

DIAGNOSTIC APPROACHES

Detection of the Airway Obstruction Stage in Asthma Using Impulse Oscillometry System

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Objective. Although spirometry is the most common method for evaluating the airway obstruction stage in asthma patients, it is difficult to perform in some patients. The aim of this study was to evaluate whether impulse oscillometry, an easy-to-perform technique, can detect asthmatic airway obstruction stage. **Methods.** A total of 80 subjects, including healthy volunteers and patients with asthma, were enrolled in this study. The asthma patients were classified into three groups according to American Thoracic Society (ATS)/European Respiratory Society (ERS)-2005: the mild group (forced expiratory volume in 1 second (FEV₁) ≥ 70% predicted (Pred), $n = 20$), the moderate group (50% Pred ≤ FEV₁ < 70% Pred, $n = 20$), and the severe group (FEV₁ < 50% Pred, $n = 20$). Spirometry and impulse oscillometry (IOS) parameters were obtained from every subject. Correlation analysis was used to compare spirometry measurements and IOS parameters. One-way analysis of variance (ANOVA) was performed to compare IOS parameters among different groups. The potential of using all individual IOS parameters to detect the different stages of asthmatic airway obstruction was evaluated by the receiver operating characteristic (ROC) curve analysis. **Results.** The correlation analysis showed that IOS parameters, such as respiratory resistance at 5 Hz (R_5), respiratory resistance at 10 Hz (R_{10}), respiratory resistance at 20 Hz (R_{20}), difference in resistance between 5 Hz and 20 Hz (R_{5-20}), impedance at 5 Hz (Z_5), resonant frequency (Fres), and area of reactance (AX) were negatively correlated with FEV₁ and peak expiratory flow (PEF), while reactance at 5 Hz (X_5) was positively correlated with FEV₁ and PEF. The increase in R_5 , R_{10} , R_{20} , Z_5 , R_{5-20} , Fres, ($-X_5$), and AX parameters corresponded significantly with an increase in the airway obstruction stage, as determined by one-way ANOVA. ROC curve analysis revealed that all the IOS parameters studied, except for Fres, were capable of classifying asthmatic airway obstruction. R_5 , R_{5-20} , and Z_5 were the most accurate parameters. **Conclusion.** IOS provides an accurate, reliable, and patient-friendly technique for classifying asthmatic airway obstruction.

Keywords airway resistance, asthmatic, IOS, ROC, spirometry

INTRODUCTION

Asthma is considered to be a serious global health problem (1). The main pathologic feature of asthma is episodic airway obstruction. This is usually detected and monitored by spirometry. However, spirometry requires a considerable degree of effort and cooperation from the subjects. Children (2), elderly patients, those with an inability to comprehend, or those with other serious conditions usually have difficulty in completing this test successfully (3, 4). Impulse oscillometry (IOS) involves the modification of the forced oscillation technique (FOT) introduced by Dubois in 1956 (5), in which only tidal breathing is needed. Therefore, the IOS can be considered to be a type of FOT, but pseudorandom noise signals are replaced by rectangular waveform impulses. Additionally, IOS has a different set of data outputs and can be used as an alternative in patients whose airway obstruction cannot be measured by spirometry.

When IOS is performed, brief random pressure pulses are generated by a loudspeaker and superimposed on the subject's tidal breathing. The impedance of the respiratory system (Z) and its two basic components, namely respiratory resistance (R) and reactance (X) are estimated

simultaneously. R , which is measured at various pulse frequencies, mainly reflects the caliber of the airways at different levels, while X mainly reflects the elastic and mass-inertial properties of the airways, lung tissue, and thorax. The resonant frequency (Fres) is determined by the frequency at which X crosses zero and when both the elastic and inertial forces are equal and opposite in magnitude (6). Area of reactance (AX) represents a summation of the reactance values below the Fres. Several studies on the clinical application of IOS in asthma patients have been performed. IOS parameters showed a good relationship between the characteristic asthmatic symptoms and the evaluation of reversible airway obstruction (7, 8) as well as the bronchial hyperresponsiveness (4, 9, 10), thus providing objective parameters to diagnose asthma (11). A correlation between IOS and spirometry has also been reported. However, most of these results were based on asthmatic children (12). Moreover, although the usefulness of IOS in assessing the severity of asthma has been reported (13–15), there is little data on the potential of IOS measurements to classify asthmatic airway obstruction stages systematically.

In this study, we examined the correlation between IOS and spirometry parameters. We also evaluated the differences in the IOS parameters at the different airway obstruction stages in asthma. Additionally, the

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sensitivity (Se) and specificity (Sp) of IOS measurements to clarify asthmatic airway obstruction stages were also computed through receiver operating characteristic (ROC) curve analysis.

