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The RAD score: a simple acute asthma severity score compares favorably to more complex scores

Donald H Arnold, MD, MPH, Tebeb Gebretsadik, MPH, Thomas J Abramo, MD, Karel G Moons, PhD, James R Sheller, MD, and Tina V Hartert, MD, MPH

Departments of Pediatrics, Division of Emergency Medicine (Drs. Arnold and Abramo), Biostatistics (Ms. Gebretsadik, Dr. Moons), Medicine, Division of Allergy, Pulmonary and Critical Care Medicine (Dr. Sheller and Hartert), and the Center for Asthma and Environmental Research (Drs. Arnold and Hartert and Ms. Gebretsadik), Vanderbilt University School of Medicine, Nashville, Tennessee; and The Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, The Netherlands (Dr. Moons).

Introduction

Assessing acute asthma severity is subjective and imprecise, in part because physicians have limited objective means with which to make this determination.¹⁻³ Percent predicted forced expiratory volume in 1 second (%FEV₁) by spirometry is the accepted reference standard for severity of airflow obstruction but requires personnel training, is age and effort dependent, and frequently cannot be performed by patients in respiratory distress.^{4,5} When available, spirometry was used in fewer than 2% of visits for acute asthma in a pediatric emergency department (PED).⁶

Bedside acute asthma scoring might facilitate communication between health care providers and implementation of timely and appropriate therapy. If a scoring system is to fulfill these expectations, it must discriminate between levels of acute asthma severity when compared against an accepted reference standard (criterion validity), and it must change in response to treatment in a way that accurately quantifies change in the reference standard (responsiveness).⁷⁻¹⁰

Two scoring systems have been internally validated for criterion validity and responsiveness.¹¹⁻¹⁴ The Preschool Respiratory Assessment Measure (PRAM) was developed and internally validated in children ages 3 to 6 years using respiratory resistance by forced oscillometry as the criterion measure.¹² These investigators noted modest criterion validity (Spearman's rho: 0.31) and responsiveness (rho: 0.32). Their subsequent study of the PRAM in children ages 2-17 years used the treating physician's decision to admit or discharge as the criterion standard, and noted criterion validity (Spearman's rho: 0.4) and

Corresponding author: Donald H Arnold, MD, MPH Rm 1438A Vanderbilt Children's Hospital Vanderbilt University Medical Center Nashville, TN 37232-9001 don.arnold@vanderbilt.edu Phone: 615-579-0516 Fax: 615-507-1943.

Contributors Statement

Dr. Arnold designed the study, enrolled participants and is the primary author of the manuscript. Ms. Gebretsadik assisted with study design and conducted the statistical analysis. Drs. Abramo and Sheller assisted with manuscript preparation. Dr. Moons provided guidance on the analysis and assisted in writing the manuscript. Dr. Hartert assisted with study design and assisted in writing the manuscript.

Author Disclosure Statements

Dr. Arnold holds two patents along with Precision Pulsus, Inc. (Apnea detection system and Method and apparatus for measuring pulsus paradoxus). Ms. Gebretsadik has no conflict of interest to disclose. Dr. Sheller has no conflict of interest to disclose. Dr. Abramo has no conflict of interest to disclose. Dr. Hartert has received lecture fees from Merck and has received industry-sponsored grants from MedImmune.

responsiveness (ρ : 0.7).¹³ The Pediatric Asthma Severity Score (PASS) was developed in children ages 1 to 18 years using hospitalization decisions and, in participants > 6 years of age, peak expiratory flow rate (PEFR) as outcome measures.¹⁴ The PRAM has 5 components, and the PASS has 3 components, with each component scored on 3 levels. These scores are notable contributions and are of particular value for research. However, it is yet to be determined whether inclusion of more variables and more levels of severity for each variable improves the validity of the score or may instead lead to overfitting to the population in which it was developed and to decreased generalizability.¹⁵

In addition, clinicians may be more likely to use a scoring system at the bedside if it is comprised of a minimum number of component variables that are easy to remember and to use, a quality termed ‘usability.’⁷ Usability may be enhanced if each score component is sufficiently informative as a dichotomous variable, although dichotomizing continuous variables may also result in decreased criterion validity and responsiveness. On the other hand, score components that represent the important physiologic events of acute asthma enhance validity.¹⁶

With these features in mind, several clinical measures that may be preselected as score components because they are available at the bedside and representative of acute asthma physiology. Tachypnea is a physiologic response to increased functional residual capacity and decreased tidal volume in acute asthma and an accurate count of respiratory rate on room air and at rest is an objective and valid measure. Normal values for children are well-established, and a rate of 24/minute is the 97.5 percentile for children ages 5 to 17 years.¹⁷ Any accessory muscle use is associated with a statistically and clinically significant decrease in %FEV₁ in patients with acute asthma.^{18,19} Finally, decreased audibility of breath sounds on auscultation is the most apparent sign of decreased ventilation available at the bedside. These three bedside measures might be combined as a simple acute asthma score.

