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Research Article

Utility of Phase Angle to Identify Responders with Acute Airway Obstruction in the Emergency Room

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Background: Few studies combine impulse oscillometry (IOS) and respiratory inductance plethysmography (RIP) for assessing acute obstruction in the pediatric emergency department (ED). We correlated the clinical score, IOS and RIP, and evaluated their ability to differentiate "responders" from "non-responders" at baseline.

Methods: A study of 40 patients in mild-to-moderate respiratory distress. Clinical score consisted of: respiratory rate (RR), wheezing, and degree of muscular retraction. Biomarkers included: IOS [Respiratory resistance (Rrs_{5-20}), reactance (Xrs_5), resonant frequency (fres) and IOS severity score] and RIP [Phase angle, phase relation during total breath (PhRTB) and labored breathing index (LBI)]. Measurements were performed before and after pharmacotherapy. The percent change in Rrs_5 ($\Delta\%Rrs_5$) was used as the gold standard.

Results: Twelve of 40 patients (6-18 yrs.) completed all testing. Median IOS score was 2 (moderate obstruction). Baseline Xrs_5, fres, and LBI correlated with RR; Phase angle and PhRTB correlated with the clinical score. Higher baseline Rrs_{10} and phase angles were associated with larger decreases in $\Delta\%Rrs_5$. Receiver operating characteristic demonstrated: Rrs_{10} (AUC 0.86), RR (AUC 0.86) and phase angle (AUC 0.83).

Conclusions: Compared to clinical asthma scores, IOS (Rrs_{10}) and RIP parameters (phase angle) may better identify responders from non-responders to pharmacotherapy in pediatric ED settings.

Keywords: Impulse Oscillometry; Respiratory Inductance Plethysmography; Phase Angle; Airway Obstruction; Respiratory Resistance; Clinical Asthma Score; Pharmacotherapy; Emergency Room

Abbreviations:

IOS: Impulse Oscillometry;
RIP: Respiratory Inductance Plethysmography;
ED: Emergency Department;
BMI: Body Mass Index;
HR: Heart Rate;
RR: Respiratory Rate;
Rrs: Respiratory Resistance;
Rrs_5 respiratory resistance at 5 hertz;
$\Delta\%Rrs_5$ percent change in $Rrs_{5;}$

$Rrs_{10:}$ Respiratory Resistance at 10 Hertz;
$Rrs_{15:}$ Respiratory Resistance at 15 Hertz;
$Rrs_{20:}$ Respiratory Resistance at 20 Hertz;
Xrs: Respiratory Reactance;
$Xrs_{5:}$ Respiratory Reactance at 5 Hertz;
Fres: Resonant Frequency;
PhRTB: Phase Relation during Total Breath;
LBI: Labored Breathing Index;
PFT: Respiratory Function Testing;
TAM: Thoracoabdominal Motion Analysis;
TAA: Thoracoabdominal Asynchrony;
r_s: Spearman's r;
CV: Coefficient of Variation;
AUC: Area under the Curve

Introduction

Asthma exacerbations represent a significant proportion of pediatric emergency department (ED) visits, with higher at-risk based emergency visits than adults [1]. Management decisions are largely based on respiratory physical examination findings (wheezing, air entry, contraction of accessory respiratory muscles), vital signs [heart rate (HR), respiratory rate (RR)], and pulse oximetry; currently these components are integrated completely or partially into an emergency severity assessment, creating different clinical scoring systems [2-6].

Over recent years, a number of studies have shown the utility of respiratory impedance using oscillometry measurements in various clinical settings, - either by Impulse Oscillometry (IOS) or Forced Oscillation Technique - for detecting airway obstruction and assessing bronchodilation challenge in stable asthmatic children [7,8]. In contrast, only a handful of studies have evaluated the value of oscillometry measurements for scoring asthma severity in the ED and objectively assessed the response to therapy, reporting contradictory results [9,10].

