Original Article

Usefulness of impulse oscillometry for the assessment of bronchodilator response in elderly patients with chronic obstructive airway disease

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Background: Impulse oscillometry (IOS) is a noninvasive and convenient technique to measure both airway resistance and reactance. This study aimed to evaluate whether IOS can be used to measure bronchodilator response (BDR) in elderly patients with asthma and chronic obstructive pulmonary disease (COPD) and also describe the difference between asthma and COPD.

Methods: Seventy patients (30 and 40 with asthma and COPD, respectively) over 65 years of age were enrolled. IOS and spirometry measurements were obtained before and after bronchodilator administration. Correlation analysis was used to compare the percentage changes in spirometry and IOS parameters after bronchodilator administration between the asthma and COPD groups.

Results: The changes in IOS parameters after bronchodilator administration were strongly correlated with changes in forced expiratory volume at 1 second (FEV_1) and forced expiratory flow at 25–75% ($FEF_{25–75}$). However, the percentage changes in IOS parameters failed to discriminate between the asthma and COPD groups. Receiver operating characteristic curve (ROC) analysis of resistance at 5 and 20 Hz (R5–20) at the best cutoff (–15.4% change) showed both high sensitivity and specificity for BDR.

Conclusions: IOS serves as a reliable and useful technique for identifying BDR in elderly patients with chronic obstructive airway disease. There was a difference in IOS parameters between the asthma and COPD groups; however, it was difficult to distinguish between both diseases. Further larger studies are required to investigate the real implications of using IOS in the clinical practice.

Keywords: Asthma; bronchodilator response (BDR); chronic obstructive pulmonary disease (COPD); oscillometry; spirometry

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Introduction

Chronic obstructive airway diseases, including asthma and chronic obstructive pulmonary disease (COPD), are characterized by chronic airway inflammation and airflow limitation and are one of the most common diseases in elderly individuals. The two conditions can be distinguished by differences in the age of onset, clinical manifestations, smoking history, atopic status, and comorbidities (1,2). However, this discrimination can be particularly difficult in older populations. In addition, patients frequently present features of both diseases, which is referred to as asthma-COPD overlap syndrome (ACOS) (1,3,4). Recent guidelines have proposed diagnostic criteria to distinguish asthma from COPD by clinical assessment of symptoms

and demonstration of airflow limitation (1). However, spirometry performance remains challenging for many elderly patients who have comorbidities that affect the test procedure and in cases where patient cooperation is lacking. Therefore, a more readily available test for bronchodilator response (BDR) is crucial for patient assessment.

Impulse oscillometry (IOS) measures airway resistance and reactance during tidal breathing. While conventional spirometry requires a forced expiratory maneuver, IOS is an effort-independent and patient-friendly modality for evaluating lung function and peripheral airway dysfunction (5). Recent studies have shown that IOS could be useful for diagnosing asthma and assessing asthma control, especially in children (6,7). Although IOS is being used increasingly in various asthma and COPD studies, its clinical utility remains unclear. To date, few investigations have used IOS parameters to evaluate airway reversibility in asthma and COPD (8,9).

This study aimed to evaluate whether IOS could demonstrate a BDR and play a role as an alternative to spirometry in elderly patients with chronic obstructive airway disease, such as asthma and COPD. In addition, we examined differences in IOS parameters between patients with asthma and COPD. Furthermore, the sensitivity and specificity of IOS measurements for identification of the BDR were computed.

Methods

Patients

The study enrolled 70 patients (>65 years of age) with asthma (n=30) or COPD (n=40) from the Haeundae Paik Hospital's outpatient clinics at the Inje University in Busan, Korea between June 2011 and October 2014. The study was approved by the hospital's medical ethics committee (approval number: 2012-090), and informed consent was obtained from all the enrolled patients. Asthma diagnosis was based on a clinical history of variable respiratory symptoms and pulmonary function according to the Global Initiative for Asthma (GINA) guidelines (1). COPD was diagnosed based on a clinical history of progressive, exertional dyspnea and pulmonary function characterized by not fully reversible airflow obstruction, which was defined as forced expiratory volume in 1 second (FEV_1)/forced vital capacity (FVC) <70% after bronchodilator administration (2). Patients with COPD had a smoking history of more than 20 pack-years. One pack-year was defined as twenty cigarettes smoked every day for one year. Patients who were not willing to enroll in the study and those with moderate-to-severe bronchiectasis, tuberculosis-destroyed lung, interstitial lung disease, active respiratory infectious disease, severe mental illness, moderate-to-severe heart failure, malignancy, and other severe systemic diseases were also excluded.

