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Prediction of Pneumonia in a Pediatric Emergency Department

Mark I. Neuman, Michael C. Monuteaux, Kevin J. Scully and Richard G. Bachur

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Prediction of Pneumonia in a Pediatric Emergency Department

WHAT'S KNOWN ON THIS SUBJECT: Use of chest radiography in the evaluation of children with possible pneumonia varies widely. Although studies have identified certain historical features and physical examination findings associated with pneumonia, none have specifically addressed the criteria for obtaining a chest radiograph.

WHAT THIS STUDY ADDS: Clinical data can stratify children for pneumonia risk. Children with hypoxia and focal lung findings are high risk whereas those without hypoxia, fever, and ausculatory findings are low risk. For low-risk patients, clinical follow-up should be considered over obtaining a radiograph.

abstract

OBJECTIVE: To study the association between historical and physical examination findings and radiographic pneumonia in children who present with suspicion for pneumonia in the emergency department, and to develop a clinical decision rule for the use of chest radiography.

METHODS: We conducted a prospective cohort study in an urban pediatric emergency department of patients younger than 21 who had a chest radiograph performed for suspicion of pneumonia ($n = 2574$). Pneumonia was categorized into 2 groups on the basis of an attending radiologist interpretation of the chest radiograph: radiographic pneumonia (includes definite and equivocal cases of pneumonia) and definite pneumonia. We estimated a multivariate logistic regression model with pneumonia status as the dependent variable and the historical and physical examination findings as the independent variables. We also performed a recursive partitioning analysis.

RESULTS: Sixteen percent of patients had radiographic pneumonia. History of chest pain, focal rales, duration of fever, and oximetry levels at triage were significant predictors of pneumonia. The presence of tachypnea, retractions, and grunting were not associated with pneumonia. Hypoxia (oxygen saturation ≤92%) was the strongest predictor of pneumonia (odds ratio: 3.6 [95% confidence interval (CI): 2.0–6.8]). Recursive partitioning analysis revealed that among subjects with O_2 saturation >92%, no history of fever, no focal decreased breath sounds, and no focal rales, the rate of radiographic pneumonia was 7.6% (95% CI: 5.3–10.0) and definite pneumonia was 2.9% (95% CI: 1.4–4.4).

CONCLUSION: Historical and physical examination findings can be used to risk stratify children for risk of radiographic pneumonia. *Pediatrics* 2011;128:246–253

AUTHORS: Mark I. Neuman, MD, MPH,[a] Michael C. Monuteaux, ScD,[a,b] Kevin J. Scully, BS,[a] and Richard G. Bachur, MD[a]

[a]Division of Emergency Medicine and [b]Clinical Research Program, Children's Hospital Boston, Boston, Massachusetts

KEY WORDS
pneumonia, prediction, decision rule, chest radiograph

ABBREVIATIONS
CXR—chest radiograph
ED—emergency department
OR—odds ratio
CI—confidence interval

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Address correspondence to Mark I. Neuman, MD, MPH, Division of Emergency Medicine, 300 Longwood Ave, Boston, MA 02115. E-mail: mark.neuman@childrens.harvard.edu

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The use of chest radiography in the evaluation of children with possible pneumonia varies widely. The reasons for this variation include the lack of a gold standard for the diagnosis of pneumonia, difficulties in appreciating subtle signs of pneumonia (particularly in young children and infants), and the differential availability of radiology across practice settings. In addition, variability exists in the interpretation of chest radiographs (CXRs) for the diagnosis of pneumonia, and even under ideal circumstances it is difficult to distinguish viral from bacterial pneumonia solely on the basis of the CXR alone.

Studies that have sought to develop clinical decision rules for the evaluation of children with suspected pneumonia have been limited by their retrospective nature or small sample size.[1–6] Although in these studies certain historical features and physical examination findings associated with pneumonia have been identified, in few has the criteria for obtaining a CXR been specifically addressed.

We have conducted the largest prospective evaluation of children who underwent radiography for the suspicion of pneumonia in the emergency department (ED) setting to better identify patients at both low and high risk of radiographic pneumonia. We sought to assess the relation between historical and physical examination findings and radiographic pneumonia, and to develop a clinical decision rule to guide physicians in the use of radiography for children at risk of pneumonia.