METHODS AND MATERIALS

Study Design

Healthy controls and asthma patients were selected according to the inclusion and exclusion criteria. Each subject was taught, by a lung function test technician, how to perform IOS and spirometry correctly. Then IOS and spirometry parameters would be tested, and IOS was always performed before spirometry measurements. Finally, we collected the data for further analysis.

Subjects

Eighty subjects were enrolled in this study, including 20 nonsmoking controls with normal spirometric evaluations and 60 acute asthma patients from the outpatient department. Pulmonologists diagnosed all of the asthma patients according to the Global Initiative for Asthma (GINA) criteria (1). The selection criteria included a history of asthma: clinical symptoms such as episodic breathlessness, wheezing, cough, and tightness after an incidental allergen exposure, and the lung function test. The exclusion criteria included any other coexistent lung disease and cardiovascular comorbidity.

Written informed consent was obtained from all participants before inclusion in the study, and this study was approved by the local Ethics Committee of the Shanghai Pudong New Area People's Hospital.

Asthma patients were divided into three groups according to the degree of airway obstruction: the mild group (forced expiratory volume in 1 second (FEV_1) $\geq 70\%$ predicted (Pred), $n = 20$), the moderate group ($50\% \text{ Pred} \leq FEV_1 < 70\% \text{ Pred}$, $n = 20$), and the severe group ($FEV_1 < 50\% \text{ Pred}$, $n = 20$). This classification was made according to American Thoracic Society/European Respiratory Society (ATS/ERS)-2005 (16). In this study, the moderate group includes the moderate and moderately severe stages of airway obstruction, as described in ATS/ERS-2005. The severe and the very severe stages, according to ATS/ERS-2005, were merged together as the severe group in our study. Baseline data of the subjects, such as age, sex, body weight, and height, were also obtained.

Impulse Oscillometry

A MasterLab IOS System (Erich Jaeger GmbH, Friedberg, Germany) was used. It was calibrated using a 3-L syringe for volume calibrations and a reference resistance ($0.2 \text{ KPa/L} \cdot (\text{s}^{-1})$) for pressure calibrations. Calibration for body temperature and pressure of saturated gas was also performed. During measurements, all subjects were seated upright and wore a nose clip. While they breathed spontaneously through a mouthpiece, they closed their lips tightly

around it to avoid air leakage. In order to decrease the shunt compliance of the cheeks, patients supported their cheeks and chins with their hands. Impulse was applied for 30 seconds in each IOS test. Artifacts caused by coughing, breath-holding, swallowing, and vocalizations were not included. IOS parameters such as respiratory impedance at 5 Hz (Z_5), respiratory resistance at 5 Hz (R_5), respiratory resistance at 10 Hz (R_{10}), respiratory resistance at 20 Hz (R_{20}), difference in resistance between 5 Hz and 20 Hz (R_{5-20}), reactance at 5 Hz (X_5), Fres, and AX were recorded.

Spirometry

Spirometric measurements were performed by using a computerized spirometer (Erich Jaeger GmbH, Germany). The system was calibrated for body temperature and pressure and volumes of the saturated gas. Subjects wearing a nose clip were coached through standard forced expiratory maneuvers before the test. FEV_1 and peak expiratory flow (PEF) were measured, and the values were expressed as the predicted percentage. The best of three technically acceptable blows was selected, and the best value was recorded.

Statistical Analysis

SPSS version 10.0 (SPSS Inc., Chicago, IL, USA) was used to analyze the data. We compared spirometry measurements and IOS parameters, including R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , and Fres, using Pearson correlation coefficient. Since X_5 and AX failed to show a perfect linear correlation with FEV_1 and PEF, we used Spearman's correlation coefficient to evaluate their relationship with spirometry parameters.

Before performing the one-way ANOVA, the IOS parameters were checked for normal distribution and equal variance. As equal variances were not assumed, we compared IOS parameters among different groups by their logarithmic transformation through the one-way ANOVA. Additionally, since X_5 was negative, its absolute value before the transformation was taken.

The potential of using all individual IOS parameters to detect the different stages of asthmatic airway obstruction was evaluated by the ROC curve analysis, and the cutoff point, Se, Sp, and area under the curve (AUC) were calculated. The values were considered as hierarchical standards to categorize the severity of asthmatic airway obstruction.

RESULTS

Correlation Analysis of Spirometric and IOS Parameters

Our results showed that all the IOS parameters significantly correlated with FEV_1 ($p < .001$), with a negative correlation between FEV_1 and R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , Fres, and AX, and a positive correlation between FEV_1 and X_5 . The scatter and r values are shown in Figure 1. Figure 2 shows similar results for PEF, which had a significantly negative correlation with R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , Fres, and AX and significantly positive correlation with X_5 ($p < .001$).