Our objective was to assess whether a simple, bedside acute asthma severity score comprised of three standard clinical measures performs as well as more comprehensive asthma scores.

Methods

Patients and Setting

This study was performed in an urban, academic children's hospital ED. We recruited a convenience sample of participants between 7am and 10pm on weekdays who were aged 5 to 17 years with an established diagnosis of asthma and signs or symptoms of an acute exacerbation²⁰ requiring treatment with systemic corticosteroid (CCS) and inhaled albuterol. Participants previously enrolled or with clinical or radiographic evidence of pneumonia or other reason for pertinent signs and symptoms were excluded.

Our electronic patient data system was programmed to notify the investigator by pager when a patient meeting screening criteria was admitted to the PED. Data were captured at the bedside and from an electronic medical record system.

Baseline time point was immediately prior to CCS and albuterol treatment. Demographic data and asthma history were recorded at baseline, and vital signs, physical examination findings, spirometry, and asthma scores were recorded at baseline and at 2 hours after initiation of CCS treatment if the participant remained under care in the PED. The Vanderbilt University Human Research Protection Program reviewed and approved this study protocol (#080058) and informed, written participant assent and parent consent were obtained.

Acute Asthma Severity Scores

We preselected three variables for the prototype asthma score based on the criteria that each variable is: 1) physiologically plausible as an indicator of acute asthma severity; and 2) available at the bedside and recorded as part of routine care of the pediatric patient with an asthma exacerbation. With these considerations we chose to examine these three variables as components of the **Respiratory rate - Accessory muscle use - Decreased breath sounds (RAD)** score (**Table 1**).

The PRAM and PASS scores were chosen for comparison because these scores have been subjected to internal validation against a reference measure (i.e., airway resistance and PEFR).^{12,14} Each component of the RAD, PRAM and PASS (**Table 2**) was collected at baseline and 2 hours after CCS treatment. Respiratory rate was determined with the participant at rest and on room air by counting the number of capnometry waveforms for a full minute using an Oridion Pediatric Microstream sensor (Oridion Corp, Needham MA) and Philips MP60 bedside monitor (Philips Corp, Boeblingen, Germany). Visible contraction of the scalene, sternomastoid/suprasternal, intercostal, and subcostal muscles were recorded as four separate variables.¹² Accessory muscle use was defined as any visible contraction of one or more of these muscle groups. Decreased breath sounds on auscultation was defined as any localized or diffuse decrease in audibility of breath sounds using a Littman Master Classic II stethoscope (3M Corp., St. Paul, MN).

Outcome measurement

We used %FEV₁ as the reference standard for airflow obstruction against which to compare the acute asthma severity scores for determination of criterion validity. Participants performed spirometry using a MicroDirect MicroLoop spirometer (Micro Medical, Kent, England) in accordance with American Thoracic Society (ATS) 1994 spirometry standards.²¹ %FEV₁ and other parameters were calculated based on Knudson standards.^{22,23}

Some participants could not perform 3 forced airway maneuvers for each trial in accordance with ATS criteria. Some of these trials included at least one FVC maneuver with flow-volume and volume-time curves meeting ATS criteria for start-of-test and end-of-test. A standing pulmonary function test oversight committee reviewed these non-ATS trials to determine whether the data should be included in analyses. This committee is comprised of an ATS-certified pediatric pulmonary function lab technician and a pulmonologist-pulmonary physiologist. Each member recorded their determination whether a non-ATS trial should be retained for analysis based on the volume-time and flow-volume curves and spirometry calculations. Each committee member was blinded to the other's determination and to all other participant data. We included a non-ATS trial in data analysis when both members independently determined that it was of high quality.

Statistical Analysis

Descriptive statistics are presented as mean (SD) if normally distributed or median (IQR). Race and ethnicity are categorized in accordance with NIH guidelines.²⁴ Effect sizes for regression analyses are reported using β -coefficients with 95% confidence intervals (CI), and the coefficient of variation (R^2) for explained model variation. Covariates for adjustment included age, sex, and race.