METHODS

Study Design

We conducted a prospective cohort study in an urban pediatric ED with ~56 000 visits annually. Children younger than 21 who underwent a CXR for the evaluation of possible pneumonia were included in the study. Patients were excluded from the study if they had a CXR for an indication other than suspicion of pneumonia or if they had a significant previous medical history that would predispose a patient toward pneumonia, such as sickle cell disease, cardiac disease, immunodeficiency, or severe neurologic disorder. The study took place between November 2006 and May 2009.

All physicians who worked in the ED were asked to participate in the study and were informed about the study details before involvement. Physicians completed a brief questionnaire about their patient's presentation after requesting a CXR for suspicion of pneumonia but before viewing the radiograph or obtaining a reading from radiology. After completion, questionnaires were placed in secure lockboxes located throughout the ED. All physicians who participated in the study were board-certified pediatric emergency medicine physicians or general pediatricians. Questionnaires completed by residents required the real-time review and signature of the attending physician to verify the data.

Definitions

The identification of pneumonia was based on the final attending pediatric radiologist's report in the electronic medical chart. A patient was considered to have radiographic pneumonia if the CXR had definite findings of pneumonia, and also included radiographs with equivocal findings of pneumonia. Within the subset of patients with radiographic pneumonia, we defined a group of patients with definite pneumonia, which included children with CXR reports with descriptors such as "consolidation," "infiltrate" or "pneumonia." Radiographic findings of equivocal pneumonia included those with descriptors such as "atelectasis versus infiltrate," "atelectasis versus pneumonia," or "likely atelectasis but cannot exclude (or rule out) pneumonia." If the CXR reading included terminology such as "normal chest," "normal radiograph," "clear lungs," "no acute pulmonary findings," "atelectasis," or "peribronchial cuffing," it was considered negative for pneumonia.

Data Collection

There were 2 primary mechanisms for data collection in our study: information from prospectively collected questionnaires and medical chart review. Questionnaires asked physicians to remark on such factors as the patient's appearance, level of respiratory distress, symptoms (fever, cough, wheezing, chest pain, difficulty breathing), and the reason(s) for obtaining the CXR (height and duration of fever, respiratory distress, cough, hypoxia, increased white blood cell count). Particular attention was paid to the presence and location of physical examination findings, such as retractions, grunting, focal decreased breath sounds, wheezing, and rales. The questionnaires were designed in the fixed-choice format to prevent free text responses (Fig 1).

The electronic medical charts were reviewed by the study investigators to obtain basic demographic information (eg, age, gender), vital signs (eg, temperature, oxygen saturation, respiratory rate), treatment in the ED, disposition, radiograph results, and final diagnosis. Tachypnea was defined by age-specific thresholds as measured by the respiratory rate at triage.[6,7] The medical charts were also reviewed to assess for comorbid conditions that predispose toward pneumonia, including asthma, reactive airway disease, and bronchiolitis.

To evaluate enrollment bias, we audited daily radiography logs for the first 3 days of each month during the first year of the study period. We estimated the enrollment rate by dividing

