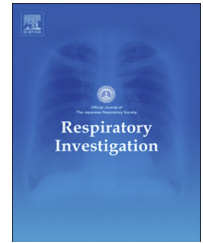




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Original article

Evaluation of airway responsiveness using colored three-dimensional analyses of a new forced oscillation technique in controlled asthmatic and nonasthmatic children



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ABSTRACT

Background: Bronchodilator response (BDR) is routinely used in asthma management. A new forced oscillation technique (FOT) is able to quickly measure respiratory system resistance (Rrs) and reactance (Xrs) at each tidal breath phase. The present study evaluated bronchial changes by using the new FOT.

Methods: Respiratory resistance and reactance were measured using FOT in 132 children (age, 10.86 ± 4.78 years; M:F=88:44), including asthmatic ($n=98$) and nonasthmatic children ($n=34$), pre- and post-bronchodilator inhalation in an asymptomatic state. Whole-breath or within-breath changes in Rrs and Xrs were measured and compared pre- and post-bronchodilator inhalation and between each group. All patients performed spirometry and forced expiratory nitric oxide pre- and post-bronchodilator inhalation.

Results: Spirometric parameters showed significant positive changes at V_{50} and V_{25} in both groups; however, these changes were not significantly different between the groups. eNO was significantly higher in the asthmatic group than in the nonasthmatic group; however, there was no significant change pre- and post-inhalation in either group. Rrs in the asthma group was significantly higher in the expiratory phase than in the inspiratory phase. Rrs and Xrs before and after bronchodilator inhalation were significantly different in

Abbreviations: BDR, bronchodilator response; FEV₁, forced expiratory volume in 1 s; FOT, forced oscillation technique; Rrs, respiratory system resistance; Xrs, reactance; eNO, forced expiratory nitric oxide; Fres, resonant frequency

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the asthma group alone, except for the expiratory–inspiratory phase of each of these parameters. Changes in Rrs and Xrs at 5 Hz (R5 and X5) in a whole-breath and the inspiratory phase were significantly different between the groups.

Conclusions: Changes in X5 and R5 reflect bronchial reversibility. The new FOT is useful for asthmatic children.

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1. Introduction

The reversibility of airways is one of the major criteria of asthma in children [1,2], and responses to bronchoconstrictors, bronchodilators, or both are routinely used in asthmatic pediatric patients to make a diagnosis and evaluate the severity of asthma [3,4]. Bronchodilator provocation has been recommended for the measurement of bronchial reversibility in children because of its safety. Reactions to bronchoconstrictors and bronchodilators are commonly characterized by a decrease or increase in forced expiratory volume in 1 s (FEV₁) from the baseline value and a decrease in airway resistance [5,6]. In adults, increases in baseline FEV₁ values of at least 12–15% and an absolute change of 200 mL have been defined as a significant response. However, bronchodilator responses may not be as large in younger children because of smooth muscle immaturity. Furthermore, most asthmatic children have FEV₁ values that are close to those of normal children who may exhibit smaller changes in FEV₁ than those obtained in previous reports [7].

The forced oscillation technique (FOT) has been increasingly used in children because it is a noninvasive method that can quickly measure respiratory system resistance (Rrs) and reactance (Xrs) over a wide range of frequencies while breathing at rest [8]. Recently, Kurosawa et al. developed a new method for the FOT using three-dimensional color images with an added time axis to visualize respiratory cycle dependence; Rrs was shown to be higher and Xrs was more negative in the expiratory phase than in the inspiratory phase [9,10]. Three-dimensional colored images could potentially become a tool with which to understand the complex oscillatory properties of the respiratory system.

However, there have been no reports on the evaluation of airways using the new FOT in which respiratory cycle dependence may be visualized during the bronchodilator provocation test in children. The aim of the present study was to assess bronchial reversibility by using the new FOT between asthmatic children receiving treatment and non-asthmatic children. We performed the bronchodilator provocation test in these children during an asymptomatic state.

