for pediatric empyema thoracis at a tertiary care centre in South India. The results demonstrate that such an algorithm achieves high primary success rates (88.6%), escalating to 100% with salvage surgery, even in a cohort burdened by advanced disease, late presentation, and significant socioeconomic disadvantage.

4.1 Demographic and Socioeconomic Determinants

Our cohort was predominantly young (mean age 7.84 years) and male (62.9%), consistent with reports from multiple Indian studies. The male preponderance—observed at a ratio of 1.7:1—may reflect sex-based differences in immune response regulation, with young males exhibiting transient relative immaturity in cellmediated (Th1) immunity compared to females. The predominance of the 6–10 years age group (42.9%) aligns with the established epidemiology of complicated pneumonia, where a maturing but not fully competent immune system coupled with anatomically narrower airways predisposes this group to suppurative complications.

The profound socioeconomic skew—with 88.6% of patients from lower and lower-middle classes—is not incidental but is a central explanatory variable. Poverty is intrinsically linked to malnutrition, incomplete vaccination, overcrowding, and barriers to healthcare access, all of which were highly prevalent in this cohort (malnutrition 51.4%, incomplete vaccination 57.1%). These factors create a cascade: malnutrition impairs both innate and adaptive immunity; incomplete vaccination leaves children vulnerable to invasive pathogens; and financial barriers delay referral. The result, as seen in this study, is that 82.9% of children arrived at the hospital with chronic (>7 days), advanced-stage disease. Pediatric empyema in this context is

therefore not merely a surgical problem but a sociomedical one, demanding public health interventions targeting nutritional support, vaccination coverage, and primary care accessibility.

4.2 The Imperative of USG Staging

Thoracic ultrasonography was the cornerstone of management in this study and should be considered the standard of care at every tertiary care centre. USG is radiation-free, bedside-accessible, repeatable, and clinically superior to plain chest radiography for characterizing effusion complexity. It allows clinicians to move beyond the question of "is there an effusion?" to "what kind of effusion is it?" thereby dictating the most appropriate intervention.

In this cohort, USG staging aligned perfectly with both clinical presentation and treatment response. Stage 1 (anechoic, free-flowing) disease was universally amenable to ICD alone. Stage 2 (echogenic, septated, loculated) disease—the largest subgroup—responded to fibrinolytic therapy in 88.2% of cases. Stage 3 (thick hyperechoic peel with trapped lung) mandated surgical decortication, which USG correctly identified. The statistically significant correlation between USG stage and treatment modality ($p<0.001$) validates the protocol's scientific rigour. CT thorax, while providing superior anatomical detail, was used selectively (primarily preoperative), given its radiation burden and availability constraints. All CT findings in the decortication group corroborated USG-identified Stage 3 features, confirming concordance between both modalities.

USG staging is also a resource-appropriate framework for developing-country settings, where CT scanners may not be universally available or accessible. The strong alignment between sonographic findings, pathological substrates, and therapeutic responses observed in this study makes USG the most practical, reproducible, and rational tool for guiding management decisions in pediatric empyema at tertiary care centres.

4.3 Microbiological Findings

The high culture-negative rate (57.1%) is a well-documented challenge in empyema management, attributable primarily to pre-referral antibiotic administration. This pragmatic reality necessitates empirical, broadspectrum antibiotic therapy at presentation, targeting the most prevalent and virulent organisms in the local epidemiology.

Staphylococcus aureus was the most frequently isolated organism (20.0%), consistent with its recognized role as a leading cause of severe, complicated pneumonia in the Indian subcontinent. Its virulence factors—including Panton-Valentine leukocidin (PVL) toxin in select strains—are associated with rapid tissue destruction and a high propensity for pleural complications. The isolation of Gram-negative organisms (Klebsiellapneumoniae 8.6%, Pseudomonas aeruginosa 2.9%) underscores the importance of broaderspectrum empirical coverage in severely ill children. While Streptococcus pneumoniae (11.4%) was less dominant than historically reported, possibly reflecting partial protection from incomplete PCV vaccination, it remains a significant cause of invasive pleural disease. The high culture-negative rate also argues strongly for integrating molecular diagnostic techniques—such as multiplex PCR—into future clinical practice to improve pathogen identification and facilitate targeted antibiotic stewardship.

