ABSTRACT

OBJECTIVES: This report describes the creation and successful implementation of a complicated pneumonia care algorithm at our institution. Outcomes are measured for specific goals of the algorithm: to decrease radiation exposure, surgical risk, and patient charges without adversely affecting clinical outcomes.

METHODS: We describe steps involved in algorithm creation and implementation at our institution. To depict outcomes of the algorithm, we completed a retrospective cohort study of hospitalized pediatric patients with a diagnosis of complicated pneumonia at a single institution between January 2010 and April 2016 who met criteria for the algorithm. Charts were manually reviewed and data were analyzed via Wilcoxon rank sum, χ², and Fisher’s exact tests.

RESULTS: Throughout the algorithm creation process, our institution began to see a change in practice. We saw a statistically significant decrease in the number of patients who underwent a chest computed tomography scan and an increase in patients who underwent a chest ultrasound (P < .001). We also saw an increase in the use of chest tube placement with fibrinolytics and a decrease in the use of video-assisted thoracoscopic surgery as the initial chest procedure (P ≤ .001) after algorithm implementation. These interventions reduced related charges without significantly affecting length of stay, readmission rate, or other variables studied.

CONCLUSIONS: The collaborative creation and introduction of an algorithm for the management of complicated pneumonia at our institution, combined with an effort among physicians to incorporate evidence-based clinical care into practice, led to reduced radiation exposure, surgical risk, and cost to patient.
Evidence-based research has pointed to potential improvements in the care of pediatric patients with complicated pneumonia, specifically in the area of imaging and surgical intervention. Previous imaging recommendations have favored chest computed tomography (CT) as the modality of choice for evaluating complicated pneumonia. Recent studies demonstrate ultrasound to be as effective, with CT failing to provide any additional clinically useful information when compared with ultrasound, even in the setting of lung abscess and necrosis.\(^1\)\(-\)\(^4\) Chest ultrasound has shown to be more cost-effective than CT, which becomes a consideration when equal clinical information can be attained from either test.\(^4\)

Surgical preference and data about chest tube placement with fibrinolytics in lieu of video-assisted thoracoscopic surgery (VATS) are more controversial, because information about outcomes is sparse.

Although previous approaches to surgical intervention in cases of complicated pneumonia supported the use of early VATS, more recent prospective studies comparing the effectiveness of VATS and chest tube placement with fibrinolytics have pointed toward chest tube placement with fibrinolytics as the procedure of choice in most cases.\(^5\)\(-\)\(^8\) In 3 prospective, randomized studies chest tube with instillation of fibrinolytics was equal to VATS for the treatment of empyema and resulted in shorter or equal length of stay and lower cost.\(^6\)\(-\)\(^8\) Studies that looked at cost saw significantly lower cost as an advantage to using a chest tube with fibrinolytics.\(^6\)\(^7\) In a retrospective study comparing multiple chest procedures, Gates et al\(^9\) found that cases without surgery had a shorter length of stay and hospital charges compared with patients with surgery. Evidence supports favorable outcomes when both of these management approaches are combined to manage complicated pneumonia. In 2 studies where a complicated pneumonia algorithm was evaluated, decrease in chest CT use was seen along with other favorable indicators such as lower readmission rate and fewer VATS, without any negative impact on length of stay or painful procedures.\(^10\)\(^11\)

**METHODS**

The overall goal of the complicated pneumonia algorithm was to standardize and improve care, basing decisions on clinical judgment, paired with evidence-based recommendations. The primary aim of this study is to describe this process and evaluate the effect of algorithm implementation on imaging, procedural intervention, and associated charges. The secondary aim is to compare the subgroup of patients with VATS and those with chest tube with fibrinolytics to assess the impact of using the less invasive procedure on hospital course and cost.

**Algorithm Creation and Implementation**

Our institution previously used chest CT and early VATS in the management approach of complicated pneumonia. As new research was published about the use of ultrasound in lieu of CT scans, some physicians began to use ultrasound more frequently, but the practice was not widely accepted. Motivated by an abstract at a national conference about the implementation of a complicated pneumonia guideline at another institution, one of the authors (M.A.) organized a group of interested physician leaders to review the literature and present at a formal journal club.\(^12\) The journal club, held in January 2012, included a team of physicians from the hospitalist, general surgical, infectious disease, radiology, and pulmonology services, as well as representatives from pharmacy, nursing, imaging, and quality improvement teams. A selected physician from each team rigorously reviewed the literature and presented relevant information based on the strength of the study and results. The literature review, discussion during the journal club, local antibiotic resistance patterns, and additional discussions between the physician champions led to the agreed-upon algorithm.

