Airway Oscillometry in Adults and Children

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Mass General Brigham

Disclosures

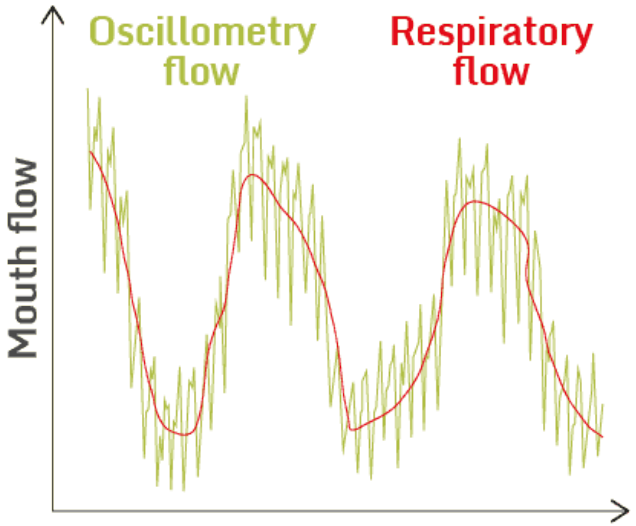
- Dr. El Boueiz:
  - Educational Speaker, Chiesi
  - Educational Speaker, Thorasys Thoracic Medical Systems

- Dr. Moschovis:
  - Educational Speaker, Thorasys Thoracic Medical Systems

Outline

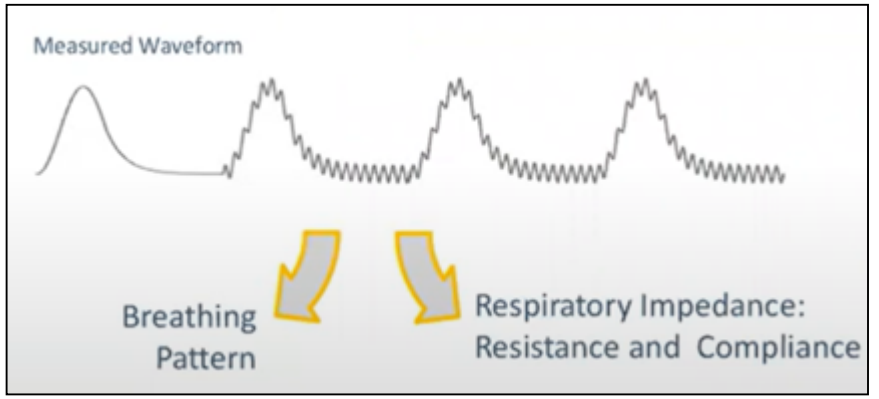
- Overview of oscillometry
- Fundamentals of respiratory mechanics
- How to interpret the oscillogram
- The value of oscillometry in:
  - Asthma
  - Tracheobronchomalacia (TBM) / Excessive dynamic airway collapse (EDAC)

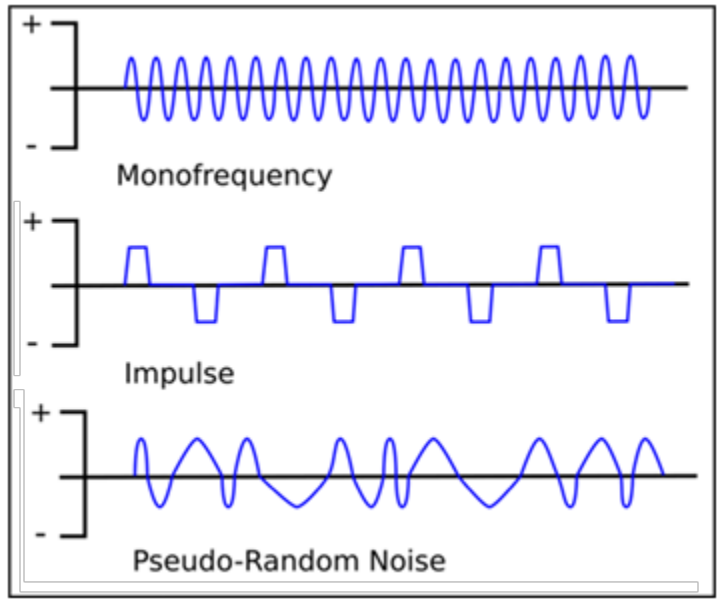
Airway oscillometry overview



Airway oscillometry (AOS)

- Group of techniques for measuring breathing mechanics by superimposing small pressure waves on top of normal tidal breathing.
- 3 main approaches:
  - Forced Oscillation Technique (FOT) single frequency technique: Uses a single, continuous oscillation frequency. Like a speaker playing a single steady tone.
  - Impulse Oscillometry (IOS): Uses brief pressure impulses that contain multiple frequencies simultaneously. Like striking a drum periodically, with each hit containing a mix of frequencies.
  - Pseudo-Random Noise (PRN): Uses a combination of multiple sine waves at different frequencies applied simultaneously. Like playing multiple musical notes together to create a chord.
- Most commercial oscillometry systems use either IOS or PRN
- We will use the acronym AOS (Airway Oscillometry) as a broad term encompassing all these techniques.





Commercially available oscillometry devices

- Antlia Pro (iCALTECH Innovations, India)

- Pulmoscan (Cognita Labs, USA)

- Q-i2m (Cosmed, Italy)

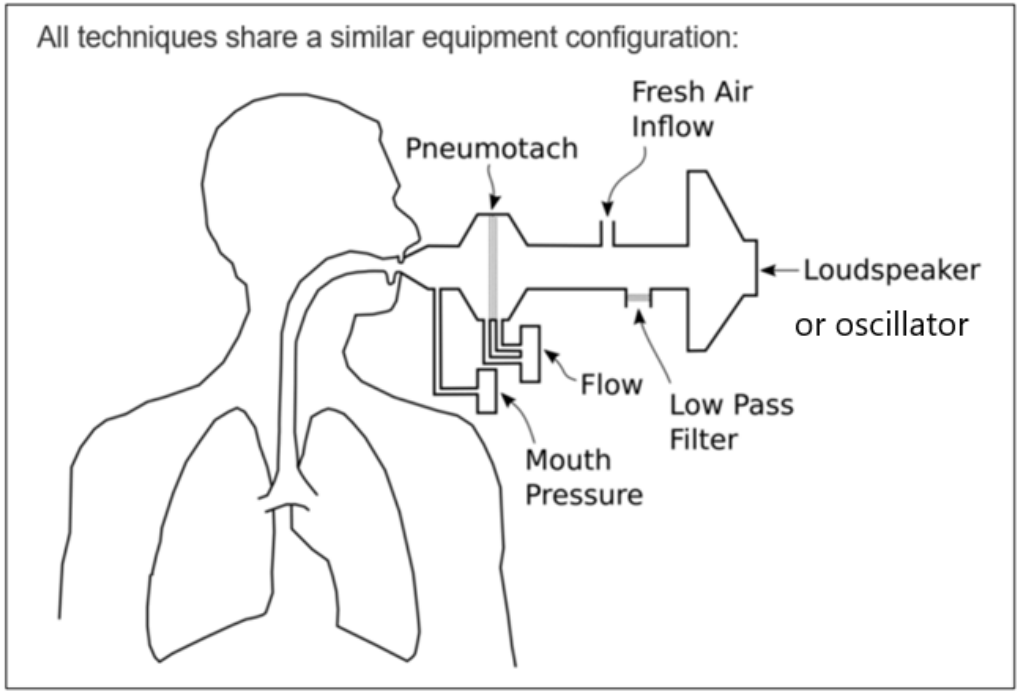
- MasterScreen IOS, Vyntus IOS (Vyaire Medical, USA)

- Resmon Pro, First (Restech, Italy)

- MostGraph-01, MostGraph-02 (Chest MI, Japan)

- TremoFlo (ThoraSys, Canada)

They differ in several important features, including measurement capabilities, frequency range, measured parameters, technology, user interface, test duration, patient cooperation, portability, calibration requirements, clinical validation, and cost.