IOS is a clinical method for respiratory function testing (PFT) that measures airway resistance, elastic and inertive properties of the lungs, and chest wall [11]. It determines the relationship between pressure and flow using an impulse signal. The respiratory inductance plethysmography (RIP) is a noninvasive respiratory technique. RIP determines breathing efforts and asynchronous breathing patterns using thoracoabdominal motion analysis (TAM) to derive markers of thoracoabdominal asynchrony (TAA). As such, these markers represent the degree to which chest and abdominal excursions are out of phase due to respiratory abnormalities such as airway obstruction [12,13].

In the present study, we compare IOS/RIP measurements with vital parameters and the clinical severity score. The aims were 1) to correlate respiratory functional biomarkers and the clinical asthma score in pediatric patients who presented with acute airway obstruction, 2) to determine the actual bronchodilation response, and 3) to evaluate the baseline discriminatory influence of this clinical score and objective functional measurements to distinguish children with significant response to the respiratory standard of care therapy from non-responders. We hypothesized that the discriminative properties of the noninvasive pulmonary function measures in the ED setting are better than the clinical asthma score in the identification of responders.

Methods and Materials

Subjects

Study of 40 patients (aged 3 to 18 years) presenting to the ED with the chief complaint of wheezing or asthma. The study was conducted after the review and approval of the A. I. duPont Hospital Institutional Review Board. Once the patient was identified by the research team, written and informed parental consent/assent was obtained from the parent/guardian. To be eligible for enrollment in the study, patients were required to be in mild-to-moderate respiratory distress based on the Emergency Severity Index version 4 (ESI v.4). This widely used index consists of a five-level triage system based on patient acuity and resource utilization, recently tested for pediatric application [14-16]. ESI v.4 levels 1, 2 and 3are the highest acuity and priority patients in comparison to lower-acuity patients (4 and 5 ESI v.4 levels). Exclusion criteria were severe respiratory distress warranting immediate intervention or ESI v.4 level 1 and 2, underlying lung disease (including but not limited to cystic fibrosis, pulmonary hypertension or thoracospinal/ muscular disorders), and age lower than 3 years or greater than 18 years.

Protocol

The initial evaluation was performed before any respiratory function testing (PFT) and consisted of a standardized clinical examination encompassing objective measurements, including vital signs [RR, HR, transcutaneous oxygen saturation] and the modified asthma score calculated as follows: RR based on patient's age (less than 7 years: 0 –30 = 0, 31 – 45 = 1, 46 – 60 = 2, >60 = 3 scores ; greater than 7 years: 0 – 20 = 0, 21 – 35 = 1, 36 – 50 = 2, >50 = 3), wheezing (absent = 0, expiratory only = 1, expiratory and inspiratory = 2, audible without stethoscope = 3), and degree of retractions (none = 0, mild = 1, moderate = 2, severe = 3) (2). BMI percentile values were score from 1 - 4 as follow: Less than 5th percentile = 1, 5th to less than 85th percentile = 2, 85th to less than 95th percentile = 3, ≥ than the 95th percentile = 4 [17].

Measurements

PFT was performed at baseline, prior to implementing standard of care treatment (i.e., protocol-determined care for asthmatic patients) and after the initial treatment was given. In the present study, the pulmonary biological markers assessed by the IOS technique included: respiratory resistance (Rrs) from 5-20 Hz ($Rrs_{5,}$ $Rrs_{10,}$ $Rrs_{15,}$ Rrs_{20}), reactance at 5Hz (Xrs_5), and resonant frequency (fres). For recordings, the child was asked to breathe quietly for 15-30 seconds using an oval mouthpiece, with the head in a neutral position and nose clips in place. Small rectangular mechanical impulses were applied to the respiratory system. The technique and equipment have been described in detail previously [18,19]. Reference values were used to determine percent from pre-

dicted -the test result as a percent of the predicted values- [20-22]. Standard data, including age, height, weight, sex, race and body mass index (BMI) were taken into account with regard to predicted values. The IOS severity score is a respiratory functional score developed to measure the severity of the respiratory obstruction based on respiratory impedance [23,24]. IOS severity score ranges from zero (normal) to IV (very severe) and was assessed based on Rrs_5 and Xrs_5, as shown in Table 1.

Table 1. Impulse oscillometry scores to assess the degree of severity of the respiratory dysfunction in subjects 2 years old and older.