The draft of the algorithm was disseminated to all team members in April of that year for review and edits before widespread implementation and dissemination.

The pathway and recommendation in its entirety were made available online on our hospital system intranet on April 1, 2013. Figure 1 includes the visual pathway, which is part of a larger educational document. Dissemination and use of the algorithm involved several approaches beginning directly after the initial meeting and continuing after the official rollout. A major point of clarity reached through literature review was the choice of imaging.\(^1\)\(^-\)\(^4\)

In the earliest stages, physicians on the team began to personally educate colleagues when a CT was ordered on a patient with complicated pneumonia. This informal education helped push the initial success in imaging change.

Additional adoption of the algorithm was accomplished with 2 major efforts: incorporation of the algorithm recommendations into the electronic medical record order set and education of the pediatric residents. An order set was created that highlighted the use of ultrasound over CT as the preferred modality and provided the correct antibiotic and fibrinolytic dosing as recommended in the algorithm. A link to the algorithm in the order set allowed easy access to the algorithm and supporting information for reference. The order set was created in partnership between the PICU and hospitalist services facilitating the use in both areas of the hospital.

In a teaching institution with a medium-sized pediatric residency program with...
house officers that provide 24-hour services in the emergency department, PICU, and inpatient service, the opportunity for widespread adoption hinged on education of the pediatric house staff. The physician champions used existing resident didactic sessions and grand rounds presentations as venues for distributing the algorithm and the evidence supporting its implementation. The algorithm has been incorporated in the inpatient curriculum, and senior residents are expected to understand and teach the components and evidence-based literature for complicated pneumonia to interns and rotating students.

After implementation of the algorithm, patient data were collected to track adherence and successes. The algorithm does not attempt to override clinician judgment, and although its use was strongly encouraged, it was not strictly enforced. Throughout its implementation, we evaluated adherence by tracking outcomes such as timing and use of laboratory tests, timing of surgical consults, use of ultrasound over CT scans, and use of recommended initial antibiotic choice.

![Complicated bacterial pneumonia pathway](image)

**FIGURE 1** Complicated bacterial pneumonia pathway. BMP, basic metabolic panel; CBC, complete blood cell count; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; FIO2, fraction of inspired oxygen; ID, infectious disease; IV, intravenous.
Preliminary data were presented at a morbidity and mortality conference 1 year after the official algorithm implementation and described remarkable success in using ultrasound over CT scans but uncovered system issues related to chest tube care and fibrinolytic administration when chest tubes were placed by interventional radiology. After placement of chest tubes by interventional radiology, care was transitioned to the hospitalist service staff, who had little experience with management or administration of fibrinolytics. This led to an important dialogue and decision by surgical services to manage all chest tubes and fibrinolytics regardless of the method of chest tube placement. The resolution of this important system problem resulted in a more linear increase in the use of chest tubes with fibrinolytics.

Evaluating the Complicated Pneumonia Algorithm

To evaluate the success of the complicated pneumonia guideline at our hospital, we completed a retrospective cohort study for pediatric patients age 3 months to 18 years admitted to our institution between January 1, 2010 and April 1, 2016 with a diagnosis of complicated pneumonia. Initial charts were identified with International Classification of Diseases, Ninth Revision (ICD-9) diagnosis codes for pneumonia-related illness and 1 of the following additional qualifiers used to filter cases of simple pneumonia: chest CT, chest ultrasound, or pleural culture. ICD-9 codes related to pneumonia included 011.2, 481, 482.0, 482.1, 482.30, 482.31, 482.32, 482.39, 482.40, 482.41, 482.42, 482.81, 482.82, 482.89, 482.9, 483.8, 486, 490, 510.0, 510.9, 511.1, 511.9, 513.0, and 518.89. Equivalent ICD-10 codes were substituted after the updates in coding. Charts were then manually reviewed to ensure that cases met the inclusion and exclusion criteria chosen for the pediatric complicated pneumonia algorithm (Fig 1).