2. Materials and methods

2.1. Study subjects

Table 1 shows the characteristics of the study subjects comprising 132 pediatric outpatients at the Minami Wakayama Medical Center. All participating individuals were divided into 2 groups: asthmatic (n=98; mean age, 10.9±6.3 years;

M:F=59:34; height, 138.4±18.0 cm; weight 35.1±12.8 kg) and nonasthmatic (n=34; mean age, 10.7±3.6 years; M:F=29:10; height, 141.6±19.7 cm; weight, 36.6±13.6 kg). There were no significant differences between the ages, heights, weights, and body surface areas of each group. The asthmatic diagnoses and classifications were performed according to international guidelines [11,12]. Children with mild persistent asthma and moderate persistent asthma were treated with continuous medication, including inhaled corticosteroids, leukotriene receptor antagonists, or both. Seventy asthmatic children were treated with inhaled corticosteroids. All drugs were withdrawn 12 h before the test. Asthmatic children had no asthmatic symptoms for at least 3 months before the test. Children in the nonasthmatic group had never had wheezing episodes or other respiratory diseases. Written informed consent was obtained from all children or their legal guardians, and the study protocol was approved by the Ethics Committee of our institution.

2.2. Respiratory impedance [13]

Respiratory impedance was measured with FOT using a commercially available machine (MostGragh-01; Chest M.I., Co Ltd, Tokyo, Japan), which was developed by Kurosawa et al. [9,10] and met the standard recommendations [8].

By using this machine, both random noise and Hanning impulses were available as oscillation signals. Impulse oscillatory signals generated by a loud speaker at intervals of 0.25 s were applied to the respiratory system through the mouthpiece while tidal breathing at rest. Mouth pressure and flow signals were measured and calculated to obtain the Rrs and Xrs properties against oscillatory frequencies ranging from 5 to 35 Hz. During measurements, subjects firmly supported their cheeks to reduce upper airway shunting while sitting with their neck in a comfortable neutral posture. As the curves of Rrs and Xrs frequencies could be obtained every 0.25 s, they were serially lined up by assigned color gradients along the time axis, resulting in colored three-dimensional imaging patterns. The oscillatory properties results were available as the mean values of inspiration or

Table 1 – Characteristics of study patients.

N=132	Asthmatic n=98	Nonasthmatic n=34
Age, years	10.9±6.3	10.7±3.6
Gender (M:F)	59:34	29:10
Height, cm	138.4±18.0	141.6±19.7
Weight, kg	35.1±12.8	36.6±13.6
Body surface area	1.1±0.2	1.2±0.3
Values are mean ± SD or numbers.		

expiration phases or mean changes during the respiratory cycle, thereby enabling whole-breath or within-breath (inspiratory–expiratory) analyses.

The index of respiratory resistance was R_{rs} at 5 and 20 Hz (R_5 and R_{20} , respectively) and the difference between R_5 and R_{20} (R_5-R_{20}). In addition, the index of reactance was X_{rs} at 5 Hz (X_5) and the resonant frequency (F_{res}). Each oscillatory index was expressed as a whole-breath and inspiratory and expiratory phases.

2.3. Spirometry

Spirometry was performed using a FUDAC-77 spirometer (Fukuda Denshi, Saitama, Japan) after recording breath sounds. Spirometric parameters included FVC, FEV_1 , MMEF, PEF, FEF50, and FEF75. These parameters were expressed as a percentage of normal predicted values. The rate of change was measured as differences in spirometric parameters after bronchodilator inhalation.

2.4. Forced expiratory nitric oxide

An online measurement was performed according to the European Respiratory Society/American Thoracic Society recommendations [14,15] by using a chemiluminescence

analyzer (Model 280i, Nitric Oxide Analyzer; Sievers, Boulder, Colorado). Daily calibration was performed using 100% nitrogen to zero and an analyzed standard gas (nitric oxide, NO, 0.64 ppm) (Taiyonsan, Tokyo, Japan) for the span. Without holding their breath, patients exhaled from their total lung capacity to their residual volume at a consistent flow rate of 50 mL/s. Environmental NO levels were measured before each study, and the measured samples were excluded if environmental NO levels exceeded 10 ppb. All participants performed the test in a seated position without a nose clip.

2.5. Study design

Respiratory impedance was measured in all children using FOT before bronchodilator inhalation. After measuring the respiratory impedance, a procaterol solution (30 μ g/2 mL saline) was inhaled using a nebulizer (Alfresa, Osaka, Japan) according to international guidelines.