- Nose clipping: Prevents air from escaping through the nasal passages, ensuring accurate airflow measurement through the mouth.
- Cheek bracing: Reduces vibrations from soft tissue, which can distort the oscillometry readings, leading to more reliable results.
- Loudspeaker or oscillator: Generates pressure oscillations at various frequencies.
- Pneumotach: Has pressure sensors to measure airflow (essential for calculating parameters such as airway resistance and reactance).

Measurement sequence

Patient's Quiet Breathing

+

Oscillations

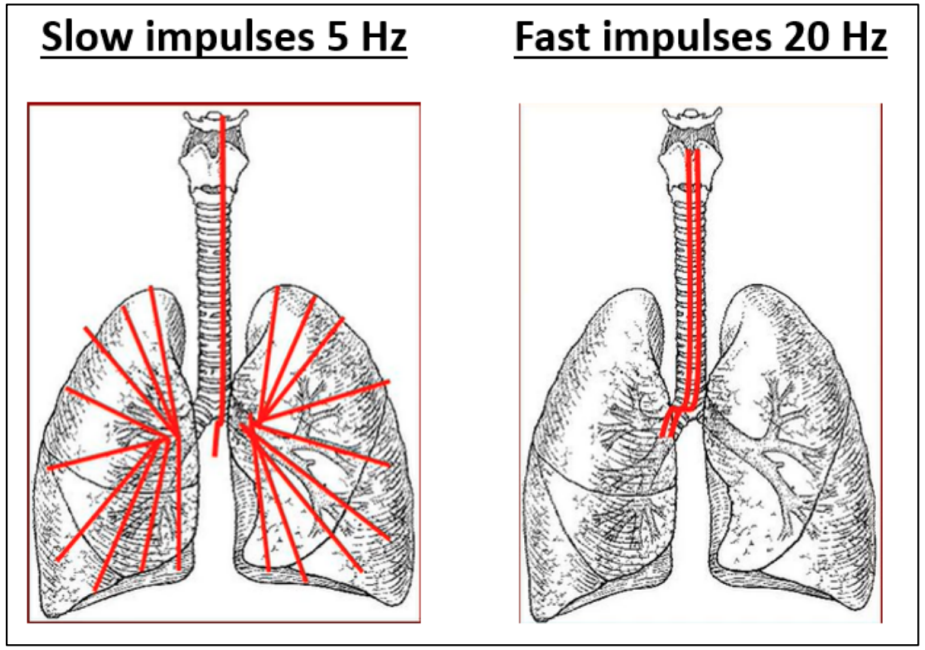
=

Measured Waveform

Breathing Pattern

Respiratory Mechanics

Airway oscillometry (AOS)



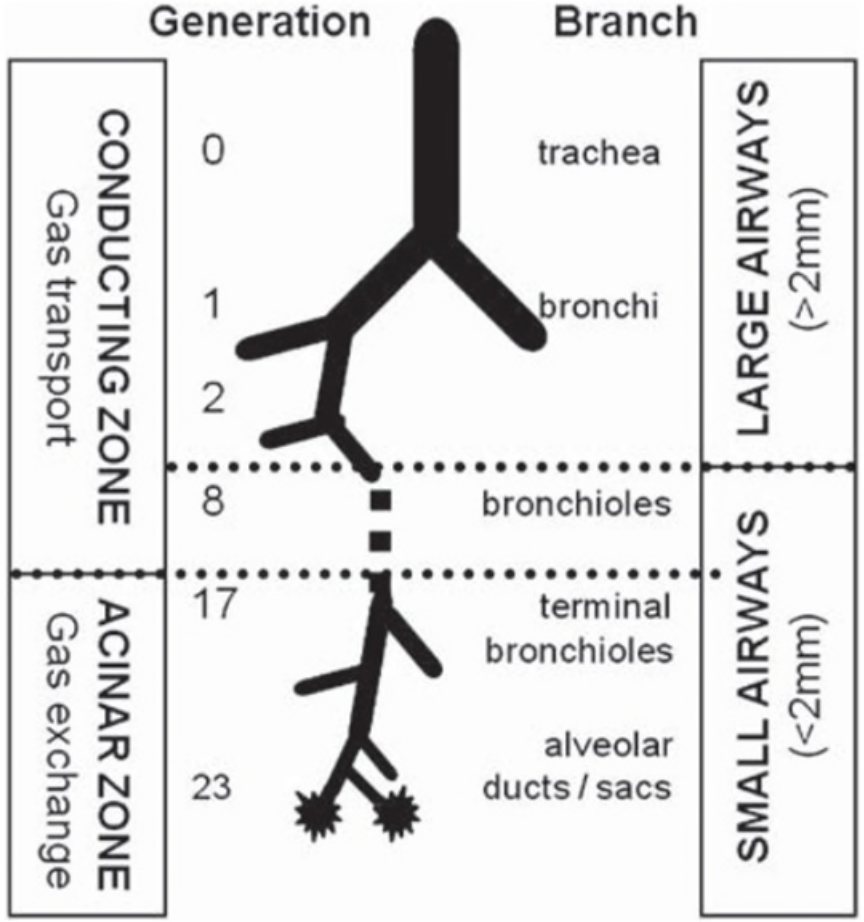
- Low frequencies:
  - Deep penetration
  - Total airways (central and peripheral)
- High frequencies:
  - Low penetration
  - Upper (large, central) airways

Higher oscillation frequencies are reflected from the larger airways
Lower frequencies travel more peripherally before returning to the mouth

Frequency-independent change	When resistance values do not vary at different frequencies. If overall resistance is increased, this may be indicative of proximal obstruction.
Frequency-dependent change	When resistance varies with frequency more than age-dependant normal values. This may be indicative of distal obstruction.

Small airways

- < 2 mm in diameter
- Devoid of cartilage and mucous secreting glands
- Major site of pathology in many lung diseases, including asthma and COPD
- “Zone of silence”:
  - Minimal contribution to total airway resistance.
  - Because the lungs have an extensive reserve of small airways, dysfunction must reach a critical threshold before symptoms or measurable impairment appear.
  - Poor sensitivity of routine tests