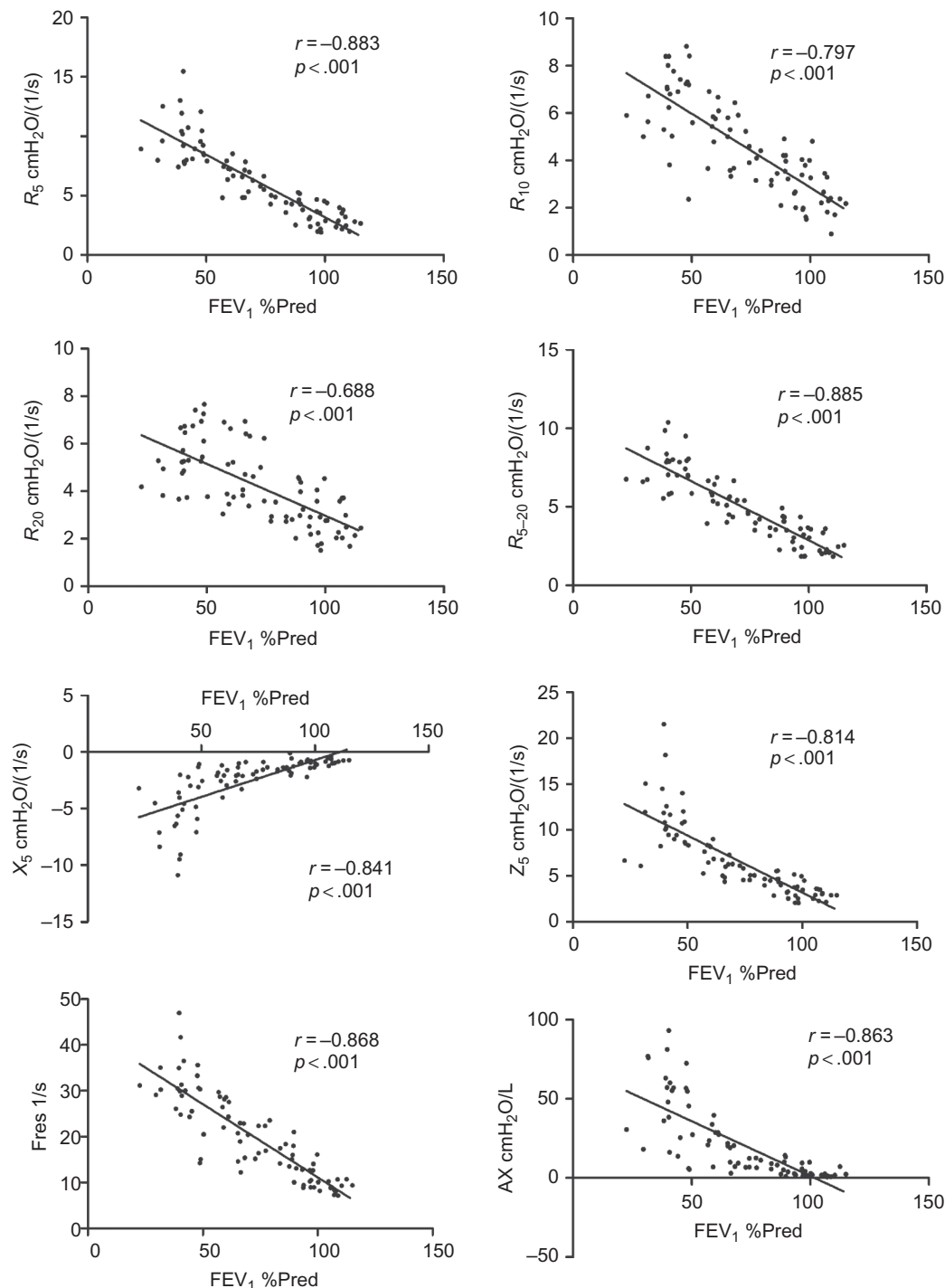


FIGURE 1.—Correlation between FEV₁ and respiratory resistance at 5 Hz (R_5), respiratory resistance at 10 Hz (R_{10}), respiratory resistance at 20 Hz (R_{20}), difference in resistance between 5 Hz and 20 Hz (R_{5-20}), reactance at 5 Hz (X_5), respiratory impedance at 5 Hz (Z_5), resonant frequency (F_{res}), and area of reactance (AX). FEV₁ shows a significantly negative correlation with R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , F_{res} , and AX and significantly positive correlation with X_5 ($p < .001$).