After 15 min, respiratory impedance measurements were performed repeatedly. To avoid any influence of forced breathing after respiratory impedance measurements, after the FOT, children performed spirometry and forced expiratory nitric oxide (eNO) each time.

The children performed these tests in an asymptomatic state. Children in either the asthmatic or nonasthmatic group

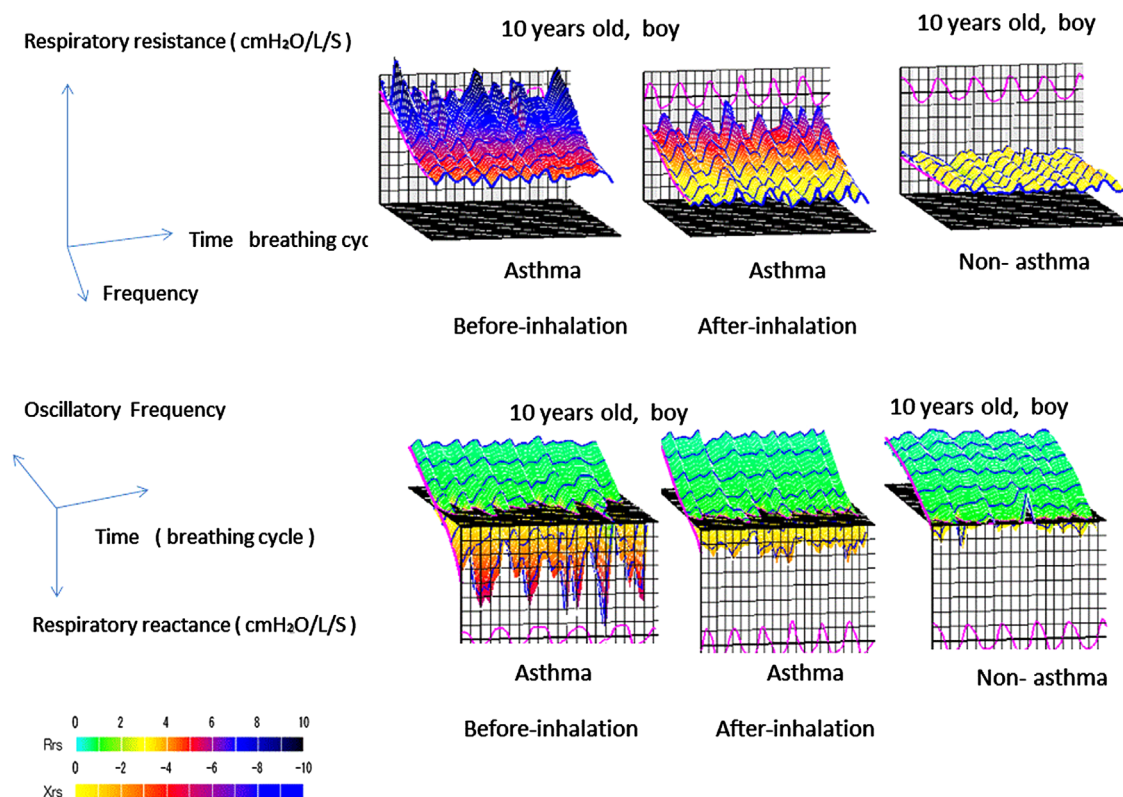


Fig. 1 – Colored three-dimensional images. The typical colored three-dimensional images with an added time axis to visualize respiratory resistance in a 10-year-old boy. Respiratory resistance and respiratory reactance were shown by colors according to each approximate value ($\text{cm H}_2\text{O/L/s}$): 1–2, green; 3, yellow; 5, red; and 8, blue. The reactance was also colored as follows: plus values, green, and minus values, from yellow to blue. Colorimetric displays enabled us to interpret the values measured, including green, which represented low or normal resistance, and blue, which represented very high resistance. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