Resistance specifications [hPa.s/L]	Xrs_5 > Xrs_5 predicted - 1.5	Xrs_5 predicted - 1.5 ≥ Xrs_5 > Xrs_5 predicted - 3	Xrs_5 predicted - 3 ≥ Xrs_5 > Xrs_5 predicted - 6	Xrs_5 ≤ Xrs_5 predicted - 6
Rrs_5 < 150%predicted	Normal [a]	I (mild)	II (moderate)	III (severe)
150% ≤ Rrs_5 < 200% predicted	I (mild)	II (moderate)	III (severe)	III (severe)
200% ≤ Rrs_5 < 300% predicted	II (moderate)	III (severe)	III (severe)	III (severe)
Rrs_5 ≥ 300%predicted	III (severe)	III (severe)	III (severe)	IV(very severe)

[a] Respiratory function is abnormal if respiratory resistance at 5Hz (Rrs_5), respiratory reactance at 5Hz (Xrs_5), or both parameters enter the abnormal range.

The relationship between thoracic and abdominal respiratory motion, named thoracoabdominal motion (TAM), was assessed using RIP technique with the SomnoStarPT Unit (Sensormedics, Yorba Linda, CA) and inductance bands (RespiBands Plus; VIASYS Respiratory Care, Yorba Linda, CA). Recordings were made with the patient in the sitting position at the ED; during the test, real-time raw signals and Konno-Mead loops were monitored to ensure adequate signal quality and to select suitable breathing epoch of 10 consecutive breaths for further analysis using RespiEvents software 5.2 (NIMS, Miami, FL). The technique and equipment have been described in detail previously [18,19,25]. TAA is defined as the process in which chest and abdominal excursions are moving in opposite directions. The following indices of TAA were assessed here: phase angle (phase delay between the thoracic and abdominal excursions); phase relation during total breath (PhRTB) which measures the percentage of the total breath duration for which the rib cage and abdomen are in TAA; and labored breathing index (LBI) which is the product of the maximal compartmental amplitude (the sum of the maximal peak-to-trough amplitudes of rib cage and abdominal excursion) divided by the tidal volume. Regional reference values were used [26].

Therapy

The prescribed clinical treatment was at the discretion of the treating physician who was blinded to the results of the PFT measurements. For moderate asthma exacerbation, the treatment regimen included a short-acting $beta_2$-agonist albuterol nebulizer treatment (0.15 mg/kg/dose, max 5 mg) and an anticholinergic, ipratropium bromide nebulizer treatment (250 mcg for patients less than 20 kg or 500 mcg for patients greater than 20 kg) plus systemic oral corticosteriods (Prednisone 2 mg/kg, max 60 mg) followed by either one hour of continuous albuterol nebulization (continuous therapy) or two additional nebulized albuterol and ipratropium bromide treatments 15 minutes apart (intermittent therapy). For mild asthma exacerbations, the therapy included albuterol nebulizer treatment with or without oral corticosteroids.

Statistics

Continuous variables were summarized overall by mean and SEM, unless indicated otherwise. Ordinal variables are displayed as medians (ranges). To evaluate the response to standard of care, the percent change in Rrs_5 ($\Delta\%Rrs_5$), the ratio of the % difference between the postdilation and predilation values over the predicted value was used as the gold standard. A one-tail paired t- test or Wilcoxon signed rank sum test was used to compare biomarkers' responses to standard of care treatment. The discriminative effectiveness of baseline respiratory function, scores and vital respiratory profiles was evaluated and compared by receiver operating characteristic (ROC). For this analysis, the group who responded to the standard of care (decrease Rrs_5 by > 20%) was labeled as responders compared to the group of non-responders. This oscillometric percent change in Rrs_5 by > 20% has already been used as the lower cut-point to evaluate the reversibility response in children with and without asthma [7]. For each variable the area under the curve (AUC) with the 95% CI was obtained. For each of the ROC a cut-point level was determined and the respective sensitivity and specificity percentages were reported. For the comparison of the areas under the ROC curves with the null hypothesis value, Alpha was set at 0.05 and Beta at 0.20; the required sample size for Rrs_5, IOS score, Rrs_{10}, RR and phase angle was calculated as follows: n = 10, n = 12, n = 18, n = 18, n = 22, respectively. The necessary sample size for the correlation coefficient (r) at baseline for IOS score, fres Xrs_5, LBI, PhRTB, and phase angle was calculated to be: n = 9, n = 10, n = 20, n = 10, n = 15, n = 19, respectively; the r after therapy for Rrs_5, Rrs_{10}, IOS score and phase angle was: n = 14, n = 18, n = 19, n = 26, respectively. Rrs_5 was included in the ROC analysis; Rrs_5 compares to $\Delta\%Rrs_5$ to discriminate responders from non-responders, and functions as the reference variable of the other variables tested. Spearman's r (r_s) were reported. Analyses were conducted using a combination of softwares (GraphPad Prism version 5.02 for Windows; GraphPad Software, San Diego, CA, USA, and SPSS version 19; IBM, Chicago, IL, USA).