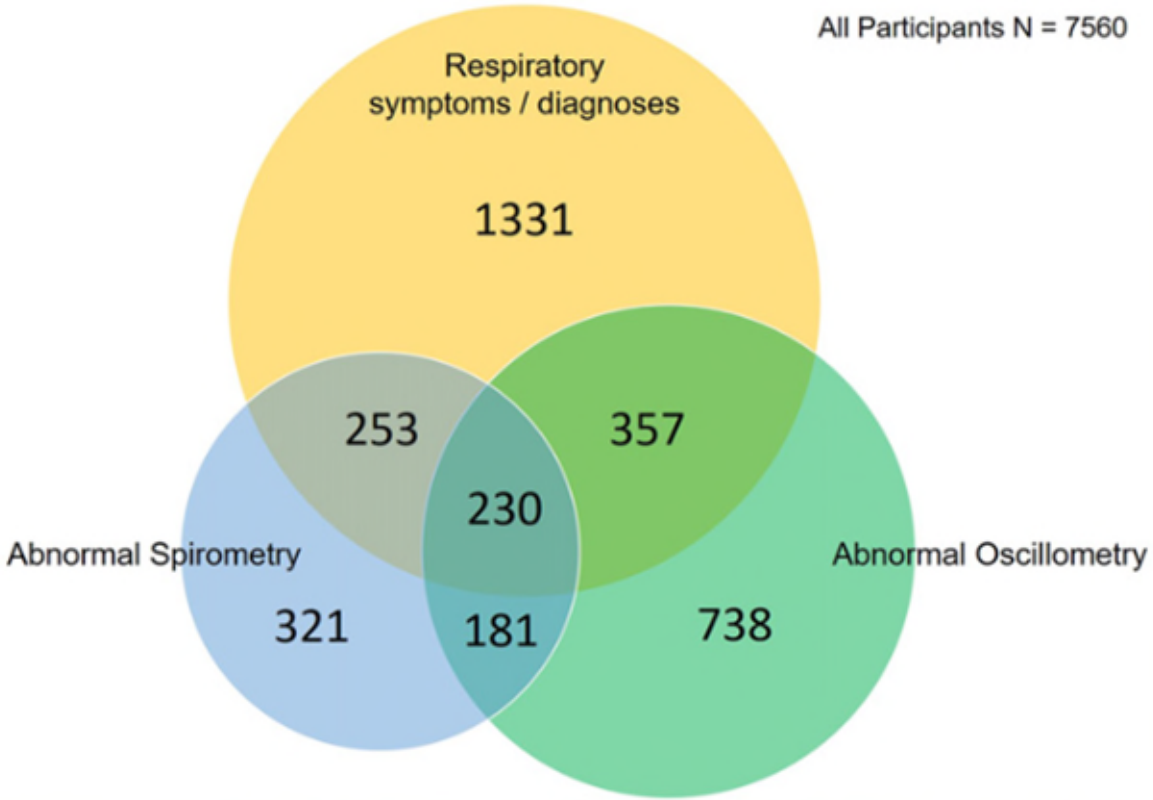
Am J Respir Crit Care Med 1998;157:S181-S183.
J. Appl. Physiol. 27(3):328-335.

Assessment of small airways

- Small airways have proven difficult to study due to their relative inaccessibility to biopsy and their small size which makes their imaging difficult.

Spirometry does not fully assess the small airways

By the time significant changes in FEV_1 have occurred, there has likely been substantial disease progression and airway remodeling, leaving limited capacity for reversal and recovery.



Am J Respir Crit Care Med 2024; 209(4): 444-453.

Assessment of small airways

	Outcome	Measures
Spirometry	Dynamic volumes and flow	FEF_{25-75}, ratio of forced vital capacity to relaxed vital capacity*
Single-breath and multiple-breath nitrogen washout	Air trapping and ventilation heterogeneity	Functional residual capacity, ratio of closing volume to vital capacity, ratio of residual volume to total lung capacity, S_{acin}, S_{cond}
Impulse oscillometry	Airway obstruction and capacitance	R5–R20, reactance area under curve, reactance at 5 Hz, resonant frequency
Whole-body plethysmography	Airway obstruction and air trapping	R_{aw}, ratio of residual volume to total lung capacity
Oesophageal balloon	Small airway closure	Closing volume and dynamic compliance
Exhaled-breath nitric oxide	Airway inflammation	Alveolar and bronchial nitric oxide fractions
Imaging	Air trapping and regional distribution	High-resolution CT, gamma scintigraphy, PET, hyperpolarised ^{3}He MRI
Bronchoscopy	Airway resistance and inflammation	Wedged airway resistance, transbronchial biopsy, bronchoalveolar lavage
Late-phase induced sputum sample investigation	Airway inflammation	Cell and cytokine profile

Lancet Respir Med. 2014;2(6):497-506.

AOS advantages

- Requires only passive cooperation of the subject (effort-independent)
  - ✓ Useful in patients with neuromuscular disease and children
- Sensitive to lung periphery
- Portable
- Easy maintenance
- Easy calibration
- Commercial availability of devices

AOS main limitations

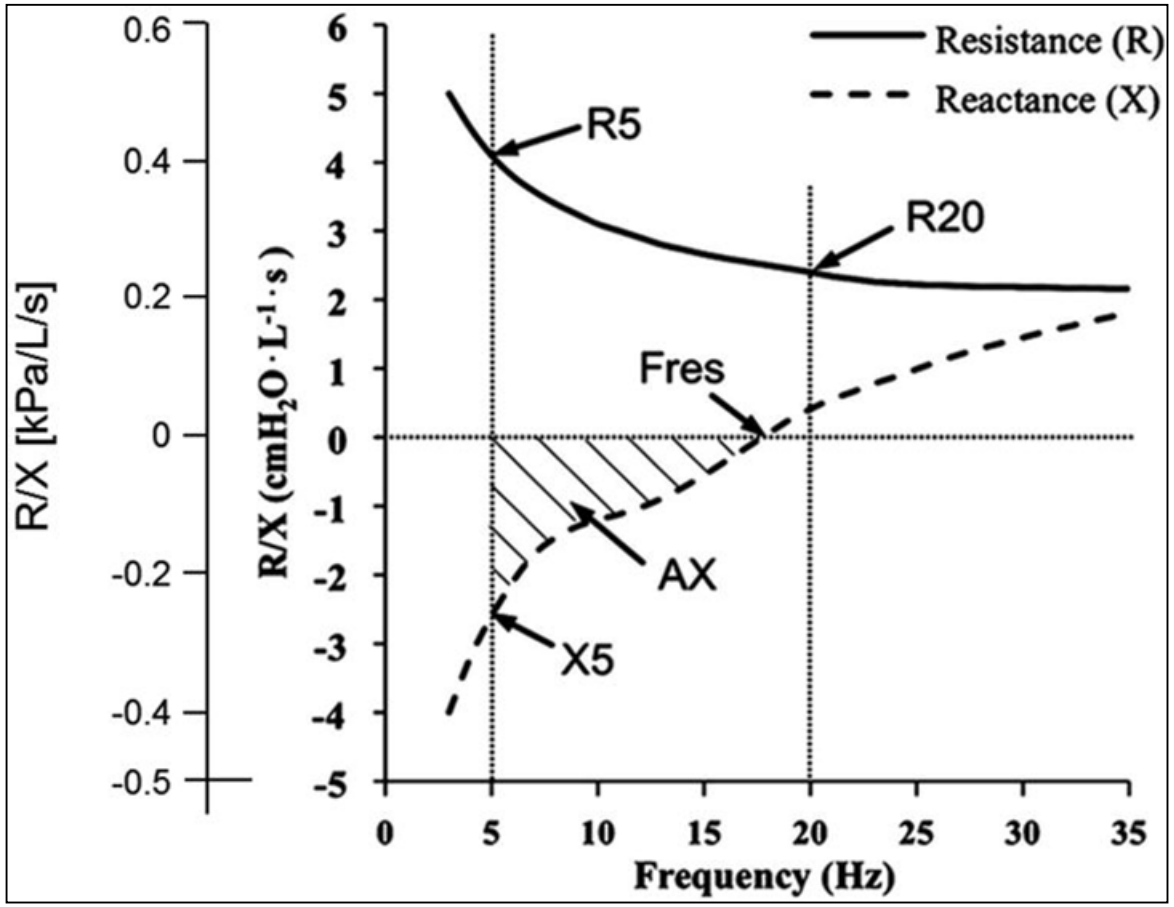
- Less familiarity among healthcare providers compared to spirometry.
- Limited availability in some healthcare settings.
- Lack of extensive evaluation over different disease conditions.
- Limited standardization of protocols and reference values across devices.
- Controversy regarding the best way to interpret AOS results.

However, these limitations can be overcome
once the technique is adopted widely, and more thorough studies are conducted.

