Evaluation of a Clinical Practice Algorithm for Pediatric Complicated Pneumonia: A Retrospective, Observational, Single-Center Study

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ABSTRACT

OBJECTIVE: The diagnostic evaluation, antibiotic treatment, and type and timing of surgical intervention for pediatric patients with complicated pneumonia is not standardized and may lead to increased length of stay, more radiation exposure, and higher cost. A multidisciplinary team at our institution developed a clinical practice algorithm for pediatric complicated pneumonia to align and optimize care. The aim of this study was to examine the effectiveness of this algorithm in improving overall patient care while minimizing changes in physician workload.

STUDY DESIGN: A clinical practice algorithm for pediatric complicated pneumonia was created and implemented at our institution in February 2018 based on expert opinion and literature review, providing guidance on options for imaging, antibiotics, and interventions based on clinical characteristics. Retrospective data were collected for 31 months before and after implementation excluding a six-month transition period.

RESULTS: Forty patients were identified (pre-protocol implementation=25, post-protocol implementation=15). There were no differences in age, race/ethnicity, and size of pleural effusion between groups. Following protocol implementation, the time to pediatric surgery consult, number of consulting services, ICU admission, number and types of radiologic studies, and readmission rates remained unchanged. Protocol implementation was associated with a significant decrease in the need for repeat procedures (32% vs. 0%, p=0.02). There was a trend toward decreased length of stay (10.0 vs. 9.0 days, p=0.31).

CONCLUSIONS: Implementation of our institutional protocol did not increase utilized services and was associated with a decrease in the need for additional procedures after treatment failure. Larger prospective studies may help optimize the approach to complicated pneumonia.

INTRODUCTION

Community-acquired pneumonia (CAP) remains a worldwide leading cause of morbidity and mortality in children aged between 28 days and five years despite a decrease in the incidence of CAP in the last two decades.[1,2] Complicated CAP includes the development of parapneumonic effusion, empyema, multilobar disease, cavitary abscess, necrotizing pneumonia, pneumothorax, and bronchopleural fistula.[1,2] Up to one third of children with pneumonia may develop these complications,[3,4] and the proportion of pneumonia hospitalizations attributed to complicated CAP has increased over time and now accounts for more than 8% of all pneumonia admissions.[2,5] Pediatric patients with complicated CAP incur higher resource use with longer hospitalization, higher intensive care unit (ICU) admission rates, higher rates of mechanical ventilation, increased 30-day readmissions, and increased costs compared to uncomplicated CAP.[2] However, the diagnostic evaluation, choice and duration of antibiotic therapy, and type and timing of surgical intervention for pediatric patients with complicated pneumonia is not standardized; significant controversy and practice variation remain across institutions.[6–10]

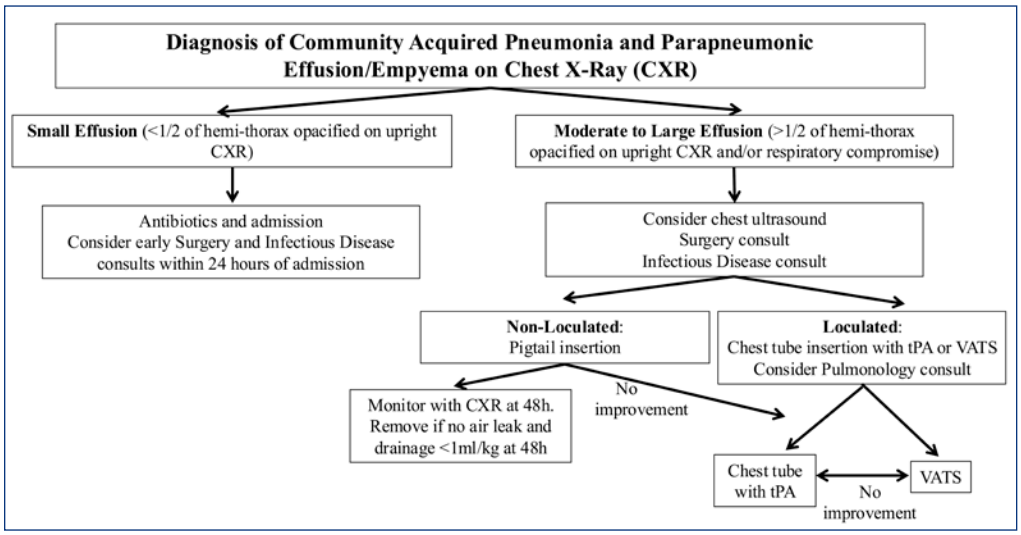
Review of practice patterns and outcomes at our institution demonstrated significant variability in the management of patients presenting with complicated CAP. In 2018, a multidisciplinary team including representatives from pediatric hospital medicine, infectious disease, pulmonology, radiology, critical care, emergency medicine, and surgery developed a clinical practice algorithm for pediatric complicated CAP with the goals of aligning and optimizing care and decreasing the hospital length of stay. The aim of this study was to determine the effectiveness of this clinical practice algorithm in improving overall patient care while minimizing changes in physician workload.