Study design

This was a single-center prospective study. Before inclusion, physicians reviewed the medical history and disease control status of each patient. In patients without a history of recent exacerbation over at least 4 weeks, baseline spirometry and IOS measurements were recorded. The patients allowed maintained use of their prescribed medication without any changes at least before 4 weeks. Albuterol was administrated as two puffs of 100 μg through a pressurized metered dose inhaler. Spirometry and IOS were repeated 15 minutes after albuterol administration. IOS was always performed before spirometry to avoid the influence of the forced maneuver.

Spirometry

We used the computerized spirometers, Vmax Encore 22D and 29C (SensorMedics Corp., Yorba Linda, California, USA), for all measurements. Spirometry was performed according to American Thoracic Society (ATS) guidelines (10). FVC, FEV_1, FEV_1/FVC, and forced expiratory flow at 25–75% ($FEF_{25–75}$) were measured. Predicted spirometry values were calculated in accordance with Choi's equation, which has been validated for the Korean population (11). The best of at least three technically acceptable results was selected.

IOS

IOS was performed using the MasterScreen IOS system (Cardinal Health Germany, 234 GmbH, Hoechberg, Germany) following a standardized protocol based on the manufacturer's instructions. Each patient was seated upright, wore a nose clip, and pressed on their cheeks with their hands to prevent an upper airway shunt. To avoid air leakage, patients sealed their lips tightly around the mouthpiece. While the impulse produced by the speaker is moving with patient's breathing, a pressure and flow transducer measured inspiratory and expiratory flow and pressure changes in the respiratory system. Mean respiratory resistance values were calculated over a period

Table 1 Baseline characteristics of the patients

Characteristics	Asthma (n=30)	COPD (n=40)
Sex (male/female)	7/23	36/4
Age, year (SD)	74.70 (4.84)	74.35 (4.70)
Height, cm (SD)*	154.97 (7.11)	163.2 (6.99)
Weight, Kg (SD)	61.93 (10.94)	60.50 (8.23)
Current smokers, No. (%)	1 (3.3)	8 (20.0)
Ex-smokers, No. (%)	1 (3.3)	29 (72.5)
Treatment No. (%)		
Oral medication except OCS	4 (13.3)	2 (5.0)
LAMA or LABA	0	7 (17.5)
ICS	2	0
LAMA + LABA	0	2 (5.0)
ICS + LABA	5 (16.7)	5 (12.5)
ICS + LAMA + LABA	0	5 (12.5)
LAMA or LABA + oral medication except OCS	0	2 (5.0)
ICS + LAMA + oral medication except OCS	13 (43.3)	4 (10.0)
ICS + LAMA + LABA + oral medication except OCS	1 (3.3)	10 (25.0)
ICS + LAMA + LABA oral medication + OCS	0	1 (2.5)

*, P<0.05 between groups. COPD, chronic obstructive pulmonary disease; SD, standard deviation; OCS, oral corticosteroid; LAMA, long-acting muscarinic antogonists; LABA, long-acting β2-agonist; ICS, inhaled corticosteroid.

of 30 seconds in a frequency range of 5 to 35 Hz. IOS parameters such as resistance at 5 Hz (R5), resistance at 20 Hz (R20), frequency dependence of resistance calculated as the difference between resistance at 5 and 20 Hz (R5–20), reactance at 5 Hz (X5), resonant frequency (Fres), and area of reactance (AX) were recorded. R5 and R20 represent total airway resistance and resistance of the central, large airway, respectively. In central, large airway obstruction, the resistance increases at all frequencies. Conversely, in small airway obstruction, the resistance at lower frequencies increases but is unchanged at higher frequencies that do not reach the small airways. Reactance at low frequencies, such as X5, can provide information about the distal airway. Fres represents the degree of airway obstruction and is elevated in both restrictive and obstructive pulmonary disease. AX is another common parameter, and represents the total reactance at all frequencies between 5 Hz and Fres (5,12,13). In the present study, we rejected IOS measurements with coherence values <0.6 between 5 and 15 Hz, or <0.8 for frequencies >20 Hz. The best of three acceptable attempts with the lowest respiratory resistances was chosen for the final data analysis. During this study, one technician obtained all IOS measurements.