Results

The study was conducted over 12 months (February 2010 - January 2011). As shown, a total of 40 patients were enrolled (Chart 1). Overall 90% performed baseline IOS testing and 95% performed RIP testing after being triaged; 50%

Chart 1.

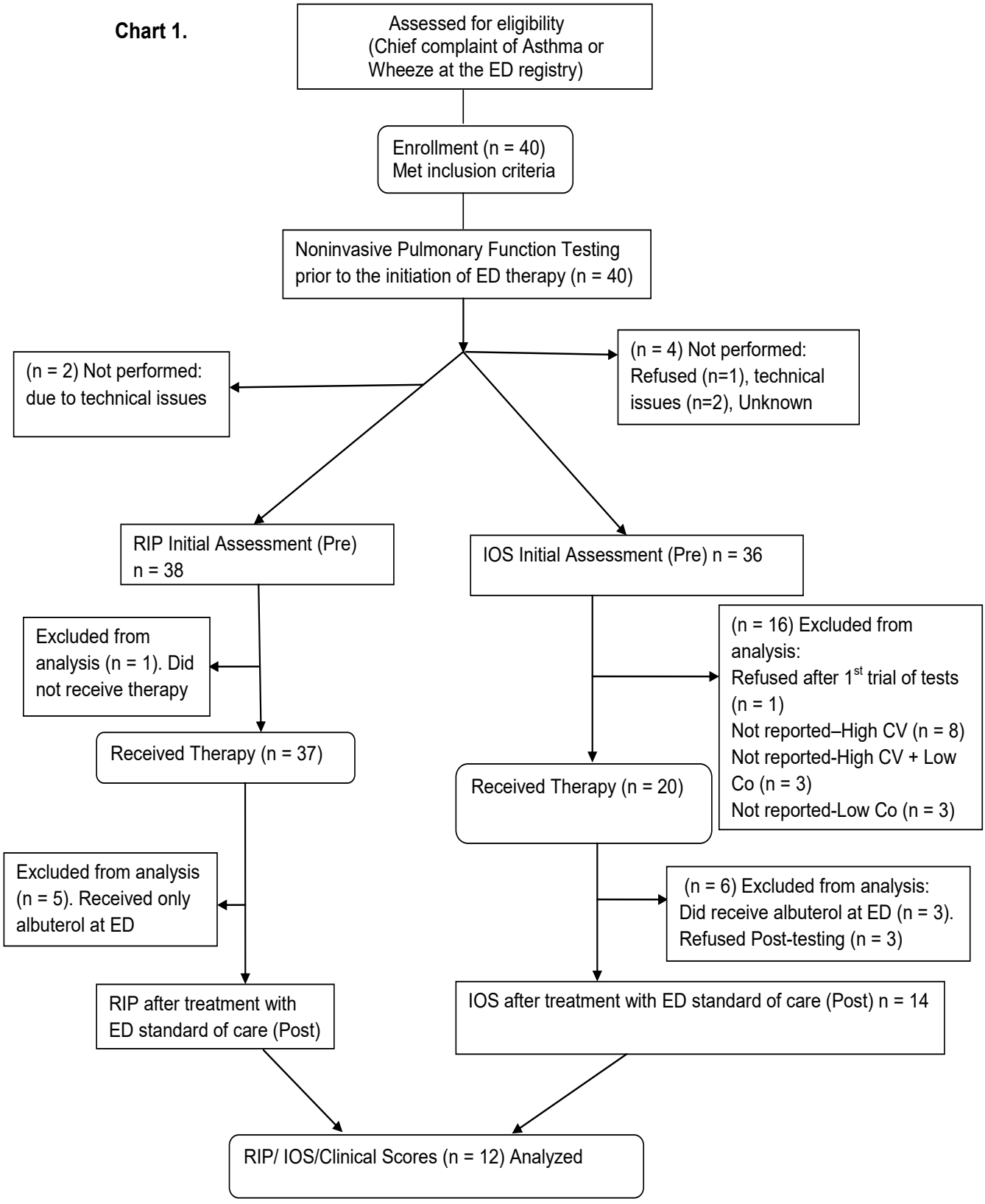

Chart 1. Summary of the analysis of participants through the clinical research study. Number of observations (n = 40, initially). ED, Emergency department; RIP, Respiratory inductance plethysmography; IOS, Impulse Oscillometry; Co, Coherence; CV, coefficient of variation.

demonstrated an intra-individual CV ≤ 8% for Rrs_5. Sixteen patients were excluded from the initial IOS analysis mainly due to higher CV or low coherence. The most common reason for not performing the IOS test was technical issues (equipment/technicians) followed by subjects reasons.

Baseline profile

The respiratory profile of the participants who completed both, the pre and post IOS and RIP tests (n=12), are presented in Table 2. Fifty-eight percent of the patients were male, 50% self-identified as African-American, 33% were Caucasian, and 16% were Hispanic. The mean (range) age, weight and height were 9.8 (6 - 18) years, 144 (104 - 188) cm, and 30.8 (12.2 - 88.1) kg respectively. The mean (range) BMI score was 2 (1 - 4), corresponding to healthy weight status. Compared with reference vital values [25], RR and HR at baseline were elevated