Some participants did not remain in the PED at 2 hours and would not have data acquisition at this time point and some were not able to perform forced vital capacity maneuvers at one time point. These participant characteristics might confound comparisons of airflow measurements as a function of time. Adjusting for these characteristics using a baseline acute asthma severity score or %FEV₁ would not be appropriate because these are the

explanatory and outcome variables for the analyses. We therefore also adjusted analyses for baseline severity using the Global Initiative for Asthma (GINA) chronic severity score (controlled/uncontrolled).²⁵

Our primary analytic approach to assess for criterion validity and responsiveness was multivariable linear regression. For criterion validity assessment, multiple linear regression models, adjusted for the above mentioned variables, were used to assess the proportion of variation of %FEV₁ at baseline that was explained by each score. R² was calculated for a 'basic characteristics' model including age, sex, race, and GINA chronic severity score. In separate models PRAM, PASS or RAD was then added to this model to assess their additional contribution.

For analyses of change in scores during treatment (responsiveness), we used percent change in %FEV₁ ($\Delta\%$ FEV₁) as the dependent variable, calculated as: (%FEV₁ at 2hours) – (%FEV₁ at baseline). We performed multivariable linear regression analyses of $\Delta\%$ FEV₁ while adjusting for baseline %FEV₁ using the basic characteristics model alone, as well as added to the PRAM, PASS or RAD. The effect and variation explained by absolute change in respective asthma score were assessed for responsiveness to $\Delta\%$ FEV₁.

As noted, some values for %FEV₁ at baseline and at 2 hours were missing. It is generally accepted that missing values are often not completely at random.^{26,27} Hence, complete case analysis could lead to biased results. Therefore we used multiple imputation for missing values of %FEV₁ to assess for potential bias or loss of power with complete case analysis. Multiple imputation was performed with the aregImpute algorithm statistical package.²⁸

Residuals for multivariable analyses were checked and were found to be normally distributed, and a plot of the residuals against fitted values did not detect systematic patterns to suggest that these values were not randomly distributed. (Dupont reference) R-software version 2.9.1 were used for data analysis and a two-sided 5% significance level was used for all statistical inferences.²⁹

Results

During the study period April 7, 2008, to July 2, 2010, 662 patients meeting inclusion criteria were approached for study participation, 639 participants were enrolled, and data from 536 were analyzed (**Figure 1**). Demographic and asthma characteristics of the study participants are presented in **Table 3**. The overall population of patients ages 5 to 17 years of age who presented to the PED with acute asthma exacerbations during the study period (n = 2,591) had similar demographic characteristics: median age (8.83 years), gender (male 61%) and race (African-American 57%, White 40%, Other 3%), Medicaid insurance 59%. **Table 4** includes the distribution of demographic and clinical variables by baseline %FEV₁ missingness status. Subjects with baseline %FEV₁ missing were younger and had higher respiratory rate. In multivariable regression analyses an IQR difference of 4.7 years for age was associated with decreased odds of %FEV₁ missingness (OR: 0.73, 95%CI: 0.54, 0.98), and an IQR difference of 8/min for respiratory rate was associated with increased odds of %FEV₁ missingness (OR 1.48, 95%CI: 1.13, 1.94). Because of differences in these characteristics for %FEV₁ and informative missingness, results are presented for both MI and complete case analyses.

The three scores each had a statistically significant R² and similar additional increase in R² over that achieved by the basic demographic characteristics alone, indicating that each score has criterion validity (**Table 5**). Values for R² using multiple imputation of missing %FEV₁ values were: 0.090 [base model]; 0.447 [PASS]; 0.481 [PRAM]; 0.465 [RAD]) and using

complete case analysis were 0.076 [base model]; 0.434 [PASS]; 0.462 [PRAM]; 0.426 [RAD]). The absolute change in each score over the first 2 hours of treatment explained the variance of $\Delta\%FEV_1$ better than the basic demographic characteristics alone (R^2 : 0.021 [basic demographic characteristics]; 0.109 [PASS]; 0.106 [PRAM]; 0.139 [RAD]).

The basic demographic characteristics and each of the three individual scores were additionally adjusted for baseline $\%FEV_1$ and examined for responsiveness to $\Delta\%FEV_1$ (Table 6). This adjustment resulted in clinically significant incremental improvements in R^2 for explanation of the variance of $\Delta\%FEV_1$ over the basic demographic characteristics. This indicates that pretreatment $\%FEV_1$, if available, provides greater explanation of change in $\%FEV_1$ during the first 2 hours of treatment than these basic demographic characteristics or acute asthma scores.

