Allergol Immunopathol (Madr). 2022;50(SP3):10–16 eISSN:1578-1267, pISSN:0301-0546

Allergologia et immunopathologia
Sociedad Española de Inmunología Clínica, Alergología y Asma Pediátrica
www.all-imm.com

ORIGINAL ARTICLE

Impulse oscillometry in children and adolescents with persistent asthma and its correlation with spirometry

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Received 13 August 2022; Accepted 21 October 2022
Available online 19 December 2022

KEYWORDS
Asthma;
Child;
Oscillometry;
Respiratory Function Tests;
Spirometry

Abstract
Introduction: Asthma is one of the most common chronic diseases of childhood. Spirometry is the traditional test for assessing lung function, while impulse oscillometrics is an alternative resource that measures the impedance of the respiratory system.
Objective: To evaluate the pulmonary function of children and adolescents with asthma by impulse oscillometry and correlate the findings with those obtained by spirometry.
Methods: A cross-sectional study in which the pulmonary function of asthmatic children and adolescents aged between 6 and 18 years was evaluated, categorized by the level of disease control according to the Asthma Control Test (ACT) or Children Asthma Control Test (C-ACT) into controlled (ACT/C-ACT>19; n = 70) and uncontrolled (ACT/C-ACT ≤ 19; n = 60).
Results: A total of 130 asthmatic children and adolescents were evaluated (51% were males). There were no significant differences in the parameter values of both tests when patients were divided by the level of asthma control. Altered impulse oscillometry and spirometry were performed in 20 and 25% of the cases, respectively. Changes in impulse oscillometry were more frequent in patients with controlled asthma. R5 (%), X5 (%), and Fres showed moderate correlation with the main spirometric parameters, being stronger between X5 (%) and FEV_1/FVC (%) (r: −0,58; P < 0,05) in patients with controlled asthma. Bronchodilator response was observed in a similar number of patients in both exams, but with reasonable agreement.
Conclusions: Impulse oscillometry values showed a weak or moderate correlation with spirometry values.

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https://doi.org/10.15586/aei.v50iSP3.751

Introduction

Asthma is one of the most common chronic diseases of childhood and an important public health problem that affects patients and their families in a complex and prolonged way.[1-3] It currently represents the third leading cause of hospitalization among children and adolescents in Brazil, and, according to the latest data from the World Health Organization, it is estimated that between 250 and 300 million people in the world have asthma,[4-6] with prevalence varying between 1 and 18% in different countries; however it has stable prevalence and decreased mortality rate in the most varied age groups and in all social segments in the last decades.[5,7,8]

Asthma management aims to reduce and control symptoms, prevent attacks, and maintain lung function and activities of daily living, as well as physical activity. The level of asthma control depends on clinical and functional parameters, being traditionally classified as controlled, partially controlled, and uncontrolled.[5]

Although the diagnosis of asthma is fundamentally based on the patient's clinical history and physical examination, pulmonary function tests allow the establishment of a functional diagnosis,[9] assessing the airflow limitation, as well as its severity, considered extremely important in the control of asthma and respiratory diseases in general.[10]

Spirometry is the most used pulmonary function assessment test, but it requires the performance of forced respiratory maneuvers, thus requiring maximum cooperation from the patient to be evaluated, and its performance can often be difficult in some children due to the difficulty in performing consistent and reproducible respiratory maneuvers.[11,12] Therefore, spirometry may present limitations in the assessment of pulmonary function in children and adolescents with asthma, requiring the use of other resources.[13]

An alternative to spirometry would be the assessment of pulmonary function through the measurement of airway resistance by impulse oscillometry, Impulse Oscillometry System (IOS), a noninvasive, quick, and easy method that requires only passive cooperation from the patient and does not depend on forced respiratory maneuvers.[14,15] The test is based on the production of pressures applied in the mouth and transmitted to the lungs, thus allowing the measurement of resistance and reactance of the respiratory system. It can also be used to assess the pulmonary function of children and adolescents with asthma.[14,16,17]

Impulse oscillometry can help in the assessment of pulmonary function, as well as in diagnosing and evaluating therapeutic responses in chronic lung diseases.[18,19] According to Komarow et al.,[20] impulse oscillometry parameters were sensitive to identification of asthmatic patients, especially during exacerbations, and to exclude nonasthmatic patients.[20] Kim et al.[21] and Nielsen and Bisgaard[22] observed significant correlations between spirometry parameters and impulse oscillometry parameters in a study evaluating children with hyperactive airways,[21] and in adults with chronic obstructive pulmonary disease,[22] respectively.