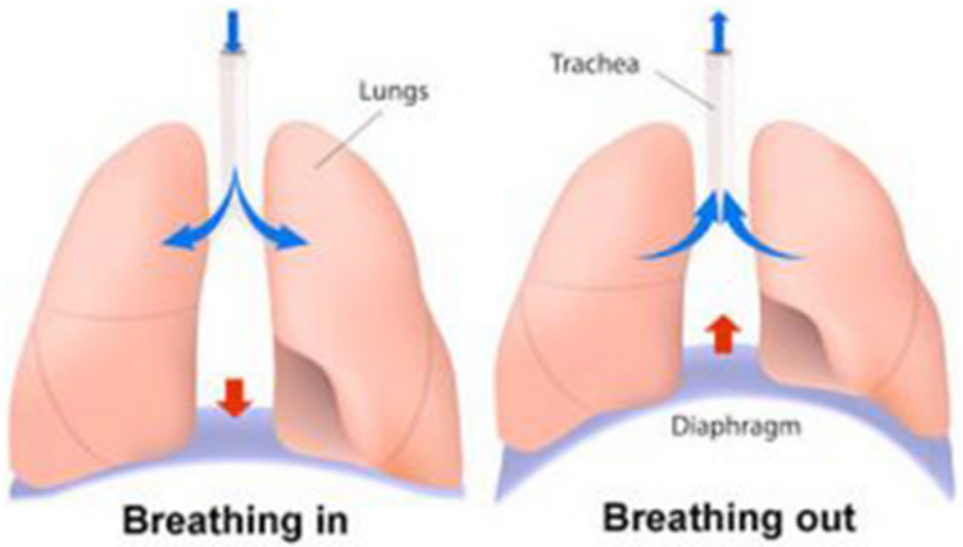
Quality control

- Three replicates are used to derive a coefficient of variation at the lowest oscillation frequency of ≤10% in adults.
- Identification of artifacts with strategies to remove them.

AOS - Plotting airway resistance and reactance against frequency

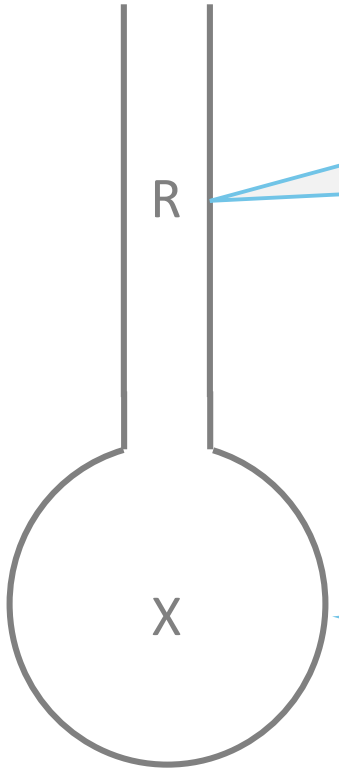


Respiratory mechanics basics



Respiratory mechanics basics

For the gas to reach the alveoli,
the respiratory tract offers hurdles/opposing forces that need to be overcome



Resistance
- "Pipe" component
- Pressure required to drive flow

Reactance (compliance and inertance)
- "Balloon" component
- Expansion resulting from applied pressure

Resistance is how hard it is to push air through the straw or pipe (airways).

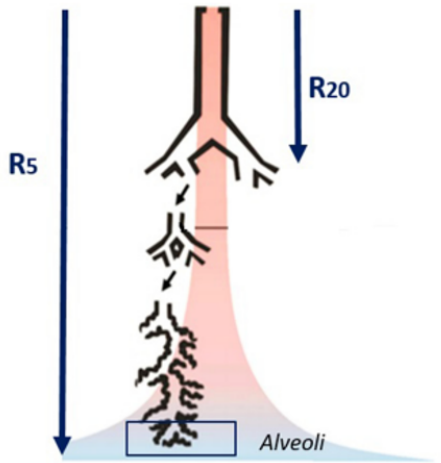
Reactance reflects how easy or hard it is to inflate the balloon (lungs and chest wall).

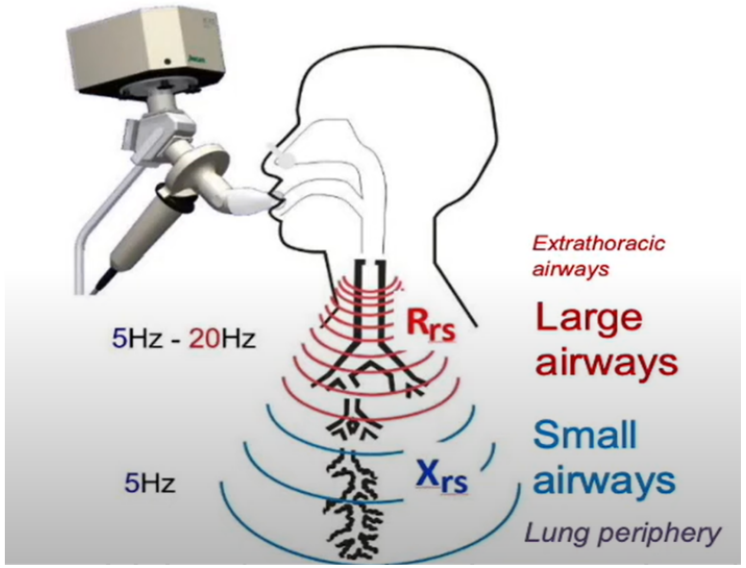
Impedance

Respiratory resistance (Rrs)

- Includes central/proximal and peripheral/distal airways, lung tissue, and chest wall resistance
  - R5 = Total resistance
  - R20 = Central resistance
  - R5-20 = Peripheral resistance

$$\text{Resistance} = \frac{\Delta \text{Pressure}}{\text{Flow}}$$



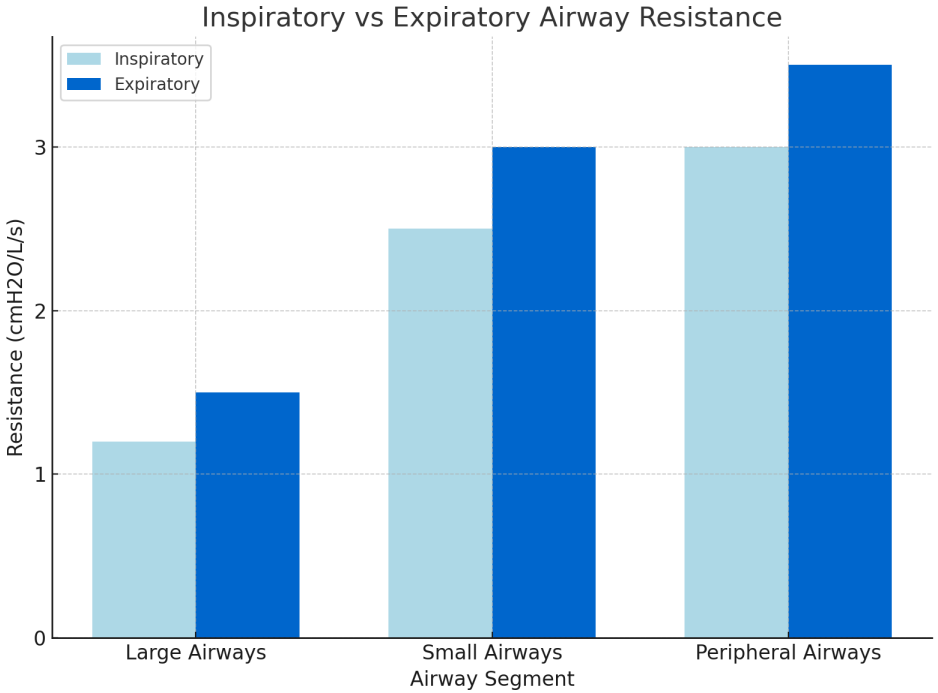


Respiratory resistance (Rrs)

- Includes central/proximal and peripheral/distal airways, lung tissue, and chest wall resistance
  - R5 = Total resistance
  - R20 = Central resistance
  - R5-20 = Peripheral resistance
- Obstruction:
  - Rrs is increased
  - Site of airway obstruction is inferred from the pattern of Rrs, as a function of oscillation frequency
    - ✓ Central/proximal airway obstruction elevates Rrs evenly independent of oscillation frequency
    - ✓ In peripheral/distal airway obstruction, Rrs is highest at low frequencies and falls with increasing frequency

Inspiratory *vs.* expiratory airway resistance

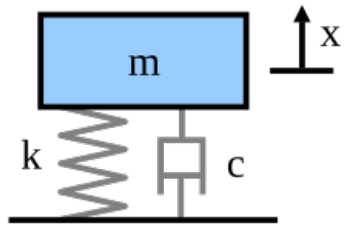
- Expiratory resistance is generally higher than inspiratory resistance, particularly in the small and peripheral airways.
- Intra-breath oscillometry: Measures airway function during different phases of a single breath.