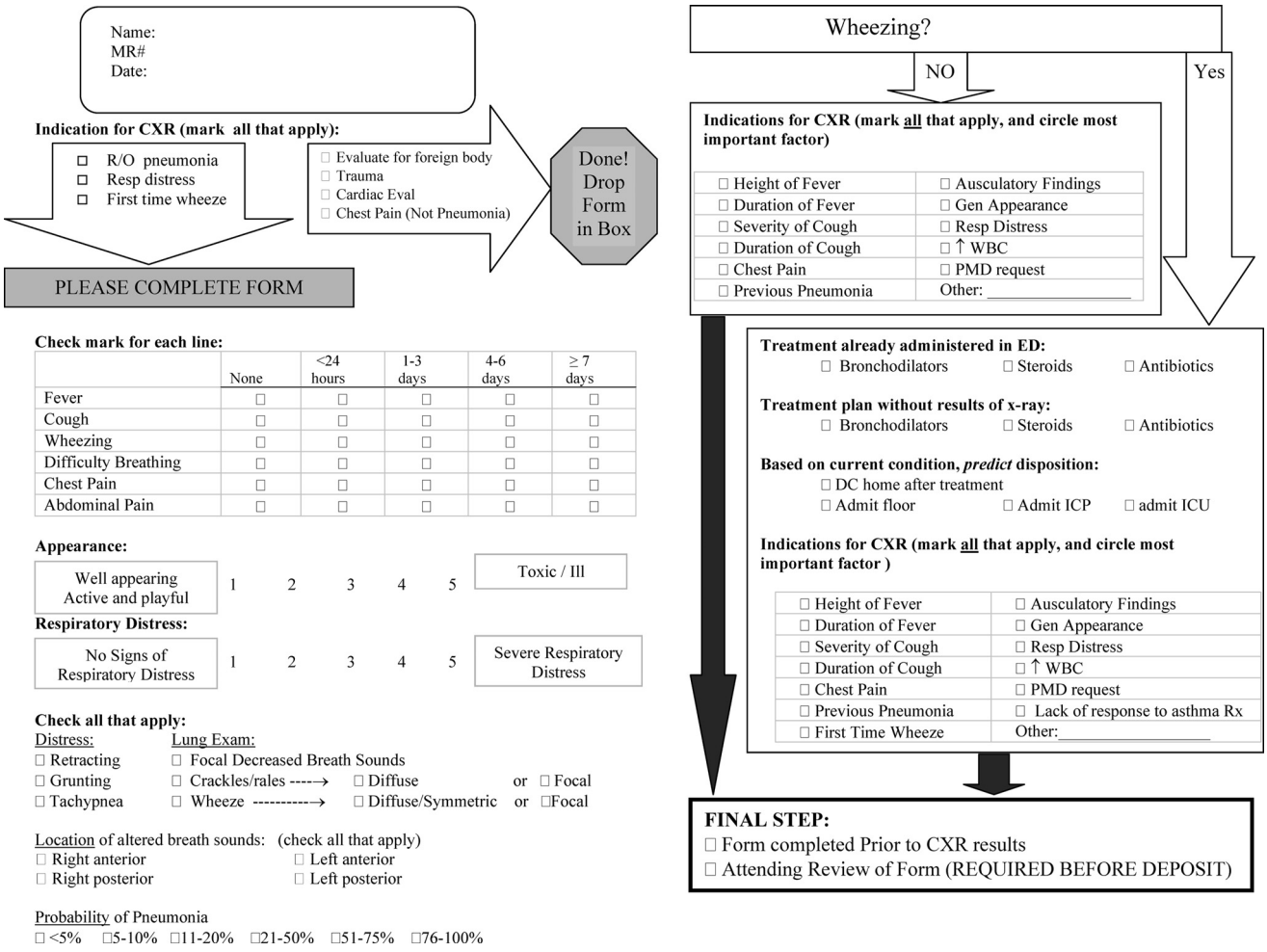

FIGURE 1
Data collection form.

the total numbers of study subjects by the total number of eligible patients who had a CXR performed to evaluate for pneumonia.[8] The rates of pneumonia were then calculated for enrolled and not-enrolled children.

Data Analysis and Statistical Methods

All data were entered into a secure electronic database with data validation rules. Descriptive and multivariate data analysis were performed with Stata 10.1 (Stata Corp, College Station, TX). First, we assessed the relation between historical features and physical examination findings and radiographic pneumonia. We estimated a multivariate logistic regression model with pneumonia status (radiographic pneumonia versus no pneumonia) as the dependent variable, and the independent variables were the historical (difficulty breathing, chest pain, distress, cough, fever) and physical examination findings (tachypnea defined by age-specific respiratory rate thresholds measured at triage, retractions, grunting, focal decreased breath sounds, rales, focal rales, focal wheezing, triage temperature, and room air oximetry value). Temperature at triage was dichotomized (<38°C or ≥38°), whereas history of fever, history of cough (none, up to 72 hours, or >72 hours), and oxygen saturation at triage (97%–100%, 93%–96%, or ≤92%) were modeled as categorical variables. Hypoxia was defined as oxygen saturation ≤92%. We also estimated a model with definite pneumonia as the dependent variable and the same historical and physical examination findings as the independent variables. The odds ratios (OR) with a 95% confidence interval (CI) was calculated for all variables. All statistical tests were 2-tailed.