In this context, evaluating the pulmonary function of children and adolescents with asthma using two auxiliary resources for diagnosis, impulse oscillometry and spirometry, will support an initial purpose so that impulse oscillometry is incorporated as a complementary resource to spirometry together with the guidelines for the treatment of asthma in children.[18] Therefore, the objective of this study was to evaluate the pulmonary function of children and adolescents with asthma using impulse oscillometry and to correlate its values with those obtained by spirometry.

Materials and Methods

Characterization of study

This was a cross-sectional study, approved by the Research Ethics Committee of Federal University of São Paulo – UNIFESP-EPM, under process number 0130/2016. Data collection was conducted at the pulmonary function laboratory of the Allergy Outpatient Clinic, Clinical Immunology and Rheumatology Department, Pediatrics Department, Federal University of São Paulo – UNIFESP-EPM, and included asthmatic children and adolescents from both sexes aged between 6 and 18 years divided into two groups, the controlled and uncontrolled asthmatic groups. All patients must have undergone the asthma diagnosis according to GINA[4] criteria and being followed for at least 6 months.

Children and adolescents with a history of cognitive impairment and other respiratory or systemic diseases that could affect lung function, with signs or symptoms of an acute respiratory infection in the 20 days before the exams, with asthma exacerbation in the last 15 days, or who underwent inapppropriate exams and/or that did not fit within the acceptability and reproducibility criteria were excluded from the study.

Data collection process

In addition to the free and informed consent form and the free informed assent form, the Children Asthma Control Test (C-ACT) or Asthma Control Test (ACT) questionnaires and an evaluation form prepared by the researchers were applied, referring to the history of the disease (time of illness, medications in use) and demographic characteristics. Children and adolescents who had ACT or C-ACT $\leq$19 were considered as uncontrolled asthmatics.

Anthropometric data were measured using an analog scale and a Welmy® stadiometer. Subsequently, impulse oscillometry and spirometry tests were performed (in this sequence), using the MasterScreen™ equipment (CareFusion, USA), which was calibrated daily before the tests were performed using a 3 L syringe. The examinations were conducted according to recommendations of the *American Thoracic Society* (ATS).[19]

The impulse oscillometry test was performed with the patients seated, with the head in a neutral position and the mouth attached to the mouthpiece, using a nose clip. They were instructed to breathe spontaneously, at tidal volume, without contracting the glottis and with manual support of the cheeks, in order to avoid the *"Upper Airway Shunt"* effect.

Measures that were not presented by the patients were considered acceptable: swallowing, glottal closure, leakage around the mouthpiece, inadequate sealing of the nose clip, hyperventilation, or visible artifacts. The average values of the following oscillometric parameters were considered: total resistance measured at 5 Hz (R5), resistance measured at 20 Hz (R20), reactance measured at 5 Hz (X5), and resonance frequency (Fres), based on the Vogel and Smith reference values.[17] Exams that presented at least two R5 measurements with a coefficient of variation lower than 10% were considered reproducible.[20] Exams with at least two acceptable and reproducible measurements were valid.[20]

A normal impulse oscillometric test was considered when R5 and R20 values were less than 130% of predicted in children and less than 150% of predicted in adolescents, X5 values were greater than the difference between predicted X5 and 2.0 cmH2O/L/s (>X5 predicted - 2.0 cmH_2O/L/s) and Fres values lower than 20.[12,21-23]

Then, the spirometry test was performed according to technical standardization.[24] In the same equipment, with the patients seated and with the head in a neutral position, the mouthpiece was placed on the tongue, between the teeth, and the lips closed, preventing leakage. Inspiration was requested up to total lung capacity (TLC), followed by forced and prolonged expiration up to residual volume (RV). Curves that presented an abrupt and unhesitating start of the test and duration of forced expiration, for at least 3 s with a plateau of at least 1 s, were considered acceptable. Measures of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), ratio between FEV_1 and FVC (FEV_1/FVC), and forced expiratory flow between 25 and 75% of FVC ($FEF_{25-75\%}$) were recorded in absolute values and percentages of predicted values, according to Pereira et al.[19] Curves where the two highest values of FVC and FEV_1 differed by less than 200 ml were considered reproducible. Exams with at least two acceptable and reproducible curves were valid.

A spirometry test was considered normal when the values of FVC, FEV_1, and FEV_1/FVC were equal to or greater than the lower limit of normality (LLN). Restrictive disorder was suggested when FVC values were lower than LLN and normal FEV_1/FVC, and obstructive disorder was characterized when FEV_1/FVC values were lower than LLN. Patients with abnormalities only in $FEF_{25-75\%}$ were not considered to have abnormal tests.[25]

Data analysis

All data were transcribed into the Excel 2018 program and later analyzed using the Statistical Package for the Social Sciences (SPSS) version 18.0. For data analysis, nonparametric tests were used, considering the nature of the variables, and the descriptive analysis was performed by calculating the median and the interquartile range (IQR).