Lung mechanics in disease. Respirology. 2016.
Current Opinion in Physiology, 2021, Volume 22, 100441.

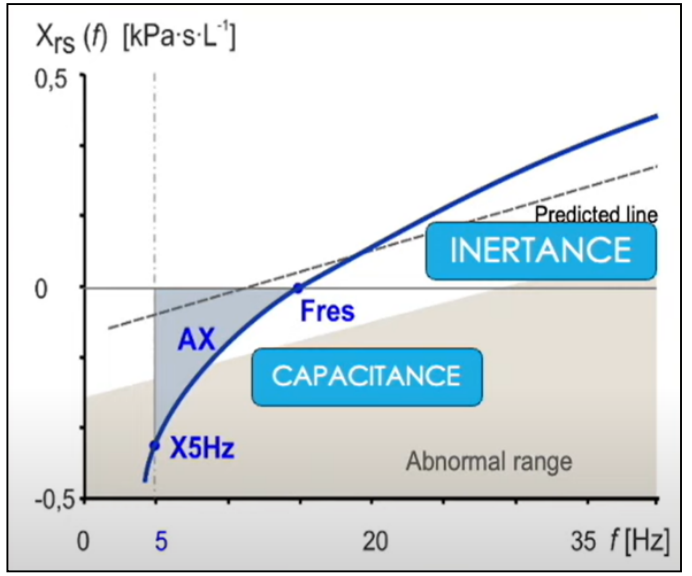
Respiratory reactance (Xrs)

- Reactance is a mix of how stretchy your lungs are and how much effort it takes to move air in and out → Reactance (X) = Capacitance (C) + Inertance (I)
- Think of the respiratory system like a spring-mass system:
  - When you push or pull a spring-mass system:
    - The spring resists stretch and tries to return to its original length.
    - The mass resists changes in motion due to its inertia. It does not want to start moving, and once moving, it does not want to stop
  - When oscillating pressure waves move air in and out:
    - The spring = capacitance → It stretches and recoils, just like the lungs and chest wall store and release energy during breathing (elastic recoil).
    - The mass = inertance → It resists changes in motion, just like the moving column of air resists rapid acceleration or deceleration (air inertia).
    - The friction → creates resistance (R)



- Reactance determines how the system stores and transfers energy during oscillation. Whether it behaves more like an elastic spring or a moving mass depends on frequency.

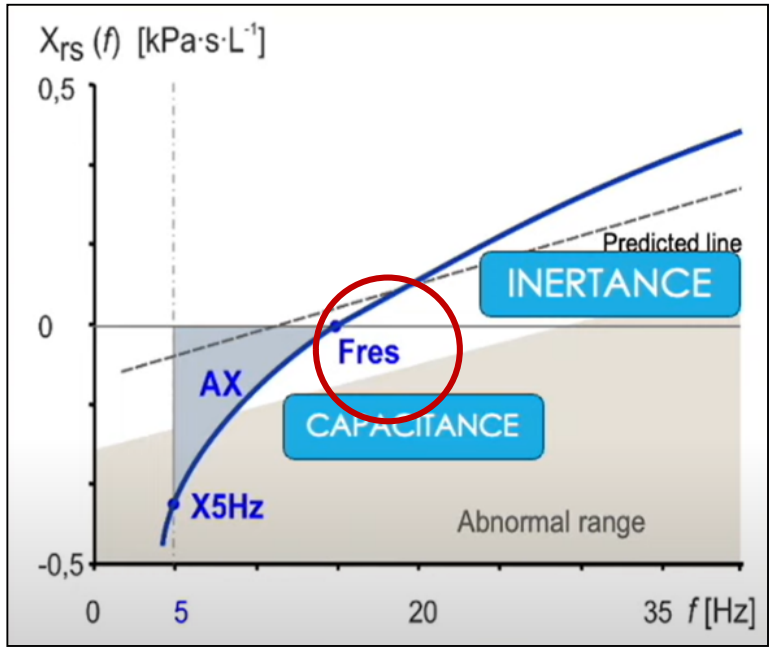
Respiratory reactance (Xrs)



- Xrs shows how lungs and chest wall react to airflow
- Xrs is influenced by the oscillation frequency:
  - Low frequency: Acts like a spring (compliance dominates) → Negative reactance
  - High frequency: Acts like mass resisting movement (inertia of air in larger airways dominates) → Positive reactance
- X5 (reactance at 5 Hz):

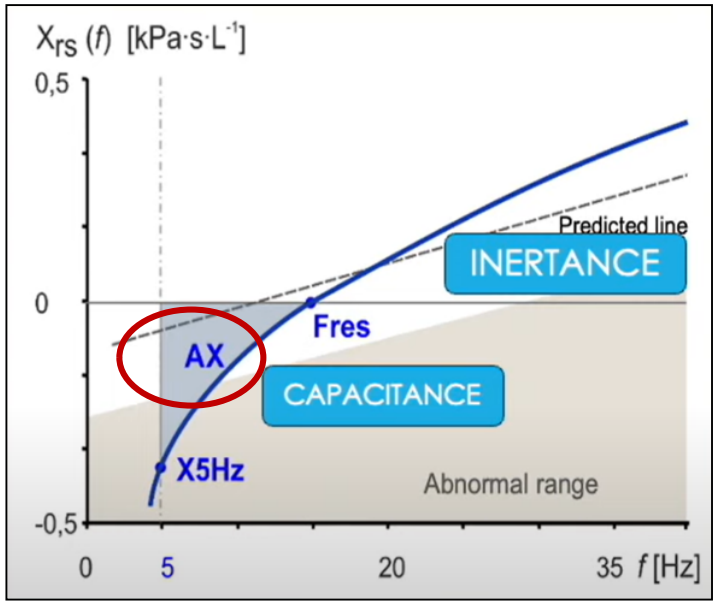
Condition	What happens	Effect on X5	Why
Normal lungs	Balanced elastic and inertial properties	Mildly negative X5	Normal compliance and homogeneous mechanics
Obstructive disease	Small airways are narrowed or collapse early	More negative X5	Lungs behave like stiffer springs due to uneven ventilation and regional loss of recoil
Restrictive disease	Lungs are stiff but uniformly restricted	Less negative (or near zero) X5	Elastic stiffness is high but uniform, less frequency dependence

Resonant frequency (Fres)