Because data on oxygen saturation at triage were missing on 199 subjects (5%), we repeated the multivariate analysis while assigning these patients a value for this variable that was outside the observed range (ie, a value equal to the lowest observed value minus 1) and including a binary variable

that indicated the presence or absence of an observed oximetry value. Although sacrificing precision by introducing an additional covariate, this method allowed us to generate model estimates using these 199 patients.

We then developed a clinical decision tree to risk-stratify patients being considered for pneumonia and thereby guide clinicians around the use of radiography. We performed a recursive partitioning analysis using CART 5 software (Salford Systems, Stanford, CA). Variables that were significant or near significant ($P \leq .20$) in the multivariate logistic model described above were designated as candidate variables for inclusion in the recursive partitioning analysis. We applied a cost ratio of 5:1 for falsely categorizing a patient as not having pneumonia (ie, false-negative) compared with misclassifying a patient with radiographic pneumonia (ie, false-positive). The "optimal" tree as determined by the default CART algorithm was presented. We then performed multivariate analyses and recursive partitioning analysis on the subset of children younger than 5. The institutional review board approved this study. Data collection was compliant with the Health Insurance Portability and Accountability Act of 1996.

TABLE 1 Demographics of Study Population ($n = 2574$)

Characteristic	
Age, median (IQR), y	2.3 (0.9–5.2)
Age, *N* (%), y	
<2	1189 (46.2)
2–4.9	712 (27.7)
5–9.9	401 (15.6)
10–21.9	272 (10.6)
Male, *N* (%)	1381 (53.7)
Triage temperature, *N* (%), °C	
<38	1624 (63.4)
38.0–38.9	564 (21.9)
39.0–39.9	311 (12.1)
≥40	64 (2.5)
Age-specific tachypnea (RR measured at ED triage, breaths/min), *N* (%), y	
All ages	510 (19.8)
<2 (≥60)	133 (11.2)
2–4.9 (≥50)	65 (9.1)
5–9.9 (≥30)	106 (26.4)
10–21 (≥25)	206 (75.7)
Triage oxygen saturation %, *N* (%)[b]	
97–100	1663 (70.0)
93–96	593 (25.0)
≤92	119 (5.0)
Duration of fever, *N* (%)	
None	651 (25.3)
≤72 h	1497 (58.2)
>72 h	426 (16.6)
Duration of cough, *N* (%)[a]	
None	224 (8.8)
≤72 h	1346 (52.9)
>72 h	974 (38.3)
Wheezing present upon examination in ED, *N* (%)	704 (27.4)
Patients with WBC done, *N* (%)	749 (29.1)
WBC count, mean (SD)	13.1 (7.1)
Radiographic pneumonia, *N* (%)	
Definite pneumonia	199 (7.7)
Radiographic pneumonia	422 (16.4)
% Admitted to hospital, *N* (%)	576 (22.4)
Definite pneumonia	67 (34.2)
Radiographic pneumonia	133 (31.7)

IQR indicates interquartile range; WBC, white blood cell; RR, respiratory rate.
[a] Duration of cough was missing in 30 patients.
[b] Triage oxygen saturation was missing in 199 patients.

RESULTS

Subjects

The demographic and clinical characteristics of the sample are shown in Table 1. The majority of the sample was younger than 5, with a median age of 2.3 years. Subjects were slightly more likely to be male (54%). At triage, 20%, 5%, and 37% of subjects presented with age-adjusted tachypnea, hypoxia, and pyrexia, respectively. Seventy-five percent and 91% of patients reported a history of fever and cough, respectively. Wheezing was observed in 27% of patients. The proportion of patients with radiographic pneumonia was 16%, whereas 8% were classified as having definite pneumonia. Radiographic findings among children with definite pneumonia included lobar consolidation (73%), multilobar consolidation (21%), and consolidation with pleural effusion (6%). Overall, 22% of patients were hospitalized.

Enrollment

Overall, 51% of eligible patients were enrolled on the basis of review on radiology logs for the first 3 days of each month during the first 12 months of the study period. On the basis of our sampling, patients eligible but not enrolled did not differ from enrolled patients with respect to age (median age of 2.3 years in both groups) or the rate of definite pneumonia (6.2% versus 6.0%, respectively, $P = .5$).

