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Research of the diagnostic utility of impulse oscillometry in patients with bronchiectasis

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Abstract
Background: Bronchiectasis is a chronic respiratory condition in which infection, inflammation, and damage of the airways all play a role. Intense airway inflammation is precipitated by pathogenic insults, resulting in chronic airway damage. Impulse oscillometry (IOS) is a noninvasive approach that might offer worldwide information on airway resistance by researching the mechanical waves superimposed upon breathing movements. It has been observed that IOS may differentiate peripheral airways abnormalities in chronic obstructive pulmonary disease (COPD), asthma, interstitial pulmonary disease (ILD) and pulmonary fibrosis (CF) with high degree of precision.
Methods: This research was carried out on 40 cases with bronchiectasis diagnosed by HRCT. Such cases were classified into two groups, according to Bronchiectasis Severity Index (BSI)(108): group I: Included 20 cases with mild to moderate bronchiectasis and group II: Included 20 cases with severe bronchiectasis. Cases included in the research were subjected to full history taking and complete physical examination. This includes: Complete blood count (CBC), sputum culture, chest x-ray to exclude cases with other lung diseases, High-Resolution Computerized Tomography (HRCT), that were interpreted for the presence, pattern and distribution of bronchiectasis, arterial blood gases, echocardiography, measuring systolic pulmonary artery pressure, pulmonary function tests (PFT), Impulse Oscillometry and reactance area (AX) were measured.
Results: Regarding disease duration, no significant differences was found between both groups while a statistically significant difference was observed between groups regarding the used medications. Regarding laboratory investigations, no significant difference was observed among the groups for any of the measured measurements. Regarding functional assessment data, A statistically evident difference was found between groups in the following: MEF 50%, FEV1% predicted, FEV1/FVC% and FVC% with no significant differences in FEV1. Regarding IOS measurements, A statistically evident difference was found between both groups in R5% predicted while no difference was observed regarding R5 actual, R20, AX, or X5.
Positive correlation was very high in between HRCT score and each of FEV1% predicted, FVC (%) AX, R5% predicted, R5 actual, R20 and X5 but negative correlation was very high in between HRCT score and MEF 75%, FEV1/FVC%
Conclusions: IOS measurements are markedly increased in cases with bronchiectasis and they are correlated with spirometric measurements and HRCT scores.

Keywords: Impulse oscillometry, HRCT, bronchiectasis**,** pulmonary function tests

Introduction
Bronchiectasis is a chronic lung illness in which infection, inflammation, and destruction of the airways are involved. The pathogenic insults cause intense airway inflammation, which results in persistent airway damage [1, 2].
In bronchiectasis, it is well-established that chest CT, particularly HRCT, provides more detailed information than chest X-rays (CXRs). A CT scan, unlike pulmonary function tests or CXRs, can diagnose bronchiectasis, localise and accurately describe areas of parenchymal abnormality, identify bronchiolar abnormalities and mucus plug up to terminal bronchi, and identify focal areas of air trapping as an indicator of peripheral airways disease [3].
In addition to high-resolution computed tomography (HRCT), pulmonary function tests (PFT) has served as the cornerstone of lung function tests used to evaluate bronchiectasis. Unfortunately, the significant delay between the onset of bronchiectasis and the radiologic and clinical diagnosis, when abnormalities are manifest, has limited the utility of PFT.

Inasmuch as the majority of controls demonstrated normal gas-exchange capacity, the diffusing capacity tests are also of limited value. Therefore, new techniques are advantageous for diagnosing bronchiectasis-related lung function impairment [4, 5].

Impulse oscillometry (IOS) is a technique that can provide global information regarding airway resistance by analysing the mechanical wave superimposed on respiratory manoeuvres. It is known that IOS can differentiate peripheral airways disorders in bronasthma, COPD, ILD, spinal muscular atrophy, and CF with high sensitivity. In addition, it can serve as a surrogate for PFT in reflecting changes in pulmonary function before and after bronchial provocation test makes it a valuable tool for identifying changes in airway calibre [6].

The aim of this research was to investigate the diagnostic utility of impulse oscillometry and its correlation with radiology and disease severity in cases with bronchiectasis.

