Predicting the Need for Hospitalization in Children with Acute Asthma*

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In an attempt to identify factors which influence the decision of physicians to admit patients with acute asthma to the hospital, we studied prospectively 200 children (age 5.6 ± 3.1 years, mean ± SD) presenting to our emergency room with acute asthma. The children were assessed on arrival, and on disposition from the Emergency Room by one of the investigators. After obtaining historic data, a clinical score was assigned, and oxygen saturation and pulmonary function were measured. Of the 134 (67 percent) children who were discharged home from the Emergency Room, five returned within seven days and one was subsequently admitted. The clinical score on disposition was the sole variable found to best predict the decision for hospitalization (sensitivity 73 percent, specificity 95 percent). Of the variables obtained at presentation, the resulting decision tree found the clinical score to predict the decision for hospitalization (sensitivity 79 percent, specificity 75 percent). When the individual components of the clinical score were analyzed, the degree of dyspnea, as assessed by the investigator, was chosen as the rule to predict the hospitalization decision (sensitivity 88 percent, specificity 71 percent). We conclude that the decision with respect to the need for hospitalization in acute childhood asthma, is in practice based mainly on careful clinical evaluation. Pulmonary function and SaO₂ measurements, although helpful adjuncts in the assessment of acute asthma, do not appear to contribute to the identification of patients who need hospital admission. (CHEST 1990; 98:1355-61)

Acute asthma is the most common medical emergency in children and is responsible for increasing hospitalization and death rates in several countries.1-4 It is, therefore, becoming increasingly important to optimize the assessment and treatment of patients with acute asthma. In the Emergency Room setting, the most critical issue facing the attending physician is deciding when outpatient therapy of acute asthma is adequate, or when hospitalization is indicated. Traditionally, this decision is reached on the basis of patient history, findings on physical examination, laboratory measurements, and response to therapy. The literature relevant to this issue is confusing with respect to the relative importance of the various components of patient assessment. Thus, although Lulla and Newcomb5 found that a history of asthma symptoms of greater than 24 hours in duration reduced the likelihood of successful treatment and discharge from the ER, this observation was not confirmed by subsequent investigators.6-10 No individual clinical measurement has been shown to predict the outcome of acute asthma reliably, and thus, a variety of multifactorial scoring systems have been devised. Fischl et al11 developed an index primarily based on clinical assessment, which they claimed could reliably predict the outcome of adult patients treated in the ER for acute asthma. However, subsequent prospective studies12,13 failed to confirm the predictive accuracy of this index. Conflicting results were also obtained when clinical scoring systems were applied to children with asthma in acute-care settings. Some investigators14,15 have been able to distinguish between patients who need to be admitted to the hospital and those who can be discharged on the basis of a spirometric threshold, but this again has not been a universal finding.16,17 Similarly, variable results have been obtained when the value of arterial blood gas measurements were used in predicting patient outcome.14 In a recent study, Geelhoed et al18 measured oxygen saturation by pulse oximetry in a group of children with acute asthma, and found that an initial saturation of 91 percent differentiated patients with a favorable vs unfavorable outcome.

Most of the above cited works recently have been evaluated by Wasson et al,19 and severe methodologic defects have been demonstrated. These defects included failure in definition of outcome, and lack of blind assessment of the predictive variables and the

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outcome decision. The purpose of this study was to assess the usefulness of historic data, clinical score, spirometry, oxygen saturation, or any combination of these variables in predicting the outcome of acute asthma episodes in children. In this study, we used the "CART" statistical software based on a tree-structured form of discriminant analysis, to build and assess clinical prediction rules. As compared to more traditional methods such as multivariate discriminant analysis, this method can produce more flexible decision rules. In particular, it is more effective at detecting interactions among the predictors.

**METHODS**

Our study population was comprised of 200 children who presented to the ER of the Hospital for Sick Children, Toronto, between September and December 1988, for the treatment of acute asthma when one of the investigators was available. Children with acute bronchiolitis or with complicating pulmonary or cardiac disorders were excluded from the study.