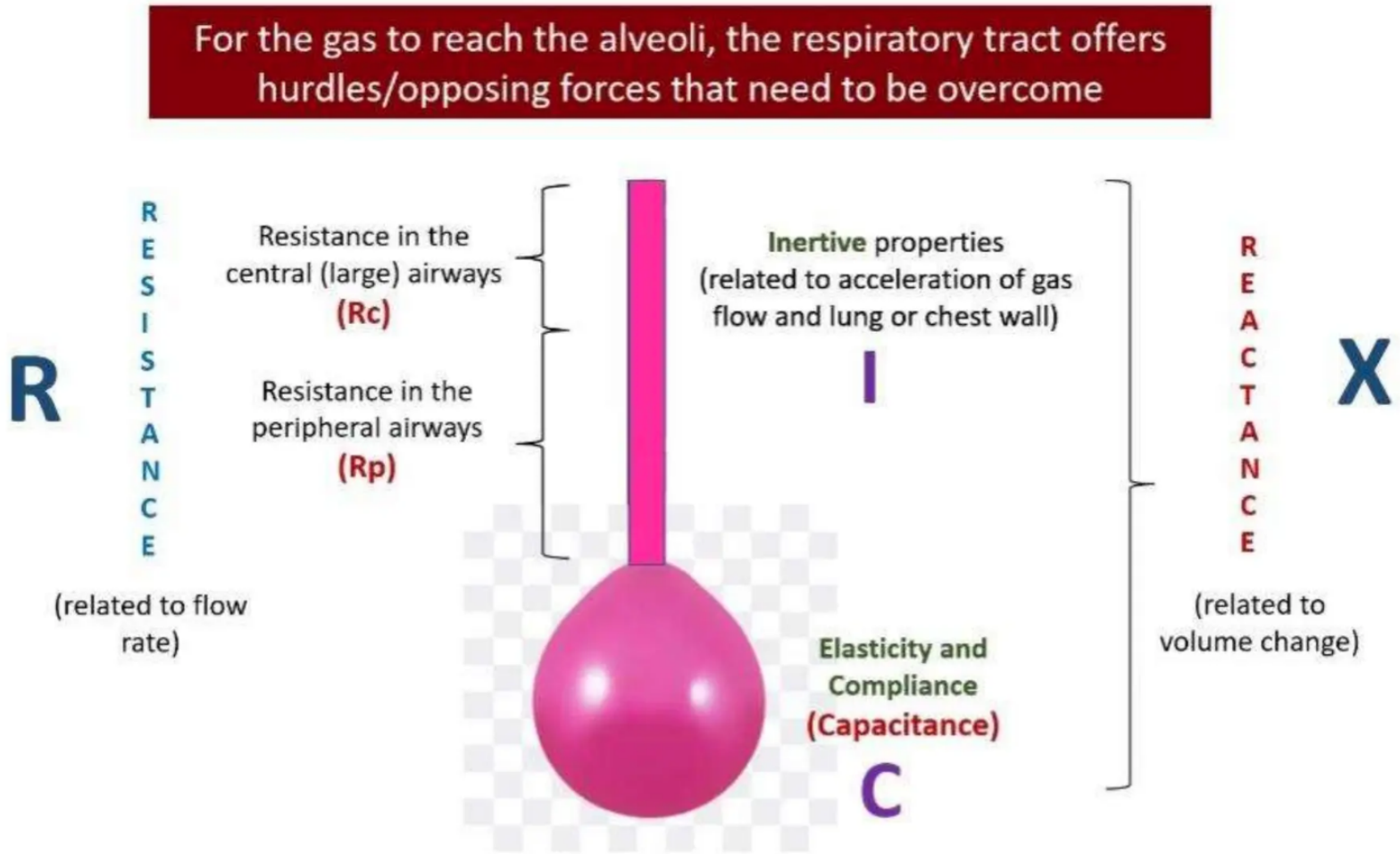
- Fres is the point where:
  - Inertance = Capacitance
  - Total reactance = 0
- What it means:
  - Below Fres: Elastic forces dominate.
  - Above Fres: Resistance to airflow changes dominates.
- Fres in lung diseases:
  - In obstructive lung diseases: Fres increases due to narrowed airways making it harder for air to flow.
  - In restrictive lung diseases: Fres is slightly increased due to uniform lung stiffness with less pronounced negative reactance compared to obstruction.

Reactance area (AX)

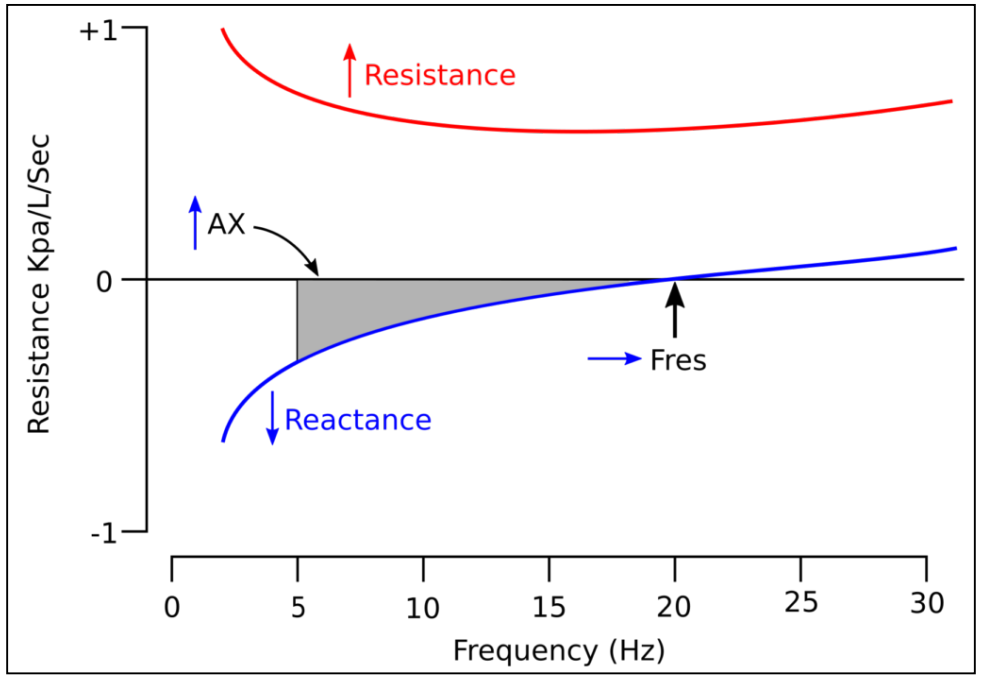


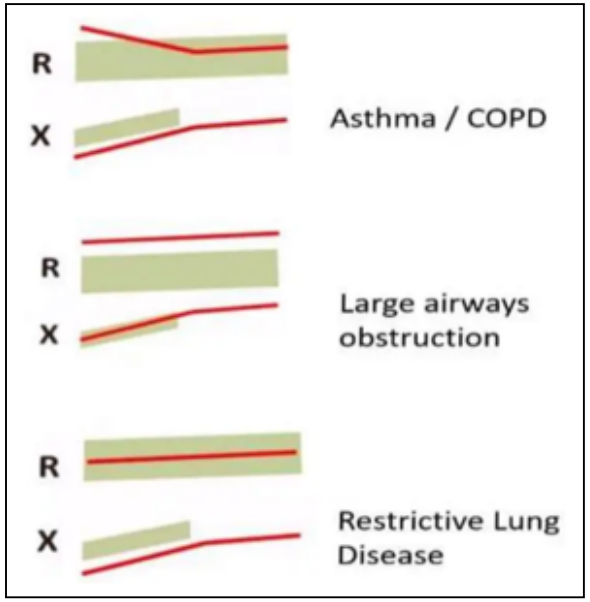
- AX (Goldman Triangle):
  - Area *under* the reactance curve from the lowest frequency to Fres
  - Represents the total reactance (Xrs) (how the lungs respond to airflow across frequencies).
  - Reflects the elastic (spring-like) behavior of the lung, particularly in the small airways.
  - A higher AX indicates uneven expansion and stiffer or obstructed airways, signifying greater small airway dysfunction.
    - Increased AX in obstructive lung diseases: Narrowed airways cause greater resistance and more negative reactance.
    - Elevated AX in restrictive lung diseases: Uniform lung stiffness causes a reactance increase that is less pronounced than in obstruction.