To verify differences in clinical and demographic characteristics between patients grouped according to the level of asthma control, the chi-square (or Fisher's) test was applied. To study the correlations between the parameters of the pulmonary function tests, the Spearman correlation test was applied, which was classified as: weak correlation, r = 0.10–0.30; moderate correlation, r = 0.31–0.69; and strong correlation, r = 0.70–1.0. In order to verify differences in the parametric values of the pulmonary function tests between the patients grouped according to the level of asthma control, the Mann–Whitney test was applied. To assess the agreement between the bronchodilator responses in the groups of patients, Kappa test was applied and, to verify differences between the level of asthma control and the level of pharmacological treatment of asthma according to GINA (ranging from 1 to 4), the Kruskal–Wallis test was applied. For all statistical tests used, the rejection level for null hypothesis was set at 5%.

Results

A total of 135 children and adolescents were evaluated, 5 patients being excluded for not performing tests within the criteria of acceptability and reproducibility.

Of the 130 children and adolescents included, 66 (51%) were male, with a median age of 11 years (IQR: 9–14 years) (Table 1).

All 130 children and adolescents completed the asthma control questionnaire, ACT or C-ACT. The median ACT/C-ACT values were 19 (IQR: 16–23), and 60 patients (46%) had values ≤19, indicative of uncontrolled asthma. Therefore, 70 patients (54%) were considered to have controlled asthma, and 60 patients (46%) were considered to have uncontrolled asthma. There were no differences in clinical and demographic characteristics between patients with controlled and uncontrolled asthma.

The children and adolescents were classified according to the distribution by the treatment stages of GINA[5] as follows: 29 patients in Stage 1, 28 in Stage 2, 25 in Stage 3, and 48 in Stage 4. According to this distribution, patients in Stages 1 and 2 were classified as having mild asthma (44%), and patients in Stages 3 and 4 were classified as having moderate-severe asthma (56%).

The values of the impulse oscillometry exam parameters and the main spirometry parameters did not show significant differences when the patients were divided by the level of asthma control (Table 2).

Table 1 Clinical and demographic characteristics of the studied patients.

Characteristics	Studied patients (n = 130)
Age (median/IQR)	11 (9–14)
Gender (male) (n/%)	66 (51%)
Height (m)	1.46 (1.31–1.60)
Weight (kg)	44.0 (31.8–53.5)
BMI (kg/m^2)	20 (17.0–21.3)
Length of illness (years; median)	8
Mild asthma (n/%)	57 (44%)
Moderate–severe asthma (n/%)	73 (56%)
Values - ACT/C-ACT (median/IQR)	19 (16–23)
Controlled asthma - ACT/C-ACT (n/%)	70 (54%)

BMI: body mass index; IQR: interquartile range

Table 2 Impulse oscillometry and spirometry parameter values of the patients divided by the level of asthma control.

	Controlled asthma (n = 70)		Uncontrolled asthma (n = 60)		
Parameters	Median	IQR	Median	IQR	P
R5 (%)	114.0	89.2–132.5	110.7	85.8–126.9	0.50
R20 (%)	105.8	90.2–117.8	106.1	86.1–117.3	0.56
X5 $cmH_2O/L/s$	–2.2	–2.8–−1.4	–2.2	–2.6–−1.4	0.48
X5 (%)	136.0	87.6–168.5	77.9	52.8–149.6	0.23
Fres	24.5	18.5–27.5	21.9	16.3–24.4	0.11
RB-R5 (%)	–19.4	–28.0–−9.4	–15.8	–25.5–−6.9	0.10
FVC (%)	98.3	86.6–108.6	97.2	88.0–105.4	0.65
FEV_1 (%)	92.4	81.9–104.0	89.0	74.0–103.8	0.28
FEV_1/FVC (%)	93.7	87.6–100.2	91.2	81.5–101.3	0.16
$FEF_{25-75\%}$ (%)	71.3	52–85.4	66.9	42.4–90.3	0.26
RB-FEV_1 (%)	9.4	0.8–15.1	11.0	2.8–17.3	0.46

RB-R5: Bronchodilator response from impulse oscillometry; RB-FEV1: Bronchodilator response of spirometry

Of the total, 26 patients (20%) had some change in impulse oscillometric values and 33 patients (25%) had some change in spirometry values (Table 3). Among these patients, 10 (8%) had abnormal values in both lung function tests.

Analyzing the bronchodilator responses obtained in impulse oscillometry and spirometry for all patients studied, we observed an agreement of 70% and a Kappa value of 0.327. In patients with controlled asthma, we observed an agreement of 70% and a Kappa value of 0.331, and in patients with uncontrolled asthma, an agreement of 73% and a Kappa value of 0.338 were observed, both of which were interpreted as reasonable agreement values.

