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Usefulness of Impulse Oscillometry in Predicting the Severity of Bronchiectasis

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Abstract

Background: Bronchiectasis is a chronic respiratory disease that leads to airway inflammation, destruction, and airflow limitation, which reflects its severity. Impulse oscillometry (IOS) is a non-invasive method that uses sound waves to estimate lung function and airway resistance. The aim of this study was to assess the usefulness of IOS in predicting the severity of bronchiectasis.
Methods: We retrospectively reviewed the IOS parameters and clinical characteristics in 145 patients diagnosed with bronchiectasis between March 2020 and May 2021. Disease severity was evaluated using the FACED score, and patients were divided into mild and moderate/severe groups.
Results: Forty-four patients (30.3%) were in the moderate/severe group, and 101 (69.7%) were in the mild group. Patients with moderate/severe bronchiectasis had a higher airway resistance at 5 Hz (R5), a higher difference between the resistance at 5 and 20 Hz (R5–R20), a higher resonant frequency (Fres), and a higher area of reactance (AX) than patients with mild bronchiectasis. R5 ≥0.43, resistance at 20 Hz (R20) ≥0.234, R5–R20 ≥28.3, AX ≥1.02, reactance at 5 Hz (X5) ≤−0.238, and Fres ≥20.88 revealed significant univariable relationships with bronchiectasis severity ($p<0.05$). Among these, only X5 ≤−0.238 exhibited a significant multivariable relationship with bronchiectasis severity ($p=0.039$). The receiver operating characteristic curve for predicting moderate-to-severe bronchiectasis of FACED score based on IOS parameters exhibited an area under the curve of 0.809.
Conclusion: The IOS assessed by the disease severity of FACED score can effectively reflect airway resistance and elasticity in bronchiectasis patients and serve as valuable tools for predicting bronchiectasis severity.

Keywords: Bronchiectasis; Impulse Oscillometry; Disease Severity

Introduction

Bronchiectasis is a chronic respiratory condition characterized by the abnormal dilatation of the bronchi, leading to symptoms such as persistent coughing, increased sputum production, and frequent respiratory infections[1]. Previous studies have reported an increasing prevalence of bronchiectasis, both in the United Kingdom, with a 40% rise between 2004–2014[2] and globally[3]. South Korea also recorded a prevalence ranging from 464 to 480 cases per 100,000 individuals from 2012 to 2017[2-4].

The prognosis of bronchiectasis varies significantly, with some patients experiencing a milder form over an extended period, whereas others undergo rapid progression with frequent exacerbations and accelerated lung function decline[1,5]. Accurate assessment of bronchiectasis severity is crucial for providing comprehensive care and predicting disease progression. Currently, bronchiectasis severity index (BSI) and the FACED (an acronym derived from five variables, F: forced expiratory volume in 1 second [FEV_1]; A: age; C: chronic colonization by *Pseudomonas aeruginosa* [PA], E: radiological extension [number of pulmonary lobes affected], and D: dyspnea) score are the two leading methods used to evaluate bronchiectasis severity in adults[6,7]. The BSI is a multi-dimensional scoring system developed to predict disease severity, hospitalization, and mortality in bronchiectasis, whereas the FACED score incorporates factors such as patient age, FEV_1, bacterial colonization, radiological extent of bronchiectasis, and dyspnea level to provide a reliable measure of disease severity and prognosis.

Impulse oscillometry (IOS) is a non-invasive method of measuring the mechanical properties of the respiratory system, offering an alternative to traditional methods, such as spirometry. By oscillating sound waves of different frequencies through the respiratory system, IOS can measure airway resistance and reactance[8]. Its ability to be performed during normal tidal breathing with minimal patient cooperation renders it particularly useful for older patients or those with cognitive impairments, poor motor skills, and breathing difficulties[9]. Owing to its ability to detect peripheral airway damage and changes in lung elasticity, IOS holds promise in evaluating various respiratory conditions[10-12]. Considering that bronchiectasis, characterized by bronchial dilatation and elastin loss, results in decreased lung elasticity and mild-to-moderate airflow limitation[13], IOS can help detect such changes, suggesting its potential in assessing the severity of bronchiectasis[14].

Accordingly, we aimed to explore the potential of IOS in predicting the severity of bronchiectasis, contributing to the comprehensive management of this condition.