Methods of Comparison Before and After Algorithm Implementation

Using the above methods, we identified 570 cases with a diagnosis of pneumonia and chest CT, chest ultrasound, or pleural culture. After inclusion and exclusion criteria for the algorithm were applied by manual review, 244 cases were included: 131 preguideline and 113 postguideline. Although some practice change occurred with algorithm development, the official rollout date was selected as the pre/post comparison because it represented widespread availability to hospital personnel.

The study population of 244 cases with complicated pneumonia across 6.25 years was evaluated as a whole, and then specific variables were compared between the 2 cohorts: admission before and after guideline implementation. Variables were chosen for their effect on imaging, hospital course, and illness course and included readmission for pneumonia within 30 days, length of stay, use of chest CT, use of chest ultrasound, ICU admission, ICU length of stay, chest tube requirement and procedure, hospital day of chest tube placement, days with a chest tube, complications, number of antibiotics received, and hospital charges for imaging and chest procedures recommended in the algorithm.

Methods of Comparison of Chest Procedures: VATS Versus Chest Tube With Fibrinolytics

Patients who had, as their initial procedure, either VATS or chest tube with fibrinolytics were compared. A total of 105 cases needed chest drainage and had chest tube with fibrinolytics or VATS specifically as their first chest procedure; 71 cases with VATS as the initial chest procedure and 34 with chest tube with fibrinolytics. Cases with thoracentesis only or with chest tube placement without fibrinolytics were excluded from this analysis because they were not part of the algorithm or were so infrequently used. The focus of our comparison was between VATS and chest tube fibrinolytics. These 105 cases were compared as a subgroup for the following outcomes: length of stay, chest procedure failure rate (defined as the need for a second chest procedure), total days with chest tube (including days with second chest tube where applicable), readmission rate, and hospital charges associated with these variables. The decision to compare these specific cases against one another was made in an attempt to minimize confounding variables that would influence outcome measures.

Methods for Calculating Charges

Charges applied for analysis included professional charges and facility charges. The following Current Procedural Terminology codes were used to assess charges: VATS (an average of charges for 32651 and 32652, plus 32551 for chest tube placement), chest tube placement with imaging guidance (32557), chest tube ultrasound (76604), and chest CT (an average of charges for 71250, 71260, and 71270). All cases had either a chest CT or chest ultrasound; therefore, the hospital charge per patient was calculated for the overall number of these procedures and charges were compared before and after algorithm implementation.

Charges for the subset of patients with VATS or chest tube with fibrinolytics were compared as a subgroup. Charges calculated for each patient in the subgroup included charges for initial chest procedure, room rates for total ICU days and ward days, readmission days, and subsequent chest procedures. Charge comparisons between VATS and chest tube with fibrinolytics were categorized according to the initial chest procedure.

We predicted that using chest ultrasound over chest CT and chest tube with fibrinolytics over VATS would reduce hospital charges while also reducing exposure to radiation and surgical risk without negative impact on illness course. We chose chest ultrasound and chest tube with fibrinolytics as outcome measures to assess the impact of the algorithm itself. We selected specific variables to describe the illness course, including length of stay, need for additional chest procedures, and readmission rate. All information was entered into a Redcap database. Data were analyzed in RStudio software (RStudio, Boston, MA) including Wilcoxon rank-sum, Fisher’s exact, and $\chi^2$ tests.13,14
RESULTS
The median age of children included in the study was 4.9 years (interquartile range [IQR] 2.5–9.6); gender was nearly equal at 49% male and 51% female. The entire population of 244 cases was used to compare variables between 2 cohorts, before and after algorithm implementation.

Imaging Results
When comparing chest ultrasound and chest CT use before and after the implementation of the complicated pneumonia algorithm, we found a statistically significant decrease in the number of patients who underwent a chest CT scan and increase in the number of patients who underwent a chest ultrasound (P < .001 for both, Fig 2). During the same time period, no significant difference was seen in any of the other variables describing the illness course and hospital stay, including ICU admission rates, ICU length of stay, hospital length of stay, days with a chest tube, rate of chest procedures, or readmission. Changes in this variable can be seen on the graph as beginning even before the official rollout of the algorithm.