4.4 Validation of the USG-Guided Staged Protocol

4.4.1 Stage 1 – ICD Alone

ICD alone was applied exclusively to the 6 Stage 1 patients, all of whom had non-loculated effusions amenable to simple drainage. Four (66.7%) achieved primary treatment success. The 2 failures are clinically instructive: both likely reflected either early underestimated loculation at the time of USG assessment (operator dependency) or tube blockage from viscous pus. Both were successfully salvaged with VATS, confirming that a stepwise escalation protocol achieves 100% final success. This finding underscores the principle that Stage 1 classification does not guarantee a straightforward course, and vigilant monitoring for drainage failure remains essential in all ICD-managed patients.

4.4.2 Stage 2 – ICD + Intrapleural Streptokinase

ICD+IPSK was the workhorse of this protocol, applied to 15 Stage 2 patients as primary therapy and achieving an 88.2% success rate. This aligns with the body of evidence supporting fibrinolytic therapy as a cost-effective, minimally invasive alternative to early surgery for loculatedfibrinopurulent empyema. The mechanism—enzymatic dissolution of fibrin septations to convert a multiloculated, undrained collection into one amenable to evacuation via the existing drain—directly addresses the pathological substrate of Stage 2 disease. The 2 failures (11.8%), both requiring salvage open decortication, likely represented cases where early fibrosis had progressed beyond the threshold of enzymatic dissolution at the time of treatment. This validates the known limitation of fibrinolytics in early organizing disease and reinforces the importance of careful USG assessment before committing to a fibrinolytic trial in borderline Stage 2/Stage 3 cases.

4.4.3 Stage 3 – Surgical Intervention

For advanced organizing (Stage 3) empyema, timely and definitive surgical intervention was the cornerstone of management. Both VATS and open decortication achieved 100% primary success rates, validating the principle that matching treatment intensity to disease severity optimizes outcomes. The key distinction lies in the recovery metrics.

VATS offers compelling advantages in appropriately selected Stage 3 cases with early or moderate peel: it provides direct visualization for complete debridement, breakdown of loculations, evacuation of purulent debris, thoracic lavage, and optimal drain placement. In this study, the VATS group had the shortest mean hospital stay (8.5 days), the shortest ICD duration (6.8 days), and 100% complete radiological resolution at 3 months. Critically, no complications were recorded in the VATS group. These results are consistent with landmark evidence—most notably the randomized controlled trial by Marhuenda et al. (2014)—demonstrating VATS to be more effective than intrapleuralurokinase as a first-line treatment, with shorter hospital stay and fewer secondary procedures.

Open thoracotomy with decortication remains the most definitive procedure for the most advanced Stage 3

cases with thick, cortical pleural peels causing lung entrapment. It provides unparalleled access for radical peel removal and complete lung re-expansion. In this study, the 4 patients who underwent primary decortication achieved 100% procedural success. The longer hospital stay (14.5 days) and the procedurespecific complications (one persistent air leak, one surgical site infection) reflect the inherently greater morbidity of this open approach. Importantly, the residual radiological changes at 3 months (3 with pleural thickening, 1 with persistent collapse) in the decortication group are not a failure of surgery but rather the expected anatomical scar of the most severe initial disease burden.

The step-up protocol—reserving VATS for Stage 3 or failed Stage 2 cases and decortication for the most advanced peel disease—maximized resource utilization, minimized unnecessary surgical morbidity, and achieved excellent overall outcomes, making it particularly applicable in tertiary care centres in developing countries.

4.5 Outcomes and Follow-up

The overall primary treatment success rate of 88.6%, escalating to a final 100% with salvage surgery, is a stellar outcome that compares favourably with international standards reported from similar prospective series. The 82.9% rate of complete radiological resolution at 3 months confirms that the protocol effectively restores normal pulmonary anatomy in the vast majority of children. The concentration of all residual sequelae in the decortication group underscores a critical biological principle: the need for decortication is itself a marker of the most severe initial disease, whose intense inflammatory process inevitably leaves behind a fibrous scar. The goal in these advanced cases is functional liberation of the lung, not always perfect anatomical restoration.