Multivariate Regression

Our multivariate model of the clinical predictors of radiographic and definite pneumonia is displayed in Table 2.

TABLE 2 Triage and Clinical Predictors of Pneumonia in Multivariate Analyses

Predictors	Prevalence in Full Sample (n = 2352)[a], n (%)	Model 1: Definite Pneumonia, OR (95% CI)	Model 2: Radiographic Pneumonia, OR (95% CI)
Difficulty breathing[b]	1143 (47)	0.74 (0.50–1.09)	0.98 (0.74–1.29)
Chest pain[b]	243 (10)	2.89 (1.90–4.41)	1.52 (1.08–2.16)
Wheezing on examination	698 (30)	0.57 (0.36–0.90)	0.73 (0.54–0.98)
Respiratory distress	620 (26)	0.86 (0.53–1.38)	0.91 (0.66–1.27)
Tachypnea at triage	487 (21)	1.01 (0.68–1.51)	1.17 (0.88–1.55)
Retractions on examination	513 (22)	1.42 (0.86–2.35)	1.17 (0.83–1.66)
Grunting on examination	68 (3)	1.27 (0.50–3.20)	1.25 (0.65–2.39)
Focal decreased breath sounds	292 (12)	1.14 (0.74–1.76)	1.32 (0.96–1.82)
Rales (diffuse or focal)	710 (30)	0.68 (0.42–1.10)	0.88 (0.64–1.21)
Focal rales	360 (15)	2.27 (1.33–3.88)	1.66 (1.14–2.42)
Focal wheeze	78 (3)	1.14 (0.41–3.15)	0.75 (0.35–1.59)
Duration of fever			
None (referent)	624 (27)	—	—
≤72 hours	1359 (58)	1.83 (1.11–3.02)	1.80 (1.29–2.52)
>72 hours	369 (16)	3.62 (2.05–6.39)	3.35 (2.24–5.00)
Duration of cough			
None (referent)	129 (8)	—	—
≤72 hours	1257 (53)	0.72 (0.40–1.31)	1.19 (0.74–1.92)
>72 hours	903 (38)	0.87 (0.48–1.57)	1.26 (0.78–2.04)
Temperature at triage (≥38°)	852 (36)	1.41 (1.01–1.96)	1.24 (0.97–1.58)
Oxygen saturation at triage			
97%–100% (referent)	1647 (70)	—	—
93%–96%	588 (25)	1.62 (1.13–2.35)	1.37 (1.05–1.79)
≤92%	117 (5)	3.69 (1.99–6.82)	3.58 (2.28–5.64)

All of the predictors listed were included simultaneously in both Model 1 and Model 2.

[a] 222 study subjects were missing values for either oxygen saturation at triage or duration of cough and were excluded from multivariate analysis.

[b] Determined by parental report.

As shown, children with a history of chest pain and focal rales on examination were significantly more likely to be diagnosed with definite pneumonia relative to children without these clinical features. Conversely, children who presented with wheezing on examination were significantly less likely to be diagnosed with definite pneumonia. We also found that the duration of fever was positively correlated with the odds of a definite pneumonia diagnosis. In addition, children with fever ≥38°C or hypoxia at triage were at a significantly increased risk for definite pneumonia. When we repeated this model while including the 199 subjects with missing information on oxygen saturation at triage, the pattern of results did not change.

The results of a multivariate model of the clinical predictors of radiographic pneumonia were similar to the model that predicted definite pneumonia, with history of chest pain, focal rales, duration of fever, and oxygen saturation levels at triage emerging as significant predictors. Subjects with wheezing on examination were at lower risk of radiographic pneumonia. However, in contrast to the model that predicted definite pneumonia, triage temperature was not a significant predictor of radiographic pneumonia (P = .08). When we repeated this model while including the 199 subjects with missing information on oxygen saturation at triage, the patterns of results did not change, with the exception of focal decreased breath sounds, which was a significant predictor of radiographic pneumonia (OR: 1.39 [95% CI: 1.02–1.90]), P = .04).