The correlations between the different impulse oscillometry parameters and the spirometry parameters for the studied patients were, in general, weak, with the exception of R5 (%) and X5 (%), which showed moderate correlation with some spirometry parameters. The highest correlation coefficient found was between R5 (%) and $FEF_{25-75\%}$ (%) (Table 4).

Table 4 Spearman correlation coefficients between impulse oscillometry and spirometry parameters for the studied patients.

	Studied patients (n = 130)			
SPIROMETRY IOS	FVC (%)	FEV1 (%)	FEV1/FVC (%)	FEF25-75% (%)
R5 (%)	−0.26*	**−0.40***	**−0.42***	**−0.45***
R20 (%)	−0.12*	−0.22*	−0.26*	−0.24*
X5 (%)	−0.25*	**−0.34***	**−0.32***	**−0.37***
Fres	−0.08	−0.24*	−0.27*	−0.30*
R5-R20	−0.07	−0.19*	−0.26*	−0.28*

*P < 0.05; moderate correlations highlighted in bold.

In the controlled asthma group, the correlations between the parameters of the different pulmonary function tests were, in general, moderate, with the exception of R5 - R20, which showed a weak correlation with some spirometry parameters. The highest correlation coefficients found were between X5 (%) and FEV_1/FVC (%) and between X5 (%) and $FEF_{25-75\%}$ (%) (Table 5).

In the uncontrolled asthma group, the correlations between the parameters of the different pulmonary function tests were, in general, weak, with the exception of R5 (%) and Fres, which showed moderate correlation with some spirometry parameters. The highest correlation coefficient found was between R5 (%) and FEV_1 (%) (Table 6).

Discussion

We performed impulse oscillometry and spirometry tests sequentially, prioritizing impulse oscillometry before spirometry, because according to Komarow et al.,[20] the performance of continuous forced expiratory maneuvers can trigger bronchospasm and change the values of parameters to be measured later by impulse oscillometry.[20]

In this study, 26 patients presented some type of alteration in the impulse oscillometry exam, being 18 patients in the controlled asthma group and 8 in the uncontrolled asthma group. In the group of patients with controlled asthma, 17 had distal obstruction and 1 had proximal

Table 3 List of changes found in pulmonary function tests of the studied patients.

Change	Studied patients (n = 130)	Controlled asthma (n = 70)	Uncontrolled asthma (n = 60)
Impulse oscillometry			
Distal obstruction	23 (17%)	17 (24%)	6 (10%)
Proximal obstruction	1 (1%)	1 (1%)	0
Proximal and distal obstruction	1 (1%)	0	1 (2%)
Restriction	1 (1%)	0	1 (2%)
Bronchodilator response	42 (32%)	26 (37%)	16 (27%)
Spirometry			
Obstructive disorder	18 (14%)	6 (9%)	12 (20%)
Mixed disorder	2 (2%)	1 (1%)	1 (2%)
Restrictive disorder	13 (10%)	6 (9%)	7 (12%)
Bronchodilator response	45 (35%)	21 (30%)	24 (40%)

Table 5 Spearman correlation coefficients between impulse oscillometry and spirometry parameters for the group of patients with controlled asthma.

Controlled asthma (n = 70)				
SPIROMETRY IOS	FVC (%)	FEV1 (%)	FEV1/FVC (%)	FEF25-75% (%)
R5 (%)	−0.26*	**−0.44***	**−0.52***	**−0.57***
R20 (%)	−0.11*	−0.28*	**−0.37***	**−0.39***
X5 (%)	−0.26*	**−0.44***	**−0.58***	**−0.58***
X5	0.06	0.19*	**0.42***	**0.36***
Fres	−0.05	−0.18*	**−0.32***	−0.29*
R5-R20	−0.07	−0.15*	−0.30*	−0.28*

*P < 0.05; moderate correlations highlighted in bold.

Table 6 Spearman correlation coefficients between impulse oscillometry and spirometry parameters for the group of patients with uncontrolled asthma.

Uncontrolled asthma (n = 60)				
SPIROMETRY IOS	FVC (%)	FEV1 (%)	FEV1/FVC (%)	FEF25-75% (%)
R5 (%)	−0.27*	**−0.39***	**−0.34***	**−0.37***
R20 (%)	−0.15*	−0.20*	−0.18*	−0.19*
X5 (%)	−0.26*	−0.24*	−0.08	−0.17*
X5	0.08	0.21*	0.18*	0.22*
Fres	−0.12*	**−0.35***	−0.29*	**−0.37***
R5-R20	−0.07	−0.25*	−0.27*	−0.30*

P < 0.05; moderate correlations highlighted in bold.

obstruction. In the group of patients with uncontrolled asthma, six patients had distal obstruction, one had proximal and distal obstruction concomitantly, and one patient had an examination compatible with restriction that, due to the absence of other complementary tests, could not be confirmed.