Data and statistical analysis

Statistical analysis was performed using SAS 9.2 (SAS Institute, Cary, NC, USA). Data were assessed for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests before further analysis. Significance was defined as a P<0.05. Coefficients of correlation and regression analysis were used to identify the correlations between percentage changes in spirometry measurements and IOS parameters after bronchodilator administration. A *t*-test was used to compare means of variables of interest between the bronchodilator positive and control groups. Subgroup analyses were performed to identify differences associated with the BDR, defined as an FEV_1 change >12% of the predicted value and an increase in volume >200 mL (14) in both bronchodilator positive and negative groups by using the Mann-Whitney test. In addition, subgroup analysis was performed to identify the differences after reclassifying asthma and ACOS according to the GINA 2014 (1,3,4) and the COPD group using the Mann-Whitney test. The receiver operating characteristic curve (ROC) method was used to evaluate the utility of IOS parameters in identifying BDR. ROC area under the curve (AUC) values with estimated standard error and optimal IOS cutoff values based on maximizing the sum of sensitivity and specificity were calculated for each of the IOS values. We analyzed the AUC as the value of change for each of the IOS values before and after bronchodilator use.

Results

Baseline patient characteristics

Baseline patient characteristics are presented in *Table 1*. The mean patient age in the asthma and COPD groups was 74.7±4.8 and 74.4±4.7 years, respectively (P=0.761). The mean height of the asthma group was significantly

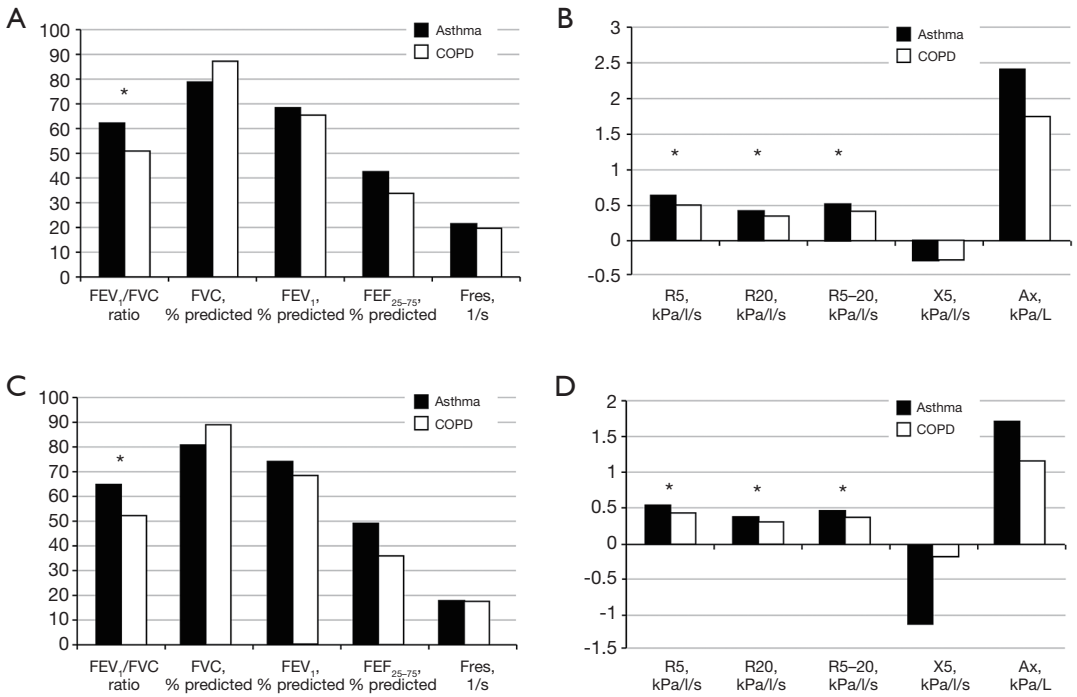

Figure 1 Spirometry and IOS profiles before and after bronchodilator administration. (A,B) Before bronchodilator administration; (C,D) after bronchodilator administration. FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; $FEF_{25–75}$, forced expiratory flow at 25–75%; Fres, resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; AX, area of reactance; IOS, impulse oscillometry. Data are means. *, asymptotic significance (P<0.001).

lower than that of the COPD group. This was due to a sex ratio imbalance between groups. There was no significant difference in weight between groups (*Table S1*). There were no intergroup differences in spirometry parameters, such as FVC, FEV_1, and $FEF_{25–75}$, before or after bronchodilator administration. However, IOS indices representing airway resistance, such as R5, R20, and R5–20, were significantly higher in the asthma group compared with those in the COPD group both before and after bronchodilator administration. There were no significant intergroup differences in Fres, X5, and AX (*Figure 1*, *Table S2*).