Patients and Methods

This research was carried out on 40 cases with bronchiectasis diagnosed by HRCT, recruited from the outcase clinic and admitted in Chest Department, Tanta University Hospitals, starting from September 2017 to September 2021. Such cases were classified into two groups, according to Bronchiectasis Severity Index (BSI) (108): group I: Included 20 cases with mild to moderate bronchiectasis and group II: Included 20 cases with severe bronchiectasis.

Exclusion criteria: Age less than 12 years, smokers or ex. smokers, concomitant chronic lung disease or malignancy on HRCT, previous resectional lung surgery, ischemic heart disease, valvular heart disease or infective exacerbation less than one month before research.

Cases included in the research were subjected to full history taking and complete physical examination. This includes: Complete blood count (CBC), sputum culture, chest x-ray to exclude cases with other lung diseases, High-Resolution Computerized Tomography (HRCT), that were interpreted for the presence, pattern and distribution of bronchiectasis, arterial blood gases, echocardiography, measuring systolic pulmonary artery pressure, PFT, Impulse Oscillometry and reactance area (AX) were measured. Analyses were conducted on the correlations between IOS measures, spirometric measurements, and disease severity indicators (BSI, FACED, and E-FACED scores). The effectiveness of the IOS measures in predicting disease severity was then evaluated by comparing them to severity indicators.

Respiratory resistance was determined at rest with a commercially available broadband IOS device (Master Screen IOS 2001, version 4.5; Erich Jaeger GmbH, Hoechberg, Germany). The procedures were carried out in accordance with the standard recommendations [7].

The cases underwent PFT using (Carefusion 234, Gmbh, Jaege, Germany) according to the recommendations of the American Thoracic Society [8]. The forced vital capacity (FVC) and forced expiration volume in 1s (FEV1) were calculated according to the formula for Japanese controls developed by the Japanese Respiratory Society [9]. Between the best two manoeuvres, there was a difference in FVC and FEV1 of no more than 5% or 200 ml. The high documented values of forced vital capacity and forced expiratory volume in one minute were. Maximal mid-expiratory flow (MMEF), mid-expiratory flow at 50% lung volume was chosen from the maneuver with the high sum of FVC and FEV1.

HRCT results were lobarly analysed using the modified Reiff score. The severity of bronchiectasis was assessed for each lobe separately (0 for none, 1 for tubular, 2 for varicose, and 3 for cystic). The best HRCT result attainable was 18. Dyshomogeneity, cystic bronchiectasis, and mostly lower lobe bronchiectasis were also established as additional imaging findings (1).

Bronchiectasis Severity Metrics

Table 1: BSI Score (10)

Bronchiectasis severity index (BSI) criteria	0 Point	1 Point	2 Points	3 Points	4 Points	5 Points	6 Points
FEV_1% predicted	>80%	50%–80%	30%–49%	<30%	-	-	-
Age (years)	<50	-	50–69	-	70–79	-	>80
Colonisation	No	Chronic colonisation with any organism	-	*P. aeruginosa* colonisation	-	-	-
Radiology: extension	<3 lobes	≥3 lobes or cystic changes	-	-	-	-	-
Dyspnoea score (MRC)	1–3	-	4	5	-	-	-
BMI kg/m^2	≥18.5	-	<18.5	-	-	-	-
Exacerbations in the last 12 months	0–2	-	≥3	-	-	-	-
Hospital admissions in the last 2 years	No	-	-	-	-	Yes	-

Informed consent was obtained from each research participants. Privacy and confidentiality of all participants were kept and the full research protocol was submitted and approved by the ethical committee.

Statistical analysis

All statistical procedures were done using SPSS software version.22. Descriptive statistics were used in the form of mean and standard deviation for quantitative variables. Frequency and percentage were used for descriptive analysis of qualitative data variables. Chi square was the used test to find the association between two qualitative variables. Independent student t-test was used to analyze the difference in means between any two different groups.