Development of Decision Tree

On the basis of the results of the multivariate logistic regression model, the follow factors were selected for inclusion in the recursive partitioning analysis predicting radiographic pneumonia: wheezing on examination, chest pain, focal decreased breath sounds, focal rales, triage temperature, triage oxygen saturation, and history of fever. As shown in Fig 2, oxygen saturation initially divided the sample into "high risk" (O_2 saturation, ≤92%; rate of pneumonia, 37%) and "intermediate risk" (O_2 saturation, >92%; rate of pneumonia, 15%) nodes. Additional splits of the "intermediate risk" node by history of fever, focal decreased breath sounds, and focal rales identified a lower risk group (n = 503). That is, among subjects with O_2 saturation >92%, no history of fever, no focal decreased breath sounds, and no focal rales, the rate of radiographic pneumonia was 7.6% (95% CI: 5.3–10.0). The rate of definite pneumonia among this same subsample was 2.9% (95% CI: 1.4–4.4).

Patients Younger Than 5

In a multivariate model that predicted definite pneumonia in children younger than 5 (n = 1901), the pattern of results was the same, with the exception of wheezing on examination, which was no longer significant (OR: 0.64 [95% CI: 0.38–1.10] P = .10). In a model that predicted radiographic pneumonia, both chest pain (OR: 1.86 [95% CI: 0.96–3.60] P = .06) and wheezing on examination (OR: 0.78 [95% CI: 0.56–1.10] P = .16) were no longer statistically significant. The remaining pattern of results was the same. In a recursive partitioning analysis, oxygen saturation remained the single best predictor of radiographic pneumonia in children younger than 5. Thirty-nine percent of children with O_2 saturation ≤92% had pneumonia, whereas 15% of children with O_2 saturation >92% had pneumonia. Although the intent was to identify a low-risk group, we were unable to further