Correlation analysis between percentage changes in IOS and spirometry parameters after bronchodilator administration

Correlations between percentage changes in IOS and spirometry parameters after bronchodilator administration were analyzed in all patients. The percentage change in FEV_1 showed significant correlation with the changes in all IOS parameters. In particular, the correlations between percentage changes in FEV_1 and those in R5 and R5–20 were relatively strong with r values of –0.671 (P<0.001) and –0.640 (P<0.001), respectively. In addition, significant correlations were also observed between the percentage change in $FEF_{25–75}$ and the percentage changes in IOS parameters (*Figure 2*, *Table S3*).

Discrimination between asthma and COPD using percentage changes in IOS parameters after bronchodilator administration

We attempted to discriminate between the asthma and COPD groups on the basis of the percentage changes in IOS parameters before and after bronchodilator administration. There were no significant intergroup differences in the percentage changes in R5 and R5–20, which showed the strongest correlation with spirometry in the whole-group analysis (*Figure 3*). In addition, there were no significant differences between groups in the other IOS parameters, such as Fres, R20, X5, and Ax (*Table S4*). However, when we reclassified ACOS under the asthma group, Fres, R5, and R5–20 showed significant differences between the asthma + ACOS group and COPD group (*Table 2*).

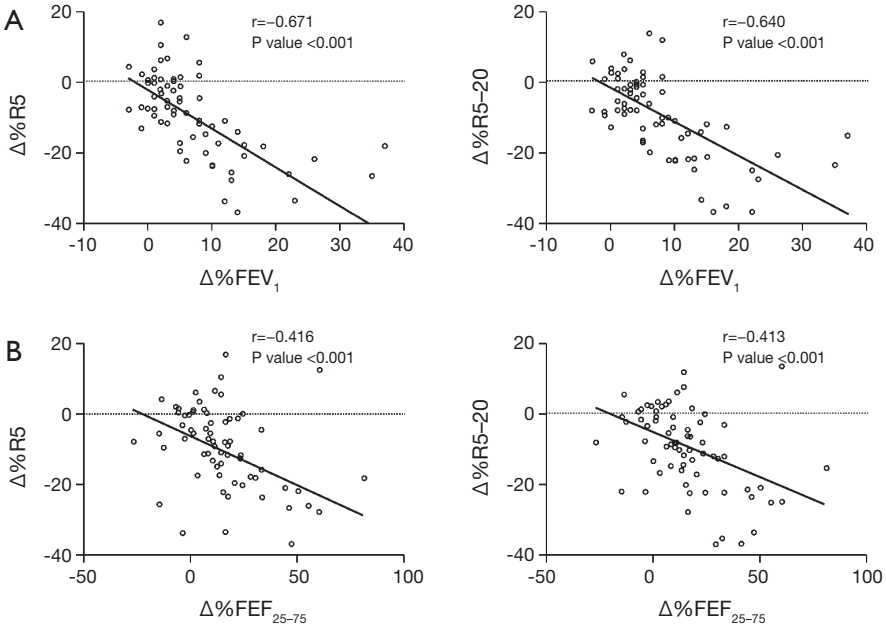

Figure 2 Correlation between percentage changes in IOS and spirometry parameters after bronchodilator administration in whole-group analysis. (A) Correlation between the percentage changes in FEV_1 and R5 and between FEV_1 and R5–20 after bronchodilator administration. The percentage change in FEV_1 showed significant negative correlations with the change in R5 (r=–0.671, P<0.001) and R5–20 (r=–0.640, P<0.001). (B) Correlation between the percentage changes in $FEF_{25–75}$ and R5 and between FEV_1 and R5–20 after bronchodilator administration. The percentage change in $FEF_{25–75}$ also showed significant negative correlations with the changes in R5 (r=–0.416, P<0.001) and R5–20 (r=–0.413, P<0.001). △%, percent change; r, Pearson correlation coefficient; FEV_1, forced expiratory volume in 1 second; R5, resistance at 5 Hz; $FEF_{25–75}$, forced expiratory flow at 25–75%; R5–20, resistance at 5 and 20 Hz; IOS, impulse oscillometry.

