Pediatric Pulmonology 38:465–469 (2004)

Can Chest X-Ray Predict Pneumonia Severity?

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Summary. Predictors of the severity of pneumonia have not been thoroughly evaluated among children in developed countries. We investigate whether chest radiographic findings could be used as predictors of severity of childhood pneumonia. The study included 167 children, aged more than 12 months, hospitalized in our department during a 4-year period with unilateral lobar or segmental pneumonia. The durations of fever and of hospitalization were considered indicators of severity of the disease. The size of the consolidation and its location in the left hemithorax were independently associated with severity of the disease. Univariate analysis showed that the mean duration of fever and of hospitalization as well as the prevalence of pleural effusion was significantly higher among children with left-sided pneumonia. A multiple logistic regression analysis revealed that only the presence of pleural effusion was significantly more likely in left-sided pneumonia (odds ratio, 2.65; 95% confidence interval, 1.09–6.47; $P = 0.031$). We conclude that the size of consolidation and the side of its location can be used as predictors of severity of pneumonia, with left-sided pneumonia running a more severe course, possibly due to increased risk for the development of pleurisy. **Pediatr Pulmonol. 2004; 38:465–469.** © 2004 Wiley-Liss, Inc.

Key words: community-acquired pneumonia; children; radiographic findings; pneumonia location; size of consolidation; severity predictor.

INTRODUCTION

Pneumonia is a well-recognized clinical entity. Despite advances in the identification of causative pathogens and the availability of antimicrobial agents and vaccinations, pneumonia remains a significant cause of pediatric morbidity, even in developed countries.[1–3] In developing countries, the situation is significantly worse, as mortality associated with pneumonia is still considerable.[4–8]

Prognostic factors for the severity of pneumonia in childhood have not been thoroughly investigated in the populations of developed countries.[9,10] The recognition of the predictors of severity of this disease should ideally be attempted separately for viral and bacterial pneumonia, provided that the isolation of the responsible etiologic factor would be feasible. While early recognition and introduction of appropriate antibiotics are critical for patients with bacterial pneumonia, the course of viral pneumonia in the majority of cases is benign and self-limited.[1,11] Despite the continuously increasing availability of tests for the identification of respiratory pathogens, the differentiation between viral and bacterial pneumonia remains a rather difficult task based exclusively on clinical manifestations.[12,13] In pediatric practice, it seems acceptable to consider a febrile child as having bacterial pneumonia if it is associated with lobar or segmental consolidation on the chest radiograph.[2,13]

The aim of this study was to investigate whether, in cases of unilateral lobar or segmental childhood pneumonia, the location and size of the consolidation can be used as predictors of pneumonia severity.

MATERIALS AND METHODS

Febrile children, 1–14 years of age, admitted to our pediatric department because of radiographically ascertained lobar or segmental pneumonia during a 4-year period, were included in this study. Patients' eligibility was determined by absence of a prior history of radiographically proven pneumonia, anatomic abnormalities of

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Received 20 November 2003; Revised 4 April 2004; Accepted 4 April 2004.

DOI 10.1002/ppul.20112
Published online 10 October 2004 in Wiley InterScience (www.interscience.wiley.com).

the respiratory tract, immunological defects, progressing neurological conditions, psychomotor retardation or congenital heart disease, chronic diseases, or other concurrent infections. Children with mild and moderate asthma under control as well as wheezing attacks were not excluded from the study. Tests for atypical bacteria were performed only if they were clinically suspected; children with serological evidence of *Mycoplasma pneumoniae* or *Chlamydia pneumoniae* infection were not included in the study. The population studied consisted of 167 children (80 boys and 87 girls) aged 1–14 years (mean age, 4.87 years; SD, 3.16 years; median age, 4.5 years). The consolidation was right-sided in 109 cases and left-sided in the remaining 58 (groups 1 and 2, respectively).