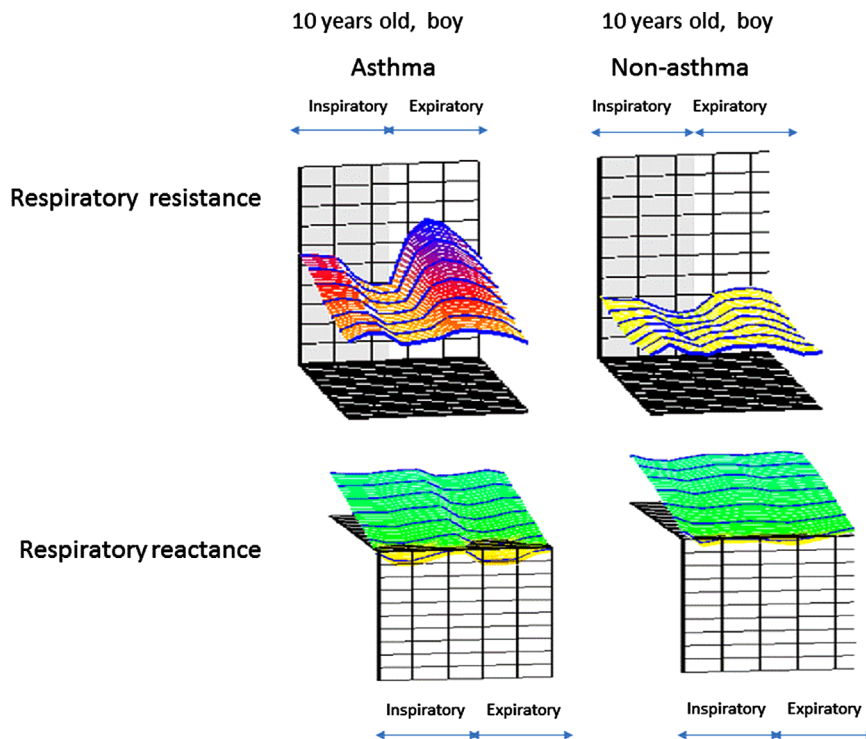


Fig. 2 – Oscillatory properties in a respiratory cycle. Asthmatic children have respiratory cycle dependence, such that Rrs was higher in the expiratory phase than in the inspiratory phase.

exhibited no symptoms of an asthma attack or a respiratory infection.

Rrs and Xrs were measured just before bronchodilator inhalation (pre-Rrs, pre-Xrs) and 15 min after (post-Rrs, post-Xrs). Changes in Rrs and Xrs (Δ Rrs, Δ Xrs, respectively) were calculated by pre-Rrs, pre-Xrs, post-Rrs, and post-Xrs.

To examine the reliability of the Rrs and Xrs measurements, one doctor measured them twice in the same subjects at a 1-min interval. To examine the validity of these measurements, 2 doctors measured them in the same subjects at a 1-min interval [16].

2.6. Statistics

Statistical analyses were conducted with a statistical software package (Stat Flex, version 6.0). Comparisons of all spirometry parameters, eNO, and respiratory impedance pre- and post-bronchodilator inhalation by the asthmatic and nonasthmatic children were performed using the paired t-test. Comparisons of the expiratory and inspiratory phases of respiratory impedance in the asthmatic and nonasthmatic children were performed using the paired t-test. Comparisons of all spirometry parameters, eNO, and respiratory impedance pre- and post-bronchodilator inhalation between asthmatic and nonasthmatic children were performed using the Mann-Whitney U test. Comparisons of the change (Δ , before–after) in all the parameters between the asthmatic and nonasthmatic children were performed using the Mann-Whitney U test. Correlation coefficients were determined using the Pearson product-moment correlation coefficient.

Data are expressed as mean $\pm$ SD. A *p* value of less than 0.05 was considered significant.

3. Results

3.1. Colored three-dimensional visualization of oscillatory properties

Fig. 1 shows the typical colored three-dimensional images with an added time axis to visualize the respiratory resistance and the respiratory reactance in 10-year-old asthmatic and nonasthmatic children.

Respiratory resistance was shown according to each approximate value ($\text{cm H}_2\text{O/L/s}$) in the following colors: 1–2, green; 3, yellow; 5, red; 8, blue; and 10, black. The reactance was also colored as follows: plus values, green; minus values, yellow to blue. Colorimetric displays enabled us to interpret the values measured, including green, which represented low or normal resistance, and blue, which represented very high resistance.

In the asthmatic group, Rrs increased at lower frequencies and decreased at higher frequencies, which implied a negative frequency dependency. Rrs was lower after inhalation than it was before inhalation. In the nonasthmatic group, the Xrs value before inhalation was more negative than that in the asthmatic group, but it became positive after β inhalation.