Based on the characteristics of impulse oscillometry, as well as on existing publications and guidelines, we expected to find that this would be the most sensitive assessment method for detecting changes in lung function, especially in the group of patients with uncontrolled asthma. Comparing the results obtained by impulse oscillometry and spirometry in this study, we observed greater sensitivity of spirometry in detecting changes in pulmonary function, especially in the group of patients with uncontrolled asthma. On the other hand, in the group of patients with controlled asthma, we observed greater sensitivity of impulse oscillometry in detecting changes in pulmonary function. These findings, however, were consequent to the unexpected number of patients with spirometry suggestive of restriction. In relation to obstructive changes, which are characteristic of asthma, impulse oscillometry was able to identify a greater number of abnormal tests compared to spirometry.

The median of the main impulse oscillometric parameters evaluated was within normal limits, but the findings were unexpected. Shi et al.[26,27] in clinical follow-up studies, found that changes in impulse oscillometry represent pathophysiological abnormalities in the central and/or peripheral airways and, if associated respiratory symptoms, reflect lack of asthma control. However, in the same study, Shi et al.[27] also found children and adolescents with controlled asthma and increased airway resistance values. The authors suggested that these children, especially those whose baseline AX value was ≥7.0 cmH_2O, would have a greater than 80% chance of losing asthma control, and hypothesized that impulse oscillometry indices can predict future loss of asthma control.[26,27]

In the study by Wang et al.,[28] the authors did not find differences in the parameters of the pulmonary function tests between patients with controlled and uncontrolled asthma, and they observed that the parameters of the pulmonary function tests were within the limit of normality in 95% of patients with uncontrolled asthma.[28]

Several factors may explain or justify the worse pulmonary function values found in the controlled asthma group. The dissociation between lung function and asthma symptoms has been recognized for a long time, as determinants of asthma control or not. Despite being internationally recognized, the definition of control used in the study, based on ACT or C-ACT cutoff score, may be subject to criticism. This observation may be relevant especially in patients with scores slightly higher than the cutoff score of ACT and C-ACT (20 and/or 21), classified as controlled even with symptoms to some degree. Some studies comparing asthma control by GINA and by ACT and C-ACT proposed higher cutoff scores for defining control, such as 23 for ACT and 22 for C-ACT.[29] Taking this observation into account and analyzing the findings of this study, we observed that among the 70 patients with controlled asthma evaluated, 18 presented scores slightly higher than the cutoff score of ACT and C-ACT (20 and/or 21); of these, 5 patients presented some type of alteration in the impulse oscillometric exam. In addition, it is not possible to rule out that patients with functional alterations are considered at risk and, therefore, receive more aggressive and/or persistent treatment, presenting a lower chance of clinical lack of control. In this study, 53% of patients in the controlled asthma group and 60% of patients in the uncontrolled asthma group had moderate and/or severe asthma.

Impulse oscillometric detection of pulmonary function alterations (distal obstruction) among patients with moderate and/or severe asthma was not high (Table 3). To date, there are few studies on reference values for oscillometric parameters in children and adolescents, and there is no consensus on the best values to be applied to Brazilian children and adolescents. Thus, we cannot guarantee that the cutoff points used are effectively adequate, which may underestimate possible functional changes in impulse oscillometric measurements.

Several authors have already proposed that the concomitant performance of spirometry and impulse oscillometry could increase the sensitivity of pulmonary function assessment compared with spirometry alone. In this study, 33 (25%) patients had altered spirometry, 16 (12%) had an exclusive change in impulse oscillometry (all with obstructive disorder), and 10 (8%) showed abnormal values in both tests. Thus, the addition of oscillometry increased the detection of pulmonary function alterations from 25 to 37% of the total number of patients evaluated. However, this analysis is superficial and very dependent on the criteria used to define or not define pulmonary function alterations; in addition, to defend the need for concomitant performance of an additional method of pulmonary function assessment with equipment of high financial value and longer time in carrying out the tests, we would depend on new studies with a greater number of participants.

