Published in final edited form as:

J Hosp Med. 2014 September ; 9(9): 559–564. doi:10.1002/jhm.2227.

Admission Chest Radiographs Predict Illness Severity for Children Hospitalized with Pneumonia

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Abstract

Objective—To assess whether radiographic findings predict outcomes among children hospitalized with pneumonia.

Methods—This retrospective study included children <18 years of age from 4 children's hospitals admitted in 2010 with clinical and radiographic evidence of pneumonia. Admission radiographs were categorized as single lobar, unilateral or bilateral multilobar, or interstitial. Pleural effusions were classified as absent, small, or moderate/large. Propensity scoring was used

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Financial Disclosure: The authors have no relevant financial relationships to disclose.

Conflict of Interest: The authors have no relevant conflicts of interest to disclose.

to adjust for potential confounders, including need for supplemental oxygen, intensive care, and mechanical ventilation, as well as hospital length of stay and duration of supplemental oxygen.

Results—There were 406 children (median age, 3 years). Infiltrate patterns included: single lobar, 61%; multilobar unilateral, 13%; multilobar bilateral, 16%; and interstitial, 10%. Pleural effusion was present in 21%. Overall, 63% required supplemental oxygen (median duration 31.5 hours), 8% required intensive care, and 3% required mechanical ventilation. Median length of stay was 51.5 hours. Compared with single lobar infiltrate, all other infiltrate patterns were associated with need for intensive care; only bilateral multilobar infiltrate was associated with need for mechanical ventilation (adjusted odds ratio [aOR] 3.0, 95% confidence interval 1.2, 7.9). Presence of effusion was associated with increased length of stay and duration of supplemental oxygen; only moderate/large effusion was associated with need for intensive care (aOR 3.2 [1.1, 8.9]) and mechanical ventilation (aOR 14.8 [9.8, 22.4]).

Conclusions—Admission radiographic findings are associated with important hospital outcomes and care processes and may help predict disease severity.

Keywords

Pneumonia; Diagnostic Imaging; Pediatrics; Pediatric Hospitals

INTRODUCTION

The 2011 Pediatric Infectious Diseases Society and Infectious Diseases Society of America (PIDS/IDSA) guidelines for management of pediatric community-acquired pneumonia (CAP) recommend that admission chest radiographs be obtained in all children hospitalized with CAP to document the presence and extent of infiltrates and to identify complications.¹ Findings from chest radiographs may also provide clues to etiology and assist with predicting disease outcomes. In adults with CAP, clinical prediction tools use radiographic findings to inform triage decisions, guide management strategies, and predict outcomes.²⁻⁷ Whether or not radiographic findings could have similar utility among children with CAP is unknown.

Several retrospective studies have examined the ability of chest radiographs to predict pediatric pneumonia disease severity.⁸⁻¹² However, these studies used several different measures of severe pneumonia and/or were limited to young children <5 years of age leading to inconsistent findings. These studies also rarely considered very severe disease (e.g. need for invasive mechanical ventilation) or longitudinal outcome measures such as hospital length of stay. Finally, all of these prior studies were conducted outside of the United States, and most were single center investigations, potentially limiting generalizability. We sought to examine associations between admission chest radiographic findings and subsequent hospital care processes and clinical outcomes, including length of stay and resource utilization measures, among children hospitalized with CAP at 4 children's hospitals in the United States.

METHODS

Design and Setting:

This study was nested within a multicenter retrospective cohort designed to validate International Classification of Diseases, 9th revision, Clinical Modification (ICD9-CM) diagnostic codes for pediatric CAP hospitalizations.¹³ The Pediatric Health Information System (PHIS) database (Children's Hospital Association [CHA], Overland Park, KS) was used to identify children from 4 freestanding pediatric hospitals (Monroe Carell, Jr. Children's Hospital at Vanderbilt, Nashville, TN; Children's Mercy Hospitals & Clinics, Kansas City, MO; Seattle Children's Hospital, Seattle, WA; and Cincinnati Children's Hospital Medical Center, Cincinnati, OH). The Institutional Review Boards at each participating institution approved the study. The validation study included a 25% random sampling of children 60 days – 18 years of age (n=998) who were hospitalized between January 1, 2010 and December 31, 2010 with at least one International Classification of Diseases, 9th edition, Clinical Modification (ICD-9-CM) discharge code indicating pneumonia. The diagnosis of CAP was confirmed by medical record review.