On arrival to the ER, the following historic data were obtained from the parents of each subject: age, sex, duration of present episode, number of previous hospital admissions, and current medications. Prior to treatment and on disposition from the ER, one of the investigators performed a physical examination and measured pulmonary function and SaO₂. From the physical assessment, a clinical score was assigned for each patient (Table 1). This clinical score is a modification of the Fisch scoring system. Dyspnea was defined as the investigator’s impression of the degree of the child’s breathlessness. A respiratory rate above 90 percent confidence limits for age was assigned a score of 1. Since it was not possible to measure pulsus paradoxus in some of our younger patients, the score was standardized by expressing the number of positive values (score = 1) for an individual patient, as a fraction of the total number of variables measured for that patient. The final score ranged from 0 to 1.0, increasing with severity. Pulmonary function was measured by a portable spirometer in children over seven years of age who were able to perform spirometry reliably. FEV₁, FVC, and PFR were measured in triplicate, the maximal values were accepted, and expressed as a percentage of the predicted value for height and sex. The SaO₂ was measured noninvasively by pulse oximetry when the patients were awake and breathing room air. On disposition from the ER, the SaO₂ measurement was made at least 30 minutes after the final treatment with nebulized albuterol.

The patients in the study were independently assessed and treated by pediatric residents, under the supervision of staff physicians, all of whom were unaware of the results of the clinical score, pulmonary function, or SaO₂ measurements. Neither the treatment, duration of ER care, nor hospitalization/discharge decisions were governed by protocol. However, the first-line treatment for acute asthma at this institution consists of one or more inhalations of a 0.5 percent solution of albuterol (0.03 ml/kg, maximum 1 ml/dose) in 3 ml normal saline solution, delivered by nebulizer at an oxygen rate of 6 to 8 L/min. The use of parenteral theophylline or corticosteroids in the present study was at the discretion of the ER physicians. In general, the decision to admit or discharge a patient was made within 2 to 4 hours of arrival in the ER.

The parents of children who were discharged home from the ER were contacted by telephone seven days later, and information was obtained regarding the need for additional ER care and/or hospitalization.

**Statistical Methods**

Outcome was defined as the decision to hospitalized or discharge a patient, made by the ER physician. The decision rule for predicting outcome was estimated and assessed using the classification tree methodology described by Breiman et al. The computations were performed using the "CART" software. This method discriminates between the outcome classes of interest through a series of binary stratifications. It searches for the cutoff among any of the variables that best separates the data with respect to outcome. The process is repeated until each subgroup reaches a minimum size. The result of the splitting process can be represented by a binary tree, with each terminal node or "leaf" representing a subgroup of the population. As the tree is usually too large to be an effective discriminator, the optimal subtree is estimated using the cross-validation technique. This method works by dividing the data into ten groups of equal size, building a tree on 90 percent of the data, and then assessing its discriminatory power on the remaining 10 percent of the data.

For descriptive purposes, boxplots were computed and plotted for each of the potentially important predictors, split by presentation or disposition status. Boxplots are a convenient method of displaying the distribution of a variable. The middle bar in the box shows the median, the outer bars show the lower and upper quartiles, and the vertical arms show the 95 percent range. Points outside of this range are possible outliers and are denoted by asterisks.

**RESULTS**

Of the 200 patients in the study, 66 (33 percent) were hospitalized, and 134 (67 percent) were discharged home. Five of the discharged patients returned to the ER within seven days, and one was subsequently hospitalized. All patients were treated with nebulized albuterol, and in addition, 8 percent

<table>
<thead>
<tr>
<th>Table 1—Clinical Scoring System</th>
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<tbody>
<tr>
<td><strong>Score = 0</strong></td>
</tr>
<tr>
<td>Heart rate</td>
</tr>
<tr>
<td>Respiratory rate*</td>
</tr>
<tr>
<td>Pulsus paradoxus</td>
</tr>
<tr>
<td>Dyspnea</td>
</tr>
<tr>
<td>Accessory muscle use</td>
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<tr>
<td>Wheezing</td>
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*Ref 22