All children were initially treated parenterally, those under age 4 years (73 children) with ampicillin, and those 4 or more years of age (94 children) with penicillin. The route of administration was changed from parenteral to oral 24–48 hr following the remission of fever, with the exception of patients with a pleural effusion that needed drainage. In those cases, treatment was appropriately modified. A minimum 10-day course of antibiotic treatment was completed in all cases.

The following information was recorded: 1) child's gender and age; 2) highest temperature and duration of fever prior to admission (an axillary body temperature of 38°C or higher was required for the inclusion in the study); 3) administration of antibiotics prior to admission; and 4) chest radiograph focusing on the location of pneumonia with respect to the affected hemithorax (left or right) and lobe (upper or lower), size of consolidation, and existence of pleural effusion. The film was interpreted by a pediatric radiologist, and this official reading was attached to the medical records. For the purposes of the study, the type and size of consolidation were assessed blindly and independently by two pediatric radiologists. Size was expressed as percentage of the thoracic cavity covered by the consolidation. A square millimeter sheet of paper was used to measure the surface of the thorax and of the consolidation, and the proportion of the occupied area was subsequently estimated. This procedure allowed comparability of measurements in proportional terms, eliminating the differences derived from the lung size and the variability of the distance from which the chest X-ray was taken. The average size of consolidation following the aforementioned procedure was used in the analysis. When the disclosure of interpretation revealed more than 10% variability, the two specialists jointly reexamined the chest radiograph, and a final estimation was made. 5) Finally, we examined inflammatory indices including white blood cell count (WBC) by automated hematology analyzer (Coulter Gen S 2 System), C-reactive protein (CRP) measured with an immunoturbidimetric assay (Roche Diagnostics), and the results of a blood culture sample taken on admission.

The following data were also recorded during patients' hospitalization: 1) presence of pleural effusion and the need for drainage at any time during hospitalization; 2) duration of fever following the introduction of antibiotic treatment; and 3) duration of hospitalization.

A patient's age, imaging findings, and inflammatory indices on admission were tested as potential risk factors for severe pneumonia. The assessment of severity of the disease was based on the total duration of fever and hospitalization. These two indicators were alternatively used in order to eliminate the bias of an arbitrarily chosen index.

Statistical Methods

Student's *t*-test, the Mann-Whitney U-test, the chi-square test, linear regression, and multiple logistic regression models were used for data analysis as appropriate. $P < 0.05$ was considered statistically significant.[14]

RESULTS

The consolidation was right-sided in 109 cases and left-sided in 58. The majority of children with left sided pneumonia more commonly had the lower lobe affected (lower lobe, 45/58, 77.5%; upper lobe, 11/58, 19.1%; upper and lower lobe, 2/58, 3.4%), while in right-sided pneumonia, the upper lobe was more commonly affected (upper lobe, 54/109, 49.5%; lower lobe, 35/109, 32.1%; middle lobe, 16/109, 14.7%; and more than one lobe, 4/109, 3.6%) ($P = 0.001$).

Clinical and laboratory characteristics of patients with right-sided pneumonia were compared to those with left-sided pneumonia in Tables 1 and 2. The parameters

TABLE 1— Mean Values of Clinical and Laboratory Data on Admission by Side of Affected Lung[1]

Variable	Right-sided pneumonia (109 cases) (mean ± SD)	Left-sided pneumonia (58 cases) (mean ± SD)	*P*
Age (years)	4.81 ± 2.95	4.98 ± 3.56	NS
Duration of fever prior to admission (days)	3.99 ± 2.51	4.55 ± 2.77	NS
Leukocytes count (/mm^3)	$(21.5 \pm 8.7) \times 10^3$	$(18.9 \pm 8.5) \times 10^3$	NS
CRP (mg/l)	(144.5 ± 84.3)	(153.2 ± 97.0)	NS
Size of consolidation (mm^2)	$7.5 \times 10^{-2} \pm 5.4 \times 10^{-2}$	$7.0 \times 10^{-2} \pm 4.7 \times 10^{-2}$	NS

[1]*P*-values derived from Student's *t*-test or Mann-Whitney U, as appropriate.