The $FEF_{25-75\%}$ is considered a marker of peripheral airways, which evaluates the average of flows corresponding to volumes between 25 and 75% of FVC, thus representing the patency of the peripheral airways, that is, flows in low volumes, being considered by some authors as an indicator of airway reversibility and responsiveness to treatment in asthmatic patients.[30]

Lange et al.[31] showed that $FEF_{25-75\%}$ can better correlate with air trapping in asthmatics than FEV_1 and FEV_1/FVC ratio.[31] However, some researchers argue that $FEF_{25-75\%}$ does not contribute to clinical decision-making in obstructive diseases, considering its determination redundant, emphasizing only the importance of evaluating FEV_1 and FEV_1/FVC.[32]

Studies that have already correlated spirometry and impulse oscillometry parameters have shown conflicting results. Lauhkonen et al.,[33] in a follow-up study of 64 children diagnosed with asthma, observed that R5 had a weak correlation with FEV_1 and moderate correlation with FEV_1/FVC and $FEF_{50\%}$.[33] Vink et al.[34] observed a strong correlation between FEV_1 and low frequency oscillometry parameters in a study involving 19 asthmatic children.[34] Another study showed a strong correlation between FEV_1, $FEF_{25-75\%}$ and FVC with parameters R5, R20, and Fres and a weak correlation with X5, in children with cystic fibrosis.[35]

In general, the possible explanations for the weak correlations between the parameters of impulse oscillometry and spirometry would be due to the differences between the exams, because impulse oscillometry assesses the impedance of the respiratory system based on tidal volume breathing, while that spirometry assesses pulmonary volumes, capacities, and flows from forced expiratory maneuvers.

In accordance with our findings, we observed stronger correlations between impulse oscillometry and spirometry parameters in the group of patients with controlled asthma.

Another important finding in our study was that the parameter $FEF_{25-75\%}$ (%) correlated best with impulse oscillometric parameters, especially in the group of patients with controlled asthma. Shi et al.[27] observed in a study of peripheral airways in asthma that $FEF_{25-75\%}$ values can be correlated with R5 values.[27] Wei et al.[36] stated in their study that impulse oscillometry is a resource that presents good correlation with spirometric parameters, especially with $FEF_{25-75\%}$ and FEV_1.[36] Su et al.[37] found a strong correlation between Fres and R5 – R20 with $FEF_{25-75\%}$.[37]

In the uncontrolled asthma group, we did not observe a similarity in the bronchodilator response between the methods, but we observed a higher response rate in spirometry in relation to impulse oscillometry (Table 3).

Analyzing the agreement in bronchodilator responses obtained by impulse oscillometry and spirometry using the Kappa coefficient of agreement, we obtained agreement values considered reasonable, but our results do not indicate that oscillometry can replace spirometry in the assessment of bronchodilator response.

It is important to highlight that the assessment of bronchodilator response by impulse oscillometric analysis may be subject to criticism, due to the lack of consensus regarding the ideal cutoff point for defining a positive response. Hellinckx et al.[15] considered a decrease in R5 value of at least 40% after bronchodilator administration for a positive bronchodilator response.[15] A Finnish study found that a 37% decrease in R5 value could indicate a positive bronchodilator response in children aged 2–7 years.[38] Peirano[39] suggested that a 20–25% reduction in R5 after bronchodilator administration would correspond to a significant bronchodilator response.[39]

The present study evaluated children and adolescents from a single center in Brazil, and extrapolation of the results for other population should be done with caution. The small number of children included in each group (70 with controlled asthma and 60 with uncontrolled asthma) constituted a major limitation of this study.

In conclusion, the findings of altered pulmonary function in children and adolescents with asthma were discordant between impulse oscillometry and spirometry, data that do not indicate that impulse oscillometry can be used as a substitute method for spirometry. The joint assessment of lung function by the two methods seems to increase the sensitivity in detecting functional abnormalities.

The correlations between impulse oscillometry and spirometry parameters showed weak or moderate correlation coefficients, being stronger in children with controlled asthma.

We observed a similarity in the prevalence of positive bronchodilator response between impulse oscillometry and spirometry, but with only reasonable agreement between them.

Conflicts of Interest

The authors declare that there are no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

References

1. Foliaki S, Annesi-Maesano I, Daniel R, Fakakovikaetau T, Magatongia M, Tuuau-Potoi N, et al. Prevalence of symptoms of childhood asthma, allergic rhinoconjunctivitis and eczema in the Pacific: The International Study of Asthma and Allergies in Childhood (ISAAC). Allergy. 2007;62(3):259–64. https://doi.org/10.1111/j.1398-9995.2007.01343.x
2. Fontes MJ, Affonso AG, Calazans GM, de Andrade CR, Lasmar LM, Nader CM, et al. Impact of an asthma management program on hospitalizations and emergency department visits. J Pediatr (Rio J). 2011;87(5):412–8. https://doi.org/10.2223/JPED.2129
3. Sociedade Brasileira de Pneumologia e Tisiologia. Diretrizes da Sociedade Brasileira de Pneumologia e Tisiologia Para o Manejo da Asma. J Bras Pneumol. 2012;38:S1–S46. https://doi.org/10.1590/S1806-37132012000300002
4. GINA. Pocket Guide for asthma management and prevention. Global Initiative for Asthma 2020 [Internet]. [Citado 2021 Julho 17]. Disponível a partir de: www.ginasthma.org