Respiratory mechanics basics



Interpretation of the oscillogram





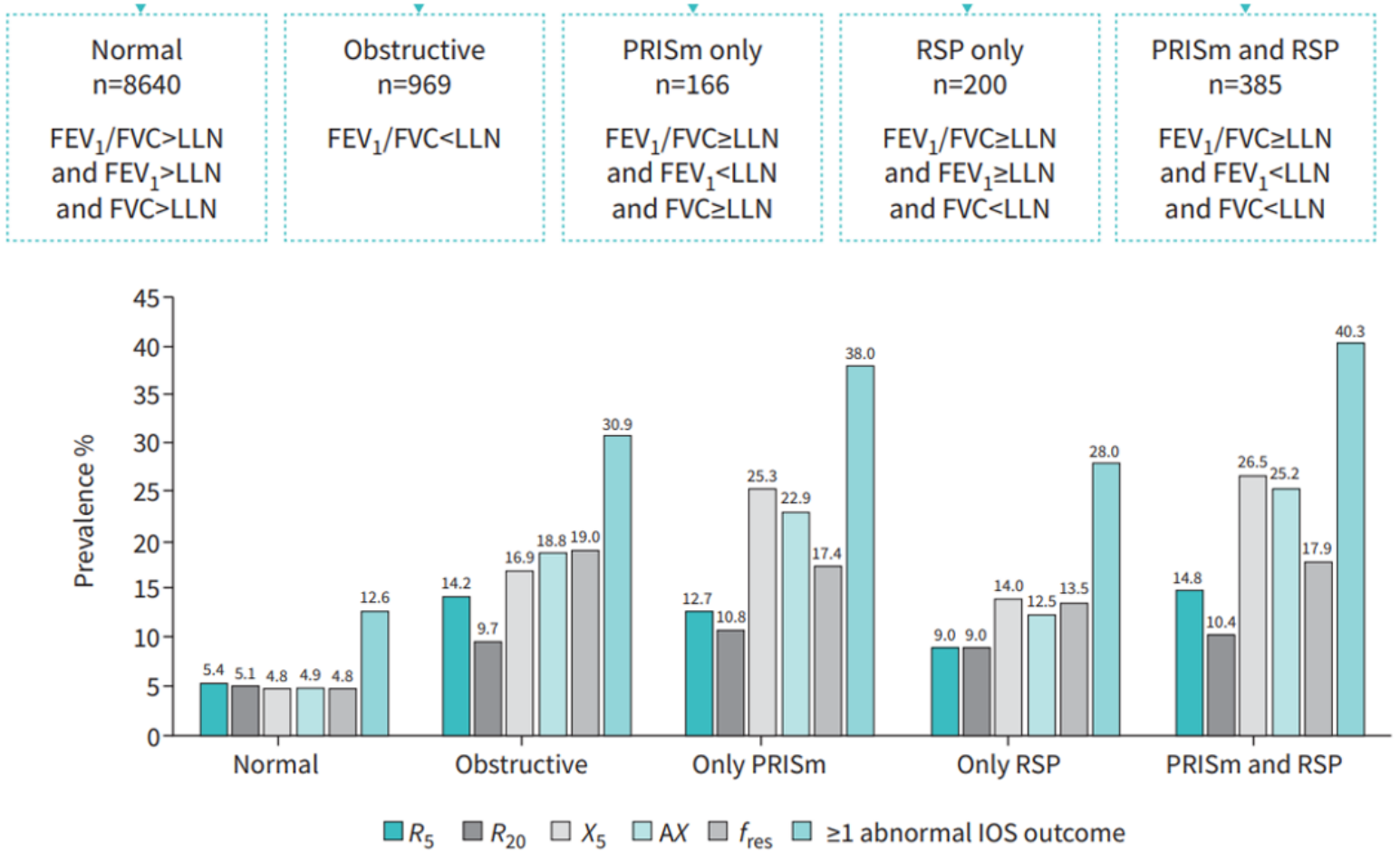
- Obstruction of the small, distal airways in the peripheral lung causes an increase in resistance (R) with a downward shift in reactance (X). In the presence of heterogeneity, R becomes curved.
- Obstruction of the large, central airways causes a parallel upward shift in resistance (R) while reactance (X) remains largely unchanged.
- Restrictive lung diseases cause a decrease in reactance (X).

Conditions	R5	R20	R5-R20	X5	Ax	Fres
Peripheral obstruction	Increased	Normal	Increased	More negative	Increased	Increased
Central airway obstruction	Increased	Increased	Normal	Normal	Normal	Normal
Combined airway obstruction	More Increased	Increased	Increased	More negative	Increased	Increased
Restrictive lung disease	Normal / Increased	Normal	Normal / Increased	More negative	Increased	Increased

Oscillometry findings in altered spirometry and relationship to respiratory symptoms

- Abnormal AOS prevalence by spirometric pattern:
  - ✓ Obstruction: 31%
  - ✓ PRISm only: 38%
  - ✓ RSP only: 28%
  - ✓ PRISm + RSP: 40%

- Abnormal reactance more prevalent than abnormal resistance across all spirometry groups, most pronounced in PRISm and PRISm+RSP



ERJ Open Res 2025;11(6):00483-2025

- AOS provides complementary physiologic information beyond spirometry
- Abnormal AOS is associated with greater respiratory symptoms and disease burden across COPD, PRISm, and RSP

TABLE 3 Clinical data of individuals with normal ($^{-}$) and abnormal ($^{+}$) impulse oscillometry (IOS) findings across the three spirometry groups: obstructive, preserved ratio impaired spirometry (PRISm) and restrictive spirometry pattern (RSP).

	Obstructive (n=969)		PRISm only (n=166)		RSP only (n=200)		PRISm and RSP (n=385)	
	IOS^{-}	IOS^{+}	IOS^{-}	IOS^{+}	IOS^{-}	IOS^{+}	IOS^{-}	IOS^{+}
Subjects	670	299	103	63	144	56	230	155
Symptoms								
Cough	**170 (25.7)**	**99 (34.0)**	25 (25.5)	17 (27.9)	33 (23.1)	15 (28.3)	53 (23.8)	39 (26.4)
Sputum production	**113 (17.1)**	**82 (28.6)**	17 (17.7)	11 (18.0)	12 (8.4)	7 (12.7)	36 (16.4)	24 (16.3)
Wheeze	**98 (14.9)**	**98 (34.6)**	17 (17.2)	14 (23.0)	**8 (5.7)**	**14 (25.9)**	24 (11.0)	20 (13.8)
Dyspnoea	**99 (15.1)**	**94 (32.9)**	**14 (14.3)**	**18 (30.0)**	12 (8.5)	9 (17.0)	40 (17.9)	34 (23.5)
Any of the symptoms listed above	**244 (37.9)**	**170 (61.4)**	38 (40.0)	29 (48.3)	41 (29.7)	23 (44.2)	86 (39.6)	65 (48.2)
Chronic bronchitis	**54 (8.2)**	**41 (14.5)**	9 (9.4)	6 (10.2)	3 (2.1)	1 (1.8)	19 (8.7)	11 (7.5)
Self-reported respiratory disease								
Sick leave due to respiratory problems	**50 (7.6)**	**39 (13.5)**	8 (8.1)	8 (10.2)	9 (6.3)	6 (11.3)	**11 (4.9)**	**18 (12.2)**
Asthma	**97 (14.7)**	**65 (22.7)**	9 (9.0)	11 (18.3)	6 (4.3)	4 (7.4)	27 (12.3)	18 (11.8)
Current asthma	**72 (11.0)**	**56 (19.7)**	7 (7.0)	8 (13.8)	5 (3.6)	3 (5.6)	20 (9.2)	17 (11.3)
COPD	**39 (5.9)**	**48 (16.8)**	**1 (1.0)**	**7 (11.7)**	1 (0.7)	0 (0.0)	4 (1.8)	6 (4.0)
Other lung disease	**20 (3.0)**	**18 (6.3)**	1 (1.0)	2 (3.3)	1 (0.7)	0 (0.0)	5 (2.3)	5 (3.3)
Spirometry								
FEV_1 % predicted	**88.2±12.6**	**74.0±14.5**	78.4±2.2	77.9±2.5	84.2±3.1	83.9±2.9	**74.1±4.8**	**71.8±6.3**
FVC % predicted	**105.3±13.7**	**92.4±13.7**	84.1±2.6	83.6±2.6	77.8±2.4	77.8±2.3	73.4±4.7	72.4±6.6
FEV_1/FVC % predicted	**84.4±5.5**	**79.6±9.1**	92.8±2.8	92.8±3.0	107.9±4.9	107.4±5.0	**100.7±6.0**	**98.9±6.2**
FEV_1/FVC	**0.67±0.1**	**0.64±0.07**	0.74±0.03	0.74±0.03	0.86±0.04	0.86±0.04	**0.81±0.05**	**0.79±0.05**