Differences in IOS Parameters with Worsening Asthmatic Obstruction Stages

There was no significant difference in gender, age, body weight, and height between the groups. All IOS parameters were normally distributed, but with unequal variances. The basic data is shown in Table 1.

In the present study, the IOS parameters were significantly different among each group. As described in Table 2, values of $\lg R_5$, $\lg R_{10}$, $\lg R_{20}$, $\lg Z_5$, $\lg R_{5-20}$,

$\lg F_{res}$, $\lg(0 - X_5)$, and $\lg AX$ significantly increased with increasing asthmatic airway obstruction stage ($p < .05$).

ROC Curve Analysis

Table 3 shows the numerical analysis of the ROC curve, including AUC, Se, Sp, and the cutoff value of each IOS parameter. The Se and Sp with ROC were compared based on the stages which were classified by FEV₁. The AUCs of R_5 , R_{10} , R_{20} , X_5 , R_{5-20} , Z_5 , and AX were >0.5 , suggesting the

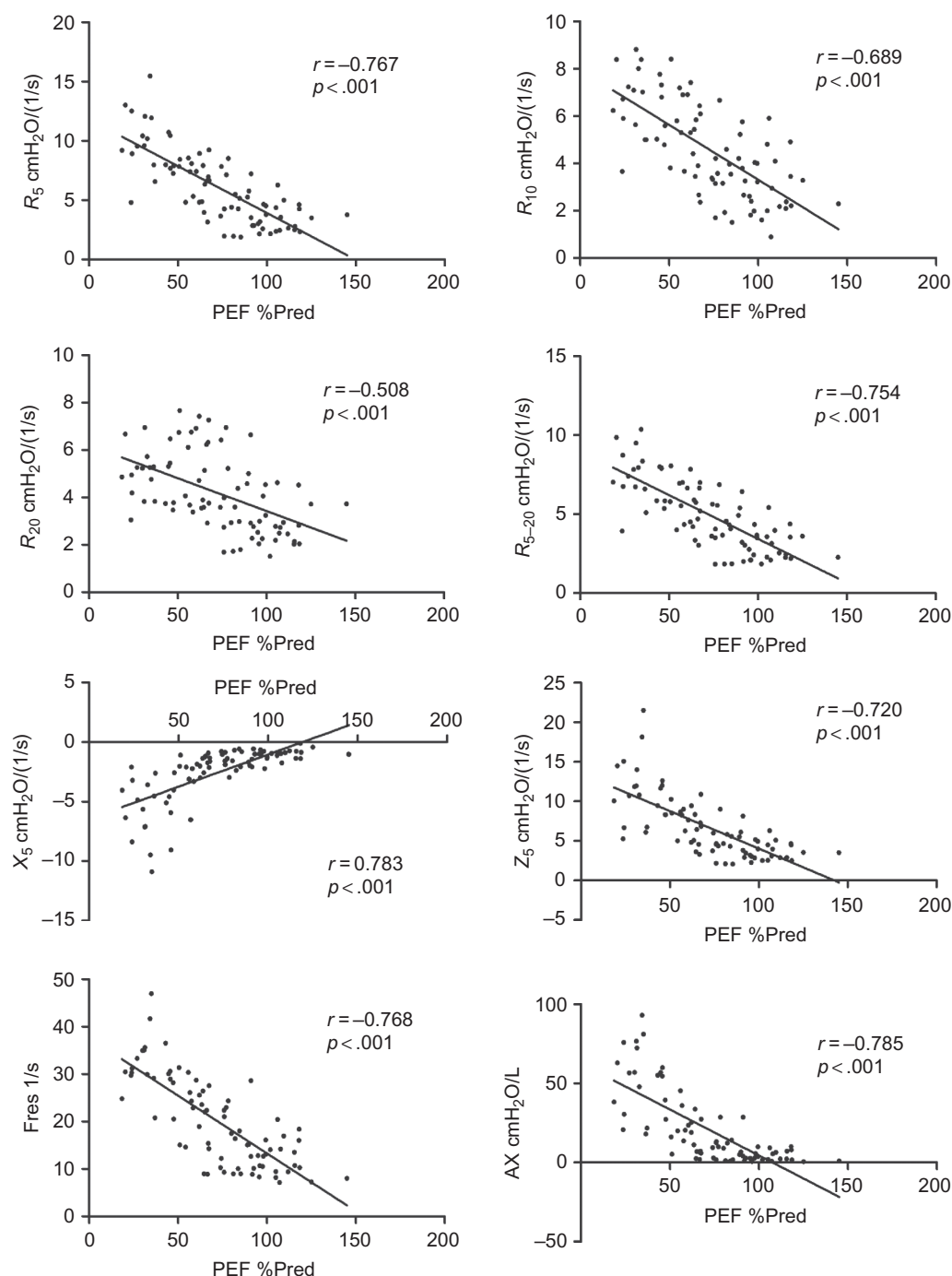


FIGURE 2.—Correlation between PEF and respiratory resistance at 5 Hz (R_5), respiratory resistance at 10 Hz (R_{10}), respiratory resistance at 20 Hz (R_{20}), difference in resistance between 5 Hz and 20 Hz (R_{5-20}), reactance at 5 Hz (X_5), respiratory impedance at 5 Hz (Z_5), resonant frequency (Fres), and area of reactance (AX). PEF shows a significantly negative correlation with R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , Fres, and AX and significantly positive correlation with X_5 ($p < .001$).