5. GINA. Pocket guide for asthma management and prevention. Global Initiative for Asthma 2021 [Internet]. [Citado 2021 Julho 17]. Disponível a partir de: www.ginasthma.org
6. Solé D, Camelo-Nunes IC, Wandalsen GF, Naspitz CK, Vanna AT, Amorim A, et al. A asma em crianças brasileiras é problema de saúde pública? Rev Bras Alerg Imunopatol. 2004;27(5):185-88.
7. Linares M, Sánchez I, Corrales R, Díaz A, Escobar AM. Pruebas de función pulmonar en el niño. Rev Chil Pediatr. 2000;71(3):228-42. https://doi.org/10.4067/S0370-41062000000300010
8. IV Diretrizes Brasileiras para o Manejo da Asma. J Bras. Pneumol. 2007;32:S447-S474. https://doi.org/10.1590/S1806-37132006001100002
9. Belgrave DC, Buchan I, Bishop C, Lowe L, Simpson A, Custovic A. Trajectories of lung function during childhood. Am J Respir Crit Care Med. 2014;189(9):1101-9. https://doi.org/10.1164/rccm.201309-1700OC
10. Al-Mutairi SS, Sharma PN, Al-Alawi A, Al-Deen JS. Impulse oscillometry: An alternative modality to the conventional pulmonary function test to categorise obstructive pulmonary disorders. Clin Exp Med. 2007;7(2):56-64. https://doi.org/10.1007/s10238-007-0126-y
11. Marotta A, Klinnert MD, Price MR, Larsen GL, Liu AH. Impulse oscillometry provides an effective measure of lung dysfunction in 4-year-old children at risk for persistent asthma. J Allergy Clin Immunol. 2003;112(2):317-22. https://doi.org/10.1067/mai.2003.1627
12. Valle E. Resistência das vias aéreas: Técnica da oscilação forçada. J Pneumol. 2002;28(Supl 3):151-54.
13. Beydon N, Davis SD, Lombardi E, Allen JL, Arets HG, Aurora P, et al. An official American Thoracic Society/European Respiratory Society statement: Pulmonary function testing in preschool children. Am J Respir Crit Care Med. 2007;175(12):1304-45. https://doi.org/10.1164/rccm.200605-642ST
14. Goldman MD. Clinical application of forced oscillation. Pulm Pharmacol Ther. 2001;14(5):341-50. https://doi.org/10.1006/pupt.2001.0310
15. Hellinckx J, De Boeck K, Bande-Knops J, van der Poel M, Demedts M. Bronchodilator response in 3-6.5 years old healthy and stable asthmatic children. Eur Respir J. 1998;12(2):438-43. https://doi.org/10.1183/09031936.98.12020438
16. Oliveira Jorge PP, Lima JHP, Chong E Silva DC, Medeiros D, Solé D, Wandalsen GF. Impulse oscillometry in the assessment of children's lung function. Allergol Immunopathol (Madr). 2019;47(3):295-302. https://doi.org/10.1016/j.aller.2018.03.003
17. Vogel J, U Smith. Impulse Oscillometry-pmi Verlags Gmbh, Frankfurt am Main 1994.
18. Frei J, Jutla J, Kramer G, Hatzakis GE, Ducharme FM, Davis GM. Impulse oscillometry: Reference values in children 100 to 150 cm in height and 3 to 10 years of age. Chest. 2005;128(3):1266-73. https://doi.org/10.1378/chest.128.3.1266
19. Pereira CA. Espirometria. J Pneumol. 2002;28(3):S1-S82.
20. Komarow HD, Skinner J, Young M, Gaskins D, Nelson C, Gergen PJ, et al. A study of the use of impulse oscillometry in the evaluation of children with asthma: Analysis of lung parameters, order effect, and utility compared with spirometry. Pediatr Pulmonol. 2012;47(1):18-26. https://doi.org/10.1002/ppul.21507
21. Kim CW, Kim JS, Park JW, Hong CS. Clinical applications of forced oscillation techniques (FOT) in patients with bronchial asthma. Korean J Intern Med. 2001;16(2):80-6. https://doi.org/10.3904/kjim.2001.16.2.80
22. Nielsen KG, Bisgaard H. Discriminative capacity of bronchodilator response measured with three different lung function techniques in asthmatic and healthy children aged 2 to 5 years. Am J Respir Crit Care Med. 2001;164(4):554-9. https://doi.org/10.1164/ajrccm.164.4.2006119