METHODS

Study Design

We performed a retrospective cohort analysis of pediatric patients seen at our institution, a tertiary care pediatric hospital, during the 31 months both before and after the implementation of the clinical practice algorithm. The six months immediately following the implementation of the pathway (February 2018–July 2018) were excluded to allow for full system integration. This retrospective study was approved by our institutional review board. Patients were identified using the pediatric surgery billing database through ICD-10 codes (J12, J13, J14, J15, J16, J17, J18, J85, J86, J90, J91) and CPT codes (32550, 32556, 32557, 32560, 32607, 32650)

Figure 1. Clinical Care Pathway for the Management of Pediatric Complicated Community-Acquired Pneumonia



Abbreviations: CXR, chest X-ray; tPA, tissue plasminogen activator; VATS, video-assisted thoracoscopic surgery

(further information on ICD-10 and CPT codes). Patients were excluded if they did not have a diagnosis of CAP, were immunocompromised, were less than two months of age, had chronic lung disease, or were tracheostomy or ventilator dependent.

Charts were reviewed for demographic information, clinical data, and outcomes. Data was managed using REDcap (Research Electronic Data Capture) software. Data was expressed as medians with interquartile ranges. All p-values were calculated by the Mann-Whitney U and Chi-Squared Tests with $p < 0.05$ considered as statistically significant. Statistical analysis was conducted using Graph Pad Prism (version 9.5.1).

Institutional pediatric complicated pneumonia clinical practice algorithm

The clinical practice algorithm for pediatric complicated CAP was developed by a multidisciplinary team of experts at our institution with consultation of the available literature.[11,12] The algorithm was adopted by our institution on February 1, 2018 and is depicted in **Figure 1**. Prior to protocol implementation, the approach to imaging, decision to consult surgery (and other services), and interventions was decided according to clinical preference and the judgement of the providers caring for the child. General education regarding the algorithm was provided by the attending-level representative involved in algorithm development for each specialty to their respective teams. The algorithm was made available to all providers on the hospital-wide website. This algorithm provides management guidance for patients found to have a parapneumonic effusion or empyema on chest X-ray (CXR).

Following diagnosis of CAP with the presence of an effusion or empyema, patients are stratified based on the size of the effusion into either small effusion (less than half of the hemi-thorax opacified on upright CXR) or moderate to large effusion (more than half of the hemi-thorax opacified on upright CXR and/or presence of respiratory compromise). Effusion size is quantified by the on-call reading pediatric radiologist. Patients with small effusions receive intravenous antibiotics and are admitted. Early surgery and infectious disease consults (i.e., within 24 hours of admission) are recommended. For patients with moderate to large effusions, surgery and infectious disease consults are recommended, as well as obtaining a chest ultrasound (US). If a non-loculated effusion is identified, pigtail chest tube insertion is recommended. A repeat CXR is obtained 48 hours following pigtail placement, and removal is considered if there is no air leak and drainage is less than 1ml/kg at 48 hours. If the patient has not improved, the guidelines for a loculated effusion should be followed. If chest US identifies a loculated effusion, chest tube insertion with tissue plasminogen activator (tPA) administration or video-assisted thoracoscopic surgery (VATS) is recommended (VATS consists of both effusion drainage and decortication); choice is based on surgeon preference. The pathway also recommends that a pulmonology consult be considered. Chest tube removal is guided by repeat CXR obtained 48 hours following procedure, and removal is considered if there is no air leak and drainage is less than 1ml/kg at 48 hours. tPA is administered at a dose of 40mg/4mL with a dwell time of one hour. tPA is repeated once daily for three consecutive days. Improvement is assessed clinically (absence of fever, decreased work of breathing), radiographically (improvement on CXR), and by decrease in chest tube output (without increased accumulation on CXR). Depending on the initial procedure and physician preference, lack of improvement may prompt further treatment with either VATS or chest tube and tPA.