usefulness of these parameters in classifying asthmatic airway obstruction stages. However, the AUC of Fres was not statistically significant ($p > 0.05$). The AUCs of R_5 , R_{5-20} , and Z_5 were >0.9 for the mild, moderate, and severe groups (Figure 3), demonstrating the maximum utility of these parameters in airway obstruction stage classification.

DISCUSSION

Our study revealed R_5 , R_{10} , R_{20} , R_{5-20} , Z_5 , Fres, and AX to have a significantly negative association with FEV₁ and

PEF, and X_5 to have significantly positive association with FEV₁ and PEF. R_5 , R_{10} , R_{20} , and R_{5-20} are measures of the caliber of the airways, while X_5 is a measure of the elastic properties of the chest (1, 17). Previous studies have revealed the IOS indices to be significantly correlated with FEV₁ and PEF in asthmatic children (12) and chronic obstructive pulmonary disease (COPD) patients (18). In this study, we observed a similar relationship between IOS parameters and FEV₁ and PEF as previously reported. We performed statistical analysis to further compare IOS indices among different airway obstruction stages.

TABLE 1.—Baseline characteristics of the study participants.

	Groups (95% confidence interval)				P-value
	Healthy group	Mild group	Moderate group	Severe group	
N	20	20	20	20	—
Gender, m/f	14/6	9/11	9/11	9/11	.289
Age, years	46.2 (40.5, 51.8)	54.8 (50.1, 59.4)	48.5 (40.3, 56.7)	52.1 (47.0, 57.2)	.165
Weight, kg	65.8 (59.7, 71.8)	63.8 (60.2, 67.4)	61.6 (56.2, 67.1)	65.1 (61.8, 68.4)	.586
Height, cm	167.5 (164.5, 170.4)	163.2 (160.0, 166.4)	163.2 (159.2, 167.1)	166.1 (162.5, 169.7)	.171
R ₅ , cmH ₂ O (1/s)	2.70 (2.43, 2.97/0.213)	4.63 (4.27, 4.99/0.167)	6.91 (6.34, 7.48/0.176)	10.10 (9.15, 11.06/0.202)	—
R ₁₀ , cmH ₂ O (1/s)	2.24 (1.95, 2.52/0.273)	3.96 (3.67, 4.26/0.157)	5.30 (4.81, 5.79/0.197)	6.83 (6.08, 7.58/0.235)	—
R ₂₀ , cmH ₂ O (1/s)	2.42 (2.13, 2.72/0.261)	3.72 (3.28, 4.16/0.253)	4.76 (4.17, 5.36/0.268)	5.82 (5.28, 6.35/0.196)	—
R ₅₋₂₀ , cmH ₂ O (1/s)	2.40 (2.15, 2.65/0.223)	4.01 (3.73, 4.29/0.149)	5.60 (5.18, 6.03/0.162)	7.81 (7.25, 8.36/0.152)	—
X ₅ , cmH ₂ O (1/s)	-0.87 (-0.98, -0.77/-0.247)	1.45 (-1.72, -1.19/-0.387)	-2.53 (-3.16, -1.91/-0.527)	-5.24 (-6.55, -3.93/-0.534)	—
Z ₅ , cmH ₂ O (1/s)	2.88 (2.63, 3.13/0.185)	4.74 (4.42, 5.06/0.145)	6.80 (6.17, 7.43/0.197)	12.06 (10.52, 13.59/0.272)	—
Fres, 1/s	10.02 (9.09, 10.96/0.200)	15.79 (13.70, 17.89/0.284)	23.54 (21.00, 26.07/0.230)	30.51 (26.93, 34.08/0.250)	—
AX cmH ₂ O/L	2.04 (1.36, 2.73/0.719)	7.78 (5.98, 9.59/0.496)	21.60 (16.78, 26.41/0.477)	50.06 (38.12, 62.00/0.510)	—
FEV ₁ , % Pred	101.87 (98.19, 105.55/0.077)	87.61 (83.00, 92.21/0.112)	57.48 (51.42, 63.54/0.225)	42.38 (39.96, 44.79/0.122)	—

Notes: R₅ = respiratory resistance at 5 Hz, R₁₀ = respiratory resistance at 10 Hz, R₂₀ = respiratory resistance at 20 Hz, R₅₋₂₀ = difference in resistance between 5 Hz and 20 Hz, X₅ = reactance at 5 Hz, Z₅ = impedance at 5 Hz, Fres = resonant frequency, AX = area of reactance, FEV₁ = forced expiratory volume in 1 second, Pred = predicted.

