

Can We Predict Which Children With Clinically Suspected Pneumonia Will Have the Presence of Focal Infiltrates on Chest Radiographs?

Tim Lynch, MD*; Robert Platt, PhD†§; Serge Gouin, MDCM||; Charles Larson, MD‡¶||; and Yves Patenaude, MD#

ABSTRACT. *Objective.* To determine predictive factors for the presence of focal infiltrates in children with clinically suspected pneumonia in a pediatric emergency department.

Methods. Children (1–16 years) with clinically suspected pneumonia were studied prospectively. The presenting features were compared between the children with and without focal infiltrates using χ^2 analysis, *t* test, and odds ratio with 95% confidence intervals. A multivariate prediction rule was developed using logistic regression.

Results. A total of 570 were studied. Risk factors (odds ratio; 95% confidence interval) for the presence of focal infiltrates included history of fever (3.1; 1.7–5.3), decreased breath sounds (1.4; 1.0–2.0), crackles (2.0; 1.4–2.9), retractions (2.8; 1.0–7.6), grunting (7.3; 1.1–48.1), fever (1.5; 1.2–1.9), tachypnea (1.8; 1.3–2.5), and tachycardia (1.3; 1.0–1.6). We then used logistic regression to develop a candidate prediction rule for the variables of fever, decreased breath sounds, crackles, and tachypnea, which had an area under the receiver operating curve of 0.668. This rule had excellent sensitivity (93.1%–98%) yet poor specificity (5.7%–19.4%).

Conclusions. Multiple predictive factors for children with suspected pneumonia have been identified. Patients with focal infiltrates were more likely in our study to have a history of fever, tachypnea, increased heart rate, retractions, grunting, crackles, or decreased breath sounds. A multivariate prediction rule shows promise for the accurate prediction of pneumonia in children. However, the prospective evaluation of this multivariate prediction rule in a clinical setting is still required. *Pediatrics* 2004;113:e186–e189. URL: <http://www.pediatrics.org/cgi/content/full/113/3/e186>; *pneumonia, chest radiographs, children, predictive factors.*

ABBREVIATIONS. ED, emergency department; OR, odds ratio; CI, confidence interval.

From the *Department of Pediatrics, Children's Hospital of Western Ontario, London, Ontario, Canada; Departments of †Epidemiology and §Biostatistics, Montreal Children's Hospital, McGill University, Montreal, Quebec, Canada; ||Department of Pediatrics, Ste-Justine Hospital, University of Montreal, Montreal, Quebec, Canada; and Departments of ¶Pediatrics and #Radiology, Montreal Children's Hospital, McGill University, Montreal, Quebec, Canada.

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Reprint requests to (T.L.) Children's Hospital of Western Ontario, 800 Commissioners Rd E, London, Ontario, Canada, N6C 2V5. E-mail: tim.lync@lhsc.on.ca

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The accurate diagnosis of pneumonia in children remains an important yet difficult clinical problem. The chest radiograph remains the diagnostic test of choice in tertiary care centers. Given that the decision to pursue a diagnostic chest radiograph in the context of suspected pneumonia is largely influenced by clinical predictors of pediatric pneumonia, it is important to have these determined accurately.

The clinical findings of patients with radiographic pneumonia have been described previously in both adult and pediatric populations in developed countries.^{1–6} Some studies limit themselves to very young children.^{7–9} However, the number of pediatric patients studied with radiographic pneumonia has been small.^{1–5}

In 1997, an evidence-based review of the literature dealing with pediatric pneumonia was published by a group of pediatric infectious disease specialists and a microbiologist.¹⁰ The authors concluded that the absence of the pulmonary cluster as defined by Leventhal¹ of respiratory distress, tachypnea, rales, and decreased breath sounds accurately excluded pneumonia. This specific recommendation was based on a study that described the clinical predictors assessed by pediatric residents of only 26 patients with pneumonia during a 6-month period.¹

In a recent publication, these evidence-based guidelines were assessed.⁴ The authors applied these guidelines to 67 children who were 5 years or younger and had radiographic pneumonia and determined that they were insufficiently sensitive for clinical decision-making⁴ (45% sensitive, 66% specific, 25% positive predictive value, 82% negative predictive value). The same group of authors attempted to establish a clinical prediction rule.⁵ In 80 children who were younger than 16 years, they concluded that the presence of any 4 of temperature $\geq 38^\circ\text{C}$, oxygen saturation $< 95\%$, positive human immunodeficiency virus status, or cough productive of colored sputum was 93% sensitive for identifying radiographic pneumonia.⁵ This prediction rule is problematic in that most children do not expectorate effectively until mid-childhood, and ambulatory pneumonia is a profound problem in immunocompetent children. Furthermore, this rule is limited in its application in centers with a low incidence of human immunodeficiency virus positivity.