in this group. With regard to TAA biomarkers, elevated values of LBI, phase angle and PhRTB were found compared with normative values. In IOS, compared with predicted values, Rrs_5 was elevated, corresponding to mild obstruction. Rrs_{10} and Rrs_{20} were within the predicted range. Baseline Xrs_5 difference to predicted was greater than 1.5 hPa.s/L, equivalent to a mild degree of peripheral obstruction. The median IOS score at baseline was 2 which corresponds to moderate respiratory obstruction. The mean (SD) fres was 19.2 (5.8).

Baseline correlations

A positive relationship was observed between Xrs_5 difference to predicted and HR (r_s = 0.62, p < 0.05), RR (r_s = 0.59, p < 0.05). As shown in figure, the relationship between fres and RR was strong; PhRTB and LBI demonstrated strong correlation with clinical asthma scores. LBI was the only TAA marker that demonstrated a strong relationship exclusively with RR. There was a strong relationship between RR and HR (r_s = 0.68, p < 0.01). No association was found between oscillometric and TAA parameters.

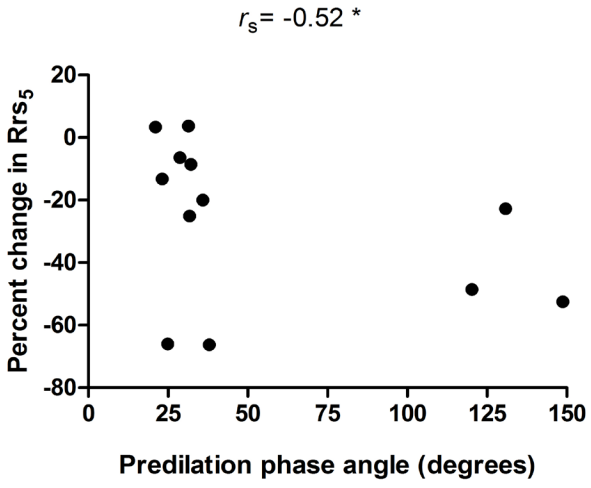

Figure. Scatter plots correlations with Spearman's correlation coefficients (r_s) between baseline phase angle values and percent change in resistance at 5Hz (Rrs_5). p values < 0.05* or < 0.01** (n = 12). Correlation strength: r_s .80 - 1.0 "very strong", r_s .60 - .79 "strong", r_s .40 - .59 "moderate".