Results

Demographic data

There was no significant differences between both groups regarding age gender, or height while a statistically significant difference was observed between groups regarding weight and BMI as shown in table.2

Table 2: Demographic characteristics of the studied cases

Items	Group I (n=20)	Group II (n=20)	χ^2	p-value
Age (years)				
Mean ± SD	46.55±10.04	52.65±8.39	0.734	0.391
Sex				
Males	9(45)	10 (50)	0.501	0.479
Females	11 (55)	10 (50)		
Height (cm)				
Mean ± SD	165.6±11.50	168.5±9.50	0.054	0.816
Weight (kg)				
Mean ± SD	78±11.50	58.45±9.50	0.310	0.007*
BMI (kg/m^2)	28.5±2.30	20.6±1.63	2.456	0.013*

A statistically evident difference was found in the following: MEF 50%, FEV1% predicted, FEV1/FVC% and FVC% with no significant differences in FEV1. Regarding IOS measurements, A statistically evident difference was found between both groups in R5% predicted while no difference was observed regarding R5 actual, R20, AX, or X5 as shown in Table 3.

Table 3: Comparison between groups in Spirometric and IOS measurements.

Items	Group I (n=20)	Group II(n=20)	χ^2	p-value
FEV1 L Mean± SD	1.33±0.985	2.50±1.10	0.757	0.384
MEF 50% Mean± SD	75.75±9.1	42.42±8.3	21.25	0.000*
FEV1% predicted Mean± SD	65.890 ±3. 5	75.92 ±13.2	8.910	0.002*
FEV1/FVC% Mean± SD	16.75 ±4. 5	79.09 ±5.25	22.45	0.000*
FVC (%)	70.05 ± 2.41	42.96 ± 3.52	28.425	0.001*
R5% predicted Mean± SD	186.62 ±10	291.75 ±11.8	28.950	0.000*
R5 actual Mean± SD	0.311 ±0. 16	0.441 ± 0.185	0.0449	0.832
R20 Mean± SD	0.316±0.095	0.346±0.045	0.002	0.958
AX Mean± SD	0.444±0.21	0.755±0.105	0.161	0.687
X5 Mean± SD	-0.146±0.025	-0.141±0.04	0.0001	0.989

Table 4 shows there was a high significant difference as regard to HRCT total score with P =0.001

Table 4: Disribution of the studied groups according to HRCT total score.

HRCT total score	Group I (n=20)		Group II (n=20)		X^2	P value
	N	%	N	%		
1-5	7	35	0	0	19.103	0.001*
6-10	10	50	8	40		
10-16	3	15	12	60		

By ROC curve there was highly statistically significant ability to predict the severity of disease using FEV1% predicted, FEV1/FVC%. For R5% predicted; there was highly statistically significant ability to predict the severity of the disease as shown in table.5

Table 5: ROC curve for detection of severe cases using FEV1% predicted, FEV1/FVC% and R5% predicted

	Area Under the Curve	P value	95% Confidence Interval				
			Lower Bound	Upper Bound	Cut off	Sensitivity%	Specificity%
FEV1% predicted	0.918	< 0.001	0.853	0.983	111.65	87.9	87.9
FEV1/FVC%	0.948	< 0.001	0.901	0.994	53.5	78.8	97
R5% predicted	0.757	< 0.001	0.641	0.872	226.65	81.8	60.6