RESULTS

Patient demographics and clinical features at presentation

During the defined study period, 40 pediatric patients were treated for complicated CAP and met inclusion criteria. As shown in **Table 1**, of these 40 patients, 25 patients were in the pre-implementation group and 15 in the post-implementation group. Median age at presentation ($p = 0.47$), race/ethnicity ($p = 0.31$), size of pleural effusion at time of surgical consult ($p = 0.67$), and days from effusion first noted to surgical consult were similar between the two groups. Measures

Table 1. Patient Demographics and Baseline Clinical Characteristics

	Pre-Implementation (n=25)	Post-Implementation (n=15)	p-value
Age at presentation, years	4.6 (2.3, 7.2)	5.8 (4.0, 9.4)	0.47
Race/Ethnicity Caucasian Hispanic African American Other	 13/25 (52.0%) 9/25 (36.0%) 0/25 (0%) 3/25 (12.0%)	 5/15 (33.3%) 5/15 (33.3%) 1/15 (6.7%) 4/15 (26.7%)	0.31
Size of effusion when consulted Small Moderate Large	 6/25 (24%) 9/25 (36%) 10/25 (32%)	 5/15 (33%) 6/15 (40%) 4/15 (27%)	0.67
Days to Pediatric Surgery Consult from Effusion	0 (0, 2.0)	0 (0, 0.5)	0.59
Maximum measured temperature, °C	39.4 (38.6, 40.0)	38.8 (38.1, 39.8)	0.36
Days of Fever (≥ 38.0°C)	5.0 (2.0, 9.0)	3.0 (0.5, 6.0)	0.06
Lowest oxygen saturation (%)	91.0 (86.0, 95.0)	94.0 (89.0, 96.0)	0.23
Highest white blood cell count (x10^9 cells/L)	17.7 (11.8, 20.6)	16.7 (13.3, 25.2)	0.51

Table 2. Clinical Outcomes Pre- and Post-Implementation

	Pre-Implementation (n=25)	Post-Implementation (n=15)	p-value
Types of initial procedures Chest tube VATS	 6/19 (32%) 13/19 (68%)	 1/8 (13%) 7/8 (87%)	0.30
Number of drainage procedures	1.0 (1.0, 2.0)	1.0 (0, 1.0)	0.04*
Second procedural intervention	8/25 (32%)	0/15 (0%)	0.02*
No drainage procedures	6/25 (24%)	7/15 (47%)	0.14
Median number of images per patient pre-procedure	3.0 (2.0, 5.0)	3.0 (2.0, 4.0)	0.67
ICU admission Days in ICU	12/25 (48%) 0 (0, 5.0)	5/15 (33%) 0 (0. 2.5)	0.82 0.81
Supplemental oxygen Days of supplemental oxygen	20/25 (80%) 4.0 (2.0, 6.0)	7/15 (47%) 0 (0, 2.0)	0.03* 0.01*
Median number of consulting services per patient	3.0 (3.0, 4.0)	4.0 (2.5, 4.5)	0.60
Intubation Days of intubation	8/25 (32%) 0 (0, 1.0)	1/15 (7%) 0 (0, 0)	0.06 0.23
Length of stay, days	10.0 (6.0, 12.0)	9.0 (2.0, 11.5)	0.31
Readmission	2/25 (8%)	2/15 (13%)	0.59

Abbreviations: VATS, video-assisted thoracoscopic surgery; ICU, intensive care unit

of vital signs, including the maximum temperature (p = 0.36), days with a fever (p = 0.06), and the lowest oxygen saturation (p = 0.23), were also similar between the two groups. Finally, there was no significant difference between the maximum white blood cell count in each group (pre-implementation 17.7 [11.8, 20.6] x10^9 cells/L, post-implementation 16.7 [13.3, 25.2] x10^9 cells/L; p = 0.51).