Fig. 2 shows the oscillatory properties of a respiratory cycle in a 10-year-old boy. Asthmatic children exhibited respiratory cycle dependence, such that Rrs was higher in the expiratory phase than in the inspiratory phase.

Table 2 – Change in lung function with inhaled bronchodilators.

	Asthmatic (n=98)		Nonasthmatic (n=34)	
	Pre	Post	Pre	Post
FVC (%)	103.5 ± 13.1	103.4 ± 11.6	99.7 ± 10.1	99.7 ± 8.1
FEV ₁ (%)	93.9 ± 10.0	92.0 ± 23.8	96.7 ± 17.6	98.5 ± 15.8
MMEF (%)	109.4 ± 34.3	115.7 ± 12.7	98.5 ± 23.6	105.3 ± 25.2
PEF (%)	116.8 ± 30.4	114.5 ± 40.1	114.8 ± 28.0	113.4 ± 36.6
FEF ₅₀ (%)	94.7 ± 21.4*	99.3 ± 31.2*	103.1 ± 26.0*	108.4 ± 31.0*
FEF ₇₅ (%)	77.6 ± 25.6*	81.6 ± 34.7*	85.1 ± 27.1*	95.8 ± 32.1*
Rate of change (%)				
FVC (%)	1.0 ± 4.0		0.2 ± 4.3	
FEV ₁ (%)	3.5 ± 5.2		2.8 ± 7.1	
MMEF (%)	13.2 ± 16.4		8.9 ± 12.4	
PEF (%)	3.6 ± 10.5		3.0 ± 20.4	
FEF ₅₀ (%)	13.3 ± 19.3		9.8 ± 8.5	
FEF ₇₅ (%)	17.0 ± 32.0		19.0 ± 42.0	

Values are mean ± SD or numbers.
* $p < 0.05$ pre versus post.

Table 3 – Change of eNO with inhaled bronchodilators.

	Asthmatic (n=98)		Nonasthmatic (n=34)	
	Pre	Post	Pre	Post
eNO (ppm)	38.6 ± 53.5	35.8 ± 25.0	14.4 ± 10.3	13.5 ± 11.9
Rate of change (%)	2.6 ± 1.3		1.8 ± 5.2	

Values are mean ± SD or numbers.
* $p < 0.05$ versus nonasthmatic

3.2. Reliability of new forced oscillation technique measurements

Sixty-seven children participated in evaluating the reliability of our method for lung sound analysis. Intra- and interobserver correlation coefficients for respiratory impedance were 0.95 and 0.99, respectively, implying small variations within and between observers. Repeatability coefficients for intra- and interobservers for respiratory impedance were 1.29 and 1.15, respectively. By using the Bland–Altman method, the differences in the respiratory impedance values showed a small variation for both intra- and interobservers.

3.3. Comparison of spirometric parameters between the asthmatic and nonasthmatic groups

All 132 children performed the spirometry test, and the results are shown in Table 2. There were significant differences in %FEF₅₀, and %FEF₇₅ between the asthmatic and nonasthmatic groups both before and after bronchodilator inhalation ($p < 0.05$, $p < 0.05$, respectively). However, the %FEV₁

of the asthmatic group was not significantly different from that of the nonasthmatic group.

There was no significant increase in any spirometric parameter before or after inhalation in either group. The rate of change was also not significantly different between the asthmatic and nonasthmatic groups.

3.4. Comparison of eNO between the asthmatic and nonasthmatic groups

The eNO was measured in all 132 children, and the results are shown in Table 3. The eNO was significantly higher in the asthmatic group than in the nonasthmatic group. There was no significant difference in the rate of change between the groups.

3.5. Whole-breath analysis: comparison of respiratory impedance parameters pre- and post-inhalation between the asthmatic and nonasthmatic groups

Respiratory impedance was measured in all 132 children, and the results are shown in Table 4. There were significant improvements in all parameters after bronchodilator inhalation only in the asthmatic group. There was a significant difference in the X5 between the asthmatic group and nonasthmatic group only after inhalation.

