Original Article

# Assessment of airway reversibility in asthmatic children using forced oscillation technique – A single-center experience from North India

***Neeraj Gupta, Anil Sachdev, Dhiren Gupta, Suresh Gupta***

*Department of Pediatrics, Division of Pediatric Emergency, Critical Care, Pulmonology and Allergic Disorders, Institute of Child Health, Sir Ganga Ram Hospital, New Delhi, India*

## ABSTRACT

**Background:** Lung function testing is recommended for the management of asthma. Due to certain limitations of conventional spirometry in vulnerable patients, forced oscillation technique (FOT) has been studied with promising results. As there is a paucity of data from developing world, we planned to conduct this study in children using FOT. To assess airway reversibility after inhaled salbutamol in asymptomatic children with suspected asthma. **Settings:** This study was conducted at pediatric asthma clinic of a tertiary care referral hospital in North India. **Design:** This was a prospective interventional study over 1-year period. **Subjects and Methods:** Asymptomatic children between 2 and 18 years of age, with history suggestive of asthma, were eligible for participation. Baseline and postbronchodilator pulmonary functions were assessed using FOT. Airway resistance and reactance were monitored at various frequencies. SPSS version 17 was used for statistical analysis. **Results:** Among the 345 enrolled children, baseline mean ± standard deviation total airway resistance ($R_5$), central airway resistance ($R_{19}$), peripheral airway resistance ($R_5$–$R_{19}$), reactance ($X_5$), and resonant frequency (Fres) were 6.85 ± 2.60, 5.23 ± 1.93, 1.6 ± 1.16, and – 2.54 ± 1.36 cm$H_2O$/L/s and 17.28 ± 3.06 Hz. The median (interquartile range) percentage change after inhaled salbutamol was 19.9 (11.40, 29.12), 22.86 (6.88, 38.76), 14.08 (3.40, 22.62), 39.20 (8.20, 62.39), and 15.79 (8.33, 27.27) in respective parameters. All changes were statistically significant. The studied respiratory variables were in maximum negative correlation with height, followed by body mass index. **Conclusions**: FOT is a simple technique for monitoring lung functions in children during asthma management.

**KEY WORDS:** Airway resistance, forced oscillation technique, impulse oscillometry, reactance, resonant frequency

**Address for correspondence:** Dr. Neeraj Gupta, Department of Pediatrics, Division of Pediatric Emergency, Critical Care, Pulmonology and Allergic Disorders, Institute of Child Health, Sir Ganga Ram Hospital, Rajinder Nagar, New Delhi - 110 060, India.
E-mail: drneeraj1979@gmail.com

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## INTRODUCTION

Repeated cough and breathlessness are quite common in children, who are often labeled as asthma based on symptomatology. Pulmonary function testing is required for making a diagnosis of asthma.[1] However, objective assessment of airway characteristics is rarely made due to limitations of available diagnostic modalities like spirometry in smaller children.[2]

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Forced oscillation technique (FOT), an easy and rapid tool, has been suggested for monitoring of respiratory parameters in the literature.[3] FOT is based on ultrasonic signal transduction over normal tidal breath with requirement of minimal cooperation from the patient. It has been used earlier in preschool children, the elderly, and ventilated patients and during sleep to measure respiratory impedance (resistance and reactance) and resonant frequency.[4] Airway characteristics are measured at various frequencies to demarcate the location of airway involvement.

There have been limited studies using FOT till date. There is no literature available, to the best of our knowledge, from the developing countries in the pediatric population. Hence, we conducted this study to assess airway reversibility using FOT in children with clinical diagnosis of asthma, who presented to a pediatric asthma clinic in North India. We have measured the baseline and postbronchodilator respiratory characteristics in children using this technique.

## SUBJECTS AND METHODS

### Study settings

This prospective, interventional study was conducted at a pediatric asthma clinic of a tertiary care multidisciplinary 650-bedded referral teaching hospital from North India. The institutional ethics committee approval was obtained before conducting the study.