Study Population

This study was limited to children from the validation study who met criteria for clinical and radiographic CAP, defined as: 1) abnormal temperature or white blood cell count; 2) signs and symptoms of acute respiratory illness (e.g. cough, tachypnea); and 3) chest radiograph indicating pneumonia within 48 hours of admission. Children with atelectasis as the only abnormal radiographic finding and those with complex chronic conditions (e.g., cystic fibrosis, malignancy) were excluded using a previously described algorithm.¹⁴

Outcomes

Several measures of disease severity were assessed. Dichotomous outcomes included supplemental oxygen use, need for intensive care unit (ICU) admission, and need for invasive mechanical ventilation. Continuous outcomes included hospital length of stay and, for those requiring supplemental oxygen, duration of oxygen supplementation, measured in hours.

Exposure

To categorize infiltrate patterns and the presence and size of pleural effusions, we reviewed the final report from admission chest radiographs to obtain the final clinical interpretation performed by the attending pediatric radiologist. Infiltrate patterns were classified as single lobar (reference), unilateral multilobar, bilateral multilobar, or interstitial. Children with both lobar and interstitial infiltrates, and those with mention of atelectasis, were classified according to the type of lobar infiltrate. Those with atelectasis only were excluded. Pleural effusions were classified as absent, small, or moderate/large.

Analysis

Descriptive statistics were summarized using frequencies and percentages for categorical variables and median and interquartile range (IQR) values for continuous variables. Our

primary exposures were infiltrate pattern and presence and size of pleural effusion on admission chest radiograph. Associations between radiographic findings and disease outcomes were analyzed using logistic and linear regression for dichotomous and continuous variables, respectively. Continuous outcomes were log-transformed and normality assumptions verified prior to model development.

Due to the large number of covariates relative to outcome events, we used propensity score methods to adjust for potential confounding. The propensity score estimates the likelihood of a given exposure (i.e. infiltrate pattern) conditional on a set of covariates. In this way, the propensity score summarizes potential confounding effects from a large number of covariates into a single variable. Including the propensity score as a covariate in multivariable regression improves model efficiency and helps protect against overfitting.¹⁵ Covariates included in the estimation of the propensity score included age, sex, race/ethnicity, payer, hospital, asthma history, hospital transfer, recent hospitalization (within 30 days), recent emergency department or clinic visit (within 2 weeks), recent antibiotics for acute illness (within 5 days), illness duration prior to admission, tachypnea and/or increased work of breathing (retractions, nasal flaring, or grunting) at presentation, receipt of albuterol and/or corticosteroids during the first 2 calendar days of hospitalization, and concurrent diagnosis of bronchiolitis. All analyses included the estimated propensity score, infiltrate pattern, and pleural effusion (absent, small, or moderate/large).

RESULTS

Study Population (Table I)

The median age of the 406 children with clinical and radiographic CAP was 3 years (IQR: 1-6 years). Single lobar infiltrate was the most common radiographic pattern (61%). Children with interstitial infiltrates (10%) were younger than those with lobar infiltrates of any type (median age 1 vs. 3 years, $p=0.02$). A concomitant diagnosis of bronchiolitis was assigned to 34% of children with interstitial infiltrates but only 17% of those with lobar infiltrate patterns (range 11-20%, $p=0.03$). Pleural effusion was present in 21% of children and was more common among those with lobar infiltrates, particularly multilobar disease. Only 1 child with interstitial infiltrate had a pleural effusion. Overall, 63% of children required supplemental oxygen, 8% required ICU admission, and 3% required invasive mechanical ventilation. Median length of stay was 51.5 hours [IQR: 39, 91] and median oxygen duration was 31.5 hours [13, 65]. There were no deaths.

Outcomes According to Radiographic Infiltrate Pattern

Compared to children with single lobar infiltrates, the odds of ICU admission was significantly increased for those with either unilateral or bilateral multilobar infiltrates (unilateral, adjusted odds ratio [aOR] 8.0, 95% CI [2.9, 22.2]; bilateral, aOR 6.6 [2.1, 14.5]) (Figure I, Table II). Patients with bilateral multilobar infiltrates also had higher odds for supplemental oxygen use (aOR 2.7 [1.2, 5.8]) and need for invasive mechanical ventilation (aOR 3.0 [1.2, 7.9]). There were no differences in duration of oxygen supplementation or hospital length of stay for children with single vs. multilobar infiltrates.