TABLE 2.—Difference in IOS parameters by their logarithmic transformation between each group.

	Groups (95% confidence interval)			
	Healthy	Mild	Moderate	Severe
N	20	20	20	20
lgR ₅ , lgcmH ₂ O (1/s)	0.42 (0.38, 0.47)	0.67 (0.64, 0.71) ^a	0.83 (0.79, 0.87) ^{a,b}	1.00 (0.96, 1.04) ^{a,b,c}
lgR ₁₀ , lgcmH ₂ O (1/s)	0.77 (0.62, 0.91)	1.37 (1.29, 1.44) ^a	1.65 (1.55, 1.75) ^{a,b}	1.88 (1.74, 2.03) ^{a,b,c}
lgR ₂₀ , lgcmH ₂ O (1/s)	0.37 (0.32, 0.42)	0.56 (0.51, 0.61) ^a	0.66 (0.61, 0.72) ^{a,b}	0.76 (0.71, 0.80) ^{a,b,c}
lgR ₅₋₂₀ , lgcmH ₂ O (1/s)	0.37 (0.33, 0.41)	0.60 (0.57, 0.63) ^a	0.74 (0.71, 0.78) ^{a,b}	0.89 (0.86, 0.92) ^{a,b,c}
lg(0 - X ₅), lgcmH ₂ O (1/s)	-0.07 (-0.12, -0.02)	0.10 (-0.03, 0.24) ^a	0.35 (0.25, 0.45) ^{a,b}	0.65 (0.52, 0.78) ^{a,b,c}
lgZ ₅ , lgcmH ₂ O (1/s)	0.45 (0.41, 0.49)	0.69 (0.66, 0.73) ^a	0.82 (0.78, 0.87) ^{a,b}	1.06 (1.00, 1.12) ^{a,b,c}
lgFres, lg1/s	0.99 (0.95, 1.03)	1.18 (1.12, 1.24) ^a	1.36 (1.31, 1.41) ^{a,b}	1.47 (1.41, 1.53) ^{a,b,c}
lgAX lgcmH ₂ O/L	0.53 (0.24, 0.81)	1.87 (1.54, 2.20) ^a	2.91 (2.59, 3.22) ^{a,b}	3.68 (3.29, 4.08) ^{a,b,c}

Notes: ^ap < .05 compared with healthy group.

^bp < .05 compared with mild group.

^cp < .05 compared with moderate group.

lg = logarithmic transform, R₅ = respiratory resistance at 5 Hz, R₁₀ = respiratory resistance at 10 Hz, R₂₀ = respiratory resistance at 20 Hz, R₅₋₂₀ = difference in resistance between 5 Hz and 20 Hz, X₅ = reactance at 5 Hz, Z₅ = impedance at 5 Hz, Fres = resonant frequency, and AX = area of reactance.

When comparing IOS parameters of patients at different airway obstruction stages, we found that an increase in R₅, R₁₀, R₂₀, R₅₋₂₀, Z₅, Fres, and AX, and a decrease in X₅ corresponded significantly with an increase in the airway obstruction stage. This result is consistent with previous studies (14). Our evaluation included a greater number of parameters, including Z₅, X₅, R₅₋₂₀, and AX. Additionally, the subgroups of asthma patients were classified by the airway obstruction stages according to ATS/ERS-2005 (16) and not by the severity of asthma described in GINA-2003. The significant differences seen in our study suggest that IOS parameters are useful for evaluating the asthmatic airway obstruction stage. Further, in order to identify the specific IOS parameters with the most potential for differentiating between the airway obstruction stages, ROC curve analysis was performed. The area under the ROC curve can help distinguish between parameters with a perfect test value (AUC = 1), highly accurate values (0.9 < AUC < 1), less accurate values (0.5 < AUC ≤ 0.9), and those parameters that are non-informative (AUC = 0.5), according to an arbitrary