### Inclusion criteria

Children presenting to pediatric asthma clinic over 12-month period, who satisfied all of the following criteria, were eligible for enrollment in the study:

1. Age in between 2 and 18 (completed) years
2. History of episodic cough and/or breathing difficulty with one of the following:
    a. ≥3 episodes in previous 12 months
    b. Symptoms more at night or early morning
    c. Symptomatic relief with bronchodilator use
3. Informed parental/caregiver consent obtained

### Exclusion criteria

Children with any one of the following characteristics were excluded:

1. Those who received bronchodilators before presentation
    a. Short-acting $\beta_2$-agonist (SABA) in previous 8 h
    b. Long-acting $\beta_2$-agonist (LABA) in previous 24 h
2. Uncontrolled symptoms
3. Those who were unable to complete FOT maneuver
4. Previously enrolled in the study.

### Interventions

After obtaining informed parental consent and recording anthropometric measurements (weight, height, and body mass index [BMI]), all the enrolled children underwent FOT maneuver, performed by a trained technician under supervision of a qualified pediatric pulmonologist. Three (out of maximum five) acceptable and valid attempts were recorded for both baseline and postbronchodilator airway dynamics. Any respiratory effort interrupted by coughing, crying, swallowing, vocalization, glottis closure, leak around mouthpiece, incomplete occlusion of nose by nose clip, irregular breathing including acute hyperventilation were considered unacceptable and discounted automatically by the machine.[5] Attempts were considered valid if the coefficient of variation between 2 sets of data, for resistance at 5 Hz ($R_5$), was <20%.[4] 400 mcg of inhaled salbutamol, via metered-dose inhaler with spacer with or without mask, was used for bronchodilation.

### Procedure

Respiratory parameters were evaluated by FOT using Resmon™ Pro FOT machine. The machine was calibrated, once daily in the morning, using an inbuilt module and external resister, as per the recommendations in the technical module.[6] Both patients and caregivers were familiarized about the procedure via a test video demonstration beforehand in their local language. FOT maneuver was performed with the patient sitting in upright position on an examination chair with uncrossed legs, straight back, and slightly extended neck to keep disposable mouthpiece (attached to FOT machine) just in front of a patient's mouth, at comfortable height.[7] A nose clip was applied to occlude the external nasal passage, and mouthpiece was held by the patient with teeth and surrounding lips to prevent any air leak. Patients' cheeks were held firmly by either caregiver standing behind the child (for smaller children) or child himself to prevent any loss of sound wave energy during the procedure.[6] After appropriate positioning, FOT maneuver was performed for a maximum of 10 efforts of tidal breathing or a maximum of 60 s in each attempt, whichever is earlier. The mean value of initial 3 acceptable and valid attempts was recorded (out of maximum 5 attempts).[4,8] The procedure was repeated 15 min after inhaled bronchodilator for assessment of the reversibility of baseline parameters.

### Monitoring

Airway impedance parameters [resistance(R) and reactance (X)] were monitored at various frequencies.[6] $R_5$ and $R_{19}$ depicted resistance at total and large airways, respectively, whereas smaller airways resistance was calculated by their difference ($R_5$–$R_{19}$).[5] Reactance was measured at 5 Hz ($X_5$).[9] Fres, point at which $X_5$ value is zero, was monitored for all the attempts.

### Outcome measures

The baseline mean resistance of total ($R_5$), central ($R_{19}$), and peripheral ($R_5$–$R_{19}$) airways, $X_5$, and Fres was compared after bronchodilation. The results were represented in mean absolute and median percentage change. Changes in respiratory parameters (R, X, and Fres) were also recorded with age, height, and BMI. An attempt was made to determine gender variation on measured parameters.

### Statistical analysis

Statistical analysis was performed by SPSS program for Windows, version 17.0 (SPSS, Chicago, IL, USA). Continuous variables were presented as mean ± standard deviation (SD), age was presented as median with interquartile range (IQR), and other categorical variables were presented as absolute numbers and percentages. Data were checked for normality before analysis. A paired *t*-test was used to evaluate the significance of mean differences in variables recorded before and after bronchodilator use. The relationship between height and BMI on airway characteristics was evaluated by Pearson correlation. ANOVA was used to detect the influence of gender. For all statistical tests, $P \leq 0.05$ was considered statistically significant.