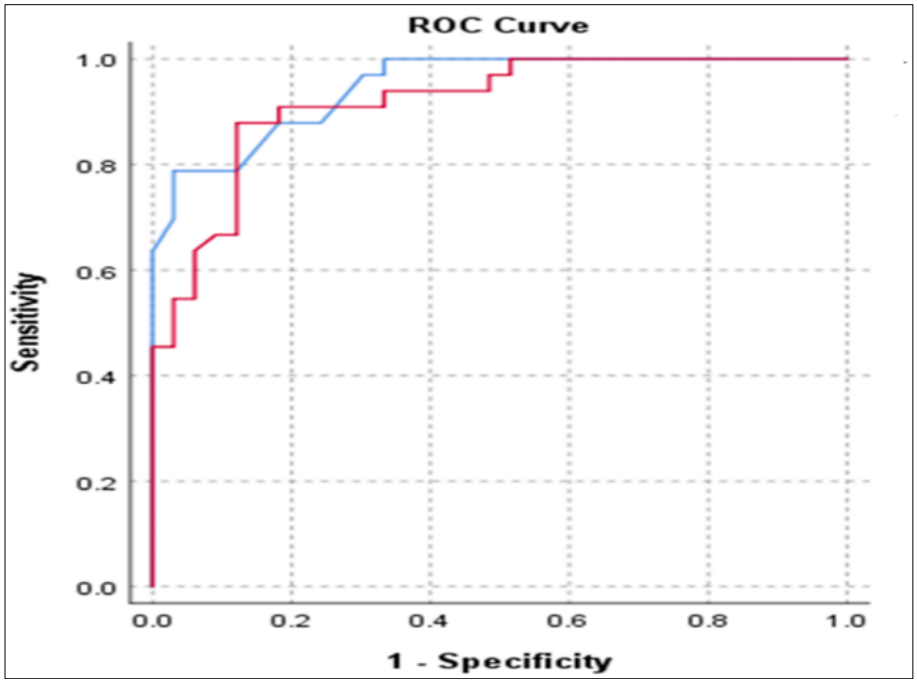

Fig 1: ROC curve for detection of severe cases using FEV1% predicted, FEV1/FVC%

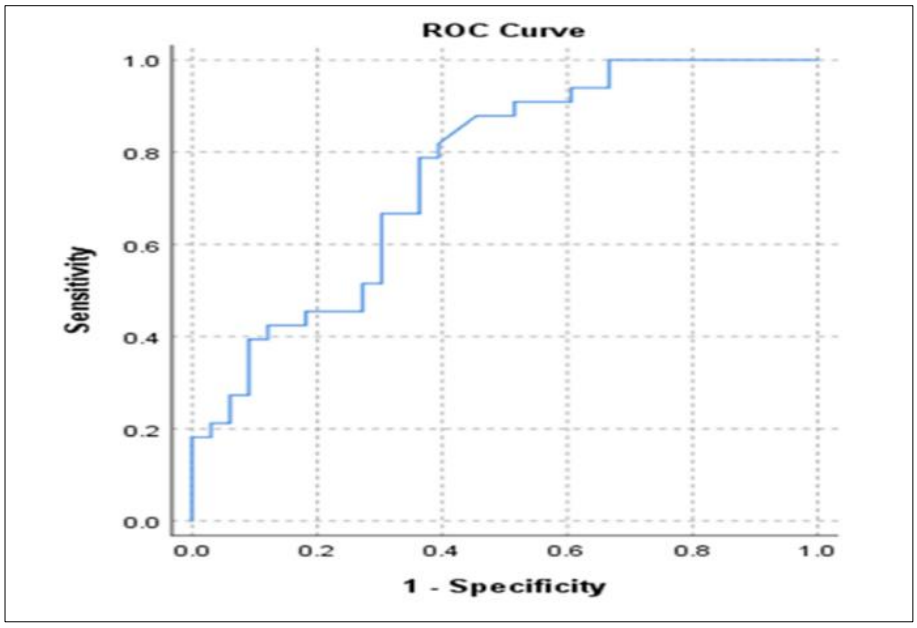

Fig 2: ROC curve for detection of severe cases using R5% predicted

Positive correlation was very high in between HRCT score and each of FEV1% predicted, FVC (%) AX, R5% predicted, R5 actual, R20 and X5 but negative correlation was very high in between HRCT score and MEF 75%, FEV1/FVC% as shown in Table 6.

Table 6: Correlation between HRCT score with spirometric measurements and IOS measurements

Spirometric Measurements		**HRCT score**
FEV1% predicted	rs	0.583
	P	0. 001*
FEV1/FVC%	rs	-0.546
	P	0.014*
MEF 50%	rs	-0.568
	p	0.006*
FVC (%)	rs	0.753
	p	0.025*
IOS measurements		HRCT score
R5% predicted	rs	0.587
	p	0.001*

R5 actual	rs	0.586
	p	0.001*
R20	rs	0.510
	p	0.006*
AX	rs	0.643
	P	<0.001*
X5	rs	0.685
	P	0.035*

Correlation between spirometric measurements and IOS measurements is shown in Table 7.