TABLE 2— Mean Values of Duration of Disease Activity in Children With Pneumonia by Side of Affected Lung[1]

Index of severity of pneumonia	Right-sided (109 cases), mean ± SD (days)	Left-sided (58 cases), mean ± SD (days)	*P*
Total duration of fever	4.02 ± 2.82	5.57 ± 4.19	0.002
Duration of fever after antibiotic introduction	1.17 ± 2.29	2.29 ± 3.40	0.03
Duration of hospitalization	3.58 ± 2.22	5.24 ± 4.55	0.043
Total disease duration	6.74 ± 4.01	9.08 ± 5.45	0.001

[1]*P*-values derived from Mann-Whitney U-test.

studied were age, duration of fever prior to admission, laboratory indices WBC and CRP, and size of consolidation; no differences were found between right- and left-sided pneumonia cases (Table 1). Disease activity assessed by Mann-Whitney U-test was prolonged in patients with left-sided vs. right-sided (Table 2).

In an effort to assess the significance of predictors of pneumonia severity, we used simple linear regression analysis models, using two different dependent variables: total duration of fever and duration of hospitalization (both log-transformed). The independent variables evaluated as predictors in the two different models were: age, sex, duration of fever and administration of antibiotics prior to admission, size of consolidation and presence of pleural effusion in chest X-ray (CXR) on admission, location of consolidation (right-left), WBC, and CRP. In Table 3, we present the pairs of variables, the beta coefficients, and their significance (*P* values). The size of consolidation and the side of the affected lung were correlated with severity of the disease, irrespective of the dependent variable that was used as index of severity.

The only complication seen in this series of patients was pleural effusion. It was found in 35/167 patients (20.9%). Five of them were in need of a drainage tube. However, the incidence of pleural effusion was lower in patients with right-sided pneumonia (12/109, 11%) compared to those with left-sided (23/58, 39.6%) ($P < 0.001$). Pleural effusion was mainly found in lower lobe pneumonia, as it was identified in 21/47 (45%) patients with the left lower lobe affected compared to 2/11 (18.1%) of those with pneumonia of the left upper lobe. The distribution of pleural effusion followed a similar pattern in right-sided pneumonia, as it was observed in 10/35 (28%) children with consolidation of the right lower lobe and in only 2/74 (2.7%) with consolidation of the right upper or middle lobes ($P < 0.001$).

We also used a multiple logistic regression model to investigate whether and to what extent the higher incidence of pleural effusion in left-sided pneumonia was the underlying factor which contributed to the prolonged duration of disease in left-sided pneumonia. This analysis allowed an adjustment for mutually confounding variables. The core model included duration of fever after the introduction of antibiotics, administration of antibiotics prior to admission, extent of consolidation and its location (upper or lower lobe), presence of pleural effusion, and necessity for drainage, whereas the total duration of fever and duration of hospitalization were alternatively introduced (first and second models, respectively) to avoid consequences of colinearity.

The multiple logistic derived odds ratios (ORs) showed that the presence of pleural effusion and the location of consolidation with respect to the lobe were the only factors significantly associated with the side of pneumonia. The development of pleural effusion was substantially and significantly more likely in left-sided pneumonia compared to right-sided (first model: OR, 2.65; 95% confidence interval (CI), 1.09–6.47; $P = 0.031$; second model: OR, 2.61; 95% CI, 1.06–6.45; $P = 0.036$). There was also a nearly 3-fold higher probability for left-sided pneumo-

TABLE 3— Significant Predictors of Pneumonia Severity Derived From Linear Regression Analysis Models

Dependent variable of severity of pneumonia	Significant predictive factors	Beta coefficient	*P*
Total duration of fever (log)	Duration of fever prior to admission	0.062	<0.001
	Size of consolidation (% coverage of thorax)	1.18	<0.001
	Side (baseline = right side)	0.112	0.001
Duration of hospitalization (log)	Pleural effusion (baseline = no effusion)	0.166	0.001
	Size of consolidation (% coverage of thorax)	1.28	0.001
	Administration of antibiotics prior to admission (baseline = no antibiotics)	0.149	0.004
	Side (baseline = right side)	0.083	0.041

nia to be located in the lower lobe (first model: OR, 3.25; 95% CI, 1.37–7.69; $P = 0.007$; second model: OR, 2.92; 95% CI, 1.26–6.76; $P = 0.012$).