3.6. Within-breath analyses: comparison between inspiratory and expiratory phases

The results are shown in Table 4. In the asthmatic group, the Rrs in the expiratory phase was significantly higher than that in the inspiratory phase; however, in the nonasthmatic group, the Rrs in the expiratory phase was not significantly higher than that in the inspiratory phase, except for R5–R20. In addition, Fres in the asthmatic group was significantly higher than that in the nonasthmatic group; however, X5 was not significantly different between the groups.

Table 4 – Change in whole-breath and within-breath analyses of the respiratory system's resistance and reactance.

	Asthmatic		Nonasthmatic	
	Pre	Post	Pre	Post
R5 (cm H₂O/L/s)				
Whole breath	5.85 ± 2.32**	4.81 ± 1.87**	5.53 ± 2.42	4.85 ± 2.21
Inspiratory	5.30 ± 2.08 **	4.26 ± 1.69 **	5.03 ± 2.19	4.44 ± 2.07
Expiratory	6.37 ± 2.56**	5.38 ± 2.14**	6.04 ± 2.70	5.26 ± 2.38
Expiratory–inspiratory	1.11 ± 0.90	1.08 ± 0.77※	1.01 ± 0.77	0.80 ± 0.64※
R20 (cm H₂O/L/s)				
Whole breath	4.48 ± 1.46**	3.87 ± 1.33**	4.12 ± 1.55	3.68 ± 1.52
Inspiratory	4.24 ± 1.38 **	3.58 ± 1.21 **	3.85 ± 1.42	3.47 ± 1.46
Expiratory	5.23 ± 4.65 *	4.16 ± 1.59 *	4.37 ± 1.69	3.89 ± 1.61
Expiratory–inspiratory	0.55 ± 0.50	0.57 ± 0.45	0.52 ± 0.39	0.41 ± 0.37
R5–20 (cm H₂O/L/s)				
Whole breath	1.34 ± 0.99 **	0.93 ± 0.70 **	1.41 ± 0.99	1.16 ± 0.75
Inspiratory	1.06 ± 0.89 **	0.67 ± 0.62 ※※	1.17 ± 0.88	0.96 ± 0.72 ※
Expiratory	1.61 ± 1.13 **	1.19 ± 0.81 **	1.66 ± 1.11	1.36 ± 0.82
Expiratory–inspiratory	0.55 ± 0.45	0.50 ± 0.38	0.48 ± 0.41	0.40 ± 0.35
X5 (cm H₂O/L/s)				
Whole breath	–1.27 ± 1.12 **	–0.82 ± 0.80** ※	–1.42 ± 1.20	–1.29 ± 1.29 ※
Inspiratory	–1.18 ± 0.98 **	–0.76 ± 0.73 ** ※	–1.24 ± 0.96	–1.16 ± 1.03※
Expiratory	–1.31 ± 1.35 **	–0.87 ± 0.95 ** ※	–1.59 ± 1.49	–1.39 ± 1.47※
Expiratory–inspiratory	–0.13 ± 0.64 ※	–0.12 ± 0.57	–0.35 ± 0.74 ※	–0.22 ± 0.46
Fres (Hz)				
Whole breath	17.34 ± 6.29**	8.93 ± 3.27 ** ※	11.56 ± 4.61	10.44 ± 3.79 ※
Inspiratory	12.12 ± 18.40*	8.37 ± 2.97*※	11.05 ± 4.11	9.76 ± 3.91 ※
Expiratory	10.97 ± 5.14**	9.33 ± 3.82 **	12.07 ± 5.21	10.78 ± 4.03
Expiratory–inspiratory	0.72 ± 1.93	0.72 ± 2.10	1.02 ± 1.75	0.69 ± 1.23

Values are mean ± SD or numbers *p < 0.05 pre versus post, ** p < 0.005 pre versus post ※ p < 0.05 asthmatic versus nonasthmatic
 *†p < 0.05 expiratory phase versus inspiratory phase **†p < 0.005 expiratory phase versus inspiratory phase

3.7. Within-breath analyses: comparison before and after inhalation between the asthmatic and nonasthmatic groups

There were significant improvements in Rrs, X5, and Fres after bronchodilator inhalation only in the asthma group.

There was a significant difference in X5 in the expiratory–inspiratory phase only before inhalation. In addition, after bronchodilator inhalation, there were significant differences in R5–R20, X5, and Fres in the inspiratory phase and X5 in the expiratory phase between both groups.