guideline based on a suggestion by Swets in 1988 (19). IOS parameters, particularly R₁₀ and AX, have been shown to have high AUCs by the ROC curve analysis, which is performed to detect clinical asthma in children (2). In our study comprising adult asthma patients, we found most IOS parameters including R₅, R₁₀, R₅₋₂₀, Z₅, and AX to be highly accurate, with their AUCs > 0.9, in classifying patients with mild asthma vs. healthy controls. However, other IOS parameters, such as R₂₀ and X₅, had lower AUCs (0.884 and 0.834, respectively), and Fres had no statistical significance, with a p-value > 0.05. When performing ROC curve analysis between the moderate and mild asthma groups, R₅, R₅₋₂₀, and Z₅ were found to have the most potential for distinguishing between the two stages, with their AUCs > 0.9. In addition to R₅, R₅₋₂₀, and Z₅, R₁₀ and AX also had AUCs > 0.9 when ROC curve analysis was performed between the severe and moderate asthma groups. These results revealed R₅, R₅₋₂₀, and Z₅ to be the most accurate parameters for classifying asthmatic airway obstruction stages. R₅ and Z₅ are parameters measured by IOS at a frequency of 5 Hz, which is adequately low to

TABLE 3.— Receiver operating characteristics analysis by all IOS parameters.

Stage	IOS	AUC (95% confidence)	Sensitivity	Specificity	Youden index	Cut off point (cmH ₂ O(1/s))	P-value
Mild-healthy	R_5	0.985 (0.958, 1.012)	0.900	1.000	0.900	3.520	.000
	R_{10}	0.978 (0.942, 1.013)	0.850	1.000	0.850	2.81	.000
	R_{20}	0.884 (0.780, 0.988)	0.700	1.000	0.700	2.625	.000
	R_{5-20}	0.975 (0.935, 1.015)	0.900	1.000	0.900	3.085	.000
	Z_5	0.990 (0.967, 1.013)	0.950	1.000	0.950	3.565	.000
	X_5	0.834 (0.691, 0.976)	0.950	0.700	0.650	-1.310	.000
	Fres	0.668 (0.478, 0.857)	0.800	0.650	0.450	11.685 (1/s)	.070
	AX	0.980 (0.807, 1.008)	0.950	0.850	0.800	3.925 (cmH ₂ O/L)	.000
Moderate-mild	R_5	0.933 (0.860, 1.005)	0.950	0.800	0.750	6.025	.000
	R_{10}	0.847 (0.717, 0.978)	0.950	0.650	0.700	4.955	.000
	R_{20}	0.763 (0.616, 0.909)	0.600	0.850	0.450	3.630	.005
	R_{5-20}	0.916 (0.831, 1.002)	0.750	0.800	0.550	4.365	.000
	Z_5	0.910 (0.817, 1.003)	0.950	0.800	0.750	5.900	.000
	X_5	0.792 (0.648, 0.937)	0.850	0.700	0.550	-1.995	.002
	Fres	0.847 (0.725, 0.970)	0.800	0.850	0.650	18.660 (1/s)	.000
	AX	0.870 (0.753, 0.987)	1.000	0.750	0.750	16.07 (cmH ₂ O/L)	.000
Severe-moderate	R_5	0.954 (0.897, 1.010)	0.900	0.900	0.800	7.985	.000
	R_{10}	0.986 (0.967, 1.005)	1.000	0.933	0.933	3.310	.000
	R_{20}	0.746 (0.592, 0.901)	0.600	0.900	0.500	4.735	.008
	R_{5-20}	0.958 (0.900, 1.015)	1.000	0.850	0.850	6.915	.000
	Z_5	0.993 (0.974, 1.011)	1.000	0.850	0.850	9.230	.000
	X_5	0.805 (0.663, 0.947)	0.750	0.800	0.550	-2.980	.001
	Fres	0.815 (0.673, 0.957)	0.950	0.700	0.650	29.835 (1/s)	.001
	AX	0.964 (0.925, 1.003)	0.950	0.933	0.883	3.925 (cmH ₂ O/L)	.000

Notes: R_5 = respiratory resistance at 5 Hz, R_{10} = respiratory resistance at 10 Hz, R_{20} = respiratory resistance at 20 Hz, R_{5-20} = difference in resistance between 5 Hz and 20 Hz, X_5 = reactance at 5 Hz, Z_5 = impedance at 5 Hz, Fres = resonant frequency, and AX = area of reactance.