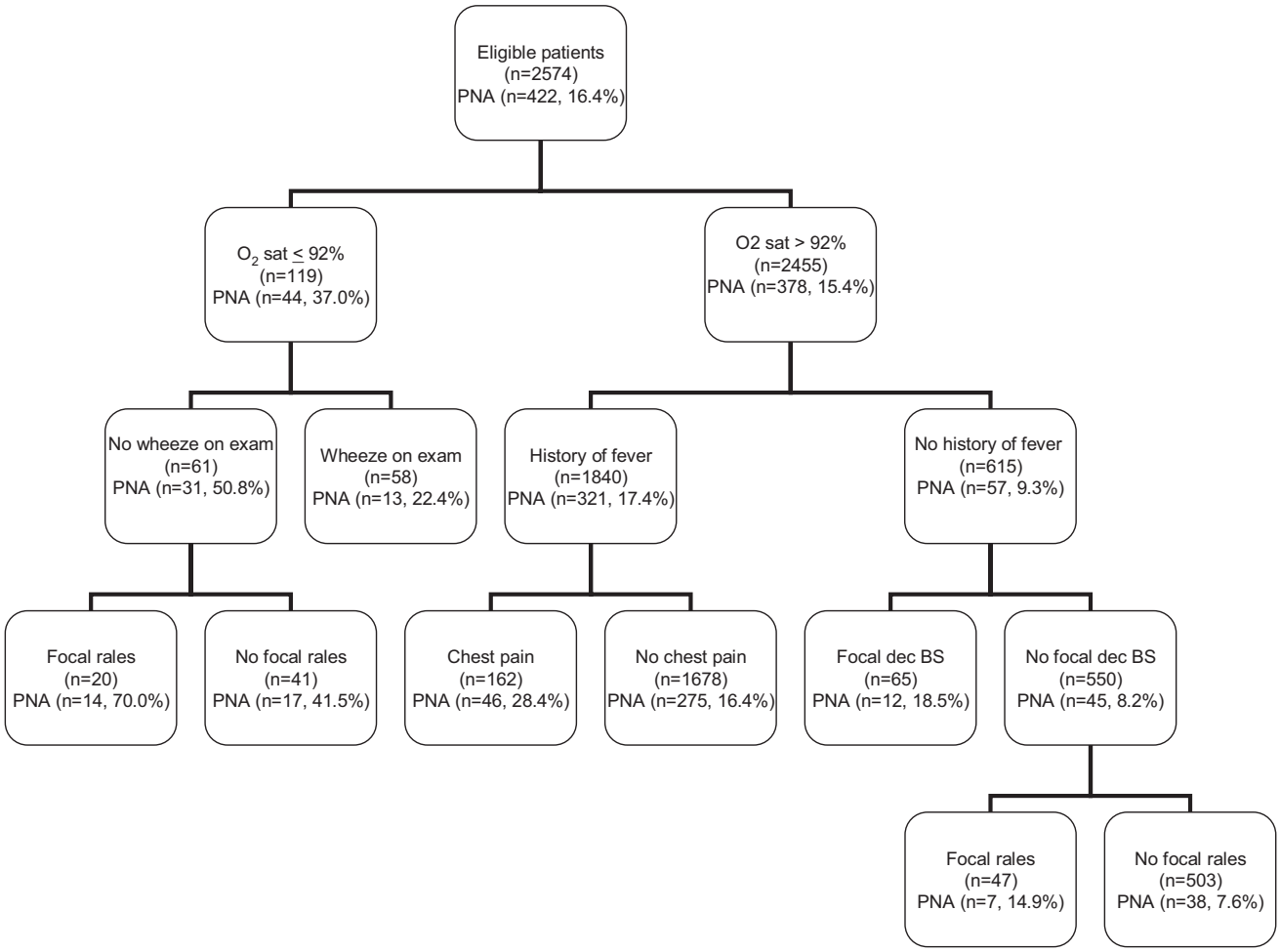

FIGURE 2

Stratification of patients on the basis of risk of radiographic pneumonia using recursive partitioning analysis ($n = 2574$). We included variables that were significant at the $P < .2$ level in multivariate logistic regression model. We assigned a cost of 5:1 for falsely categorizing a patient as not having pneumonia compared with misclassifying a patient with radiographic pneumonia. dec BS indicates decreased breath sounds.

characterize a low risk population among children younger than 5.

DISCUSSION

Historical and physical examination findings can be used to stratify children for risk of radiographic pneumonia. Unfortunately, the test characteristics of individual physical examination findings, such as focal rales, lack adequate sensitivity and specificity to confirm or exclude the diagnosis of pneumonia. Certain characteristics such as hypoxia, lack of wheeze, and focal rales place children at increased risk of radiographic pneumonia, whereas the rate of pneumonia is lower in the absence of hypoxia and fever, and without focal ausculatory findings.

The development of a clinical practice guideline for the use of chest radiography for the diagnosis of pneumonia in children may improve the quality of care and reduce CXR use. Identification of a lower-risk population may help to reduce unnecessary testing and radiation exposure, whereas identification of a high risk group will help ensure that radiography is performed to confirm a suspected diagnosis of pneumonia. Many previous studies that have sought to predict pneumonia in children have been limited by their small sample size[1,9,10] or select patient population,[3,4,6,7] or have been conducted in resource poor settings,[11,12] where the rate of pneumonia is considerably higher than in industrialized nations.

No single or combination of physical examination findings will have perfect sensitivity for the identification of pneumonia in children. Occult pneumonia or radiographic pneumonia in a child without respiratory distress or ausculatory findings on examination is well described in up to 5% to 10% of children for whom a CXR is obtained.[6,13,14] These observations highlight the challenges in the development of a highly sensitive

clinical decision tool to help clinicians manage children with suspected pneumonia.

In our study we expand and refine the findings of other studies in which predictors of pneumonia in children have been investigated. The major strength of our study lies in its prospective data collection and large sample size. Lynch et al[2] found the following findings to be associated with a focal infiltrate on CXR: history of fever; tachypnea; retractions; grunting; rales; and decreased breath sounds. Oxygen saturation was not studied because it was inconsistently recorded in their study, and 36% of their study population had radiographic pneumonia. The high rate of pneumonia may be because of their exclusion of young infants and children with asthma, in whom the rate of radiographic pneumonia is lower. More recently, Bilkis et al[11] validated the decision rule described by Lynch et al[2] that looked at the combination of 4 findings (fever, localized rales, decreased breath sounds, and tachypnea) and procured another decision rule. However, in that investigation, 69% of study subjects had radiographic pneumonia. Our study differs from these studies in that all children who had a CXR performed for the evaluation of pneumonia were eligible for inclusion, which is reflected in our lower rates of pneumonia (definite pneumonia, 8%; radiographic pneumonia, 16%). We believe that our rate of radiographic pneumonia is within the typical range of other studies in children,[1,5,10,15] which may make our findings more generalizable to a population of children for whom a CXR is obtained to evaluate for pneumonia in an ED setting. In one such study, Mahabee-Gittens et al[5] found that oxygen saturation $<$96%, nasal flaring, and age $>$12 months were associated with radiographic infiltrates among children 2 to 59 months evaluated in an ED setting.