Pharmacological bronchodilation response

Standard of care therapy was associated with significant increases in HR, and the difference of Xrs_5 from predicted became significantly less positive. Decreases in fres, clinical asthma score, phase angle, PhRTB, IOS asthma score, Rrs_5 and Rrs_{10} were observed (Table 2). No changes in RR, pulse oximetry, LBI and Rrs_{20} were found. Higher phase angle values (Figure) were associated with larger decreases after bronchodilation, suggesting basal airway obstruction.

Table 2. Scores and respiratory profiles at baseline and after therapy in the group of patients who completed the pre/post impulse oscillometry (IOS) and respiratory inductance plethysmography testing (n=12).

Biomarker (reference value)	Baseline Values (Predilation) [b]	After Therapy (Postdilation) [b]	%Change/p value [d]
Respiratory rate, br/min (15 - 20)	25 (1.2)	26 (1.7)	6.7/0.15
Pulse oximetry, %, (≥ 95%)	97.8 (0.4)	97.9 (0.5)	0.09/0.44
Heart rate, beats/min, (60 - 100)	105 (4)	131 (5.8)	5.8/**
Clinical asthma score [a]	4 (2-6)	2 (0-5)	-48/**
LBI, 1.01 (0.01)	1.09 (0.03)	1.06 (0.01)	-0.04/0.08
Phase angle, degrees, 15.7 (4.0)	55.5 (13)	28.1 (8.3)	-38/*
PhRTB, %, 10.1 (1.8)	29.3 (3.1)	22.7 (2.4)	-19.5/**
IOS asthma score [a]	2 (0-3)	0 (0-1)	-64/**
Rrs_5, %, ≤ 150%	186.9 (20.1)	123.6 (8.9)	-27/**
Rrs_{10}, %, ≤ 150%	146.3 (13.4)	114.9 (6.7)	-17.2/*
Rrs_{20}, %, ≤ 150%	142.1 (12.1)	124.1 (7.9)	-9.4/0.06
Xrs_5 difference, ≤ 1.5 [c]	2.81 (0.9)	-0.5 (0.3)	na/**
Resonant frequency, Hz	19.2 (1.7)	15.7 (2.0)	-23.8/**

[a] Score data are presented as medians (ranges). [b] The rest of the data including respiratory resistance at 5Hz (Rrs_5), respiratory resistance at 10Hz (Rrs_{10}), respiratory resistance at 20Hz (Rrs_{20}), labored breathing index (LBI), phase relation during total breath (PhRTB) are shown as means (SEM). [c] Respiratory reactance at 5 Hz (Xrs_5) is display as Xrs_5 predicted ≤ 1.5 - Xrs_5 actual. [d] p values < 0.05* or < 0.01** denoted a significant difference between the pre and post dilatation tests using one-tail paired t- test or Wilcoxon signed rank sum test. br/min, breaths per min; resonant frequency (fres); na, not applicable.

ROC analysis

Results of the ROC analysis of the discriminative capacity of the baseline variables listed in Table 2 demonstrated that Rrs_5- as expected- had the best capacity to discriminate between children with respiratory pharmacotherapy reversibility > 20% (responders) or < 20% (non-responders) AUC 0.94 (0.81, 1.07), followed by the IOS score [AUC 0.91 (0.75, 1.07)], Rrs_{10} [AUC 0.86 (0.58, 1.07)], RR [AUC 0.86 (0.63, 1.08)] and phase angle [AUC 0.83 (0.58, 1.07)]. The optimal lower cut-point level with their respective sensitivity and specificity for all of the parameters is shown in Table 3.