DISCUSSION

It is generally accepted that the majority of children with bacterial pneumonia can be treated as outpatients.[1,15] The decision for hospitalization should be based on assessment of the severity of illness, the age of the patient, and the cooperation of the family. It is therefore obvious that the establishment of criteria of severity would facilitate the clinician's decision. Although there are different scores of severity for pneumonia in adulthood, there are no similar indicators available for children.[16–20] To the best of our knowledge, radiographic findings have not been assessed as predictors of severity in childhood pneumonia, with the exception of pleural effusion.

The parameters that were used for the evaluation of severity of pneumonia are all routinely recorded in patients with pneumonia admitted to our department, and therefore there was no bias with respect to missing data. Ideally the identification of severity factors for pneumonia should also take into account its etiology (viral, bacterial, or mixed).[15,21,22] However, we believe that our approach of studying children with unilateral lobar or segmental pneumonia minimizes the possibility of including viral pneumonia,[2,9,11] and therefore the population studied was rather homogenous in that respect.

The results of this study demonstrated that right lung pneumonia is more common, with the upper lobe more frequently affected, while in left-sided pneumonia the lower lobe is preferably involved. It was also found that left-sided pneumonia was more severe compared to right-sided, as indicated by the increased risk for the development of complications and delayed response to treatment. These findings suggest a difference in the pathogenesis of right- vs. left-sided pneumonia, which may at least in part be explained by the anatomical characteristics of the bronchial tree. Airborne pneumonia is more frequent in the right lung due to the greater diameter of the right main-stem bronchus, its decreased length, the greater airflow through the right lung, the position of the carina to the left of the midline, and the smaller angle of divergence of the right main-stem bronchus from the tracheal axis, although there are contradictions regarding the latter.[3,23,24] On the other hand, in case of hematogenous dissemination of bacteria, both lungs should be equally affected. Therefore, more severe pneumonia as a result of bacteremia may be overrepresented in proportional terms among cases of left-sided pneumonia. Moreover, the drainage of accumulated mucus from the right lung is easier, contributing to faster recovery compared to the left.

Pleural effusion was the only complication developed in our patients. Left-sided pneumonia resulted more frequently in pleural effusion compared to right-sided pneumonia, and this complication seemed to be the main cause of the delayed response to treatment. Drainage of pleuritic fluid is less efficient in left hemithorax consolidations: gravity inhibits the drainage of the lower lobes, more commonly affected in left-sided pneumonia. Indeed, lower-lobe pneumonia was more frequently associated with reactive pleural effusion for both left- and right-sided pneumonia. Pleural effusion was identified as an independent severity factor, irrespective of the location of pneumonia. This is in agreement with the generally accepted guidelines for the management of pneumonia in childhood which consider parapneumonic effusion an indication for hospitalization.[1,3]

We also found that the size of the consolidation could also be used as a predictor of the clinical course of the disease. The implications of the radiographic pattern of pneumonia, as reflected by the extent, density, and evolution of infiltrates, have already been shown in adult settings.[25] In our study, we used a two-dimensional estimate. We chose not to use a lateral film, as it would augment the amount of administered radiation without necessarily adding substantial information.[26] Despite this limitation, our findings suggest that the imaging spread of consolidation reflects, to some extent, the proportion of inflamed lung parenchyma.

In conclusion, our findings indicate that the extent of lung consolidation in the chest X-ray and the location of pneumonia should be taken into consideration for the assessment of severity of the disease, as children with left-sided pneumonia are at increased risk for developing parapneumonic effusion.

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