Materials and Methods

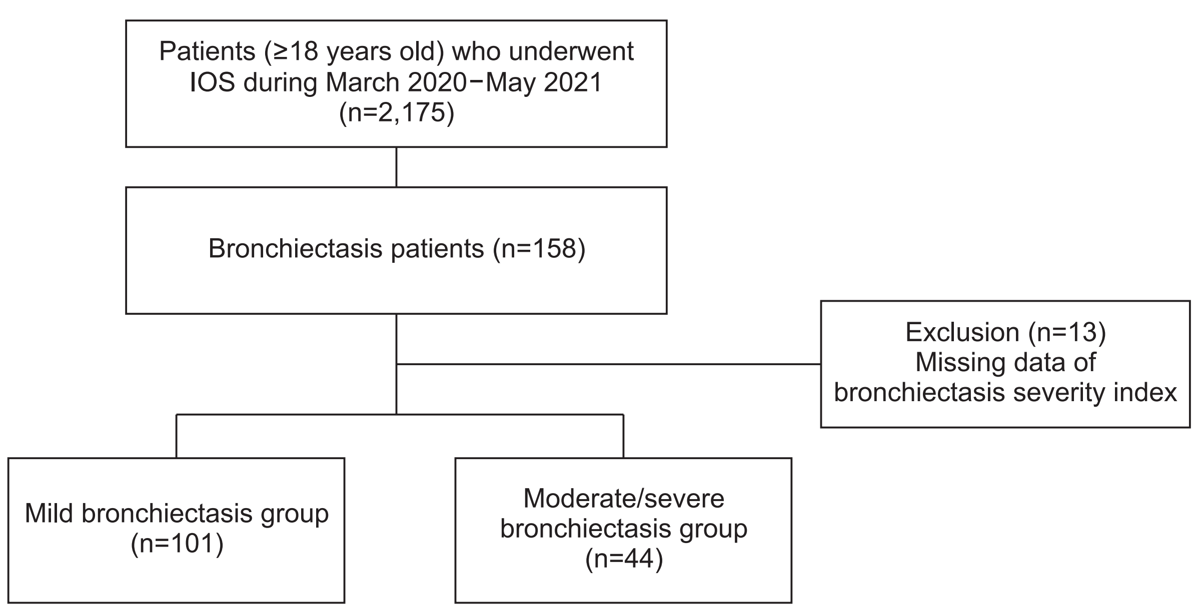
1. Patients and study design

In this retrospective study, we reviewed the medical records of patients aged 18 and above who underwent IOS examinations between March 2020 and May 2021. The bronchiectasis was defined based on chest computed tomography (CT) findings, which indicated widened bronchi with an internal diameter higher than that of the adjacent pulmonary artery and/or visible airways in the lung periphery. Patients with symptoms related to bronchiectasis, such as cough, sputum production, or dyspnea, were included. The patients who did not undergo the test for assessing the FACED score were excluded.

2. Bronchiectasis severity assessment

Bronchiectasis severity was analyzed using the FACED score, validated in patients with non-cystic fibrosis bronchiectasis. The FACED score includes variables such as age, FEV_1, modified Medical Research Council scale score, chronic colonization by PA, and radiologi-

Figure 1. Flowchart of the study patients. IOS: impulse oscillometry.



cal extent of disease on chest CT. Based on the FACED score, patients were categorized into two groups: mild (0–2 points in FACED score) and moderate/severe (higher than 3 points in FACED score). Supplementary data, including baseline patient characteristics, laboratory results, spirometry findings, and IOS parameters, were collected. The Institutional Review Board of the Yongin Severance Hospital approved this study, and