3.8. Comparison of changes in all parameters pre- and post-inhalation between the asthmatic and nonasthmatic groups

The results are shown in Table 5. There were significant differences in ΔR5 and ΔX5 in whole-breath analysis between the asthmatic and nonasthmatic groups. There were also significant differences in ΔR5 and ΔX5 in the inspiratory phase between both groups. The results of ΔX5 in the inspiratory phase are shown in Fig. 3 (p = 0.0052). However, there was no significant difference in the other parameters between the groups.

3.9. ROC curve analysis for ΔX5 predicting bronchial reversibility test

The ΔX5 cut-off value was defined for values greater than 0.46 with a probability of 99% for the positive bronchial reversibility test result with the area under the curve of 0.63 ± 0.05. The cut-off value of ΔX5 was 0.46 with sensitivity, specificity, and positive predictive values of 100%, 88% and 76%, respectively.

4. Discussion

The present study successfully demonstrated the reliability of respiratory impedance in assessing bronchial reversibility using colored three-dimensional analyses of the new FOT in asthmatic and nonasthmatic children. Our study is the first to compare respiratory Rrs and Xrs with colored three-dimensional images between asthmatic and nonasthmatic children.

Even younger children who could not perform forced breathing were able to perform the forced oscillation technique because this method measures breathing at rest. We could evaluate airway resistance and the reactance components in both the inspiratory phase and expiratory phase. We could observe more subtle changes than those measured by conventional methods that allowed us to evaluate each component according to the breath phase.

Reactions to bronchoconstrictors and bronchodilators are commonly characterized by a decrease or increase in a baseline FEV₁ value and a decrease in airway resistance [5,6]. However, in the present study, a significant increase in FEV₁ was not observed in either group. Spirometric parameters showed significant positive changes at V₅₀ and V₂₅ in the asthmatic group; however, no significant differences were observed between the groups. No significant variations were seen in the FEV₁ value during the treatment, which suggests that functional stability or the absence of an obstruction may not reflect the adequate management of asthma in children [17].

In contrast, eNO was significantly higher in the asthmatic group than in the nonasthmatic group. Previous studies have

Table 5 – Amount of change in whole-breath and within-breath analyses of the respiratory system's resistance and reactance.

Amount of change (pre - post)	Asthmatic	Nonasthmatic
$\Delta R5$		
Whole breath	$1.04 \pm 1.08^*$	$0.68 \pm 1.15^*$
Inspiratory	$1.04 \pm 1.03^*$	$0.59 \pm 1.21^*$
Expiratory	1.02 ± 1.27	0.77 ± 1.17
Expiratory–inspiratory	0.02 ± 0.71	0.20 ± 0.67
$\Delta R20$		
Whole breath	0.60 ± 0.77	0.43 ± 0.76
Inspiratory	0.66 ± 0.69	0.38 ± 0.81
Expiratory	1.06 ± 4.41	0.48 ± 0.75
Expiratory–inspiratory	-0.02 ± 0.34	0.10 ± 0.37
$\Delta R5-20$		
Whole breath	0.40 ± 0.62	0.24 ± 0.55
Inspiratory	0.38 ± 0.58	0.20 ± 0.54
Expiratory	0.42 ± 0.73	0.29 ± 0.61
Expiratory–inspiratory	0.04 ± 0.45	0.08 ± 0.38
$\Delta X5$		
Whole breath	$0.42 \pm 0.71^*$	$0.12 \pm 0.44^*$
Inspiratory	$0.42 \pm 0.65^{**}$	$0.07 \pm 0.42^{**}$
Expiratory	0.44 ± 0.95	0.19 ± 0.58
Expiratory–inspiratory	0.007 ± 0.52	0.13 ± 0.56
$\Delta Fres$		
Whole breath	8.41 ± 6.32	1.12 ± 1.86
Inspiratory	3.74 ± 17.6	1.29 ± 2.61
Expiratory	1.64 ± 3.88	1.28 ± 2.26
Expiratory–inspiratory	0.0004 ± 1.94	0.32 ± 1.52

Values are mean $\pm$ SD or numbers.
^{*} $p < 0.05$ asthma versus nonasthmatic.
^{**} $p < 0.01$ asthma versus nonasthmatic.

shown that the level of fractional exhaled eNO was significantly elevated in uncontrolled asthma [18]. We concluded that the asthmatic children who participated in this study may have had slight bronchial inflammation, even though they were adequately treated with continuous medication and their symptoms were stable.