Analysis of Protocol Implementation

As shown in **Table 2**, after clinical practice algorithm implementation there was an associated, non-significant increase in the performance of VATS as the primary procedure (68% pre-implementation versus 87% post-implementation), although this did not reach statistical significance (p = 0.30). None of the patients who underwent VATS received tPA administration post-operatively, and there were no associated post-operative complications following VATS in this cohort. Following implementation, patients underwent a lower total number of procedural intervention (p = 0.04; note that although medians are 1.0 for both groups, the mean number of procedural interventions was 1.5 ± 1.3 versus 0.5 ± 0.5 procedures), and no patient required a second drainage procedure (32% pre-implementation versus 0% post-implementation; p = 0.02). The proportion of patients not requiring any drainage procedure (p = 0.14), requiring ICU admission (p = 0.82), and undergoing intubation (p = 0.06) were similar between the two cohorts. There was an increased proportion of patients requiring supplemental oxygen pre-implementation (80% compared to 47%; p = 0.03). No change in the number of radiologic studies obtained prior to the first procedure (p = 0.67) or the total number of consulting services (p = 0.60) for each patient was observed. There was a trend towards decreased length of stay following implementation (10.0 [6.0, 12.0] days pre-implementation versus 9.0 [2.0, 11.5] days post-implementation; p = 0.31), though this trend was not statistically significant. Pneumonia-related 30-day readmission rates were similar (p = 0.59). There were no deaths in either group.

DISCUSSION

Despite an increase in complicated CAP in the pediatric population,[2,5,13] considerable variation in the management and consequently the outcomes of these patients persists across institutions.[6–9] This stems from a lack of standardized management guidelines for this condition, in turn reflecting the lack of strong evidence-based literature regarding diagnostic work-up, optimal antibiotic therapy, appropriate surgical intervention, and long-term care.[2] With the goals of improving timeliness of care, and thereby improving the outcomes of pediatric patients with complicated CAP treated our institution, we developed a multidisciplinary consensus-based

clinical practice algorithm for the diagnosis and management of this condition. Importantly, representatives from all specialties that may be involved in the care of these patients (including pediatric hospital medicine, infectious disease, pulmonology, radiology, critical care, emergency medicine, and surgery) provided specialty-specific input and expertise and reviewed and approved the algorithm prior to implementation. In the present study, we sought to evaluate the approach to and clinical outcomes of complicated CAP following institution-wide implementation of this care pathway.

While the British Thoracic Society (BTS) and the American Pediatric Surgical Association (APSA) acknowledged the limited and often poor-quality available evidence, they both developed guidelines on various aspects of care in complicated CAP.[12,14] Further, several clinical care algorithms have been proposed, some of which have undergone evaluation following institutional implementation.[1,7,9,10] In brief, APSA recommends pleural fluid evacuation for large effusions, loculated effusions, and moderate effusions with failure to progress or symptoms (grade C recommendation), whereas BTS recommends drainage for enlarging effusions and those that compromise respiratory function. Both APSA and BTS posit that chemical debridement should be first trialed, when available, as it involves decreased resource utilization compared to VATS.[12,14] Neither provide guidelines on which consulting services should be involved and when consultation should be initiated; this has been standardized as part of our algorithm to promote timeliness of care. Pillai et al devised a comprehensive literature-based diagnosis and management algorithm offering guidance in the emergency department/outpatient setting for uncomplicated pneumonia in children, as well as inpatient care, discharge, and outpatient care for complicated pneumonia.[7] Using a cross-sectional study design, they found decreased computed tomography (CT) scan usage, decreased VATS, and decreased readmission without increased length of stay or vancomycin use following implementation of their protocol.[7] Similarly, Quick et al developed an evidence-based inpatient complicated CAP pathway and noted similar findings following implementation: decreased CT scan usage, increased US usage, and decreased use of VATS as the initial procedure without effects on length of stay or readmission.[9]