The primary objective of our study was to determine which clinical factors accurately predict the

presence of focal infiltrates in children 1 to 16 years of age with clinically suspected pneumonia in a pediatric emergency department (ED). Secondary objective were to determine the accuracy of the evidence-based guidelines previously discussed and to develop a predictive rule for the presence of infiltrates.

METHODS

Study Design

The study was a prospective cohort study conducted in a pediatric tertiary referral center with approximately 75 000 patient visits to its ED annually. Pneumonia is diagnosed in approximately 3% of these patients. It is estimated that >5000 chest radiographs are performed annually in ED patients with suspected pneumonia. Any child who was aged 1 to 16 years, presented to the ED with the clinical suspicion of pneumonia, and had a chest radiograph ordered during the study period of May 1998 through December 1999 was eligible for enrollment in this study.

Patients who were younger than 1 year were excluded because of the higher likelihood of bronchiolitis being diagnosed and the resultant variation of chest radiograph interpretation. Patients who were older than 16 years were excluded as they are more comparable to adult patients. Also, patients were excluded when they had chronic respiratory disease (eg, cystic fibrosis, bronchopulmonary dysplasia), chronic congenital or complex cardiac disease, gastroesophageal reflux disease, sickle cell anemia, malignancy, or spastic quadriplegia. Children with asthma were excluded when they were having an acute exacerbation, eg, requiring >1 bronchodilator treatment or systemic steroids in the ED. Patients were also excluded when they had a recent history of pneumonia confirmed by radiography in the previous 8 weeks or when they had taken antibiotics within the previous 2 weeks. As well, patients were excluded when they were critically ill, because only the portable frontal view is typically performed.

The patients were recruited by 11 designated full-time attending board-eligible/board-certified pediatric emergency physicians. Once inclusion and exclusion criteria were confirmed and informed consent was obtained by the recruiting physician, patients had frontal and lateral chest radiographs taken.

The gold standard was taken as consensus of 2 of 3 pediatric radiologists. Radiology review consisted of 1 of 7 radiologists who reported the films in real time and 1 designated, blinded study radiologist who reviewed all study films. When the initial 2 readings were discordant, a third reading was done by a second designated, blinded study radiologist. The radiologists were asked to classify the radiographs as positive when pulmonary opacities were present and negative when they were absent. The interobserver reliability among the radiologists was tested a priori. The weighted κ level of agreement (± 1 standard deviation) was 0.57 ± 0.17 among the 7 radiologists.

Outcome Measures

The primary outcome variable was the difference in the presenting clinical symptoms and signs between children with and without focal pulmonary infiltrates. A secondary outcome variable was to determine the accuracy of the previously recommended evidence-based guidelines. A candidate prediction rule for the presence of infiltrates was also developed.

Data Collection

The charts of all patients who had suspected pneumonia and had a chest radiograph performed during the study period were reviewed. Baseline demographic variables such as age and gender were collected in a prospective manner by the completion of a study questionnaire at the time of recruitment. Physicians completed the questionnaire indicating vital signs (temperature, respiratory rate, heart rate, and oxygen saturation), history (asthma), respiratory symptoms (cough, shortness of breath, pleuritic chest pain, coryza, wheeze), general symptoms (chills, irritability, poor feeding), and respiratory signs (retractions, tracheal tug, nasal flaring, grunting, crackles, bronchial sounds, wheezes, dullness to percussion, decreased breath sounds). Because the age of some

patients limited exact symptom definitions, difficulty breathing was used interchangeably with shortness of breath, and pleuritic chest pain was inclusive of any chest discomfort with breathing. Physicians checked questionnaire boxes indicating the presence of each study symptom and sign. The physicians were expected to complete the questionnaire during the ED evaluation. All ED charts were reviewed during the study period to ascertain the number of patients missed and excluded and the reasons.

Sample Size

The sample size for the multivariate analysis was calculated on the general requirement for 10 observations per predictor variable. We estimated that 200 patients with positive radiographs would be required because we planned to enter 20 variables in the analysis.

Statistical Analysis

Data were analyzed with SPSS and S-Plus. Continuous data were analyzed with the *t* test statistic, and categorical data were analyzed with the χ^2 statistic. $P < .05$ was considered statistically significant. The odds ratio (OR) with 95% confidence intervals (CIs) was calculated. As well, the sensitivity, specificity, and positive and negative predictive values of each clinical variable were calculated. Finally, we used logistic regression to develop a multivariate prediction rule. The regression analysis was backward stepwise on the basis of statistical significance of the likelihood ratio test and predictive ability of the whole model. The model significance was $P < .001$.