On other hand, the new method clearly demonstrated that Rrs was higher and Xrs was more negative in the expiratory phase than in the inspiratory phase. This has been referred to as respiratory cycle dependence in asthma [13]. In this study, Rrs was significantly higher in the expiratory phase than in the inspiratory phase pre- and post-bronchodilator inhalation only in the asthmatic group. X5 was not significantly different between each respiratory phase; however, Xrs became slightly negative in all subjects.

Previous studies using oscillometry have shown that R5, R20 (R5–R20), X5, Fres, and AX values in children with uncontrolled asthma significantly differ from those in non-asthmatic children or children with controlled asthma [19].

In this study, no significant differences were observed before inhalation between the asthmatic and nonasthmatic groups, except for X5 during the expiratory–inspiratory phase; however, all oscillometry indexes were significantly different pre- and post-inhalation in the asthmatic group only.

Furthermore, changes in $\Delta R5$ and $\Delta X5$ helped to discriminate between the asthmatic and nonasthmatic children. If

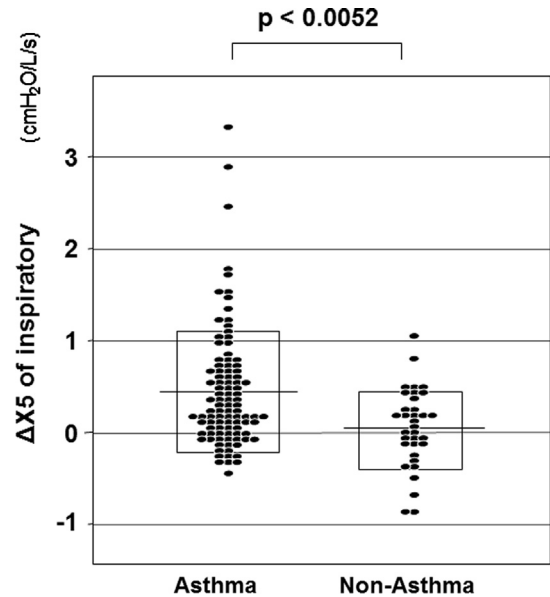


Fig. 3 – $\Delta X5$ in the inspiratory phase between the asthmatic and nonasthmatic groups. In the asthmatic group, the $\Delta X5$ in the inspiratory phase was 0.42 ± 0.65 ; in the nonasthmatic group, the $\Delta X5$ was 0.07 ± 0.42 . There was a significant difference in $\Delta X5$ in the inspiratory phase between the asthmatic and nonasthmatic groups ($p = 0.0052$).

the $\Delta X5$ value in the inspiratory phase is more than 0.46, the diagnosis of asthma in children may be expedited by the bronchodilator provocation test during an asymptomatic state.

Previous studies have shown that R5 is the index that exhibits the greatest sensitivity to salbutamol inhalation, even in healthy children. On the other hand, X5 was not modified by salbutamol inhalation in healthy children [20,21]. The X5 was significantly more sensitive than R5 in small asthmatic children [22–25]. However, the sensitivity of X5 may be reduced in cases with very high airway resistance [26].

The Rrs is mainly determined by the caliber of airways, whereas the Xrs is mainly determined by the elastic and mass-inertial properties of the airways, the lung tissue, and the chest wall. Airway muscle tone itself has the most potent effect on changes in airway wall oscillations.

The present results suggest that the new FOT provides specific information on airway narrowing, and the potent changes observed in X5 before and after bronchodilator inhalation appear to reflect bronchial reversibility, which may depend on bronchial hyperresponsiveness induced by muscle tone [27], vagal nerve tone [28], or both. Therefore, our results are consistent with previous observations of bronchial reversibility, and the new FOT is useful for measuring bronchial reversibility in children.

5. Conclusions

Using one important examination, we demonstrated that it was possible to diagnose asthmatic children by evaluating changes in respiratory impedance during tidal breathing using FOT capable of colored three-dimensional data visualization. The new FOT is a safe and simple modality to

perform and does not require any strenuous efforts from children.

Conflict of interest

There is no conflict of interest.

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