## RESULTS

A total of 378 children satisfied the inclusion criteria. Thirty-three children were excluded either due to recent bronchodilator (SABA or LABA) use (18) or with uncontrolled symptoms (9) or those who were unable to complete FOT in desired attempts (6). Out of 345 children, who were included during the 1-year study period, boys (214) outnumbered girls (131) [Table 1]. The mean (SD) height and BMI of participants were 137.51 (21.12) cm and 19.10 (4.99) kg/m$^2$, respectively. The median age (IQR) of the study participants was 10 (6, 13) years with major representation from children between 6 to 12 years (46%). Approximately one-fourth of the study population were preschool children (26%).

**Table 1: Baseline characteristics of study population**

| | |
|---|---|
| Number of participants | 345 |
| Male: female | 1.6:1 |
| Anthropometric parameters, mean±SD | |
| Height (cm) | 137.51±21.12 |
| BMI (kg/m$^2$) | 19.10±4.99 |
| Median age (IQR) in years | 10 (6, 13) |
| Age groups (in completed years), *n* (%) | |
| 2–6 | 89 (26) |
| >6–12 | 159 (46) |
| >12–18 | 97 (28) |
| Airway parameters, mean±SD | |
| Total airway resistance (R5) | 6.85±2.60 |
| Large airway resistance (R19) | 5.23±1.93 |
| Peripheral airway resistance (R5–R19) | 1.6±1.16 |
| Reactance at 5 Hz (X5) | −2.54±1.36 |
| Resonant frequency (Fres) | 17.28±3.06 |

R and X (cm$H_2O$/L/s); Fres (Hz). IQR: Interquartile range, SD: Standard deviation

The baseline mean ± SD resistance of entire respiratory system ($R_5$) was 6.85 ± 2.60 cm$H_2O$/L/s in the study population. There was a significant contribution from large central airways (5.23 ± 1.93) as compared to small peripheral portion (1.6 ± 1.16). The initial mean (SD) $X_5$ and Fres were −2.54 (1.36) cm$H_2O$/L/s and 17.28 (3.06) Hz, respectively.

There was a significant response to inhaled salbutamol [Table 2], with an average absolute change (95% confidence interval) of 1.42 (1.26, 1.58) in $R_5$, 0.75 (0.65, 0.85) in $R_{19}$, 0.63 (0.53, 0.73) in $R_5$–$R_{19}$, -0.64 (-0.78 – -0.50) in $X_5$, and 2.772 (2.52, 3.02) in Fres values. Median (IQR) percentage changes of 19.90 (11.40, 29.12) in $R_5$, 22.86 (6.88, 38.76) in $R_{19}$, 14.08 (3.40, 22.62) in $R_5$–$R_{19}$, 39.20 (8.20, 62.39) in $X_5$, and 15.79 (8.33, 27.27) in Fres were observed.

Table 3 depicts the variation of respiratory parameters in preschoolers (2–6 years), school-age children (6–12 years), and adolescents (12–18 years). The airway resistance at all frequencies was maximum in preschool children. Reactance became less negative with reduction of resonant frequency as the age advanced.

One hundred and eighty-seven children (54.2%) were <140 cm height with only minor contribution (7) from children under 100 cm [Table 4]. Similar trends of reducing resistance and reactance (less negative) were noticed with increment in height, but this consistency was not uniform in resonant frequency.

There was a significant proportion (52.8%) of underweight children in the study population. Underweight children had maximum resistance and reactance values [Table 5]. Only 13 children were obese with mean (SD) reactance and Fres of −1.70 (0.80) cm$H_2O$/L/s and 15.33 (2.41) Hz at presentation.

Table 6 shows the correlation of various anthropometric parameters with respiratory variables. Age, height, and BMI were in negative correlation with resistance and Fres. Reactance at 5 Hz showed a positive correlation with measured anthropometric variables. There was no influence of gender on baseline respiratory parameters.