Following implementation of our institutional clinical practice algorithm, the number of drainage procedures decreased significantly. This is reflective of the finding that none of the patients in the post-implementation cohort required a second drainage procedure, compared to a 32% re-intervention rate (chest tube or VATS) in the pre-implementation cohort due to incomplete treatment of their effusion or empyema. Although consults to the surgery, infectious disease, and/or pulmonology services were recommended in portions of the algorithm, the number of consulting services per patient did not increase following protocol implementation suggesting that the overall work burden for consulting services did not increase. There was a trend towards decreased length of stay after implementation with patients in the post-implementation period staying a median of one day (mean: three days) less than those in the pre-implementation period. Despite algorithm emphasis on chest US with chest CT only indicated in very specific situations, we did not see a decrease in chest CT usage, unlike in the studies by Pillai et al and Quick et al. However, it must be noted that the initial CT usage rates were much higher in their studies (67–100% of patients) compared to 20% in our pre-implementation cohort. Despite this lower rate, as there is no proven advantage for imaging with chest CT instead of chest US for most pediatric patients with complicated CAP,[5,12,15] it may be possible to reduce radiation exposure further at our institution.

Significant institution-level and potentially provider-level variation remains in the selection of the first drainage procedure for complicated CAP.[8] The optimal surgical approach has been the focus of multiple studies; however, the current literature provides heterogenous, sometimes conflicting, data on outcomes. Two recent randomized controlled trials as well as a retrospective study found that there was no difference in outcomes of primary VATS versus chest tube with fibrinolytic therapy, except an increase in hospital cost associated with VATS.[9,16,17] Of note, these studies reported a 14.7–16.6% failure rate of primary fibrinolysis, subsequently requiring VATS as definitive intervention. However, other studies (including systematic review, randomized control trial, and retrospective cohort studies) report that VATS is associated with decreased hospital mortality, need for reintervention, length of stay, time with chest tube, and antibiotic duration in children.[6,8,18–21] Some authors suggest primary VATS is associated with a similar or lower cost than chest tube and antibiotic therapy alone.[6,18,21] The use of VATS can facilitate visualization, evacuation of pleural fluid, and mechanical debridement.[22,23] Following implementation of our institutional clinical care pathway, there was a non-significant higher rate of performance of VATS as the initial procedure (68% pre-implementation versus 87% post-implementation) compared to chest tube with or without fibrinolytics. Notably, our clinical practice algorithm did not suggest superiority of chest tube or VATS as the primary intervention, so that the increased rate of VATS post-implementation likely reflects provider preference that became apparent once the algorithm suggested either procedure was an acceptable first choice.

This study has several limitations, including those inherent to a retrospective study design. Patients were identified using billing codes and therefore we are reliant on the accuracy of the codes utilized. We attempted to minimize these effects by searching by both ICD and CPT codes and then screening patients for inclusion and exclusion criteria. Given the design of the study, it is not possible to determine causality between algorithm intervention and the clinical decisions, management approach, and outcome of patients.

The possible influence of provider and family preference cannot be ascertained. We were unable to obtain access to hospitalization costs and therefore cannot determine the financial effect this algorithm may have had. Additionally, the variables assessed in this study (chosen based on most direct relevance to pediatric surgeons) represent a portion of a larger implemented algorithm that also provided guidance on antibiotic choice and duration. These potential confounders were not specifically evaluated in this study.

In conclusion, the period after implementation of our algorithm for pediatric complicated CAP was associated with a reduced need for secondary interventions without an associated increase in the overall intervention rate or the work burden for consulting services. Standardization of care can promote improved quality of care, but larger prospective studies are needed to help optimize the approach to pediatric complicated pneumonia.

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