Table 7: Correlation IOS and spirometric measurements in the studied group

	FEV1 L		MEF 50%		FEV1% predicted		FEV1/FVC%	
	r.	p	r.	p	r.	p	r.	p
R5% predicted	0.652	0.001*	- 0.896	0.001*	0.822	0.001*	0.900	0.001*
R5 actual	0.544	0.001*	-0.386	0.015*	0.393	0.013*	0.356	0.026*
R20	0.193	0.239	-0.356	0.026*	0.308	0.056	0.390	0.014*
AX	0.640	0.001*	-0.730	0.001*	0.753	0.001*	0.661	0.001*
X5	-0.031	0.851	-0.199	0.224	0.107	0.516	0.103	0.533

Discussion

In the current research, the mean R5 actual was 0.311± 0. 16 in group I and 0.441±0.185 in group II with no significant difference in between (P=0.832) which coincide with findings in the research by Guan *et al*. who found that increased bronchiectasis severity associated with elevated R5 levels [1].

In this research, the mean X5 was -0.146±0.025 in group I and -0.141±0.04 in group II which means that with increased severity of the disease there was lower levels of X5 which coincide with findings of the research by Guan *et al*., [1] who found that Compared with controls, cases with significantly lower levels of X5.

Guan *et al*., [1] also found that the diagnostic performance of Fres was numerically but not statistically high, followed by Z5, R5, AX, R20 and X5.

In our research, the mean AX was 0.444±0.21 in group I and 0.755±0.105 in group II which means that with increased severity of the disease there was higher levels of AX which coincide with findings of the research by Guan *et al*., [1] who found that, Compared with controls, cases with bronchiectasis had substantially reduced concentrations of AX.

There is often little effect on Resistance in restrictive lung illness, but a substantial rise in AX [11]. Therefore, IOS might assist differentiate between distinct forms of lung illness and improve the diagnostic accuracy [12].

Despite this, AX provided extra information for predicting long-term asthma control [13]. Intriguingly, despite the low correlation between large- and peripheral airway characteristics and asthma symptoms, impulse oscillometry and pulmonary function tests (PFT) independently contributed to the clinical manifestation of asthma [14].

When assessed in conjunction with central airways characteristics of PFT or IOS, peripheral airway measurements may have assisted in the diagnosis of respiratory disorders. Notably, moderate bronchiectasis already possessed peripheral airway abnormalities [1].

In addition, peripheral airway characteristics had the strongest correlation with the radiological severity of disease. This suggested that peripheral airway characteristics mirrored peripheral airway abnormalities but were generally independent of illness severity measures, in contrast to central airways measurements including FEV1 and airway resistance evaluated at 20 Hz [1].

In the current research, the mean R20 was 0.316±0.095 in group I and 0.346±0.045 in group II with no significant difference in between (P=0.958) which agree with the research by Guan *et al*., [1] who found that R20 were elevated in cases with high bronchiectasis Severity Index.

Researchers have shown that peripheral airway constriction has a greater effect on measured markers of peripheral airways malfunction like R5-20 than central airways illness does, and that heterogeneity is also a key predictor of the measurements [15]. The inverse of the normal ventilation in the lung has also been identified as an important R5-20 component in a quantitative imaging biomarker analysis [16, 17].

Unequal aeration of lung areas is reflected on oscillometry characteristics, namely frequency dependence of resistance and AX, and, curiously, also corresponds with case outcome [18].

In a new research, it was stated that pulmonary density seems to be correlated to AX, and apperear to be linked in some way [19].

Recent research suggests that oscillometry would enhance COPD early diagnosis. Some researchers think that a diagnostic method for COPD could be peripheral lung compliance measured as AX. or as a follow up monitor [20].

This variable serves as a direct indicator of the ventilation diversity of the respiratory system, the R5–20 or R5–19 as well as the AX provide accurate estimates of ventilation heterogeneity [21].

In particular, R5-20 and AX, two measurements calculated from otal lung impedance, are thought to capture peripheral events in the lung [20].

In the present research, there was highly statistically significant ability to predict the severity of disease with cut off value for FEV1% predicted (111.65). At a sensitivity (87.9%) and specificity (87.9%) and AUC was 0.918 which near to the results in the research by Yamamoto *et al*., [22] who found that FEV1% predicted had AUC was 0.710 for prediction of the disease severity.