Chest Procedure Results
After implementation of the complicated pneumonia guideline, there was a statistically significant increase in the use of chest tube insertion with fibrinolytics and decrease in the use of VATS among patients who needed a chest procedure (P < .001, Fig 3). There was no significant difference in hospital length of stay in the population overall before and after algorithm implementation or in the subset of patients with VATS versus chest tube with fibrinolytics (10 days, IQR 7–14.5 and 9.5 days, IQR 7.3–13.8, respectively). The chest tube with fibrinolytics group had a failure rate of 14.7%, compared with 2.8% for those who underwent VATS as their initial chest procedure. This result was statistically significant (P = .035). Other reports in the literature have found similar failure rates for chest tubes with fibrinolytics.6–8 The median length of stay for those needing a second chest tube was 15 days (IQR 12–18).

Patient Cost Results
After algorithm implementation, charges associated with diagnostic imaging for complicated pneumonia decreased by ∼31% per patient according to hospital charges for the year 2016 (P < .001). Additionally, we reduced the use of VATS, offering patients a less invasive procedure of chest tube placement with fibrinolytics. The cost of chest procedures alone was reduced by 65% after algorithm implementation. For a more global comparison of patients with VATS and chest tube with fibrinolytics, we applied associated charges for each patient, including room charges per day on the ward and ICU, initial chest procedure charges, and second chest procedure charges and readmission room charges where applicable. There was a 19% decrease in this combined charge (Fig 4).

DISCUSSION
The creation and implementation of this algorithm had investment from committed physicians in multiple disciplines; these same people continue to be invested in the success and adherence to the algorithm 4 years after the initial idea. The continued dedication of physician and clinical staff champions, incorporation into the pediatric residency curriculum, ease of use through order sets, online availability, and data benchmarking have made this algorithm successful.

Using this algorithm, our institution successfully decreased radiation exposure for children and unnecessary health care costs by using US in lieu of the traditional chest CT to evaluate and guide treatment of complicated pneumonia in pediatric patients. Additionally, we minimized surgical risk and cost to patients by opting for chest tube with fibrinolytics rather than VATS when clinically appropriate. These changes were made without a significant change in outcomes, measured as length of stay and readmission rates, among other variables.

As seen in Fig 2, the use of chest US began to increase and use of chest CT began to decrease before the official implementation
of the algorithm, probably because of the practice change that occurred with physician leaders as the algorithm was being created. The algorithm provides a concrete document to help standardize care, but physician-led change based on the findings of the guideline group cannot be overemphasized.

Initially there was concern that optimizing chest tube with fibrinolytics use would increase length of stay related to the reported failure rates associated with this intervention. However, our results did not support that concern: The length of stay for patients undergoing VATS and those undergoing chest tube with fibrinolytic therapy was the same at 10 and 9.5 days, respectively. Despite positive clinical and cost outcome measures, chest tubes with fibrinolytics had a higher failure rate than VATS. A more patient-centered outcome study may help provide a more comprehensive picture.

These changes have also had a positive effect on costs to the patient for diagnostic imaging and surgical management. Given these results, we can conclude that this change has been successful, and we will continue to use chest US as the preferred imaging and chest tube with fibrinolytics as the preferred chest drainage procedure for evaluation and treatment of complicated pneumonia.

Limitations to this study are the retrospective design and variability between providers in the use and application of the algorithm. Sample size, particularly among those with chest procedures, is another limitation. Because of the rarity of this disease, particularly those needing chest procedures, cohorts were not matched so as to not decrease numbers. Matching cohorts may have controlled for severity of disease. We will continue to follow the results in years to come to confirm the

![FIGURE 3](image-url)  Use of VATS and chest tube with fibrinolytics over time.

![FIGURE 4](image-url)  Combined median charges associated with chest procedures and days of hospitalization.

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<th>Charge Calculations:</th>
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<tr>
<td>Initial chest procedure charge</td>
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<tr>
<td>Days in ICU x ICU room rate</td>
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<td>Days on ward x ward room rate</td>
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<tr>
<td>Charge for second chest procedure (where applicable)</td>
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<tr>
<td>+ Room rate x days of readmission (where applicable)</td>
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<tr>
<td>Total patient charge associated with chest procedure (represented as percent of highest total charge)</td>
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trends seen in these data. The variables assessed in this study are part of a larger algorithm and were implemented along with other changes such as initial antibiotics and laboratory data, introducing the risk of confounding variables. We plan to continuously evaluate other portions of the algorithm with the goal of providing the safest, most efficient care to our patients.

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Decreasing Exposure to Radiation, Surgical Risk, and Costs for Pediatric Complicated Pneumonia: A Guideline Evaluation
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