Table 3. Sensitivity and specificity of baseline respiratory function, vitals, and clinical asthma scores at a lower cut-point level in discriminating between asthmatic children with objective positive dilation response (Responders) and negative objective response (Non-responders) to standard of care inhalation therapy in the emergency department [a].

Test parameter (lower cut-point)	Sensitivity (%)	Specificity (%)
Respiratory rate, br/min (>23)	100	66
Pulse oximetry, % (<96)	50	100
Heart rate, beats/min (>104)	100	66
Clinical asthma score (>4.5)	87	83
Labored breathing index (>1.01)	100	17
Phase angle, degrees (>24)	100	33
PhRTB, % (>16.3)	100	33
IOS asthma score (>1)	100	50
Rrs_5, % predicted (>171) [b]	100	83
Rrs_{10}, % predicted (>115)	100	50
Rrs_{20}, % predicted (<104.5)	100	17
Xrs_5, difference predicted (>1.13)	100	50
Resonant frequency, Hz (>11)	100	33

[a] The percent change in Rrs_5 ($\Delta\%Rrs_5$), which is the ratio of the % difference between the postdilation and predilation values over the predicted value was used as the gold standard. [b] Rrs_5 and IOS asthma score probabilities are the reference probabilities of the variables tested. PhRTB: phase relation during total breath; Rrs_5, respiratory resistance at 5Hz; IOS: impulse Oscillometry; Xrs_5: respiratory reactance at 5 Hz.

Discussion

The feasibility of resistance measurements using oscillometry [10] and RIP techniques [25] in acutely asthmatic children in the ED was previously reported, where the success of the oscillometric test was higher than spirometry. Adequate FEV_1 or peak expiratory flow rate measurements during the acute asthma exacerbation can assist in determining the severity and guide therapeutic decisions in adults, but in children these measurements may be inadequate, unobtainable and/or of limited value for evaluation of severity in the emergency department [28,29]. Therefore, spirometry and clinical asthma severity scores in the emergency department are not comparable for detecting significant clinical changes [30].

Asthma severity scoring systems are being use as a substitute measurement of pulmonary function testing to estimate airway obstruction and to standardize, facilitate severity assessment and/or evaluate the response to treatment in children at the ED [2-4]. The oscillometric approach has already been used to evaluate the reversibility responses, and it was superior to spirometry in discriminating between children with and without asthma on the basis of their bronchodilator response of 20% to 25% decrease in Rrs_5 [7]. With regard to reversibility of acute asthma exacerbation in the ED, few studies have examined the value of oscillometry techniques for detecting acute changes in respiratory mechanics. Resistance measurements from the forced oscillatory technique were highly responsive to change (19% of change from baseline) when evaluated at 8Hz during acute asthma exacerbation in children > 3 years old [2]. The oscillatory frequency scale most frequently used by the IOS ranges from 5-35 Hz, using 5Hz increments. The cutoff for the diagnosis of significant reversibility post-dilation are either 20-25% of change at 5 Hz or 19% of change at 8 Hz, based on the oscillatory system used.

TAM analysis using the RIP technique is a noninvasive approach to quantify the clinical signs of asynchronous breathing or TAA, which represents the degree to which chest and abdominal excursions are out of phase [12]. It uses different TAM indices or biomarkers of increased work of breathing. The phase angle is the most studied TAA biomarker. In infants with bronchopulmonary dysplasia, phase angle was significantly higher than control subjects (102 vs. 8) and correlated with baseline values of resistance and compliance [12]. Previous studies have also demonstrated that, changes measured by the RIP technique in children with airflow obstruction after bronchodilators, significantly correlated with changes in lung resistance and compliance [13].

In acutely asthmatic children in the ED there is not a respiratory function method that would be regarded as the gold standard to assess significant reversibility. In the present study, we selected the $\Delta\%Rrs_5$ as the gold standard parameter for documentation of dilatation response. Our study is the first to combine IOS measurements with RIP measurements, vital parameters, clinical severity asthma scores and functional severity scores in a clinical emergency setting. The strong and moderate correlations observed between the Xrs_5 difference to predicted HR and RR respectively, may be signs of worsening of respiratory asthma status [31] or related to potential complications in the lung periphery or more widespread airway obstruction, represented by a higher Xrs_5 difference from predicted [18,32]. Tachypnea also may be a sign of acute worsening of clinical status. With re-

gard to fres, limited reference data exist, and healthy adults usually exhibit a fres <10Hz whereas healthy small children fres maybe > 20 Hz [33]. Our study demonstrated that fres at baseline was between these reported normal ranges. We do not expect relevance of fres values at baseline; the fres values are only relevant following therapeutic challenges for the evaluation of a within-individual response trend. Similar to Xrs_5, fres appears to be related to the RR in this subgroup of patients.

