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ORIGINAL RESEARCH

Admission Chest Radiographs Predict Illness Severity for Children Hospitalized With Pneumonia

Lauren McClain, MD[1], Matthew Hall, PhD[2], Samir S. Shah, MD, MSCE[3,4], Joel S. Tieder, MD, MPH[5], Angela L. Myers, MD, MPH[6], Katherine Auger, MD, MSc[4], Angela M. Statile, MD, MED[4], Karen Jerardi, MD, MED[4], Mary Ann Queen, MD[7], Evan Fieldston, MD, MBA, MSHP[8], Derek J. Williams, MD, MPH[9]*

[1]Monroe Carell Jr. Children's Hospital at Vanderbilt and the Department of Pediatrics, Vanderbilt University School of Medicine, Nashville, Tennessee; [2]The Children's Hospital Association, Overland Park, Kansas; [3]Divisions of Infectious Diseases, University of Cincinnati College of Medicine, Cincinnati, Ohio; [4]Hospital Medicine, Cincinnati Children's Hospital Medical Center and the Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, Ohio; [5]Division of Hospital Medicine, Seattle Children's Hospital and the Department of Pediatrics, University of Washington School of Medicine, Seattle, Washington; [6]Division of Infectious Diseases, Children's Mercy Hospital and Clinics and the University of Missouri School of Medicine, Kansas City, Missouri; [7]Division of Hospital Medicine, Children's Mercy Hospital and Clinics and the University of Missouri School of Medicine, Kansas City, Missouri; [8]Division of General Pediatrics, The Children's Hospital of Philadelphia and the Perelman School of Medicine at the University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania; [9]Division of Hospital Medicine, Monroe Carell, Jr. Children's Hospital at Vanderbilt and the Department of Pediatrics, Vanderbilt University School of Medicine, Nashville, Tennessee.

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 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 [CI]: 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, 95% CI: 1.1–8.9) and mechanical ventilation (aOR: 14.8, 95% CI: 9.8–22.4).

CONCLUSIONS: Admission radiographic findings are associated with important hospital outcomes and care processes and may help predict disease severity. *Journal of Hospital Medicine* 2014;9:559–564. © 2014 Society of Hospital Medicine

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 (eg, 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.

*Address for correspondence and reprint requests: Derek J. Williams, MD, 1161 21st Ave S. S2323 MCN, Nashville, TN 37232; Telephone: 615-322-2744; Fax: 615-322-4399; E-mail: derek.williams@vanderbilt.edu

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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 database (Children's Hospital Association, Overland Park, KS) was used to identify children from 4 freestanding pediatric hospitals (Monroe Carell, Jr. Children's Hospital at Vanderbilt, Nashville, Tennessee; Children's Mercy Hospitals & Clinics, Kansas City, Missouri; Seattle Children's Hospital, Seattle, Washington; and Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio). The institutional review boards at each participating institution approved the study. The validation study included a 25% random sampling of children 60 days to 18 years of age (n = 998) who were hospitalized between January 1, 2010 and December 31, 2010 with at least 1 ICD9-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 (eg, 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 (eg, 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 (ie, 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

The median age of the 406 children with clinical and radiographic CAP was 3 years (IQR, 1–6 years) (Table 1). 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 [IQR, 13–65]. There were no deaths.

TABLE 1. Characteristics of Children Hospitalized With Community-Acquired Pneumonia According to Admission Radiographic Findings

Characteristic	Infiltrate Pattern*				*P* Value†
	Single Lobar	Multilobar, Unilateral	Multilobar, Bilateral	Interstitial	
No.	247 (60.8)	54 (13.3)	64 (15.8)	41 (10.1)	
Median age, y	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)	

NOTE: Data are presented as number (%) or median [IQR]. **Abbreviations:** ICU, intensive care unit; IQR, interquartile range; O_2, oxygen.

*Children with both lobar and interstitial infiltrates were classified according to the type of lobar infiltrate

†*P* values are from χ^2 statistics for categorical variables and Kruskal-Wallis tests for continuous variables.

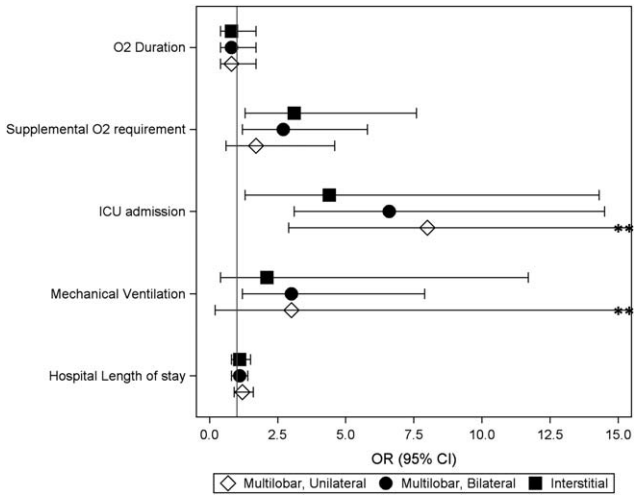

FIG. 1. Propensity-adjusted odds ratios for severe outcomes for children hospitalized with community-acquired pneumonia according to admission radiographic findings. Single lobar infiltrate is the reference. Children with both lobar and interstitial infiltrates were classified according to the type of 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 that confidence interval (CIs) extends beyond the graph. The upper 95% CI for the odds ratio (OR) for infiltrates that were multilobar and unilateral was 22.2 for intensive care unit (ICU) admission and 37.8 for mechanical ventilation. Abbreviations: O2, oxygen.