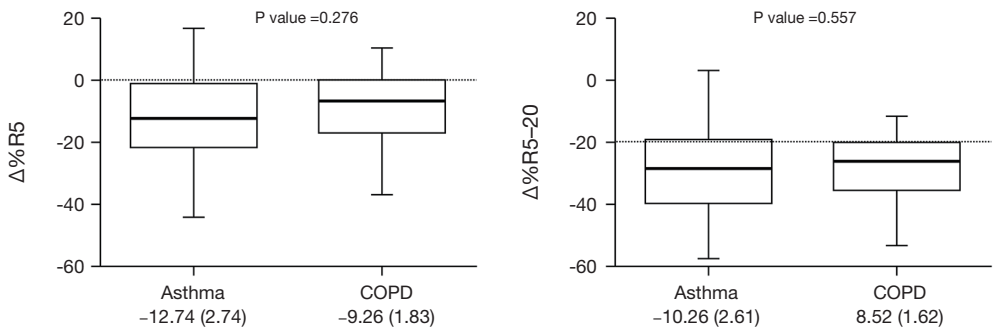

Figure 3 Discrimination between the asthma group and the COPD group based on percentage changes in R5 and R5–20. Results of a *t*-test to discriminate between the asthma and COPD groups based on percentage changes in R5 and R5–20 values show no significant difference between the two groups, with P values of 0.276 and 0.557 for percentage changes in R5 and R5–20 values, respectively. Data are means (SEM, standard error of measurement). △%, percentage change; COPD, chronic obstructive pulmonary disease; R5, resistance at 5 Hz; R5–20, resistance at 5 and 20 Hz.

Proposed cutoff values of IOS parameters for identifying BDR

Table 3 shows the numerical analysis of the ROC curve, including the AUC, sensitivity, specificity, and optimal cutoff values for each IOS parameter presented as percentage changes after bronchodilator administration. The sensitivity, specificity, and cutoff values from the ROC curves were compared with respect to BDR, which

was classified on based on FEV_1 values. Among the IOS parameters that showed statistical significance for BDR, the best cutoff point was –15.4%, which was the percentage change in R5–20 (sensitivity, 100%; specificity, 84.75%). When the discriminative properties of the percentage changes in IOS parameters for identifying a BDR were shown using ROC curves, the best profile for detecting BDR was obtained with R5–20, which had the highest AUC (0.971), followed by R5 (0.967) (*Figure 4*).

Table 2 Discrimination between ACOS + asthma and COPD based on differences in IOS parameters after bronchodilator administration

Variables	Asthma + ACOS	COPD	P value
Δ%Fres	–14.83 (1.99)	–6.70 (2.54)	0.017
Δ%R5	–13.76 (2.11)	–4.98 (1.63)	0.007
Δ%R20	–7.86 (1.98)	–4.18 (1.70)	0.226
Δ%R5–20	–11.64 (1.98)	–4.73 (1.51)	0.022
Δ%X5	–10.58 (4.30)	–9.50 (4.03)	0.871
Δ%AX	–26.80 (5.37)	–15.1 (5.53)	0.171
$\Delta\%FEV_1$	9.02 (1.38)	4.79 (0.749)	0.037
$\Delta\%FEF_{25-75}$	19.20 (3.12)	8.25 (3.00)	0.027

Data are means (SEM, standard error of measurement). ACOS, asthma-COPD overlap syndrome; COPD, chronic obstructive pulmonary disease; IOS, impulse oscillometry; Δ%, percent change; Fres: resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; Fres, resonant frequency; AX, area of reactance; FEV_1, forced expiratory volume in 1 second; FEF_{25-75}, forced expiratory flow at 25–75%.

Discussion

In this study, we identified BDR in asthma and COPD patients using IOS, which is consistent with the results of previous studies (9,15-17). There is an association between parameters such as respiratory impedance, reactance, and resistance using the forced oscillation technique (FOT) and the FEV_1, FVC, lung volume, and respiratory symptoms before and after use of Short-acting β agonist (SABA), long-acting β2-agonist (LABA), and inhaled corticosteroid/long-acting β2-agonist (ICS/LABA) in patients with COPD (18-21). Interestingly, spirometry, which is the standard method for measurement of pulmonary function, is unlikely to reflect the pathophysiology of small airway disease; therefore, there are limitations in detecting changes in small airways and airway trapping in patients with asthma and COPD. Importantly, we found that IOS differentiated small airway obstruction from large airway obstruction and was more sensitive than spirometry for peripheral airway disease. In line with this, the 2017 revision Global Initiative for Chronic Obstructive Lung Disease (GOLD) introduced a refinement of the clinical guidance system by separating spirometric evaluations. Spirometry remains a key tool in the diagnosis of COPD; however, it is excluded from pharmacotherapy recommendations. This revised assessment tool acknowledges the limitation of FEV, which can affect some therapeutic decisions for individualized patient care and highlights the importance of patient symptoms and exacerbation risks (2). IOS may be another option to replace spirometry because it detects the early pathophysiological changes in COPD that were not found on spirometry (21).