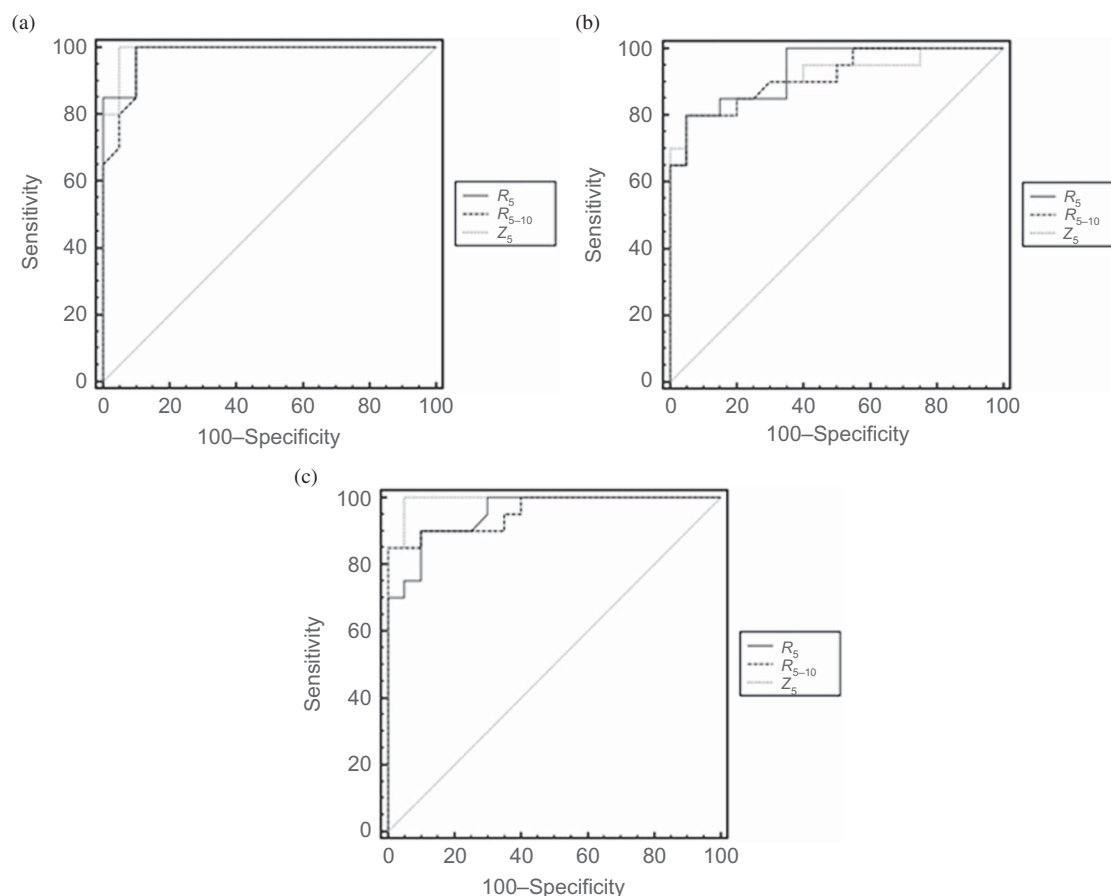


FIGURE 3.—Receiver operating characteristic curves for R_5 , R_{5-20} , and Z_5 that correspond to different stages are plotted in three boxes. (a) Mild-healthy group. (b) Moderate-mild group. (c) Severe-moderate group.

enable the impulse to reach the small airways. Therefore, they are a measure of the resistance of both the central and the peripheral airways. R_{10} and R_{20} , due to their higher frequency, mainly reflect central airway resistance. In contrast, R_{5-20} is the difference between the resistance from 5 Hz and 20 Hz and mainly reflects the resistance of the peripheral airways. There is strong evidence that small airways contribute significantly to the total airway resistance (20–22). Thus, the IOS parameters that can detect small airway obstruction will likely be more accurate in classifying asthmatic airway obstruction. X_5 is an index of respiratory reactance and is affected by various factors (23), reflecting its lower distinguishing ability in this study. Due to its inconsistent value, F_{res} does not have the potential to categorize airway obstruction. AX , which was confirmed to be accurate for classifying asthma in children (2), also showed high potential for distinguishing mild asthma vs. healthy airways and severe vs. moderate airway obstruction, with AUCs > 0.8 when moderate and mild asthma were compared. Our results indicate that R_5 , R_{5-20} , and Z_5 , in addition to diagnosing mild asthma, are also valuable in differentiating asthmatic airway obstruction stages. The Se and Sp of R_5 , R_{5-20} , and Z_5 in classifying the airway obstruction stages were high (>0.9) between each group.

In conclusion, IOS parameters, particularly R_5 , R_{5-20} , and Z_5 , are valuable in categorizing asthmatic airway obstruction. Since IOS is a noninvasive measurement and can be easily performed (23–26), it can be used as an alternative to providing objective parameters which can help to assess airway obstruction severity in certain groups of patients. The limitation of our study is the small sample size and the lack of reversibility data. Thus, the cutoff values of the IOS parameters are not accurate enough to be used in clinical practice.

DECLARATION OF INTEREST

This study was funded by the Chinese Medical Association. The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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