RESULTS

During the 19-month study period, 1100 patients met at least 1 exclusion criterion and 604 patients were eligible for study enrollment while 1 of the recruiting physicians was attending. Thirty-four of these patients declined to participate; therefore, 570 patients consented. The prevalence of patients with focal infiltrates was 35.7% (204 of 571). Overall, 97% of patients were discharged from the hospital and 3% were admitted. No patients were admitted to the intensive care unit.

None of the predictive baseline characteristics (age, gender, or asthma history) was statistically significant with respect to the presence of focal infiltrates on chest radiographs. In addition, the baseline and clinical characteristics of the 33 missed patients were similar to the included patients.

The clinical symptoms and signs were also compared. As demonstrated in Table 1, there was a significant difference between the 2 groups for the variable of fever history (previous 24 hours). Similarly, 4 clinical signs were found to be statistically significant: decreased breath sounds, crackles, retractions, and grunting. The sensitivity and specificity of the 5 statistically significant variables were determined (Table 2). The symptom with the greatest sensitivity for pneumonia was history of fever at 92%.

The presence of fever, tachypnea, and tachycardia was calculated according to standardized, age-appropriate definitions⁹ and compared (Table 3). Table 4 lists the sensitivity and specificity of the 3 vital signs. Tachypnea in itself had a specificity of 95%.

The validity of the proposed evidence-based guidelines applied to our study population was then calculated. The sensitivity of Leventhal's pulmonary cluster was 80.9%, whereas the specificity was 36.8%. The negative predictive value was 77.1%, whereas the positive predictive value was 41.4%. The best combined prediction rule using the evidence-based

TABLE 1. Comparison of Clinical Symptoms and Signs Between Two Groups

Variable	Positive CXR (n = 204)	Negative CXR (n = 367)	P Value	OR	95% CI
Fever Hx (%)	92	79	.001	3.1	1.7–5.3
Cough (%)	88	84	NS	1.4	0.8–2.50
Coryza (%)	5	4	NS	1.2	0.4–2.9
Shortness of breath (%)	5	4	NS	1.2	0.4–2.9
Wheeze (%)	4	3	NS	1.3	0.5–3.7
Pleuritic pain (%)	3	6	NS	0.5	0.2–1.2
↓ Breath sounds	54	45	.034	1.4	1.0–2.0
Crackles	43	27	.001	2.0	1.4–2.9
Bronchial sounds	7	4	NS	1.7	0.7–3.9
Wheezes	7	7	NS	1.0	0.5–2.0
Retractions	5	2	.047	2.8	1.0–7.6
Grunting	2	0	.038	7.3	1.1–48.1

CXR indicates chest radiograph; Hx, history; NS, not significant.

TABLE 2. Criterion Validity of Clinical Signs and Symptoms

Variable	Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)
Fever history	92	20	82	39
↓ Breath sounds	54	55	68	40
Crackles	43	73	70	47
Retractions	5	98	65	60
Grunting	2	100	65	80

NPV indicates negative predictive value; PPV, positive predictive value.

TABLE 3. Comparison of Vital Signs Between Two Groups

Variable (%)	Positive CXR	Negative CXR	P Value	OR	95% CI
Fever	47	31	.001	1.5	1.2–1.9
Tachypnea	13	5	.001	1.8	1.3–2.5
Tachycardia	51	40	.02	1.3	1.0–1.6

TABLE 4. Criterion Validity of Vital Signs

Variable	Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)
Fever	47	68	70	45
Tachypnea	13	95	66	60
Tachycardia	51	60	68	41

guidelines had an area under the receiver operating characteristic curve of 0.636.

We then used logistic regression using all of the studied variables with the presence of focal infiltrates as the outcome to develop a candidate prediction rule. After model reduction, our rule included presence of fever, decreased breath sounds, crackles, and tachypnea. The logistic regression equation is presented in Table 5. This rule had an area under the receiver operating curve of 0.668, which suggests a relatively effective rule. Table 6 presents the sensitivity and specificity of several combinations of predictors used in the logistic regression equation.