Table 1. Baseline characteristics according to the bronchiectasis severity

Variable	Mild group (n=101)	Moderate/Severe group (n=44)	p-value
Demographic			
Age, yr	67.87±10.33	76.20±7.34	<0.001
Sex			0.887
Male	18 (17.8)	9 (20.5)	
Female	83 (82.2)	35 (79.5)	
BMI, kg/m^2			0.540
<25	69 (68.3)	33 (75.0)	
≥25	32 (31.7)	11 (25.0)	
History of smoking (previous and current smoker)	28 (27.7)	14 (31.1)	0.676
Cumulative smoking exposure, PY	20 (10.5 to 30.0)	30 (10.0 to 50.0)	0.187
Hypertension	39 (38.6)	18 (40.9)	0.940
Diabetes mellitus	16 (15.8)	8 (18.2)	0.916
Pulmonary tuberculosis	30 (29.7)	17 (38.6)	0.388
Interstitial lung disease	3 (3.0)	0	0.603
History of operation, lung	1 (1.0)	2 (4.5)	0.454
Gastroesophageal reflux disease	25 (24.8)	9 (20.5)	0.728
Rhinitis	44 (43.6)	17 (38.6)	0.712
IOS parameter			
R5, kPa/L/sec	0.37 (0.28 to 0.50)	0.50 (0.42 to 0.65)	<0.001
R20, kPa/L/sec	0.27 (0.22 to 0.33)	0.29 (0.24 to 0.35)	0.151
R5–R20, %	26.30 (17.10 to 33.90)	43.25 (31.80 to 49.35)	<0.001
AX, kPa/L	0.66 (0.38 to 1.20)	2.41 (1.09 to 3.08)	<0.001
X5, kPa/L/sec	−0.12 (−0.17 to −0.09)	−0.27 (−0.36 to −0.16)	<0.001
Fres, Hz	17.14 (14.45 to 19.96)	23.96 (18.48 to 26.17)	<0.001
Spirometry results			
FVC, % predicted	78.8±15.2	60.5±18.1	0.286
FEV_1, % predicted	78.0±18.8	54.5±23.5	0.016
FEV_1/FVC ratio	72.0±9.1	63.6±17.4	<0.001
Other parameter for FACED score			
mMRC	0.0 (0.0 to 1.0)	1.0 (0.0 to 2.4)	0.007
Chronic colonization by *Pseudomonas aeruginosa*	1 (1)	5 (11.1)	0.011
Radiological extension (more than 2 lobes, no. of pulmonary lobes affected)	20 (19.8)	33 (73.3)	<0.001

Values are presented as mean±standard deviation, number (%), or median (interquartile range).
BMI: body mass index; PY: pack-years; IOS: impulse oscillometry; R5: resistance at 5 Hz; R20: resistance at 20 Hz; R5–R20: difference between the resistance at 5 and 20 Hz; AX: area of reactance; X5: reactance at 5 Hz; Fres: resonant frequency; FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 second; mMRC: modified Medical Research Council.

the requirement for informed consent was waived owing to its retrospective nature (IRB No. 9-2023-0115).

3. IOS and spirometry

The IOS measurements were assessed using the MasterLab IOS System (Erich Jaeger, Würzburg, Germany), preceded by conventional spirometry. Calibration was performed using a single volume of air (3 L) at different flow rates and a reference resistance device (0.2 kPa/L/sec). An experienced respiratory technician performed the IOS measurements, ensuring proper placement of the nose clip and oval hard plastic mouthpiece to prevent expired air leakage. Patients supported their cheeks with their hands to decrease shunt compliance. Results involving artifacts caused by breath-holding, coughing, vocalization, and swallowing were excluded. Various IOS parameters, including resonant frequency (Fres), resistance at 5 Hz (R5), resistance at 20 Hz (R20), difference between the resistance at 5 and 20 Hz (R5–R20), reactance at 5 Hz (X5), and area of reactance (AX), were measured. Subsequently, spirometry tests were performed using a pneumotachometer equipped with a Lilly head (MasterScreen system, Erich Jaeger) within 5 minutes post-IOS measurements. Patients were instructed to perform a standard forced expiratory maneuver, and three reproducible trials were collected for analysis, with the best result out of three attempts selected for further analyses.

4. Statistical analysis

Statistical analysis was performed using the R software version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables are presented as frequencies and percentages, whereas continuous variables are presented as mean±standard deviation or median (interquartile range). Pearson's chi-squared of Fisher's exact test was used to compare categorical variables between the mild and moderate/severe bronchiectasis groups, whereas Student's t-test or Wilcoxon rank-sum test was used for continuous variables. Youden's index was employed to obtain the optimal cut-off values for IOS parameters (Supplementary Figures S1, S2). Univariable and multivariable logistic regression analyses were performed to calculate the odds ratio with 95% confidence interval. The Least Absolute Shrinkage and Selection Operator (LASSO) regression, a shrinkage and variable selection method for regression models, is an attractive option as it address-

Table 2. Univariable and multivariable analysis according to the bronchiectasis severity