## DISCUSSION

Asthma, the most frequent diagnosis for recurrent or long-standing cough in children, is both under- and

**Table 2: Response to bronchodilator**

| Change in parameter (pre- vs. post-salbutamol) | Absolute change, mean (95% CI) | Percentage change. median (IQR) | *P* |
|---|---|---|---|
| $\Delta R_5$ | 1.42 (1.26–1.58) | 19.9 (11.40–29.12) | <0.05 |
| $\Delta R_{19}$ | 0.75 (0.65–0.85) | 22.86 (6.88–38.76) | <0.05 |
| $\Delta R_5$–$R_{19}$ | 0.63 (0.53–0.73) | 14.08 (3.40–22.62) | <0.05 |
| $\Delta X_5$ | -0.64 (-0.78–-0.50) | 39.20 (8.20–62.39) | <0.05 |
| ΔFres | 2.772 (2.52–3.02) | 15.79 (8.33–27.27) | <0.05 |

$R_5$: Resistance at 5 Hz, $R_{19}$: Resistance at 19 Hz, $X_5$: Reactance at 5 Hz, Fres: Resonant frequency, R and X (cm$H_2O$/L/s); Fres (Hz). CI: Confidence interval, IQR: Interquartile range

**Table 3: Mean (standard deviation) airway characteristics in different age groups**

| Age (*n*) | $R_5$ | | $R_{19}$ | | $R_5$–$R_{19}$ | | $X_5$ | | Fres | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 2–6 (89) | 9.28 (2.38) | 7.47 (1.99) | 7.15 (1.47) | 6.25 (1.42) | 2.01 (1.40) | 1.23 (1.10) | −3.56 (1.44) | −2.75 (1.88) | 17.14 (2.66) | 15.10 (3.00) |
| >6–12 (159) | 6.79 (1.79) | 5.40 (1.40) | 5.18 (1.49) | 4.45 (1.20) | 1.63 (1.03) | 0.95 (1.03) | −2.45 (1.13) | −1.79 (1.11) | 16.51 (2.65) | 14.61 (2.98) |
| >12–18 (97) | 4.74 (1.90) | 3.69 (1.48) | 3.58 (1.25) | 3.00 (1.08) | 1.11 (0.93) | 0.81 (0.94) | −1.76 (1.03) | −1.38 (0.93) | 14.43 (2.80) | 12.55 (2.42) |

Age (years); R and X ($cmH_2O/L/s$); Fres (Hz)

**Table 4: Mean (standard deviation) airway characteristics variation as per height**

| Height (*n*) | $R_5$ | | $R_{19}$ | | $R_5$–$R_{19}$ | | $X_5$ | | Fres | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| ≤100 (7) | 11.98 (0.76) | 8.90 (1.56) | 8.92 (0.80) | 6.94 (1.28) | 3.06 (0.96) | 1.95 (0.40) | −4.34 (1.43) | −5.32 (5.07) | 17.75 (0.35) | 15.50 (2.65) |
| >100–110 (38) | 9.27 (2.12) | 7.86 (2.09) | 7.42 (1.58) | 6.69 (1.48) | 1.84 (1.44) | 1.17 (1.19) | −3.86 (1.57) | −3.04 (1.14) | 16.47 (2.78) | 15.72 (3.05) |
| >110–120 (44) | 8.67 (2.45) | 6.96 (1.94) | 6.66 (1.17) | 5.71 (1.33) | 1.78 (1.18) | 1.26 (1.14) | −3.11 (1.13) | −2.42 (0.96) | 17.36 (2.67) | 15.09 (2.92) |
| >120–130 (46) | 7.86 (1.81) | 6.16 (1.20) | 5.82 (1.54) | 5.03 (1.27) | 2.06 (1.30) | 1.15 (0.84) | −2.84 (1.55) | −2.04 (1.38) | 17.93 (1.19) | 15.69 (2.93) |
| >130–140 (52) | 6.93 (1.69) | 5.71 (1.11) | 5.35 (1.42) | 4.77 (1.01) | 1.58 (0.92) | 0.94 (0.75) | −2.55 (0.76) | −1.89 (0.86) | 16.69 (2.19) | 14.47 (2.63) |
| >140–150 (46) | 6.53 (2.10) | 5.07 (1.67) | 4.84 (1.34) | 4.08 (1.10) | 1.69 (1.29) | 1.05 (0.92) | −2.29 (1.25) | −1.46 (1.24) | 16.38 (2.59) | 13.71 (2.70) |
| >150 (112) | 4.70 (1.56) | 3.59 (1.03) | 3.58 (1.15) | 2.98 (0.92) | 1.08 (0.76) | 0.67 (0.78) | −1.74 (0.91) | −1.31 (0.82) | 14.49 (2.98) | 12.72 (2.70) |