Recently, an oscillometry technique that can measure

Table 3 Performance of IOS cutoff values in identifying BDR

Variables	Cutoff value (%)	Sensitivity (%)	Specificity (%)	Youden index	AUC (95% confidence)
Δ%Fres	≤–18.8	90.91	81.36	0.7227	0.875 (0.744, 0.942)
Δ%R5	≤–18.2	100	86.44	0.8644	0.967 (0.894, 0.995)
Δ%R20	≤–18.1	90.91	91.53	0.8243	0.950 (0.870, 0.988)
Δ%R5–20	≤–15.4	100	84.75	0.8475	0.971 (0.900, 0.996)
Δ%X5	≤–22.0	72.73	79.66	0.5239	0.819 (0.709, 0.901)
Δ%AX	≤–36.1	100	71.19	0.7119	0.867 (0.765, 0.937)

*, asymptotic significance (P<0.001). IOS, impulse oscillometry; BDR, bronchodilator response; AUC, area under the curve; Fres, resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; AX, area of reactance.

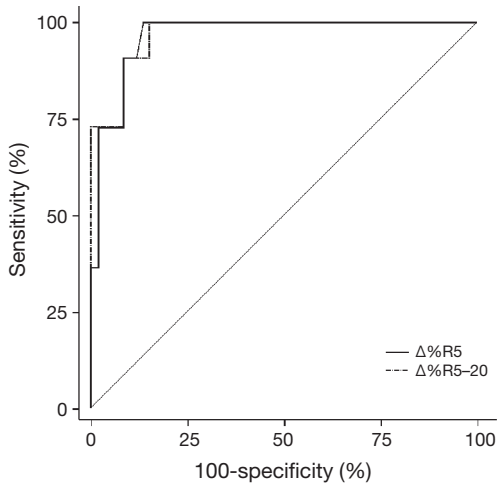

Figure 4 ROC curves of percentage changes in R5 and R5–20 for identifying BDR. ROC curves showing the relationship between sensitivity and 1-specificity of the percentage changes in R5 and R5–20 for identifying BDR. When R5 and R5–20 decrease more than 18.2% and 15.4%, respectively, the area under the ROC curve values are 0.967 and 0.971 respectively. △%, percentage change; R5, resistance at 5 Hz; R5–20, resistance at 5 and 20 Hz. ROC, receiver operating characteristic curve; BDR, bronchodilator response.

actual airway resistance and impedance has been described with extensive studies in pediatric patients (7,15,22-28). To date, many studies on the BDR of COPD patients have used the FOT method. The IOS is a variant of the FOT, which include some additional features and benefits. In FOT, sound waves of different frequencies are transmitted sequentially. This provides good temporal resolution for the measurement of respiratory resistance. In IOS, a pulse, which can be mathematically decomposed into different frequencies, is transmitted. This pulse, which contains all frequencies from 5–30 Hz, is transmitted into the lung. IOS has some advantages compared with FOT. IOS can calculate the impedance at every frequency from 5–30 Hz while FOT calculates at specific sine wave frequencies. In addition, the use of IOS decreases test duration. IOS shows improved signal to noise ratio; therefore, it is beneficial for detecting regional abnormalities. However, there are some disadvantages. IOS can be more forceful for the patient when compared with the gentler plain sinusoidal waves of FOT. Finally, it may change the lung mechanics slightly (13,29).