Variable	Univariable			Multivariable		
	Odds ratio	95% CI	p-value	Odds ratio	95% CI	p-value
Male sex	0.977	0.316–2.747	0.966	1.571	0.423–5.582	0.486
BMI <25 kg/m^2	2.104	0.828–5.883	0.132	2.089	0.645–7.602	0.235
History of smoking	0.974	0.373–2.423	0.956			
Hypertension	1.507	0.626–3.597	0.355			
Diabetes mellitus	1.173	0.338–3.653	0.789			
Pulmonary tuberculosis	1.611	0.654–3.913	0.293			
Airway disease	0.711	0.296–1.739	0.448			
History of operation, lung	2.333	0.090–60.320	0.554			
Gastroesophageal reflux disease	0.762	0.250–2.085	0.611			
Rhinitis	0.528	0.205–1.277	0.167			
R5 ≥0.43	4.415	1.792–11.824	0.002			
R20 ≥0.234	3.900	1.340–14.282	0.021			
R5–R20 ≥28.3	6.399	2.457–19.044	<0.001	1.484	0.321–6.369	0.597
AX ≥1.02	8.743	3.400–25.021	<0.001	2.630	0.423–16.872	0.297
X5 ≤−0.238	10.904	4.054–31.970	<0.001	4.205	1.113–17.517	0.039
Fres ≥20.88	6.178	2.476–16.168	<0.001	1.274	0.286–5.481	0.745

CI: confidence interval; BMI: body mass index; R5: resistance at 5 Hz; R20: resistance at 20 Hz; R5–R20: difference between resistance at 5 and 20 Hz; AX: area of reactance; X5: reactance at 5 Hz; Fres: resonant frequency.

es both problems. We used the LASSO regression to select independent IOS parameters, along with sex and body mass index (BMI), for the multivariable logistic regression analysis. A scoring tool was developed based on the beta coefficient from the multivariable logistic regression analysis to predict bronchiectasis severity. The data were randomly divided into training (70%) and validation (30%) datasets for the development and validation of the scoring tool. Various performance measures, including the area under the curve (AUC), sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were used to assess the performance of the scoring tool. The robustness of the developed scoring tool for prediction performance was determined using 5-fold cross-validation. Statistical significance was set at $p<0.05$.

Results

1. Study patients

Among the 2,175 patients who underwent IOS examinations during the study period, 158 were diagnosed with bronchiectasis. Thirteen patients who did not undergo examinations for the FACED score assessments were excluded, resulting in the inclusion of 145 patients in the final study cohort. Among these, 44 patients (30.3%) were categorized as having moderate/severe bronchiectasis, whereas 101 patients (69.7%) were classified as having mild bronchiectasis based on the FACED scores (Figure 1).

2. Baseline characteristics and airway resistance according to bronchiectasis severity

Table 1 presents the baseline characteristics of the patients in the two groups. The mean age was 76.20±7.34 in the moderate/severe group, which was significantly higher than that in the mild group ($p<0.001$). The proportion of women in the mild group was higher (82.2%) than that in the moderate/severe group (79.5%). No significant differences were observed in terms of sex, BMI, smoking history, and comorbidities between the two groups.

Spirometry results revealed that the mean FEV_1 was 78.0% predicted and 54.5% predicted in mild and moderate/severe groups, respectively. Conversely, the mean FEV_1/forced vital capacity (FVC) ratio was 72.0% and 63.6% in the mild and moderate/severe groups, respectively. In terms of the IOS parameters, patients in the moderate/severe group exhibited higher airway R5 (0.53 vs. 0.41, $p<0.001$), a greater difference between the R5−R20 (39.85 vs. 26.81, $p<0.001$), higher AX (2.44 vs. 1.06, $p<0.001$), and a higher Fres (22.52 vs. 17.54, $p<0.001$) than those in the mild group. Additionally, the X5 was lower in the moderate/severe group compared with that in the mild group (−0.28 vs. −0.14, $p<0.001$).

3. Prognostic factors of bronchiectasis severity

Univariable and multivariable logistic regression models were employed to investigate the prognostic factors related to bronchiectasis severity in our study patients (Table 2). Age, sex, BMI, and underlying comorbidities did not significantly influence disease severity. However, the IOS test parameters exhibited a significant correlation. R5 ≥0.43, R20 ≥0.234, R5−R20 ≥28.3, AX ≥1.02,

Table 3. Data regarding the bronchiectasis severity model using the impulse oscillometry parameters

Risk factor	Beta coefficient	Assigned score
Male sex	0.452	0.5
BMI <25 kg/m^2	0.737	0.7
R5−R20 ≥28.3	0.395	0.4
AX ≥1.02	0.967	1.0
X5 ≤−0.238	1.436	1.4
Fres ≥20.88	0.242	0.2
Total	-	4.2

BMI: body mass index; R5−R20: difference between the resistance at 5 and 20 Hz; AX: area of reactance; X5: reactance at 5 Hz; Fres: resonant frequency.