Height in cm; R and X in $cmH_2O/L/s$; Fres in Hz

**Table 5: Mean (standard deviation) airway characteristics variation as per body mass index**

| BMI (*n*) | $R_5$ | | $R_{19}$ | | $R_5$–$R_{19}$ | | $X_5$ | | Fres | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| <18.5 (182) | 7.63 (2.66) | 6.16 (2.14) | 5.84 (1.99) | 5.10 (1.73) | 1.72 (1.25) | 1.09 (1.09) | −2.92 (1.51) | −2.25 (1.66) | 16.17 (3.01) | 14.45 (3.18) |
| 18.5–24.9 (110) | 6.30 (2.31) | 4.99 (1.83) | 4.83 (1.73) | 4.09 (1.47) | 1.48 (1.07) | 0.90 (0.76) | −2.23 (1.11) | −1.64 (0.85) | 15.91 (2.82) | 13.89 (2.89) |
| 25–29.9 (40) | 5.48 (1.86) | 4.22 (1.48) | 4.10 (1.23) | 3.44 (1.13) | 1.38 (0.94) | 0.78 (0.58) | −1.95 (0.78) | −1.33 (0.64) | 15.17 (2.88) | 13.77 (2.78) |
| ≥30 (13) | 4.86 (1.95) | 3.61 (1.08) | 3.70 (1.40) | 3.10 (1.19) | 1.16 (0.93) | 0.68 (0.53) | −1.70 (0.80) | −1.58 (1.78) | 15.33 (2.41) | 13.50 (1.67) |

BMI: <18.5 - Underweight; 18.5–24.9 - Normal weight; 25–29.9 - Overweight; ≥30 - Obesity, BMI ($kg/m^2$); R and X in $cmH_2O/L/s$; Fres in Hz. BMI: Body mass index

**Table 6: Correlation of anthropometric parameters with measured respiratory variables**

| Parameter | $R_5$ | | $R_{19}$ | | $R_5$–$R_{19}$ | | $X_5$ | | Fres | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| Age | −0.19 | −0.19 | −0.19 | −0.19 | −0.11 | −0.27 | 0.09 | −0.02 | −0.08 | −0.43 |
| Height | −0.70 | −0.74 | −0.75 | −0.75 | −0.32 | −0.26 | 0.54 | 0.48 | −0.42 | −0.42 |
| BMI | −0.38 | −0.41 | −0.40 | −0.42 | −0.16 | −0.17 | 0.37 | 0.28 | −0.17 | −0.16 |

Age (years), height (cm), BMI ($kg/m^2$), $P$=0.01. BMI: Body mass index

overdiagnosed frequently. Demonstration of variable airflow limitation is required in addition to subjective findings of chronic airway inflammation, i.e., recurrent wheeze, shortness of breath, chest tightness, and cough of variable intensity, for labeling a person with asthma.[1] Spirometry is the gold standard technique for demonstration of airway reversibility, but requirements of technical expertise, patient cooperation, and forceful respiratory efforts are some of the limitations, especially in children and the elderly.[2,10] In a survey conducted over 3 geographically diverse organizations involving 671 primary care physicians, only 21% used spirometry routinely for making asthma diagnosis.[11] Almost 28% of the patients were misdiagnosed, and majority were started on asthma medication in the absence of objective assessment.[12]

In search of a simple and reliable tool for assessment of respiratory mechanics, FOT seems to have a good potential.[3,13] Impulse oscillometry (IOS), a type of FOT, has been used previously for diagnosis and assessment of airway reversibility where conventional spirometry is impractical.[8,14] IOS is a simple method, needing minimal cooperation, for evaluation of airway resistance and reactance.[4,7] Its utility for monitoring airway resistance has been demonstrated in children as young as 2 years of age.[6] IOS alone has been found to be a superior tool in pediatric cohort, whereas it can provide additional information regarding peripheral airway characteristics in adults when compared to spirometry.[4]