In our study, no correlation was found between Rrs_5% predicted and the asthma clinical scoring system, nor with their objective components, HR and RR. These findings are in contrast to those observed in a previous ED study where Rrs_8% predicted was found to correlate with these clinical markers of asthma severity in their severity scoring system [10]. On the other hand, a later ED study found no correlation between Rrs_8% predicted, and asthma severity assessments when 5 variables, including wheezing, air entry, contraction of scalenes, suprasternal retraction, and oxygen saturation, were used [9]. One might reflect that Xrs_5 difference from predicted was proven to be indirectly related with the clinical scoring based on its relationship with RR. The poor correlation between any of the oscillometry measurements and the total clinical asthma score may be due to the noise that other less specific components (degree of retractions or degree of wheezing) have on this scoring system. With regard to the muscular retractions, which are better evaluated by the TAM analysis, the two main markers of TAA in our study, phase angle and PhRTB were found to correlate best with the whole asthma severity score.

We found that the respiratory standard of care therapy in this group of patients with airflow obstruction resulted in a significant decrease in clinical asthma score, phase angle, PhRTB, IOS asthma score, Rrs_5, Rrs_{10} and fres as shown in Table 2. Therapy induced a decrease in IOS biomarkers (Rrs_5, Rrs_{10}, IOS score) and phase angle values that correlated with the degree of basal airway obstruction. In this regard children with $\Delta\%Rrs_5$ >20 had higher mean Rrs_{10}, IOS score, and phase angle values than children with $\Delta\%Rrs_5$ < 20. With regard to the degree of basal airway obstruction, there is evidence that the amount of bronchodilator response corresponds with the baseline lung resistance in children tested with the oscillation technique [34]. Good correlation between IOS and RIP parameters in children with airway obstruction has previously been reported by our group [19]. Our present data support the phase angle as an objective reliable indicator of baseline lung function.

Although for some of the outcomes, our study was limited by the sample size of patients that completed all aspects of the study protocol, the reported results yielded valuable insight into the utility of RIP as an objective noninvasive pulmonary tool in pediatric ED settings. The most important findings using ROC were that, after the baseline Rrs_5 and IOS score, baseline RR and baseline phase angle were superior in distinguishing between responders (reversibility) and non-responders as compared with the rest of the measured biomarkers. Further, we found that children with significant reversibility in $\Delta\%Rrs_5$ after therapy were better identified using lower cut-point values. While our study showed the utility of RIP and IOS, it also showed that appropriate training of testing personal and further automation of IOS/ RIP analysis and resulting will be necessary to integrate these modalities into the ED armamentarium environment.

Conclusions

In conclusion, this study demonstrates that the IOS and RIP techniques provide a more objective evaluation of baseline respiratory obstruction and its reversibility than does the clinical asthma score. Higher baseline Rrs_{10} and phase angle values were associated with larger decreases after bronchodilation. Resonant frequency and Xrs_5 were found to be related at baseline with RR values of the clinical asthma score and phase angle/PhRTB related with the total clinical asthma score. The feasibility of the IOS technique in the ED – at least as currently analyzed here in – is of less benefit in this ED field, as opposed to RIP technique, but IOS parameters appears to be more specific that the RIP parameters. The RIP technique holds promise for noninvasive assessment of lung dysfunction in patients during an acute asthma episode in experienced respiratory technical hands and in specialized interpretation medical facilities. Phase angle and RR baseline measures of the severity of an airway obstruction attack may better identify responders from non-responders when the penalty associated with missing a severe asthma case is high (minimize false negatives).

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