Table 2—Clinical Characteristics of Patients Who Were Discharged Home and Hospitalized (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Discharged</th>
<th>Hospitalized</th>
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</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>134</td>
<td>66</td>
</tr>
<tr>
<td>Male/Female</td>
<td>74/60</td>
<td>43/23</td>
</tr>
<tr>
<td>Age, yr</td>
<td>5.8 ± 4.0</td>
<td>5.1 ± 3.9</td>
</tr>
<tr>
<td>Previous hospitalizations, No.</td>
<td>1.65 ± 2.71</td>
<td>2.4 ± 3.1*</td>
</tr>
<tr>
<td>Symptom duration, hr</td>
<td>53.59 ± 52.4</td>
<td>33.0 ± 31.5*</td>
</tr>
<tr>
<td>Clinical score on presentation</td>
<td>0.42 ± 0.33</td>
<td>0.85 ± 0.21†</td>
</tr>
<tr>
<td>Clinical score on disposition</td>
<td>0.21 ± 0.2</td>
<td>0.82 ± 0.24†</td>
</tr>
<tr>
<td>SaO₂ at presentation, %</td>
<td>96.0 ± 2.1</td>
<td>92.5 ± 4.3†</td>
</tr>
<tr>
<td>SaO₂ on disposition, %</td>
<td>95.6 ± 2.1</td>
<td>94.0 ± 2.9†</td>
</tr>
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</table>

*p<0.01.
†p<0.001.
received intravenous theophylline, and 8 percent received systemic corticosteroids. The mean age of all patients was 5.6 ± 3.1 years (range 0.4 to 16 years). No statistically significant age difference was found in the hospitalized vs the discharged groups (Table 2). There were 117 male and 83 female subjects (1.4:1) and a similar sex ratio was noted in the hospitalized and discharged groups. When both groups were compared by univariate logistic regression analyses (Tables 2 and 3), most variables were significantly different, although the scatter of the results was high (Fig 1 and 2). A number of factors seems to be potentially predictive, especially SaO₂ on presentation, and the clinical score on presentation and on disposition. All patients with an initial SaO₂ below 91 percent were admitted to hospital (Fig 1); one patient who presented with an SaO₂ value of 90 percent was discharged but returned to the ER within 24 hours, and was then hospitalized. All patients with initial SaO₂ values above 96 percent were discharged home, and none of them subsequently returned to the ER. However, most of the patients had initial SaO₂ values between 92 and 96 percent (Fig 1). Similarly, patients with high clinical scores on presentation tended to be hospitalized and patients with low clinical scores tended to be discharged. However, there were patients with high clinical scores who were discharged and patients with low clinical scores who were hospitalized (Fig 1). The clinical score on disposition, ie, after ER treatment, seems to differentiate the groups more clearly, but still there is an area of overlap. It is also not clear from these data which clinical score or SaO₂ value, or combination of variables, would be most predictive of outcome. Further analysis was, therefore, required.

**Classification Tree Analysis**

A number of classification tree analyses were performed and are summarized in Table 4. In the first analysis, only the variables which were measured upon presentation were included as follows: age, sex, number of previous admissions, symptom duration, clinical score, SaO₂, PFR, FEV₁, and FVC. These variables are of specific interest as they are measured when the patient is first seen in the ER. The decision rule predicted that patients with clinical score ≤0.75 would be discharged home. The overall misclassifica-

![Boxplots of the variables: Symptom duration (hours), number of previous hospitalizations, clinical score on presentation and on disposition, and SaO₂ (%) on presentation and on disposition, grouped as hospitalized or discharged home. The box represents the middle 50 percent of the data. The horizontal line inside the box is the median value. The upper and lower ends of the box show the upper and lower quartiles. The vertical lines show the 95 percent range. Asterisks represent points outside this range.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21622/ on 06/21/2017)
tion rate (percentage of observations classified incorrectly) is 41/200 = 20.5 percent. Of the 41 misclassifications, 14 were patients with a clinical score ≤0.75 who should have been discharged but were admitted, and 27 were patients with clinical score >0.75 who should have been hospitalized but were discharged. Thus, if hospitalization is considered the “disease,” the rule has a sensitivity rate of 79 percent, and a specificity rate of 80 percent. These rates use the same data to estimate and assess the rule, and for this reason, tend to be somewhat optimistic. The cross-validated cost gives a more realistic estimate, and was 23 percent (Table 4). The cross-validated sensitivity and specificity values will be given in terms of their cross validated values.