FOT/IOS is based on superimposing loudspeaker-generated sound wave signals over the spontaneous tidal breath of patients and thereafter directly measuring pressure and flow characteristics of expiratory airflow at various frequencies.[7] Airway mechanical properties are determined at individual frequencies to delineate a specific portion of airway. The commonly observed and clinically relevant airway characteristics are resistance(R), reactance (X), and resonant frequency (Fres). As sound waves of smaller frequency (5 Hz) can penetrate deeper in lung parenchyma, parameters measured at these frequencies inform about the entire respiratory system, whereas larger frequency (19 Hz) determines only the central airway (>4 mm internal diameter) characteristics.[10] Consequently, the resistance of central, total, and peripheral airways (<2 mm internal diameter) may be depicted as $R_{19}$, $R_5$, and $R_5$–$R_{19}$.[5] Postbronchodilator change (Δ) in resistance can determine the reversibility in affected portion of airway. Reactance ($X_5$) was determined by capacitance of the peripheral lung tissue. A more negative $X_5$ value signifies altered compliance. Resonant frequency (Fres) is the arbitrary point where negative capacitance forces equalize positive inertial forces in the airway (point of zero $X_5$).[15] The normal value of Fres varies between 6 and 11 Hz in healthy adults and can be physiologically more in children due to narrow peripheral airways.[10] Fres increases and shifts towards right when more negative (capacitative) or less positive (inertial) forces operates as in case of peripheral obstruction or restriction. A combination of various parameters will help in determining the level and type of respiratory pathology, namely peripheral airway obstruction (↑$R_5$–$R_{19}$, ↑Fres, and more negative $X_5$), large airway obstruction (↑$R_{19}$), and restrictive diseases (more negative $X_5$ or ↑Fres).[5,7]

There is limited literature available for FOT use, especially in children, till date. Dymek *et al*. explored the potential use of FOT in preschool children for diagnosis and monitoring of asthma.[5] Komarow *et al*. suggested the utility of IOS for objective measurement of lung impedance in their study on 117 children.[16] The same group documented the use of IOS for diagnosis and monitoring of respiratory dysfunction in 10 children with adenosine deaminase deficiency.[17] Lee *et al*. tried to determine the reference values and regression equations of respiratory resistance, reactance, and resonant frequency in 390 Korean children aged 3–7 years using IOS.[18] They also postulated the cutoff value for change in $R_5$ for significant reversibility. Another group, from Mexico, recruited 283 healthy children from kindergartens and schools to determine the reference values for respiratory variables.[19] There is a lack of scientific data from the Indian pediatric population.

We have assessed airway characteristics in 345 children using FOT. More boys were recruited than girls, and the trend was similar as for other diseases in outpatient clinics. The reason could be either more predilection of diseases for males or gender discrimination for seeking medical help. Majority of the participants were in school-going age group with the median age of 10 years. Eighty-nine preschool children underwent airway assessment by FOT, the age group where spirometry is practically impossible. A 2-year, 93-cm boy was the youngest and shortest child among all the participants with the median group height of 137.51 cm. Majority (182) of the children were underweight reflecting the weaker socioeconomic status of the enrolled participants.

The baseline mean (±SD) values of resistance at wider ($R_{19}$) and narrow airways ($R_5$–$R_{19}$) were 5.23 ± 1.93 and 1.6 ± 1.16 $cmH_2O/L/s$, respectively. Mean reactance ($X_5$) and resonant frequency (Fres) were −2.54 ± 1.36 $cmH_2O/L/s$ and 17.28 ± 3.06 Hz for the entire study population. As the enrolled population was dominated by younger children, the baseline peripheral airway resistance contributed significantly (23.3%) to the total airway resistance ($R_5$) and higher mean Fres than the adult reference value of 6–11 Hz.[10]