In clinical practice, the greatest advantage of IOS is that it requires no effort from the patient. The effort-independent nature of this method for evaluating lung function during normal tidal breathing is a notable characteristic of IOS, making it easy to use in children and patients with physical and cognitive limitations (22,30). IOS is useful for evaluating airway obstruction and bronchodilator responsiveness in pediatric asthma patients. Recent studies have also reported standard values and cutoff ranges for BDR in children (6,7,9,23-27,31). In addition, several studies in adult patients with asthma and COPD (32-34) have reported that IOS parameters correlate better with asthma control in adults than spirometry indices (35). One study has suggested that IOS should be the preferred method to measure bronchodilation in COPD (36). However, the clinical implications of using the IOS index in adult patients remains under discussion. Furthermore, several studies have stated that no acceptable reference values are available for adults (30). Nevertheless, IOS indices have been suggested to be good markers not only for the diagnosis of asthma and COPD but also for the evaluation of disease control in elderly patients who experience difficulties while performing spirometry and the bronchial provocation test (9,27,28).

In our study, the percentage changes in IOS parameters after bronchodilator administration significantly correlated with the percentage changes in FEV_1 in elderly patients with asthma and COPD. Confirming BDR is important for patient assessment; therefore, IOS may be useful for finding treatable components. Our results also showed a correlation between $FEF_{25–75}$ and changes in IOS parameters. This may be due to a reduction in airway trapping *via* bronchodilator treatment leads to a reduction in resistance value, leading to increased small airway recruitment and symptom improvements. Therefore, IOS may be useful for evaluating small airway disease in elderly patients with asthma and COPD.

It was difficult to distinguish between the asthma and COPD groups using either spirometry or IOS after bronchodilator administration in the present study. These were primarily because our patients continued to receive medication for asthma or COPD and were in a stable condition. Therefore, the post-bronchodilator differences were insufficient to discriminate between the two groups. Furthermore, some IOS parameters showed different results than we expected. Patients with small airway disease are predicted to have higher Fres and AX, and lower X5. However, there were no differences between the asthma and COPD groups in this study. The first possible explanation is that the longer the disease duration of asthma, the greater occurrence of more structural changes in the airway, such as airway remodeling, can occur, which can also affect

the IOS values. Second, the mean height of the asthma patients was significantly lower than the COPD group, due to an imbalance in sex ratio between groups. Decreased height can affect the IOS parameters. As a result, Fres and resistance were increased and X5 was decreased (13,29). Nevertheless, when we classified asthma and ACOS in the same group, changes to some IOS parameters (R5, R10, R5–20, and Fres) after bronchodilator administration showed significant differences. The ACOS should be separated from the COPD group to differentiate between asthma and COPD; however, confirming BDR is more clinically useful in the evaluation of treatable characteristics. In additional studies, we plan to IOS in a clinical setting to distinguish asthma, COPD, and ACOS. We also attempted to identify the cutoff values to detect BDR because of the importance of these values in developing a treatment strategy for chronic airway obstructive disease. We found that all IOS parameters had high AUCs.

Interestingly, R5 and R5–20 values were higher in the asthma group prior before and after bronchodilator administration in our study. This was inconsistent with the findings of a previous study, in which the asthma group was differentiated from the COPD group by analysis of the differences between inspiratory and expiratory IOS parameters, although the authors of that study failed to assess discrimination by whole-breath IOS analysis (37). Previous studies have shown that IOS can measure the small airway pathophysiology not measured by spirometry (38,39). Considering the populations in these studies, small airway obstruction may have been more severe in our asthma group than in previous studies. Since the results of a study in children showed that IOS parameters can predict asthma control, it is possible that asthma control in the patients in our asthma group was insufficient (7). Larger studies are needed to elucidate differences in IOS indices between asthma and COPD and to evaluate whether increased small airway obstruction improves after intensive treatment.

There were several limitations in our study. First, we could not enroll a normal control group. However, previous studies have shown significant differences in IOS values between healthy controls and patients with asthma or COPD (9,27,28,37). Second, we have proposed a cutoff value that can define BDR through changes in IOS parameters. The sample size in our study was too small to apply our optimal cutoff values for BDR in a clinical setting; therefore, we plan to conduct a larger study to obtain more reliable results. Third, there was a difference in the mean height between the asthma and COPD groups due to differences in the sex ratio between groups. The lower mean height in the asthma group may result in increased resistance and Fres and decreased reactance.

Conclusions

Our results show that IOS is a patient-friendly complement to spirometry, which may help elderly patients with asthma or COPD who have difficulty performing spirometry. We found that IOS showed a good correlation with the index of airway obstruction in spirometry and also detected BDR well. Notably, it may be essential to use IOS more than spirometry, which has many limitations with regard to the patient's condition and effort.

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Footnotes

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The study was approved by the Haeundae Paik Hospital's medical ethics committee (IRB number: 2012-090). Informed consent was obtained from all the enrolled patients.