Compared to those with single lobar infiltrates, children with interstitial infiltrates had higher odds of need for supplemental oxygen (aOR 3.1 [1.3, 7.6]) and ICU admission (aOR 4.4 [1.3, 14.3]) but not invasive mechanical ventilation. There were also no differences in duration of oxygen supplementation or hospital length of stay.

Outcomes According to Presence and Size of Pleural Effusion

Compared to those without pleural effusion, children with moderate to large effusion had a higher odds of ICU admission (aOR 3.2 [1.1, 8.9]) and invasive mechanical ventilation (aOR 14.8 [9.8, 22.4]), and also had a longer duration of oxygen supplementation (aOR 3.0 [1.4, 6.5]) and hospital length of stay (aOR 2.6 [1.9, 3.6]) (Table III, Figure II). The presence of a small pleural effusion was not associated with increased need for supplemental oxygen, ICU admission, or mechanical ventilation compared to those without effusion. However, small effusion was associated with a longer duration of oxygen supplementation (aOR 1.7 [1, 2.7]) and hospital length of stay (aOR 1.6 [1.3, 1.9]).

DISCUSSION

We evaluated the association between admission chest radiographic findings and subsequent clinical outcomes and hospital care processes for children hospitalized with CAP at 4 children's hospitals in the United States. We conclude that radiographic findings are associated with important inpatient outcomes. Similar to data from adults, findings of moderate to large pleural effusions and bilateral multilobar infiltrates had the strongest associations with severe disease. Such information, in combination with other prognostic factors, may help clinicians identify high risk patients and support management decisions while also helping to inform families about the expected hospital course.

Previous pediatric studies examining the association between radiographic findings and outcomes have produced inconsistent results.⁸⁻¹² All but one of these studies documented radiographic characteristics associated with pneumonia disease severity.¹¹ Further, while most contrasted lobar/alveolar and interstitial infiltrates, only Patria et al distinguished among lobar infiltrate patterns (e.g. single lobar vs. multilobar).¹² Similar to our findings, that study demonstrated increased disease severity among children with bilateral multifocal lobar infiltrates. Of the studies that considered the presence of pleural effusion, only one demonstrated this finding to be associated with more severe disease.⁹ However, none of these prior studies examined size of the pleural effusion. In our study, the strongest association with severe pneumonia outcomes was among children with moderate to large pleural effusion. Significant pleural effusions are much more commonly due to infection with bacterial pathogens, particularly *Streptococcus pneumoniae*, *Staphylococcus aureus*, and *Streptococcus pyogenes*, and may also indicate infection with more virulent and/or difficult to treat strains.¹⁶⁻¹⁹ Surgical intervention is also often required. As such, children with significant pleural effusions are often more ill on presentation and may have a prolonged period of recovery.²⁰⁻²²

Similarly, multilobar infiltrates, particularly bilateral, were associated with increased disease severity in terms of need for supplemental oxygen, ICU admission, and need for invasive mechanical ventilation. While this finding may be expected, it is interesting to note that the

duration of supplemental oxygen and hospital length of stay were similar to those with single lobar disease. One potential explanation is that, while children with multilobar disease are more severe at presentation, rates of recovery are similar to those with less extensive radiographic findings owing to rapidly effective antimicrobials for uncomplicated bacterial pneumonia. This hypothesis also agrees with the 2011 PIDS/IDSA guidelines which state that children receiving adequate therapy typically show signs of improvement within 48-72 hours regardless of initial severity.¹

Interstitial infiltrate was also associated with increased severity at presentation but similar length of stay and duration of oxygen requirement compared with single lobar disease. We note that these children were substantially younger than those presenting with any pattern of lobar disease (median age 1 vs. 3 years), were more likely to have a concurrent diagnosis of bronchiolitis (34% vs. 17%), and only one child with interstitial infiltrates had a documented pleural effusion (vs. 23% of children with lobar infiltrates). Primary viral pneumonia is considered more likely to produce interstitial infiltrates on chest radiograph compared to bacterial disease, and although detailed etiologic data are unavailable for this study, our findings above strongly support this assertion.^{23,24}

The 2011 PIDS/IDSA guidelines recommend admission chest radiographs for all children hospitalized with pneumonia to assess extent of disease and identify complications that may require additional evaluation or surgical intervention.¹ Our findings highlight additional potential benefits of admission radiographs in terms of disease prognosis and management decisions. In the initial evaluation of a sick child with pneumonia, clinicians are often presented with a number of potential prognostic factors that may influence disease outcomes. However, it is sometimes difficult for providers to consider all available information and/or the relative importance of a single factor, resulting in inaccurate risk perceptions and management decisions that may contribute to poor outcomes.²⁵ Similar to adults, the development of clinical prediction rules which incorporate a variety of important predictors, including admission radiographic findings, likely would improve risk assessments and potentially outcomes for children with pneumonia. Such prognostic information is also helpful for clinicians who may use these data to inform and prepare families regarding the expected course of hospitalization.