Analysis 1 assumes equal prespecified penalty for hospitalizing a patient who should have been discharged, and discharging a patient who should have been hospitalized. In order to decrease the chance of discharging a patient who should be hospitalized, the user can obtain a more sensitive rule, but with lower specificity. Analysis 2 (Table 4) specifies that the

![Figure 2: Boxplots for pulmonary function variables on presentation and on disposition. Definition of abbreviations: PFR, peak flow rate; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity. Values are given in percent predicted. For explanation of boxplot, see Figure 1.](image)

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Results of Classification Tree Analyses*</th>
</tr>
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<tbody>
<tr>
<td>Analysis</td>
<td>Variables Analyzed</td>
</tr>
<tr>
<td>1</td>
<td>Presentation</td>
</tr>
<tr>
<td>2</td>
<td>Presentation</td>
</tr>
<tr>
<td>3</td>
<td>Presentation &amp; Disposition</td>
</tr>
<tr>
<td>4</td>
<td>Presentation &amp; Disposition</td>
</tr>
<tr>
<td>5</td>
<td>Individual Clinical score on presentation</td>
</tr>
</tbody>
</table>

*The prespecified penalties determine the relative importance of misclassifying admitted and discharged patients: Equal means 1 penalty point for either kind of error, unequal mean 5 penalty points for misclassifying a patient who was admitted, and 1 penalty point for misclassifying a patient who was discharged.

The “cost” of each decision rule is an increase of its performance. When the prespecified penalties are equal, this is the misclassification rate (% of incorrectly classified patients).

The cross-validated cost uses data splitting to give a more honest estimate of the cost than the resubstitution cost.
prespecified penalty of discharging home a patient who should have been admitted is twice that of hospitalizing a patient who should have been discharged. Once again, the resulting decision tree chose from the presentation variables only the clinical score as the prediction rule, but now with a lower cut point of 0.65. This results in a slightly higher sensitivity (80 percent) but a lower specificity (72 percent). A clinical score of >0.65 means that at least four of the variables had been assigned a score of 1 (regardless of whether pulsus paradoxus was measured). Further increasing the prespecified penalty of discharging a patient who should have been hospitalized led to little change in this rule.

The CART method also provides a ranking of the relative importance of all variables for comparative purposes. The relative importance of variables obtained at presentation were clinical score (given a relative importance of 100 by convention), \( \text{SaO}_2 \) (78), and number of previous admissions (33).

Analysis 3 adds the variables available on disposition (after ER treatment) to the available list for the CART procedure. The clinical score at disposition is now the only variable chosen by CART, with a cutpoint of 0.65, and is more predictive than the clinical score on presentation. However, the score on disposition has lower sensitivity compared to the score at presentation, although the specificity is substantially increased (95 percent). Increasing the prespecified penalty of discharging a patient who should have been hospitalized (analysis 4) lowered the cutpoint for clinical score on disposition to 0.45, with a sensitivity of 80 percent and a specificity of 89 percent. A clinical score of >0.45 means that three or more of the variables were assigned a score of 1 regardless of whether pulsus paradoxus was measured or not.

Analysis 5 examines the importance of individual components of the clinical score, along with the other presentation variables. It should be noted that the value of pulsus paradoxus as a predictive variable is hampered by the fact that it was not measured in 79 patients (39.5 percent), particularly in the younger children. Dyspnea was the sole variable chosen from all presentation variables, as a prediction rule, with a sensitivity of 88 percent, but, specificity of only 71 percent. The relative importance of all the variables on presentation were as follow: dyspnea (100), accessory muscle use (81), \( \text{SaO}_2 \) (71), wheezing (53), respiratory rate (44), FEV\(_1\) (14). The relative importance of the variables on disposition were dyspnea (100), wheezing (88), accessory muscle use (82). When the overall clinical score was included in the analysis with the individual components of the score, the overall clinical score was selected, leading to the same decision trees as in analyses 1 to 4. When each of the changes in the clinical score, \( \text{SaO}_2 \) or pulmonary function values from presentation to discharge were added to the analysis, they were not chosen as predicting variables in the decision tree.

When the 54 patients who performed pulmonary function were analyzed separately, the CART decision rules did not change.

**Discussion**

The objective of the present study was to determine the value of clinical measurements and common, noninvasive laboratory variables both alone and in various combinations in predicting physicians' decisions to admit children with acute asthma to the hospital. Although the hospitalized and the discharged groups of patients had statistically significant differences in most of the variables measured, the clinical score, based on standard physical examination, was found to be the most effective in predicting outcome. Several investigators have emphasized that the assessment of acute asthma is an ongoing process, as the degree and time course of the response to the therapy varies considerably between patients. It is, therefore, not surprising that the clinical score on disposition was more predictive of outcome than that on presentation, a finding which is in agreement with the data of Baker et al. In our study, patients with a clinical score over 0.45 on disposition were likely to be hospitalized, with 80 percent sensitivity and 89 percent specificity. The scoring system we used is based on that described by Fischl et al, suitably modified for the pediatric population. We chose this system as, unlike other scoring systems, it is composed of clinical variables which are simply and commonly measured in the assessment of patients with acute asthma, and does not involve arterial blood gas sampling.