Figure 2. Histogram of new bronchiectasis severity scoring based on a cut-off score of 2.3. A bronchiectasis severity model incorporating the impulse oscillometry parameters was developed based on the beta coefficient of the multivariable logistic regression analysis. The scoring system categorized participants into two groups using a cut-off score of 2.3.

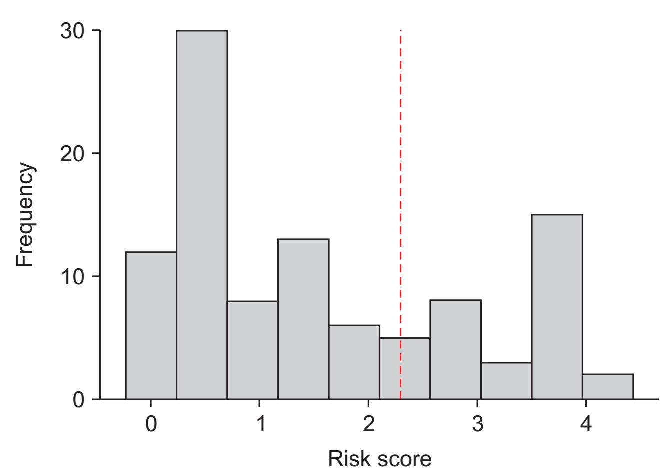


Table 4. Data regarding the training and validation datasets for predicting the severity of bronchiectasis

	Group 2 (moderate-to-severe bronchiectasis)	Group 1 (mild bronchiectasis)	Total
Training			
Score ≥2.3	21	12	33
Score <2.3	10	59	69
Total	31	71	102
Sensitivity	0.677 (0.486–0.833)		
Specificity	0.831 (0.723–0.910)		
PPV	0.636 (0.451–0.796)		
NPV	0.855 (0.750–0.928)		
Accuracy	0.784 (0.692–0.860)		
Validation			
Score ≥2.3	11	3	14
Score <2.3	2	27	29
Total	13	30	43
Sensitivity	0.769 (0.462–0.950)		
Specificity	0.800 (0.614–0.923)		
PPV	0.625 (0.354–0.848)		
NPV	0.889 (0.708–0.976)		
Accuracy	0.791 (0.640–0.900)		

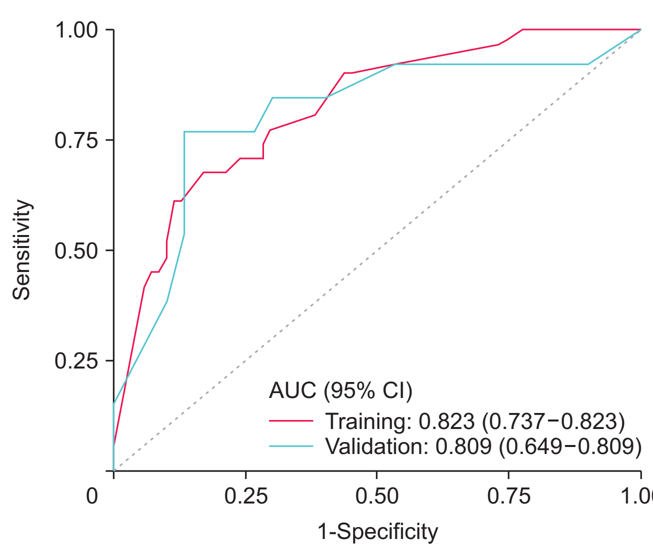
Values are presented as number or proportion (95% confidence intervals).
PPV: positive predictive value; NPV: negative predictive value.

X5 ≤−0.238, and Fres ≥20.88 indicated significant univariable relationships with bronchiectasis severity ($p<0.05$). Among these parameters, only X5 ≤−0.238 demonstrated a significant multivariable relationship with bronchiectasis severity ($p=0.039$).