Our study has several limitations. This study was retrospective and only included a sample of pneumonia hospitalizations during the study period which may raise confounding concerns and potential for selection bias. However, detailed medical record reviews using standardized case definitions for radiographic CAP were used, and a large sample of children was randomly selected from each institution. In addition, a large number of potential confounders were selected *a priori* and included in multivariable analyses; propensity score adjustment was used to reduce model complexity and avoid overfitting. Radiographic findings were based on clinical interpretation by pediatric radiologists independent of a study protocol. Prior studies have demonstrated good agreement for identification of alveolar/lobar infiltrates and pleural effusion by trained radiologists, although agreement for interstitial infiltrate is poor.^{26,27} This limitation could result in either over- or underestimation of the prevalence of interstitial infiltrates likely resulting in a non-differential bias towards the null. Microbiologic information, which may inform

radiographic findings and disease severity, was also not available. However, since pneumonia etiology is frequently unknown in the clinical setting, our study reflects typical practice. We also did not include children from community or non-teaching hospitals. Thus, while findings may have relevance to community or non-teaching hospitals, our results cannot be generalized.

CONCLUSION

Our study demonstrates that among children hospitalized with CAP, admission chest radiographic findings are associated with important clinical outcomes and hospital care processes, highlighting additional benefits of the 2011 PIDS/IDSA guidelines' recommendation for admission chest radiographs for all children hospitalized with pneumonia. These data, in conjunction with other important prognostic information, may help clinicians more rapidly identify children at increased risk for severe illness and could also offer guidance regarding disease management strategies and facilitate shared decision-making with families. Thus, routine admission chest radiography in this population represents a valuable tool that contributes to improved quality of care.

Acknowledgments

Funding source: Dr. Williams is supported by funds from NIH-NIAID K23AI104779.

Abbreviations

ICU	Intensive Care Unit
IQR	Interquartile range
PIDS/IDSA	Pediatric Infectious Disease Society/Infectious Disease Society of America

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Figure I.

Propensity-Adjusted Odds Ratios for Severe Outcomes for Children Hospitalized with CAP According to Admission Radiographic Findings^I

^ISingle lobar infiltrate is the reference; children with both lobar and interstitial infiltrates were classified according to the type of lobar infiltrate; covariates included in the propensity score included: age, sex, race/ethnicity, payer, hospital, asthma history, hospital transfer, recent hospitalization (within 30 days), recent emergency department or clinic visit (within 2 weeks), recent antibiotics for acute illness (within 5 days), illness duration prior to admission, tachypnea and/or increased work of breathing (retractions, nasal flaring, or grunting) at presentation, receipt of albuterol and/or corticosteroids during the first 2 calendar days, and concurrent diagnosis of bronchiolitis. Pleural effusion (absent, small, or moderate/large) was included as a separate covariate; ** Indicates confidence intervals extend beyond the graph. The upper 95% CI for the odds ratios for infiltrates that were multilobar and unilateral were 22.2 for ICU admission and 37.8 for mechanical ventilation.; Abbreviations: IQR-Interquartile range, O2-oxygen, ICU-intensive care unit;

Figure II.

Propensity-Adjusted Odds Ratios for Severe Outcomes for Children Hospitalized with CAP According to Presence and Size of Effusion^I

^INo effusion is the reference; covariates included in the propensity score included: age, sex, race/ethnicity, payer, hospital, asthma history, hospital transfer, recent hospitalization (within 30 days), recent emergency department or clinic visit (within 2 weeks), recent antibiotics for acute illness (within 5 days), illness duration prior to admission, tachypnea and/or increased work of breathing (retractions, nasal flaring, or grunting) at presentation, receipt of albuterol and/or corticosteroids during the first 2 calendar days, and concurrent diagnosis of bronchiolitis. Infiltrate pattern was included as a separate covariate; ** Indicates confidence intervals extend beyond the graph. The upper 95% CI for the odds ratios for mechanical ventilation were 34.2 for small effusion and 22.4 for moderate/large effusion; Abbreviations: IQR-Interquartile range, O2-oxygen, ICU-intensive care unit;