We have found a median change of 19.9% in $R_5$ after inhaled salbutamol. Previous studies have reported a 20%–40% change as significant for reversible airflow obstruction in children.[6] This large variation in bronchodilator response has been suggested by variation in health status of control group (from normal healthy to controlled asthmatic), age, height, and ethnicity.[4] Marotta *et al*. and Shi *et al*. found a 20% reduction in $R_5$ as a significant change in preschool children,[14,20] whereas Komarow *et al*. suggested an 8.6% change in $R_{10}$ for documenting reversibility in their study enrolling 117 school-age children.[17] The borderline response to bronchodilator in our study can be attributed to the selection of controlled asthmatic as a baseline rather than healthy controls. Central airways showed more reversibility (22.86%) when compared to smaller airways (14.08%) to inhaled bronchodilators. This variation could be attributed to the fact that asthma affects predominantly larger airways. Among the parameters reflecting peripheral airway health status, i.e., $R_5$–$R_{19}$, $X_5$, and Fres, the median change in $X_5$ was maximum (39.2%) postbronchodilation. This suggests more sensitivity of $X_5$, for detecting peripheral airway disease, as compared to others. Tirakitsoontorn *et al*. also demonstrated $X_5$ as the best available parameter for determining peripheral airway impairment, when compared against FEF25%–75% of spirometry, in their cross-sectional study of 139 patients with moderate-to-severe asthma, aged 4–18 years.[9] They suggested $X_5$ values of ≤−3.8, ≤−2.5, and ≤−1.5 $cmH_2O/L/s$ for preschool children, school-age children, and adolescents as optimal cutoff points for peripheral airway impairment. Our baseline values were quite similar to −3.56, −2.45, and −1.38 $cmH_2O/L/s$, respectively.

Respiratory parameters were variable as per age, height, and BMI of the patients. There was a general trend of higher resistance in younger children. The total airway resistance ($R_5$), $R_5$–$R_{19}$, $X_5$, and Fres in children under 6 years were 9.28 ± 2.38, 2.01 ± 1.40, −3.56 ± 1.44, and 17.14 ± 2.66 in our study. The respective parameters were 9.97 ± 1.576, 3.52 ± 1.311, −3.85 ± 0.572, and 19.74 ± 1.851 in a study by Zeng *et al*. in 27 preschool healthy Chinese children.[21] There was an expected reduction noticed in all the respiratory variables with increasing age and height. Dencker *et al*. also observed a similar relationship of respiratory characteristics with incremental height in 360 children, aged 2–11 years, based in Finland and Sweden.[22] Resonant frequency was more in younger children and had shown a reducing trend with advancing age. The findings were similar to a previous study by Mazurek *et al*.[23] Although van de Kant *et al*. demonstrated the adverse effect of overweight on airway functions using IOS,[24] our results are not consistent with their findings, and small sample size could be a potential contributing factor.

While comparing all the study variables, we have found the best negative correlation between all the measured respiratory variables ($R_5$, $R_{19}$, $R_5$–$R_{19}$, $X_5$, and Fres) with height, followed by BMI [Table 6]. Similarly, Park *et al*.

observed height as the best predictor in their study recruiting 133 healthy Korean preschool children.[25] Nowowiejska *et al*. also found body height as the best predictor for airway dynamics during their work on 626 Polish children between 3 and 18 years of age.[26] Shi *et al*. have not found any clear relationship between BMI and respiratory variables.[20] We have not found any significant correlation of respiratory parameters with advancing age, the findings of which were similar to previous studies.[27,28] However, Duiverman *et al*. noticed more airway resistance in younger age group in their study on 255 healthy Caucasian children of Dutch descent.[29] There was no gender difference observed in any of our study parameters, which is quite similar to previous findings.[27,28] Duivermann *et al*. found boys at disadvantage than girls in terms of respiratory characteristics.[29]

IOS parameters can vary in different ethnic groups and races.[30] As there are no established reference values of FOT/IOS respiratory parameters for Indian children, we have conducted this study to assess baseline and postbronchodilator parameters in asymptomatic children with asthma.

In view of limited utility of spirometry in the pediatric population, our study highlights the potential utility of FOT/IOS, as a useful objective tool, for diagnosis and monitoring of asthma in the vulnerable population. As we have enrolled suspected asthmatic patients only, a comparison against age and height matched healthy controls could have been better to establish a degree of deviation from normal parameters. Multicentric studies with larger sample size are required, especially from developing countries, for developing normograms.

## CONCLUSIONS

FOT/IOS is a potentially useful and feasible tool for assessment of airway reversibility in children. It can provide objectivity during management of patients who are unable to perform spirometry.

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### Conflicts of interest
There are no conflicts of interest.

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