4. Bronchiectasis severity model using the IOS parameters

A bronchiectasis severity model incorporating the IOS parameters was developed based on the beta coefficient of the multivariable logistic regression analysis (Table 3). The scoring system categorized participants into two groups using a cut-off score of 2.3 (Figure 2). To develop and validate this scoring tool, the entire dataset was randomly split into training (70%) and validation (30%) sets (Supplementary Table S1). Repeated 5-fold cross-validation using the same dataset yielded an average AUC of 0.775, indicating robust and reproducible results (Supplementary Table S2). Table 4 presents the sensitivity, specificity, PPV, NPV, and accuracy of the training and validation datasets. The sensitivity, specificity, PPV, NPV, and overall accuracy of the scoring system were 0.769, 0.800, 0.625, 0.889, and 0.791,

Figure 3. Area under the curve (AUC) based on the new scoring for the severity of bronchiectasis based on the FACED score. The AUCs of the new scoring tool using impulse oscillometry for predicting moderate-to-severe bronchiectasis of FACED scores are 0.823 (training data) and 0.809 (validation data). CI: confidence interval.



respectively (Table 4). The AUCs of the new scoring tool based on the IOS parameters for predicting moderate-to-severe bronchiectasis of FACED scores were 0.823 (training data) and 0.809 (validation data) (Figure 3).

5. Correlation between iFACED score using IOS parameters and FACED score

The iFACED score was developed using four IOS parameters (R5–R20, Ax, X5, Fres) instead of FEV_1. Points were allocated as follows: 2 points if the IOS parameter was above or below a certain cut-off, and 0 points otherwise. Figure 4 presents scatter plots and correlation values between the FACED score and four variations of the iFACED score. Figure 5 displays the receiver operating characteristics curves and AUC values for the parameters used in the iFACED, indicating a very strong correlation between the FACED score and the iFACED score with AUC values exceeding 0.9.

Discussion

We investigated the potential application of IOS in predicting the prognosis and severity of bronchiectasis. Accordingly, we included 145 patients diagnosed with bronchiectasis, among whom 44 had moderate-to-severe bronchiectasis, and the remaining 101 patients had mild forms of the condition. Our results revealed a correlation between multiple IOS parameters and the severity of bronchiectasis, suggesting that our novel scoring system incorporating IOS parameters with sex and BMI could effectively reflect bronchiectasis severity.

The IOS system measurement of airway resistance

Figure 4. The scatter plots and correlation values between the FACED score and four variations of the iFACED score. “iFACED score” is a data that replaces the forced expiratory volume in 1 second % predicted in the FACED score with the impulse oscillometry parameter. (A) Difference between resistance at 5 and 20 Hz (R5–R20), (B) area of reactance (AX), (C) reactance at 5 Hz (X5), and (D) resonant frequency (Fres).