There is wide variability in the management of children suspected to have pneumonia, which is understandable given the wide variability in clinical findings in children with pneumonia, the lack of gold standard to establish the diagnosis, and difficulties in distinguishing patients with viral and bacterial pneumonia. Rothrock et al[9] evaluated Canadian task force published guidelines for diagnosing pneumonia, which concluded that the absence of each of the 4 signs (ie, respiratory distress, tachypnea, rales, and decreased breath sounds) accurately excludes the diagnosis of pneumonia.[16] Rothrock et al[9] noted that application of these criteria had a sensitivity of 45% and specificity of 66% for the diagnosis of pneumonia in an ED population of children. Our group has demonstrated that the use of tachypnea alone does not distinguish children with and without radiographic pneumonia when applied to a US-based ED setting, yet this is the major screening tool used by the World Health Organization in resource poor settings.[8] As a result of the variability in clinical and radiographic findings observed in childhood pneumonia, many clinicians will treat patients based solely on clinical findings.[17] For example, a child with history of fever and focal rales on examination will likely be treated with antimicrobial agents for suspected pneumonia, particularly in the outpatient setting. However, our data reveal that only 25% of children with this combination of findings have a radiographic abnormality (radiographic pneumonia); 13% have pneumonia when using a stricter definition (definite pneumonia). Use of clinical criteria alone may be justified by the benefit of avoiding potentially harmful radiation but should be weighed against the burden of inaccurate diagnoses and unnecessary antibiotic use.

There are several limitations to our study. Approximately half of the eligible patients who underwent a CXR in the ED were enrolled in the study. However, patients not enrolled did not differ from those included in the study with respect to age and the presence of radiographic pneumonia. Although it is unlikely that there is enrollment bias in our sample, we were unable to verify this by looking at other objective parameters (eg, oxygen saturation, ausculatory findings). In addition, enrollment was facilitated by the availability of research staff in the ED and was not related in a systematic way to patients' or physicians' characteristics. Thus, any selection bias attributable to our enrollment rate is unlikely to compromise the validity of our findings. The study was conducted in a single ED of a tertiary care children's hospital, which may limit the generalizability to other practice settings. The entry criteria for our study required the clinical suspicion of pneumonia that prompted the decision to obtain a radiograph. We did not study all patients presenting with cough or fever, which may limit the generalizability of our findings. We enrolled children younger than 21, yet the decision to obtain a radiograph on the subset of children younger than 5 may be most challenging. Consideration of the wide age range of enrolled children should be considered when interpreting our findings. We are also unable to evaluate the reliability of specific physical examination findings because patients were only examined by the treating physician and did not undergo a second

examination for the purpose of this study. In addition, we were not able to evaluate children in whom there was suspicion of pneumonia but a radiograph was not obtained. However, recent data from our institution indicates that 83% of patients discharged from the ED with a diagnosis of pneumonia had a CXR obtained. Lastly, radiologists were not blinded to the clinical information obtained by the physician whom assessed the likelihood of pneumonia, which could further bias our results.

CONCLUSION

Historical features and physical examination findings can be used to stratify children for risk of radiographic pneumonia. Children with hypoxia and focal lung findings are at high risk of radiographic pneumonia, whereas the rate of pneumonia is low among children without hypoxia, fever, and localized ausculatory findings. For the low-risk patient, careful clinical follow-up should be considered as an alternative to obtaining a radiograph. Validation of these findings requires multicenter research and should include the assessment of the reliability of physical examination findings.

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