TABLE 5. Multivariate Model

Variable (%)	Coefficient	OR	95% CI
Fever	1.1	3.1	1.7–5.6
Decreased breath sounds	0.4	1.5	1.0–2.2
Crackles	0.7	2.0	1.4–3.0
Tachypnea	1.1	3.0	1.6–5.9

DISCUSSION

This prospective cohort study demonstrated that patients with radiographic pneumonia were more likely than patients with normal chest radiographs to have the following clinical features: history of fever, crackles, decreased breath sounds, grunting, and retractions on physical examination along with the presence of fever, tachypnea, and tachycardia.

Similar to the findings of Rothrock et al,⁴ the evidence-based guidelines were found to be insensitive (80.9%). This limits their usefulness to clinicians who would rather have a very sensitive tool to eliminate the need to perform a chest radiograph.

A predictive algorithm developed using logistic regression has several advantages. Different decisions can be made depending on combinations of symptoms. We also considered tree-based algorithms. These algorithms provided similar results.

Strong points of this study are that it was the first to evaluate prospectively the clinical findings in >200 children with radiographic-proven pneumonia. Other strengths are that the patients were studied over a 19-month period, which minimized seasonal variation. Consensus agreement of chest radiograph interpretation by the radiologists involved in the study limited the error associated with the reliance on 1 single radiologist as done in previous studies. This study focused on the use of predictive variables about which information is readily available to physicians when patients present. In an outpatient setting, it is often cumbersome to order a chest radiograph, so the need for clinical prediction is paramount.

Limitations of the study are that only full-time ED physicians were selected as participating attending physicians and that the study was conducted at a tertiary care center. Given that the overall prevalence of the radiographic diagnosis of pneumonia was 36%, the positive predictive accuracy would likely be reduced in an office setting as a result of the presence of less sick patients. Similarly, the positive and negative predictive accuracy would be affected by the different selection criteria that different physicians use when ordering a chest radiograph.

Unfortunately, the oxygen saturation for each patient was not systematically recorded. Therefore, no analysis could be performed accurately on that vari-

TABLE 6. Sensitivity and Specificity of the Presence of Combination of Variables From the Multivariate Model

Model	Fever	Decreased Breath Sounds	Crackles	Tachypnea	Sensitivity (%)	Specificity (%)
1	X	X			96.1	11.2
2	X		X		96.1	15.6
3	X			X	93.1	19.4
4	X	X	X		96.7	5.7
5	X	X		X	95.1	7.9
6	X		X	X	96.6	15
7	X	X	X	X	98	7.6

able. Furthermore, we did not adjust the initial vital signs according to the patient's temperature. No attempts were made to differentiate bacterial from viral causes of the patients' pneumonia.

This study shows the difficulties inherent in the development of a prediction rule for the presence of pneumonia. Table 6 clearly outlines this difficulty contrasting the combination variables high sensitivity with their low specificity. Symptoms that are sensitive, such as fever, are not specific because they are present in many patients without pneumonia. Symptoms that are specific, such as the presence of crackles, are not sensitive because they are apparent only in a selected group of patients. Therefore, it seems that a highly specific prediction rule is difficult to achieve. Weighing the balance between additional radiography versus missing a case of pneumonia is also a strong consideration in this regard.

In the context of pneumonia, physicians at our institution use chest radiography to confirm their clinical suspicion or to rule out pneumonia when they are unsure of their clinical finding. The application of our clinical prediction rule would potentially be applicable to the former scenario. According to Table 6, it can be seen that the combination of fever and any 1 of decreased breath sounds, crackles, or tachypnea yielded a sensitivity that ranged from 93.1% to 96.1%. One may still consider radiography in this clinical picture. Similarly, the presence of fever plus all 3 of the other variables increased the sensitivity to 98%. In this setting, one may postulate that chest radiography is not required given the high likelihood of a positive radiograph. This may be more applicable to an ambulatory care setting given that patient expectations for chest radiography in an ED may be higher.

The World Health Organization does not recommend chest radiography in the management of acute lower respiratory tract infections in children in developing countries.¹¹ A study from South Africa¹² randomized patients who met the World Health Organization case definition of pneumonia¹¹ into 1 group that underwent chest radiography and another group that did not. The presence or absence of chest radiography was not shown to affect clinical outcome in this study. Therefore, the consideration for the elimination of chest radiography in selected patients and specific settings as previously discussed is not unreasonable.

Following the guidelines for development of prediction rules suggested by Laupacis et al,¹³ this rule should be validated on new data from a similar

setting. Once this has been accomplished, clinical practice may then change.

CONCLUSION

The results of this study provide statistically significant factors that are predictive of childhood pneumonia. The use of these factors may help to guide the physician to more selective ordering of diagnostic chest radiography to provide a more accurate diagnosis of pneumonia in children and may also limit radiation exposure and expense.

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