Discussion

The RAD asthma score has criterion validity comparable to the PASS and PRAM scores as assessed by explained variation (R^2) of $\%FEV_1$. The components of the RAD score are physiologically plausible measures of acute asthma severity that confer face validity. The two features, simplicity and biologic plausibility, may enhance the clinical utility of the RAD score for bedside assessment of acute asthma exacerbations in pediatric patients. Indeed, our objective was to determine if a simple, easy to use bedside score would measure acute asthma severity as well as more comprehensive scoring systems. Although our study was performed in a PED, these features might also allow the RAD score to be used in other clinical settings.

Our results are not directly comparable to those of the PRAM and PASS studies because these investigations used different outcome measures.^{12,14} $\%FEV_1$ is the widely accepted criterion standard for assessment of the severity of airways obstruction in acute asthma. In addition, the quality and validity of $\%FEV_1$ measurement can be ascertained by examination of the flow-volume and volume-time curves. These qualities further substantiate $\%FEV_1$ as a criterion measure with which to measure the performance of an acute asthma severity score.

There are limitations to our study. It was conducted in a single site, and the RAD should be externally validated before being adopted for general use. We chose to use $\%FEV_1$ as the outcome measure both because it is accepted as the criterion standard and because there are established means by which to assess the validity and reliability of each study. In using this outcome we could not include participants less than five years of age, limiting generalizability to young children with asthma. In addition, the responsiveness of each of the three scores to change in $\%FEV_1$ during treatment was minimal. This may indicate that physical exam findings do not precisely measure change of lung function impairment during acute asthma exacerbations. Some subjects had missing $\%FEV_1$, which were not missing completely at random, but rather selectively missing as can be inferred from the associations exhibited in Table 4. It is widely acknowledged that for selectively missing values, analysis after (multiple) imputation of missing values provides less biased results than complete case analysis.^{26,27} With this in mind we did perform the latter for comparison purposes. Interestingly, both analyses led to similar inferences, though R^2 values obtained from the analysis after multiple imputation were slightly higher than those obtained using complete case analysis. This can be explained by the fact that the variables that were associated with missingness (Table 4), and thus formed part of the imputation model, were also components of the three scores or were adjusted for in the complete case analysis. Finally, we did not assess inter-rater reliability of the three scores, as this was not the aim of the present study.⁷

A limitation of all asthma scores is the need to input accurate values for each predictor variable. Variables that are objective and easy to measure accurately (e.g., respiratory rate) may introduce less inter-rater variability than those that may involve more subjective interpretation (e.g., wheezing). Additionally, a 3-point score such as the RAD may not allow the clinician to calibrate acute asthma severity as precisely as the PRAM (0 – 10 points) or PASS (0 – 6 points). However, the clinical value of a bedside score is to first objectively quantify disease severity and the need for treatment, and second, to objectively assess response to treatment in order to either increase or decrease the intensity of intervention and determine disposition. The results of this study indicate that the RAD might fulfill these expectations.

In conclusion, the RAD is a simple and easily used acute asthma score comprised of three routinely measured clinical parameters readily available at the bedside, and has comparable criterion validity when compared to two more comprehensive acute asthma scores. The RAD score may facilitate efficient and appropriate treatment and triage of the patient with an acute asthma exacerbation.

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^aOverall population of patients presenting to pediatric emergency department with final diagnosis of asthma exacerbation during study period

^bNot mutually exclusive

Figure.
Participant enrollment and study progress.

Table 1

Proposed RAD Score for Acute Asthma Severity in Pediatric Patients ages 5 to 17 years

Score Component	Operational Definition	Scoring ^a
Respiratory rate	Respiratory rate at rest, on room air ^b	24 = 0 > 24 = 1
Accessory muscle use	Any visible use of accessory muscles	present = 0 not present = 1
Decreased breath sounds	Any decreased breath sounds on auscultation	normal = 0 any decrease = 1
RAD Score	Sum of three components	0 to 3

^aSummary score value range: 0 to 3^bBased on 97.5% iiles for children ages 5 to 17 years (from Wallis et al.¹⁷)

Table 2**Components of Three Acute Asthma Severity Scores**

Score Component ^a	PASS ^b	PRAM ^c	Proposed RAD ^d
Wheezing	0 to 2	0 to 3	
Work of breathing	0 to 2		
Prolonged expiration	0 to 2		
Suprasternal retraction		0 or 2	
Scalene retraction		0 or 2	
Air entry		0 to 3	0 or 1
SpO ₂		0 to 2	
Respiratory rate			0 or 1
Accessory muscle use			0 or 1
Total score range	0 to 6	0 to 12	0 to 3

^aNumbers under each score is method of assigning score for that variable

^bPediatric Asthma Severity Score

^cPreschool/Pediatric Respiratory Assessment Measure

^dRAD score is Respiratory rate, Accessory muscle use, Decreased breath sounds.