5. CONCLUSION

This prospective study provides robust evidence that a structured, ultrasonography-guided, stage-based management protocol for pediatric empyema thoracis is safe, highly effective, clinically rational, and reproducible. The following conclusions can be drawn:

1. **USG staging is the cornerstone:** Thoracic ultrasonography is the primary, indispensable tool for staging pediatric empyema and guiding management decisions. It should be performed in every child presenting with parapneumonic effusion and should be routinely adopted at every tertiary care centre. Its radiation-free, bedside-accessible nature, and ability to characterize effusion complexity make it superior to plain radiography and comparable to CT for staging purposes.

2. **ICD+IPSK for Stage 2 is surgery-sparing:** Intrapleural streptokinase combined with ICD is a highly effective, minimally invasive, and economically appropriate strategy for loculated (Stage 2) fibrinopurulent empyema, achieving an 88.2% success rate and avoiding surgery in the majority of patients.

3. **Surgical intervention is definitive for Stage 3:** Timely surgical management for advanced organizing (Stage 3) empyema is essential. VATS offers excellent outcomes—100% success, shortest hospital stay, no complications, and complete radiological resolution—in appropriately selected patients with early-tomoderate peel. Open decortication remains the definitive procedure for the most advanced cases with thick fibrous peels causing lung entrapment.

4. **The step-up approach achieves 100% final success:** The overall primary success rate of 88.6% escalated to 100% with salvage surgery, validating the step-up protocol as efficient, rational, and thorough.

5. **Prevention demands public health action:** The high prevalence of modifiable risk factors—incomplete vaccination (57.1%) and malnutrition (51.4%)—in a predominantly lower-socioeconomic cohort mandates targeted public health interventions: improving vaccination coverage, nutritional support programmes, and enhancing access to timely primary care.

6. **Molecular diagnostics are needed:** The 57.1% culture-negative rate necessitates integration of PCR-based molecular diagnostics to improve pathogen identification and facilitate antimicrobial stewardship.

The findings of this study support standardization of the USG-guided, stage-based management protocol in tertiary care settings across developing countries. Further multicentric studies with larger sample sizes and extended follow-up are recommended to validate and refine these findings.

6. LIMITATIONS

This study has several limitations: (1) a relatively small sample size (n=35) that may limit generalizability; (2) single-centre design introducing potential institutional bias; (3) absence of randomization, with treatment allocation based on disease stage rather than randomization; (4) referral bias with the majority presenting in advanced stages; and (5) lack of long-term follow-up beyond three months and objective pulmonary function assessment. Future multicentric, randomized studies are warranted to address these limitations.

7. DECLARATIONS

Conflict of Interest: The authors declare no conflict of interest.

Funding: No external funding was received for this study.

Ethical Approval: The study was approved by the Institutional Ethics Committee of Al-Ameen Medical College, Vijayapura. Written informed consent was obtained from parents/guardians of all participants.

8. REFERENCES

1. Agarwal R, Taneja V, Saxena AK, Verma A. Pediatric empyema thoracis: a comparative analysis of management strategies. Indian J Pediatr. 2018;85(3):198–204.
2. Ahmed AE, Yacoub TE. Empyema thoracis. Clin Med Insights CircRespirPulm Med. 2010;4:1–10.
3. Balci AE, Eren N, Cakir O, Eren MN. Open drainage of postpneumonic pediatric empyemas. Ann Thorac Surg. 2002;73(3):905–908.
4. Balfour-Lynn IM, Abrahamson E, Cohen G, et al.; Pediatric Pleural Diseases Subcommittee of the BTS Standards of Care Committee. BTS guidelines for the management of pleural infection in children. Thorax. 2005;60(Suppl 1):i1–21.
5. Baram A, Yaldo AH. Ten-year experience with intrapleuralthrombolytics. Asian CardiovascThorac Ann. 2020;28(1):44–48.
6. Buonsenso D, Cataldi L, Valentini P, et al. Advances in the diagnosis and management of pediatric pleural empyema. Front Pediatr. 2024;12:1–12.
7. Chandaka H. Clinical study and management of empyema thoracis in children. [Thesis]. Rajiv Gandhi University of Health Sciences; 2019.
8. Halder S, Kumar S, Shastri S. Pediatric parapneumonic effusion and empyema: a prospective observational study. Indian J Child Health. 2019;6(2):74–79.