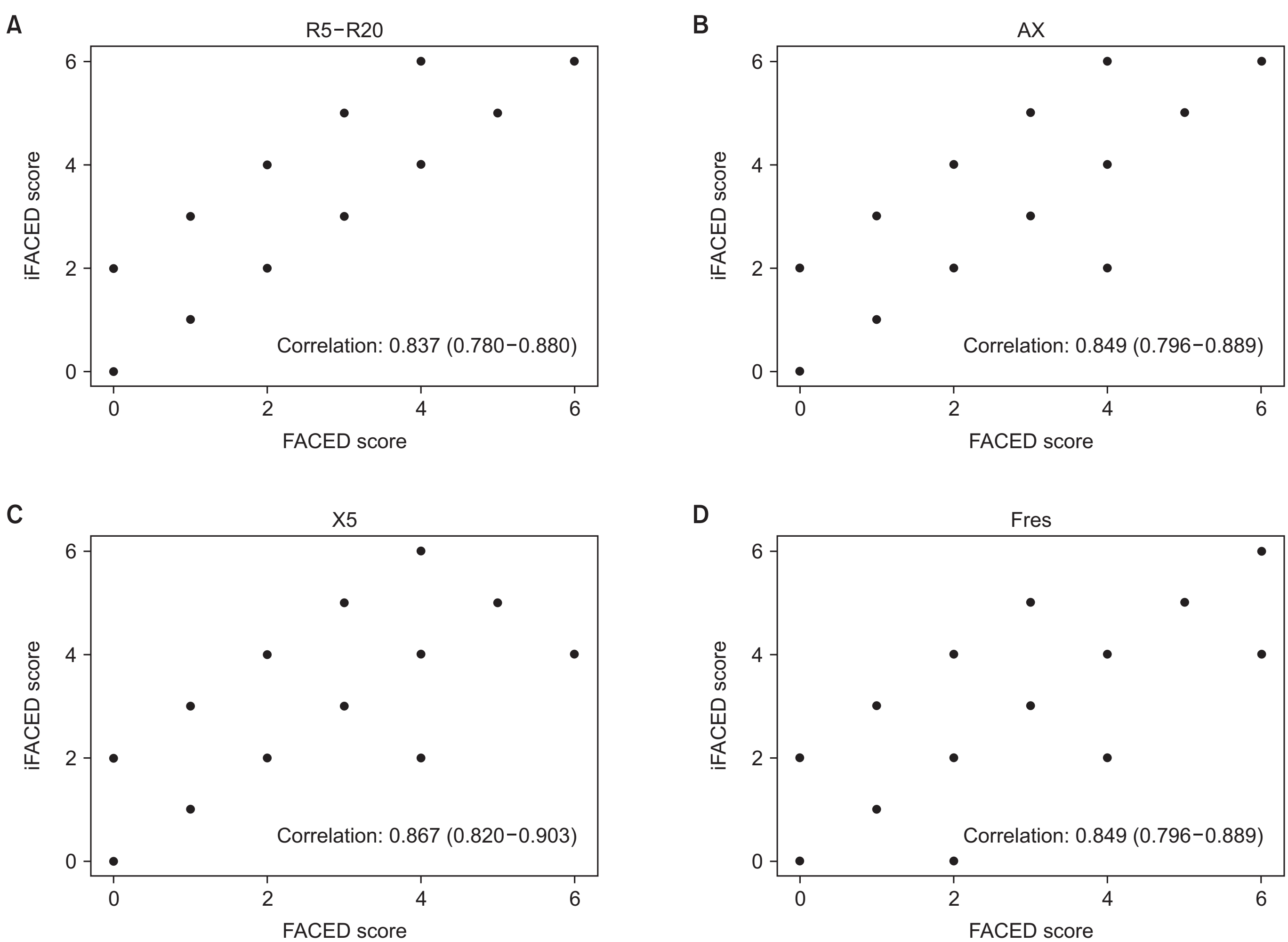
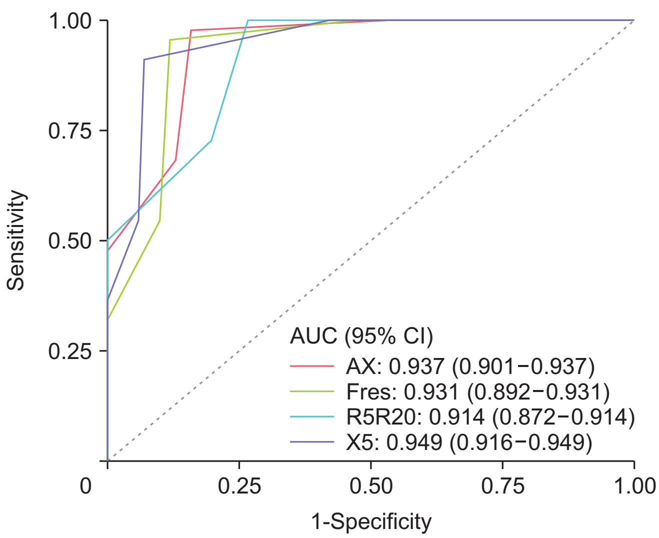


Figure 5. The receiver operating characteristic curves and area under the curve (AUC) values for the parameters used in the iFACED, indicating a very strong correlation between the FACED score and the iFACED score with AUC values exceeding 0.9. "iFACED score" is a data that replaces the forced expiratory volume in 1 second % predicted in the FACED score with the impulse oscillometry parameter. CI: confidence interval; AX: area of reactance; Fres: resonant frequency; R5–R20: difference between the resistance at 5 and 20 Hz; X5: reactance at 5 Hz.



and reactance[15]. The main parameters of the IOS include the R5, R20, R5–R20, X5, Fres, and AX[9,15]. These parameters offer a more sensitive indication of abnormal airway physiology than spirometry, presenting a novel avenue for assessing various lung diseases[16]. IOS parameters can help accurately detect airway obstruction and bronchodilator responses just as accurately as FEV_1 and FEV_1/FVC, suggesting a supplementary role for IOS in the diagnosis and treatment of adult asthma[17-21]. Additionally, IOS parameters have demonstrated utility in assessing patients with chronic obstructive pulmonary disease and interstitial lung disease, aiding in the differentiation between these conditions[22,23].