In the present research, the mean FEV1% predicted was 65.890±3. 5 in group I and 75.92±13.2 in group II with a significant difference in between (P=0.002), in Yamamoto *et al*., [22] research, IOS and PFT were not as beneficial as the BSI in predicting hospitalizations; however, inspiratory frequency and FEV1 were as useful as the FACED score in predicting hospitalizations and prognosis. PFTs, including

IOS and PFT, may be suitable for monitoring bronchiectasis as indices of disease severity. FEV1 decreases gradually and therefore may be superior in this aspect [23]; however, given the ease of measurement, inspiratory frequency may be handy as a complementary test for assessing and monitoring.

Guan *et al*., [1] also found that, Percent-of-predicted FEV1 was 74.4±22.5 and 99.9±11.1% in cases with mild to moderate bronchiectasis and controls, respectively.

Conclusion

IOS measurements are markedly increased in cases with bronchiectasis and they are correlated with spirometric measurements and HRCT scores.

References

1. Guan WJ, Gao YH, Xu G, Lin ZY, Tang Y, Li HM, *et al*. Impulse oscillometry in adults with bronchiectasis. Ann Am Thorac Soc. 2015 May 1 [cited 2023 Jan 5];12(5):657-65. Available from: www.atsjournals.org
2. Ryall B, Davies JC, Wilson R, Shoemark A, Williams HD. Pseudomonas aeruginosa, cyanide accumulation and lung function in CF and non-CF bronchiectasis cases. Eur Respir J. 2008 Sep 1 [cited 2023 Jan 5];32(3):740-7. Available from: https://erj.ersjournals.com/content/32/3/740
3. Santamaria F, Grillo G, Guidi G, Rotondo A, Raia V, De Ritis G, *et al*. Cystic Fibrosis: When Should High-resolution Computed Tomography of the Chest Be Obtained? Pediatrics. 1998 May 1 [cited 2023 Jan 5];101(5):908-13. Available from: /pediatrics/article/101/5/908/65278/Cystic-Fibrosis-When-Should-High-resolution
4. King PT, Holdsworth SR, Freezer NJ, Villanueva E, Farmer MW, Guy P, *et al*. Lung Diffusing Capacity in Adult Bronchiectasis: A Longitudinal Research. Respir Care; c2010, 55(12).
5. Davies G, Wells AU, Doffman S, Watanabe S, Wilson R. The effect of Pseudomonas aeruginosa on pulmonary function in cases with bronchiectasis. Eur Respir J. 2006 Nov 1 [cited 2023 Jan 5];28(5):974-9. Available from: https://erj.ersjournals.com/content/28/5/974
6. Hamakawa H, Sakai H, Takahashi A, Bando T, Date H. Multi-frequency forced oscillation technique using impulse oscillations: Can it give mechanical information about the lung periphery? Adv Exp Med Biol. 2013 [cited 2023 Jan 5];765:73-9. Available from: https://link.springer.com/chapter/10.1007/978-1-4614-4989-8_11
7. Oostveen E, MacLeod D, Lorino H, Farré R, Hantos Z, Desager K, *et al*. The forced oscillation technique in clinical practice: methodology, recommendations and future developments. Eur Respir J. 2003 Dec 1 [cited 2023 Jan 5];22(6):1026-41. Available from: https://erj.ersjournals.com/content/22/6/1026
8. Crapo O, Hankinson JL, Irvin C, MacIntyre NR, Voter KZ, Wise RA, *et al*. Standardization of Spirometry, 1994 Update. American Thoracic Society. https://doi.org/101164/ajrccm15237663792. 2012 Dec 20;152(3):1107-36.
9. Evans SA, Turner SM, Bosch BJ, Hardy CC, Woodhead MA. Lung function in bronchiectasis: the influence of Pseudomonas aeruginosa. Eur Respir J. 1996 Aug 1 [cited 2023 Jan 5];9(8):1601-4. Available from: https://erj.ersjournals.com/content/9/8/1601
10. Chalmers JD, Goeminne P, Aliberti S, McDonnell MJ, Lonni S, Davidson J, *et al*. The bronchiectasis severity index an international derivation and validation research. Am J Respir Crit Care Med. 2014 Mar 1 [cited 2023 Jan 5];189(5):576-85. Available from: www.atsjournals.org
11. Naglaa BA, Kamal E. Role of IOS in evaluation of cases with interstitial lung diseases. Egypt J Chest Dis Tuberc. 2016 Oct 1;65(4):791-5.
12. Eddy RL, Westcott A, Maksym GN, Parraga G, Dandurand RJ. Oscillometry and pulmonary magnetic resonance imaging in asthma and COPD. Physiol Rep [Internet]. 2019 Jan 1 [cited 2023 Jan 5];7(1):e13955. Available from: https://onlinelibrary.wiley.com/doi/full/10.14814/phy2.13955
13. Larsen GL, Morgan W, Heldt GP, Mauger DT, Boehmer SJ, Chinchilli VM, *et al*. Impulse oscillometry versus spirometry in a long-term research of controller therapy for pediatric asthma. J Allergy Clin Immunol. 2009 Apr 1 [cited 2023 Jan 5];123(4):861-867.e1. Available from: http://www.jacionline.org/article/S0091674908018915/fulltext
14. Cottini M, Licini A, Lombardi C, Bagnasco D, Comberiati P, Berti A. Peripheral airways dysfunction and poor asthma control: a dangerous liaison. Clin Mol Allergy 2021 191. 2021 May 29 [cited 2023 Jan 5];19(1):1-10. Available from: https://clinicalmolecularallergy.biomedcentral.com/articles/10.1186/s12948-021-00147-8
15. Pasteur MC, Bilton D, Hill AT. British Thoracic Society guideline for non-CFbronchiectasis. Thorax. 2010 Jul 1 [cited 2023 Jan 5];65(1):i1-58. Available from: https://thorax.bmj.com/content/65/Suppl_1/i1
16. Soares M, Bordas R, Thorpe J, Timmerman B, Brightling C, Kay D, *et al*. Validation of impulse oscillometry R5-R20 as a peripheral airways dysfunction detection tool in adult asthma. Eur Respir J. 2016 Sep 1 [cited 2023 Jan 5];48(60):OA4968. Available from: https://erj.ersjournals.com/content/48/suppl_60/OA4968
17. Bell A, Richardson M, Singapuri A, Mirkes E, Gorban A, Galban C, *et al*. Parametric response map registered CT feature and peripheral airways physiology analysis in asthma. 2017 Sep [cited 2023 Jan 5];OA4647. Available from: https://www.researchgate.net/publication/321929328_Parametric_response_map_registered_CT_feature_and_small_airway_physiology_analysis_in_asthma
18. Young HM, Guo F, Eddy RL, Maksym G, Parraga G. Oscillometry and pulmonary MRI measurements of ventilation heterogeneity in obstructive lung disease: Relationship to quality of life and disease control. J Appl Physiol. 2018 Jul 1 [cited 2023 Jan 5];125(1):73-85. Available from: https://journals.physiology.org/doi/10.1152/japplphysiol.01031.2017
19. A statistical model to estimate lung density (LD) utilizing oscillometry (OS), biometrics (BM), case reported outcomes (PRO) and pulmonary function tests