When each individual component of the clinical score on presentation was analyzed as an independent variable, the dyspnea score came out to be the most predictive, with increased sensitivity but less specificity than the overall clinical score. In the present study, "dyspnea" was defined as the observer's impression of the child's breathlessness, as most of our patients were too young to be questioned about their subjective feeling of respiratory distress. As stated by Feinstein, the need for clear definitions of the predictive variables does not preclude the use of "soft" clinical data, as long as these data can be defined precisely enough to have a similar meaning to someone else. Similarly, the wheezing score and the accessory muscle score are other examples of "soft" clinical data used in our study. They are commonly used in evaluating the severity of asthma, and although they are somewhat subjective measurements, their importance should not be minimized as long as the meaning of these terms is understood by everyone who uses them. Furthermore,
when all the studied variables were graded by degree of importance, the subjective variables were the most important in the assessment of acute asthma.

Of interest are the variables which did not exert an appreciable effect in predicting outcome in our patient population. Studies in children have previously shown that the patient's age is not predictive of hospitalization, and our study confirms this finding. Likewise, the duration of the current asthmatic attack, and the number of previous admissions, were not predictive of the need for hospitalization. These observations are in agreement with those of certain investigators, but at variance with those of others.7 With respect to the value of SaO2 measurements in predicting outcome, our data partially validate those of Geelhoed et al8 that patients with SaO2 ≤91 percent should be hospitalized. However, only 38 percent of the children who were hospitalized in our study had SaO2 values ≤91 percent (Fig 1). Furthermore, the patients with SaO2 ≤91 percent also had high clinical scores indicating apparent severe disease. Although SaO2 measurements were not predictive of outcome in our study, we would like to emphasize that the measurement of SaO2 has an important role in the management of acute childhood asthma as it allows patients who require supplemental oxygen to be identified.

Conflicting results have also been reported in the literature as to the value of lung function measurements in predicting outcome in both adults and children with acute asthma.14-17 In our study, patients who were hospitalized had significantly lower pulmonary function values as compared to those who were discharged home, but the variability of the results was very high. In addition, patients who were discharged home with low FEV1 values did not relapse. Thus, neither the initial nor the final pulmonary function measurements or the absolute change in their value with treatment were helpful in predicting outcome in our study. This is not to say that pulmonary function measurements are not important in the evaluation of acute asthma. They allow the detection of occult airway obstruction in children who may be asymptomatic, and provide an objective means of following the response to treatment.

The decision of the ER personnel in this study had a high sensitivity in identifying the need for hospitalization, although, we have no data about the specificity of this judgement. In addition, the rate of hospitalization is similar or even lower than that reported by others, indicating that there was no over-hospitalization among our patients, as compared to other centers. Furthermore, studies which have reported lower hospitalization rates for acute asthma had a higher incidence of relapse and subsequent rehospitalization.7,8,10

No written guidelines or protocols are used in our ER with respect either to treatment of acute asthma or the need for hospital admission. The latter decision is based on the clinical judgment of the attending physician. It is possible that some children in our series were hospitalized unnecessarily. It is not possible on the basis of our data to identify patients who were hospitalized and might have been safely treated at home. However, it should be pointed out that easy access to hospital and earlier admission has shown to reduce mortality and morbidity in asthma, suggesting that physicians should admit patients to hospital if in doubt.31

One should remember that the decision with respect to hospitalization is determined in part by social and behavioral factors that are specific to the patient population (eg, expected parental compliance, availability of compressor in younger children), or specific to the institution (eg, distance from residence). Therefore, the sensitivity and specificity of the prediction rule presented in this work may vary in predicting the outcome of acute asthma when applied in other institutions.

In summary, our study shows that careful ongoing clinical evaluation is superior to reliance on pulmonary function and SaO2 measurements in predicting the need for hospitalization in acute childhood asthma.

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