The detection of changes in the bronchi and reduced lung elasticity observed in bronchiectasis renders IOS a suitable tool for assessing its severity. Several previous studies have explored IOS parameters in assessing bronchiectasis severity, with some highlighting correlations between Fres and FACED scores[24], whereas others noted associations between FACED scores and peripheral resistance than X5 or Fres[25]. Despite these promising findings, uncertainties remain, warranting further investigation.

Our findings underscore the potential of IOS in assessing bronchiectasis severity, offering valuable insights into changes in airway resistance and reactance that relate to lung function deterioration in patients with bronchiectasis. Among various IOS parameters, reactance (X5), reflecting decreased lung elasticity, proved to be the most significant in representing bronchiectasis severity in the multivariable analysis. Additionally, multiple IOS parameters significantly differed between the mild and moderate/severe bronchiectasis groups. Our proposed scoring model, integrating various IOS indicators reflecting peripheral resistance and reactance, demonstrated a relatively strong correlation with the preexisting FACED score (AUC, 0.809). Also, it demonstrates a strong correlation between the FACED score and the iFACED scores, which converted from FEV_1 to one of IOS parameters (R5–R20, Ax, X5, Fres) in the existing FACED score with AUC values exceeding 0.9. However, further research is required to validate and establish the use of IOS in bronchiectasis and explore its potential application in clinical practice.

Considering the observed global increase in bronchiectasis prevalence, understanding the relationship between IOS and bronchiectasis severity is crucial. Accurate prediction of disease severity and progression is essential for effective patient management. The non-invasive and accessible nature of IOS makes it a promising tool for enhancing the assessment of bronchiectasis severity.

However, our study had some limitations. The relatively small sample size may limit the generalizability of our findings, necessitating future studies with larger patient cohorts to confirm the results and their applicability to diverse patient populations. And, the cross-sectional design of our study provides only a snapshot of patients at a particular time point, and a longitudinal study would provide further insights into the progression of bronchiectasis and the relevance of IOS parameters over time. Additionally, we were unable to analyze the another scoring system reflecting the severity of bronchiectasis, such as the BSI and E-FACED score, because it was difficult to accurately confirm the history of exacerbation. It is known that IOS measurements are influenced by gender and age-specific reference values[26]. However, finding clear references for different ages and genders among Koreans has proven difficult, our study has limitations due to the inability to present predicted values of IOS parameters adjusted through age and gender-specific references, and these limitations could influence the interpretation of our results.

Despite these limitations, our study has several strengths. It contributes to the limited research on the potential use of IOS in predicting the severity and prognosis of bronchiectasis. By clarifying the correlations between IOS parameters and bronchiectasis severity, our findings advance the understanding and application of IOS in assessing lung diseases. Furthermore, our findings pave the way for future research, particularly in refining the application of IOS in managing bronchiectasis, improving our understanding of disease progression, and enabling personalized and effective treatment strategies.

In conclusion, IOS parameters assessed by the disease severity of FACED score offer valuable insights into airway resistance and elasticity in bronchiectasis patients. As an evolving tool, IOS exhibits promise in predicting bronchiectasis severity and improving our understanding of the disease progression. However, to establish its clinical utility in managing bronchiectasis, further research involving larger patient cohorts and diverse disease stages is required to validate and extend the clinical utility of IOS in managing bronchiectasis.

Authors' Contributions

Conceptualization: Choi JS, Kim SR, Lee EH. Methodology: Choi JS, Heo SJ, Kim SR, Lee EH. Formal analysis: Choi JS, Heo SJ. Data curation: Choi JS, Heo SJ. Validation: Choi JS, Heo SJ. Investigation: Choi JS, Heo SJ, Kim SR, Lee EH. Writing - original draft preparation: Choi JS, Kim SR, Lee EH. Writing - review and editing: all authors. Approval of final manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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Supplementary Material

Supplementary material can be found in the journal homepage (http://www.e-trd.org).

Supplementary Table S1. Training and validation datasets for developing and validating the scoring tool.

Supplementary Table S2. Data regarding the repeated 5-folds cross-validation.

Supplementary Figure S1. Youden's index was employed to obtain the optimal cut-off values for impulse oscillometry parameters.

Supplementary Figure S2. Youden's index was employed to obtain the optimal cut-off values for the new scoring system using impulse oscillometry for predicting moderate-to-severe bronchiectasis of FACED scores.

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