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% confidence interval [CI]: 2.9–22.2; bilateral, aOR: 6.6, 95% CI: 2.1–4.5) (Figure 1, Table 2). Patients with bilateral multilobar infiltrates also had higher odds for supplemental oxygen use (aOR: 2.7, 95% CI: 1.2–5.8) and need for invasive mechanical ventilation (aOR: 3.0, 95% CI: 1.2–7.9). There were no differences in duration of oxygen supplementation or hospital length of stay for children with single versus multilobar infiltrates.

Compared to those with single lobar infiltrates, children with interstitial infiltrates had higher odds of need for supplemental oxygen (aOR: 3.1, 95% CI: 1.3–7.6) and ICU admission (aOR: 4.4, 95% CI: 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, 95% CI: 1.1–8.9) and invasive mechanical ventilation (aOR: 14.8, 95% CI: 9.8–22.4), and also had a longer duration of oxygen supplementation (aOR: 3.0, 95% CI: 1.4–6.5) and hospital length of stay (aOR: 2.6, 95% CI: 1.9-3.6) (Table 3, Figure 2). 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, 95% CI: 1–2.7) and hospital length of stay (aOR: 1.6, 95% CI: 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

TABLE 2. Severe Outcomes for Children Hospitalized With Community-Acquired Pneumonia According to Admission Radiographic Findings

Outcome	Infiltrate Pattern*				*P* Value†
	Single Lobar, n = 247	Multilobar, Unilateral, n = 54	Multilobar, Bilateral, n = 64	Interstitial, n = 41	
Supplemental O^2 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)	<0.01
Mechanical ventilation	5 (2)	4 (7.4)	4 (6.3)	1 (2.4)	0.13
Hospital length of stay, h	47 [37–79]	63 [45–114]	56.5 [39.5–101]	62 [39–93]	<0.01
O^2 duration, h	27 [10–59]	38 [17–77]	38 [23–81]	34.5 [17–65]	0.18

NOTE: Data are presented as number (%) or median [IQR]. **Abbreviations:** ICU, intensive care unit; IQR, interquartile range, O_2, oxygen.

*Children with both lobar and interstitial infiltrates were classified according to the type of lobar infiltrate.

†*P* values are from χ^2 statistics for categorical variables and Kruskal-Wallis tests for continuous variables.

TABLE 3. Severe Outcomes for Children Hospitalized With Community-Acquired Pneumonia According to Presence and Size of Pleural Effusion

Outcome	Pleural Effusion			*P* Value*
	None, n = 320	Small, n = 65	Moderate/ Large, n = 21	
Supplemental O_2 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	5 (1.6)	5 (7.7)	4 (19)	<0.01
Hospital length of stay, h	48 [37.5–76]	72 [45–142]	160 [82–191]	<0.01
Oxygen duration, h	31 [11–57]	38.5 [18–87]	111 [27–154]	<0.01

NOTE: Data are presented as number (%) or median [IQR]. **Abbreviations:** ICU, intensive care unit; IQR, interquartile range; O_2, oxygen.

**P* values are from χ^2 statistics for categorical variables and Kruskal-Wallis tests for continuous variables.

produced inconsistent results.[8–12] All but 1 of these studies documented ≥1 radiographic characteristics associated with pneumonia disease severity.[11] Further, although most contrasted lobar/alveolar and interstitial infiltrates, only Patria et al. distinguished among lobar infiltrate patterns (eg, 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 1 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. Although 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, although 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 to 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 1 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 requiring 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

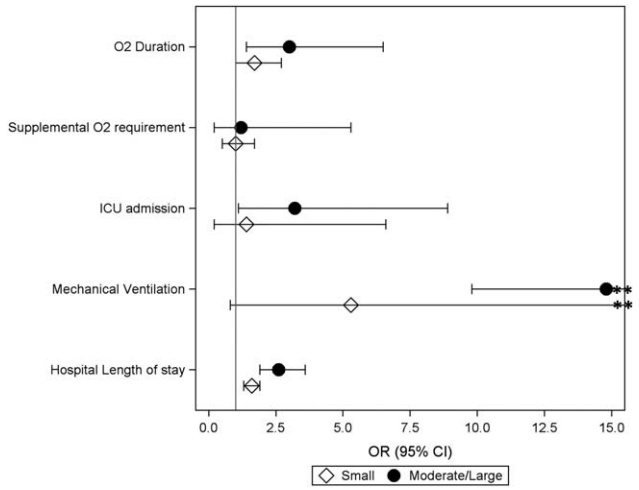

FIG. 2. Propensity-adjusted odds ratios for severe outcomes for children hospitalized with community-acquired pneumonia according to presence and size of effusion. No effusion is the reference. Covariates included in the propensity score included: age, sex, race/ethnicity, payer, hospital, asthma history, 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 interval (CI) extends beyond the graph. The upper 95% CI for the odds ratio (OR) for mechanical ventilation was 34.2 for small effusion and 22.4 for moderate/large effusion. Abbreviations: ICU, intensive care unit; O2, oxygen.

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 nondifferential bias toward the null. Microbiologic information, which may inform radiographic findings and disease severity, was also not available. However, because pneumonia etiology is frequently unknown in the clinical setting, our study reflects typical practice. We also did not include children from community or nonteaching hospitals. Thus, although findings may have relevance to community or nonteaching 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.

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