9. Hegade BG, Biradar SV. Comparative study of video-assisted thoracoscopic surgery versus open decortication in management of empyema thoracis. Indian J Surg. 2019;81(4):357–362.
10. Improta M, Lavorini F, Fontana C, et al. Pediatric empyema: clinical, laboratory and radiological predictors. J Clin Med. 2025;14:1–12.
11. Islam S, Calkins CM, Goldin AB, et al. The diagnosis and management of empyema in children: a comprehensive review from the APSA Outcomes and Clinical Trials Committee. J Pediatr Surg. 2012;47(11):2101–2110.
12. Jadhav V, Bhatt I, Nanda V, et al. VATS versus open thoracotomy in the management of empyema thoracis in children: a comparative analysis. J Indian AssocPediatr Surg. 2018;23(2):78–83.
13. Jaffe A, Balfour-Lynn IM. Management of empyema in children. PediatrPulmonol. 2005;40(2):148–156.
14. Kanthi AV, Nagaraj C, Prakash P. Culture-negative pediatric empyema: a tertiary care experience. J Pediatr Surg. 2023;58:213–218.
15. Kim HK, Cho BK, Lee HJ. Management of pediatric empyema thoracis. J Korean Med Sci. 1986;1(1):57–62.
16. Kumari S, Rup M, Singh A. Staphylococcal empyema in children: clinical analysis from Eastern India. Indian Pediatr. 2024;61:123–128.
17. Kumar V, Sethi GR, Mantan M, Aggarwal A, Garg K. Pediatric parapneumonic effusion at a tertiary care hospital in India. Indian J Pediatr. 2013;80(6):474–478.
18. Laishram S, Ngangom S. Thoracotomy with decortication for empyema: a two-year experience. Int J Sci Res. 2016;5(4):1456–1459.
19. Marhuenda C, Barcelo C, Fuentes I, et al. Urokinase versus VATS for treatment of empyema: a randomized multicenter clinical trial. Pediatrics. 2014;134(5):e1301–e1307.
20. Mohapatra B, Bhatt JR, Tripathy PK. VATS for pediatric empyema: outcomes from a tertiary centre. J Pediatr Surg. 2021;56:345–350.
21. Moral L, Santos M, Pinon M, et al. Pleural effusion in children: epidemiology and management. Arch Dis Child. 2021;106(4):359–365.
22. Rahman NM, Maskell NA, West A, et al. Intrapleural use of tissue plasminogen activator and DNase in pleural infection. N Engl J Med. 2011;365(6):518–526.
23. Rama R. VATS decortication for pediatric empyema. Ann Pediatr Surg. 2024;20:44.
24. Rup M, Singh A, Kumari S. Microbiological spectrum of pediatric empyema in Eastern India. Indian J Med Microbiol. 2024;42:68–72.
25. Sah SK, Bhatta NK, Shrestha P. Clinical profile of pediatric empyema thoracis. J Nepal Pediatr Soc. 2023;43(1):28–34.
26. Sharma R. Early thoracotomy vs delayed for empyema: outcomes in children. J Pediatr Surg. 2016;51(9):1447–1451.
27. Thakkar HS, Shendurnikar N, Desai HM, Doshi NJ. Video-assisted thoracoscopic surgery for childhood empyema. Indian J ThoracCardiovasc Surg. 2021;37:64–69.
28. Thokchom DS, Singh KD, Salam S. Antibiotics and tube thoracostomy: an effective management strategy for pediatric empyema. Indian J Child Health. 2020;7(1):14–17.