Table 1
 Characteristics of Children Hospitalized with CAP According to Admission Radiographic Findings

Characteristic	Single Lobar	Infiltrate Pattern ^I			p-value ^{II}
		Multilobar, unilateral	Multilobar, bilateral	Interstitial	
No.	247 (60.8)	54 (13.3)	64 (15.8)	41 (10.1)	
Median age, years	3 [1, 6]	3 [1, 7]	3 [1, 5]	1 [0, 3]	0.02
Male sex	124 (50.2)	32 (59.3)	41 (64.1)	30 (73.2)	0.02
Race					
Non-Hispanic White	133 (53.8)	36 (66.7)	37 (57.8)	17 (41.5)	0.69
Non-Hispanic Black	40 (16.2)	6 (11.1)	9 (14.1)	8 (19.5)	
Hispanic	25 (10.1)	4 (7.4)	5 (7.8)	7 (17.1)	
Other	49 (19.9)	8 (14.8)	13 (20.4)	9 (22)	
Insurance					
Public	130 (52.6)	26 (48.1)	33 (51.6)	25 (61)	0.90
Private	116 (47)	28 (51.9)	31 (48.4)	16 (39)	
Concurrent diagnosis					
Asthma	80 (32.4)	16 (29.6)	17 (26.6)	12 (29.3)	0.82
Bronchiolitis	43 (17.4)	6 (11.1)	13 (20.3)	14 (34.1)	0.03
Effusion					
None	201 (81.4)	31 (57.4)	48 (75)	40 (97.6)	<.01
Small	34 (13.8)	20 (37)	11 (17.2)	0	
Moderate/Large	12 (4.9)	3 (5.6)	5 (7.8)	1 (2.4)	

Data presented as number (%) or median [IQR];

^I children with both lobar and interstitial infiltrates were classified according to the type of lobar infiltrate;

^{II} p-values are from chi-square statistics for categorical variables and Kruskal-Wallis tests for continuous variables; Abbreviations: IQR- Interquartile Range, O2-oxygen, ICU-intensive care unit.

Table II
Severe Outcomes for Children Hospitalized with CAP According to Admission Radiographic Findings

Outcome	Infiltrate pattern ^I				p-value ^{II}
	Single lobar n=247	Multilobar, unilateral n=54	Multilobar, bilateral n=64	Interstitial n=41	
Supplemental O2 requirement	143 (57.9)	34 (63)	46 (71.9)	31 (75.6)	0.05
ICU admission	10 (4)	9 (16.7)	9 (14.1)	4 (9.8)	<.01
Mechanical Ventilation	5 (2)	4 (7.4)	4 (6.3)	1 (2.4)	0.13
Hospital Length of stay (hours)	47 [37, 79]	63 [45, 114]	56.5 [39.5, 101]	62 [39, 93]	<.01
Oxygen duration (hours)	27 [10, 59]	38 [17.77]	38 [23.81]	34.5 [17.65]	0.18

Data presented as number (%) or median [IQR];

^I children with both lobar and interstitial infiltrates were classified according to the type of lobar infiltrate

^{II} p-values are from chi-square statistics for categorical variables and Kruskal-Wallis tests for continuous variables; Abbreviations: IQR- Interquartile Range, O2-oxygen, ICU-intensive care unit

Severe Outcomes for Children Hospitalized with CAP According to Presence and Size of Pleural Effusion

Table III

Outcome	Pleural Effusion			p-value ^{II}
	None n=320	Small n=65	Moderate/Large n=21	
Supplemental O2 requirement	200 (62.5)	40 (61.5)	14 (66.7)	0.91
ICU admission	22 (6.9)	6 (9.2)	4 (19)	0.12
Mechanical Ventilation Hospital Length of stay (hours)	5 (1.6)	5 (7.7)	4 (19)	<0.01
	48 [37.5, 76]	72 [45, 142]	160 [82, 191]	<0.01
Oxygen duration (hours)	31 [11, 57]	38.5 [18, 87]	111 [27, 154]	<0.01

Data presented as number (%) or median [IQR];

^{II} p-values are from chi-square statistics for categorical variables and Kruskal–Wallis tests for continuous variables; Abbreviations: IQR- Interquartile Range, O2-oxygen, ICU-intensive care unit;