Table 3**Demographic and Asthma Characteristics of Study Participants**

Study Sample (n = 536)	
Demographic characteristic ^a	
Age, years	8.8 [6.9, 11.6]
Male	321 (60)
Race ^a	
African-American	309 (58)
White	225 (42)
Hispanic ethnicity ^a	38 (7)
Medicaid insurance	318 (59)
Asthma characteristic	
Uncontrolled asthma ^b	273 (51)
Currently using inhaled CCS	230 (43)
Currently using oral CCS	110 (21)
Prior PICU admission	95 (18)
Prior ETI ^c	22 (4)
PED disposition	
Discharge to home	421 (79)
Admit to floor bed	75 (14)
Admit to PICU	34 (6)

Data are presented n (%) or median [IQR] where IQR = interquartile range.

CCS = corticosteroid; PICU = pediatric intensive care unit; ETI = endotracheal intubation

^aRace and Ethnicity are categorized in accordance with NIH guidelines. Hispanic ethnicity is not mutually exclusive of race.

^bGlobal Initiative for Asthma uncontrolled asthma criteria

^cPrior endotracheal intubation for asthma

Table 4Participant Characteristics by Complete Case and Missing Values for %FEV₁ at Baseline

Characteristic	Baseline %FEV ₁ obtained (n = 352)	Baseline %FEV ₁ not obtained (n = 184)	P value ^a
Age, years [IQR] ^b	9.4 [7.6,11.9]	8.6 [6.3,11.5]	0.006
Male gender	201 (57)	129 (57)	0.47
Respiratory rate (/min), median [IQR] ^b	24 [21,30]	26 [22,30]	0.047
Magnesium treatment	42 (12)	25 (14)	0.58
Continuous albuterol treatment	225 (64)	120 (65)	0.77
Disposition			0.061
Discharge to home	286 (81)	141 (77)	
Admit to floor bed	50 (14)	25 (14)	
Admit to PICU	16 (5)	18 (10)	
GINA controlled category ^c	186 (53)	87(47)	0.22

Data are presented n (%) or median [IQR] where IQR = interquartile range.

^aWilcoxon rank sum test for continuous variables and Chi-square test for categorical variables

^bInterquartile range

^cMeeting controlled category of Global Initiative for Asthma chronic severity score for preceding 3-month period

Table 5

Criterion Validity and Responsiveness of Basic Characteristics and Three Asthma Scores for Correlation with %FEV₁

	Criterion Validity ^a		Responsiveness ^b	
	R ²	β (95% CI)	R ²	β (95% CI)
Basic characteristics ^c	0.076		0.021	
PASS ^d	0.434	−29 (−32, −25)	0.109	−0.28 (−0.40, −0.16)
PRAM ^d	0.462	−27 (−31, −24)	0.106	−0.20 (−0.29, −0.11)
RAD ^d	0.426	−37 (−42, −32)	0.139	−0.29 (−0.39, −0.18)

R² = coefficient of variation; β = beta coefficient

^aMultiple linear model was used for %FEV₁ regression before treatment (baseline) by basic demographic characteristics or by asthma score. B-coefficient represents change of %FEV₁ for and change of one interquartile range of score.

^bMultiple regression model for change of %FEV₁ over the first 2-hours of treatment by basic demographic characteristics or by asthma score, tested using Analysis of Variance

^cAge, race, gender, and Global Initiative for Asthma (GINA) chronic asthma control (controlled or uncontrolled)

^dAdjusted for basic demographic characteristics

Table 6

Responsiveness of Basic Characteristics and Three Asthma Scores for Change of %FEV₁ after adjustment for Baseline %FEV₁

	Responsiveness ^a	
	R ²	β (95% CI)
Basic characteristics ^b	0.678	
PASS ^c	0.714	−9.9 (−13.6, −6.1)
PRAM ^c	0.722	−7.9 (−10.6, −5.2)
RAD ^c	0.735	−10.9 (−14.0, −7.7)

R² = coefficient of variation; β = beta coefficient

^a Multiple regression model for proportionate change in %FEV₁ over the first 2-hours of treatment by change of baseline characteristics or asthma scores, tested using Analysis of Covariance

^b Age, race, gender, Global Initiative for Asthma (GINA) 3-month chronic asthma control and baseline %FEV₁

^c Adjusted for basic characteristics and baseline %FEV₁