(PFT). [cited 2023 Jan 5]. Available from: https://www.ers-education.org/lr/show-details/?idP=156166
20. Lipworth BJ, Jabbal S. What can we learn about COPD from impulse oscillometry? Respir Med. 2018 Jun 1 [cited 2023 Jan 5];139:106-9. Available from: http://www.resmedjournal.com/article/S0954611118301525/fulltext
21. Foy BH, Soares M, Bordas R, Richardson M, Bell A, Singapuri A, *et al*. Lung computational models and the role of the peripheral airways in asthma. Am J Respir Crit Care Med. 2019 Oct 15 [cited 2023 Jan 5];200(8):982-91. Available from: www.atsjournals.org.
22. Yamamoto Y, Miki K, Tsujino K, Kuge T, Matsuki T, Fukushima K, *et al*. Evaluation of disease severity in bronchiectasis using impulse oscillometry. ERJ Open Res. 2020 Oct [cited 2023 Jan 5];6(4):00053-2020. Available from: /pmc/articles/PMC7553116/
23. Martinez-García MA, Oscullo G, Posadas T, Zaldivar E, Villa C, Dobarganes Y, *et al*. Pseudomonas aeruginosa and lung function decline in cases with bronchiectasis. Clin Microbiol Infect. 2021 Mar 1 [cited 2023 Jan 5];27(3):428-34. Available from: http://www.clinicalmicrobiologyandinfection.com/article/S1198743X20302123/fulltext