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Supplementary

Table S1 Spirometry and IOS profiles before and after bronchodilator administration

Variables	Before bronchodilator administration			After bronchodilator administration		
	Asthma	COPD	P value	Asthma	COPD	P value
FEV_1/FVC ratio	62.10 (2.58)	50.95 (2.24)	0.000	56.10 (2.36)	52.38 (2.24)	0.002
FVC, % predicted	79.13 (3.67)	86.95 (2.45)	0.070	81.50 (3.72)	89.60 (2.45)	0.063
FEV_1, % predicted	69.00 (3.79)	65.05 (3.24)	0.430	74.67 (3.78)	68.63 (3.20)	0.225
$FEF_{25–75}$, % predicted	42.43 (4.93)	33.73 (5.08)	0.234	49.83 (5.29)	36.23 (5.04)	0.070
Fres, 1/s	21.57 (1.36)	19.86 (1.22)	0.356	18.11 (1.24)	17.72 (1.10)	0.813
R_5, kPa/1/s	0.63 (0.04)	0.49 (0.03)	0.006	0.55 (0.04)	0.43 (0.03)	0.007
R_{20}, kPa/1/s	0.41 (0.02)	0.34 (0.01)	0.004	0.38 (0.02)	0.31 (0.01)	0.005
$R_{5–20,}$ kPa/1/s	0.52 (0.03)	0.41 (0.02)	0.004	0.47 (0.03)	0.37 (0.02)	0.006
$X_{5,}$ kPa/1/s	–0.29 (0.03)	–0.27 (0.03)	0.191	–1.17 (0.93)	–0.17 (0.02)	0.216
AX kPa/L	2.42 (0.36)	1.74 (0.37)	0.199	1.73 (0.30)	1.16 (0.21)	0.102

Data represent means (SEM, standard error of measurement). IOS, impulse oscillometry; COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; $FEF_{25–75}$, forced expiratory flow at 25–75%; Fres, resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; AX, area of reactance.

Table S2 Comparison of height and weight according to disease type and sex

Variables	Height	Weight
Asthma (cm)	154.97 (7.11)	61.93 (10.94)
COPD (cm)	163.2 (6.99)	60.50 (8.23)
P value	0	0.533
Female (cm)	151.70 (4.84)	60.59 (11.73)
Male (cm)	164.67 (5.19)	61.44 (7.81)
P value	0	0.717

Data represent means (SD, standard deviation). COPD, chronic obstructive pulmonary disease.

Table S3 Pearson's correlation coefficient analysis between % change in IOS and spirometry parameters after bronchodilator administration in whole-group analysis

Variables	Δ%Fres	Δ%R5	Δ%R20	Δ%R5–20	Δ%X5	Δ%Fres
Δ%FEV_1 % predicted	−0.501*	−0.671*	−0.508*	−0.640*	−0.450*	−0.541*
Δ%$FEF_{25–75}$ % predicted	−0.402*	−0.416*	−0.381*	−0.413*	−0.235†	−0.341‡

*, P<0.001; †, P=0.051; ‡, P=0.004. IOS, impulse oscillometry; Δ%, percent change; FEV_1, forced expiratory volume in 1 second; $FEF_{25–75}$, forced expiratory flow at 25–75%; Fres, resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; AX, area of reactance.

Table S4 Discrimination between asthma group and COPD group on the basis of the percentage change in IOS parameters

Variables	Asthma	COPD	P value
Δ%Fres	−15.33 (2.51)	−9.58 (2.08)	0.08
Δ%R5	−12.74 (2.74)	−9.26 (1.83)	0.28
Δ%R20	−6.35 (2.59)	−6.78 (1.61)	0.88
Δ%R5–20	−10.26 (2.61)	−8.53 (1.62)	0.56
Δ%X5	−5.85 (7.32)	−13.47 (3.22)	0.23
Δ%AX	−22.94 (7.32)	−22.67 (4.54)	0.97
Δ%FEV_1	9.23 (1.85)	6.33 (0.96)	0.14

Data represent means (SEM, standard error of measurement). COPD, chronic obstructive pulmonary disease; IOS, impulse oscillometry; Δ%, percent change; Fres, resonant frequency; R5, resistance at 5 Hz; R20, resistance at 20 Hz; R5–20, resistance at 5 and 20 Hz; X5, reactance at 5 Hz; AX, area of reactance; FEV_1, forced expiratory volume in 1 second.