23. Qi GS, Zhou ZC, Gu WC, Xi F, Wu H, Yang WL, et al. Detection of the airway obstruction stage in asthma using impulse oscillometry system. J Asthma. 2013;50(1):45-51. https://doi.org/10.3109/02770903.2012.743154
24. Song TW, Kim KW, Kim ES, Kim KE, Sohn MH. Correlation between spirometry and impulse oscillometry in children with asthma. Acta Paediatr. 2008;97(1):51-4. https://doi.org/10.1111/j.1651-2227.2007.00526.x
25. Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, et al. Interpretative strategies for lung function tests. Eur Respir J. 2005;26(5):948-68. https://doi.org/10.1183/09031936.05.00035205
26. Shi Y, Aledia AS, Tatavoosian AV, Vijayalakshmi S, Galant SP, George SC. Relating small airways to asthma control by using impulse oscillometry in children. J Allergy Clin Immunol. 2012;129(3):671-8. https://doi.org/10.1016/j.jaci.2011.11.002
27. Shi Y, Aledia AS, Galant SP, George SC. Peripheral airway impairment measured by oscillometry predicts loss of asthma control in children. J Allergy Clin Immunol. 2013;131(3):718-23. https://doi.org/10.1016/j.jaci.2012.09.022
28. Wang X, Dockery DW, Wypij D, Fay ME, Ferris BG Jr. Pulmonary function between 6 and 18 years of age. Pediatr Pulmonol. 1993;15(2):75-88. https://doi.org/10.1002/ppul.1950150204
29. Voorend-van Bergen S, Vaessen-Verberne AA, Landstra AM, Brackel HJ, van den Berg NJ, Caudri D, et al. Monitoring childhood asthma: Web-based diaries and the asthma control test. J Allergy Clin Immunol. 2014;133(6):1599-605. https://doi.org/10.1016/j.jaci.2013.10.005
30. Rodrigues JC, Cardieri JMA, Bussamra MHCF, Nakaie CMA, Almeida MB, Silva F° LVF, et al. Provas de função pulmonar em crianças e adolescentes. J Pneumol. 2002;28(Supl 3):S207-S221.
31. Lange P, Scharling H, Ulrik CS, Vestbo J. Inhaled corticosteroids and decline of lung function in community residents with asthma. Thorax. 2006;61(2):100-4. https://doi.org/10.1136/thx.2004.037978
32. Quanjer PH, Weiner DJ, Pretto JJ, Brazzale DJ, Boros PW. Measurement of $FEF_{25-75\%}$ and $FEF_{75\%}$ does not contribute to clinical decision making. Eur Respir J. 2014;43(4):1051-8. https://doi.org/10.1183/09031936.00128113
33. Lauhkonen E, Riikonen R, Törmänen S, Koponen P, Nuolivirta K, Helminen M, et al. Impulse oscillometry at preschool age is a strong predictor of lung function by flow-volume spirometry in adolescence. Pediatr Pulmonol. 2018;53(5):552-8. https://doi.org/10.1002/ppul.23977
34. Vink GR, Arets HG, van der Laag J, van der Ent CK. Impulse oscillometry: A measure for airway obstruction. Pediatr Pulmonol. 2003;35(3):214-9. https://doi.org/10.1002/ppul.10235
35. Moreau L, Crenesse D, Berthier F, Albertini M. Relationship between impulse oscillometry and spirometric indices in cystic fibrosis children. Acta Paediatr. 2009;98(6):1019-23. https://doi.org/10.1111/j.1651-2227.2009.01246.x
36. Wei X, Shi Z, Cui Y, Mi J, Ma Z, Ren J, et al. Impulse oscillometry system as an alternative diagnostic method for chronic obstructive pulmonary disease. Medicine (Baltimore). 2017;96(46):1-12. https://doi.org/10.1097/MD.0000000000008543
37. Su ZQ, Guan WJ, Li SY, Ding M, Chen Y, Jiang M, et al. Significances of spirometry and impulse oscillometry for detecting small airway disorders assessed with endobronchial optical coherence tomography in COPD. Int J Chron Obstruct Pulmon Dis. 2018;13:3031-44. https://doi.org/10.2147/COPD.S172639
38. Malmberg LP, Pelkonen A, Poussa T, Pohianpalo A, Haahtela T, Turpeinen M. Determinants of respiratory system input impedance and bronchodilator response in healthy Finnish preschool children. Clin Physiol Funct Imaging. 2002;22(1):64-71. https://doi.org/10.1046/j.1365-2281.2002.00396.x
39. Peirano R. Oscilometría de impulso (IOS) en niños. Neumol Pediátr. 2010;5(2):89-95.