Data are presented as n, n (%) or mean±SD. Significant differences are shown in bold. FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity.

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Prediction equations in AOS

- Lack of standardized prediction equations across all devices and ethnic groups.
- No GLI database exists for oscillometry; unclear effect of race/ethnicity.

Criteria	Oostveen Prediction Equations *(Preferred)*	Brown Prediction Equations
Publication	*ERJ 2013* PMID: 23598954	*Respir Physiol Neurobiol. 2010* PMID: 20478414
Population	Large and diverse European cohort	Smaller North American cohort
Age range	4-80 years	Primarily adults
Key parameters	R5, X5, Fres, AX	Fewer parameters available
Reproducibility	Better reproducibility and accuracy	Greater variability in results
Applicability	Broader applicability across populations	Limited by smaller cohort

Z-scores *vs.* fixed cut-off values

CONTROVERSIAL

Study	Findings	Implications	Citation
"Interpreting lung oscillometry results: Z-scores or fixed cut-off values?"	- Oscillometry indices not normally distributed. - Weak correlations with demographic factors (R^2 = 0.15–0.25).	- Suggests fixed cut-off values may provide more accurate discrimination.	PMID: 37009017
"Interpreting lung oscillometry results: Z-scores instead of fixed cut-off values?"	- Z-scores provide standardized assessments. - Residuals are approximately normal.	- Supports Z-scores for standardized interpretation.	PMID: 37009021
"Normal limits for oscillometric bronchodilator responses"	- Absolute changes showed more positive responders in COPD. - Similar responsiveness across methods except in COPD.	- Choice between absolute values and Z-scores affects interpretation in COPD.	PMID: 34761000

Interpreting respiratory oscillometry in adults with asthma or COPD: findings of an international Delphi study

Li Ping Chung[1], Bruce Thompson[2], Gregory King[3], Omar S. Usmani[4], Salman Siddiqui[4], Ronald J. Dandurand[5,6], Monica Kraft[7] and Claude S. Farah [8,9,10] on behalf of the Respiratory Oscillometry Delphi Study Group

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Shareable abstract (@ERSpublications)
This international Delphi study informs clinicians in the use of respiratory oscillometry; focusing on a few key parameters will build confidence in its everyday use to assess abnormality and severity, monitor changes, and determine bronchodilator response https://bit.ly/3HPoPgI

Cite this article as: Chung LP, Thompson B, King G, *et al*. Interpreting respiratory oscillometry in adults with asthma or COPD: findings of an international Delphi study. *ERJ Open Res* 2025; 11: 00398-2025 [DOI: 10.1183/23120541.00398-2025].

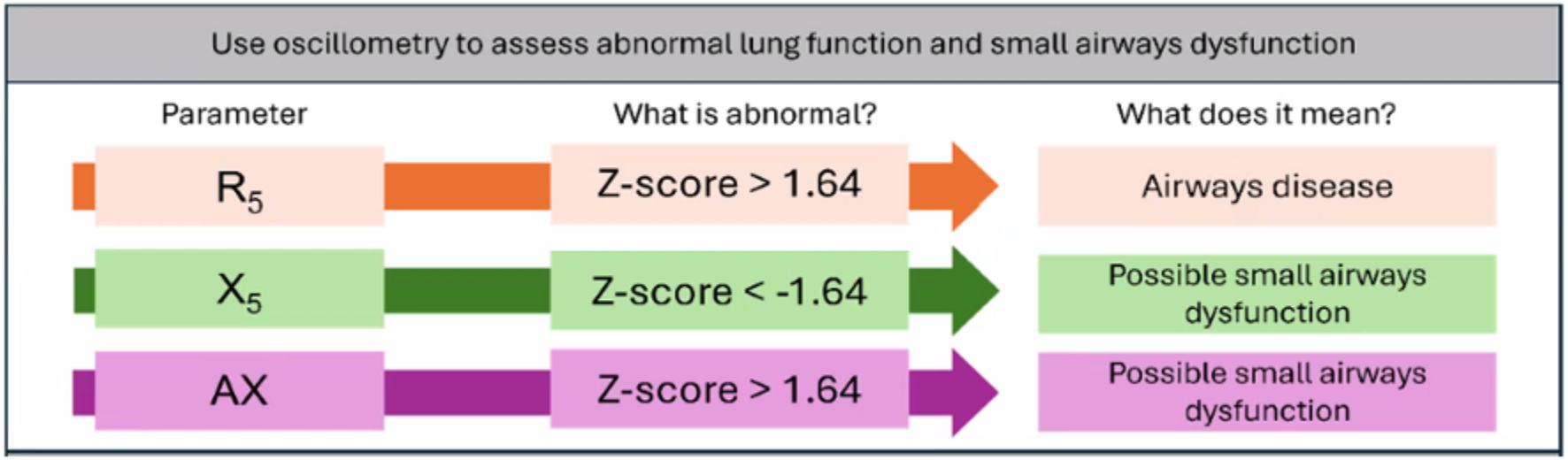
Abstract

Background Respiratory oscillometry measures the physiological effort and mechanics of moving air in and out of the lungs during normal breathing. It provides complementary information to spirometry. Uncertainty regarding the interpretation of oscillometry is a barrier to routine use. The aim of this study was to aid in oscillometry interpretation among adults with asthma or COPD by generating expert consensus statements.

Methods A Delphi method was used to develop consensus statements regarding the clinical use of oscillometry in adults to identify abnormal lung function, bronchodilator response and minimal clinically important differences. Initial statements were refined in the brainstorming round. Statements were assessed by 60 pulmonologists over three rounds, with consensus defined as ⩾70% agreement.

Results Pulmonologists agreed that oscillometry is clinically useful to assess abnormal lung function and its severity, and to measure bronchodilator response. High consensus was reached for resistance at 5 Hz (R_5, 85%), reactance at 5 Hz (X_5, 79%) and area under the reactance curve (A_X, 77%) based on z-scores, where >1.64 was considered abnormal for R_5 and A_X and < -1.64 was considered abnormal for X_5. For measuring bronchodilator response, good agreement was based on using percentage change for R_5, X_5 and A_X.

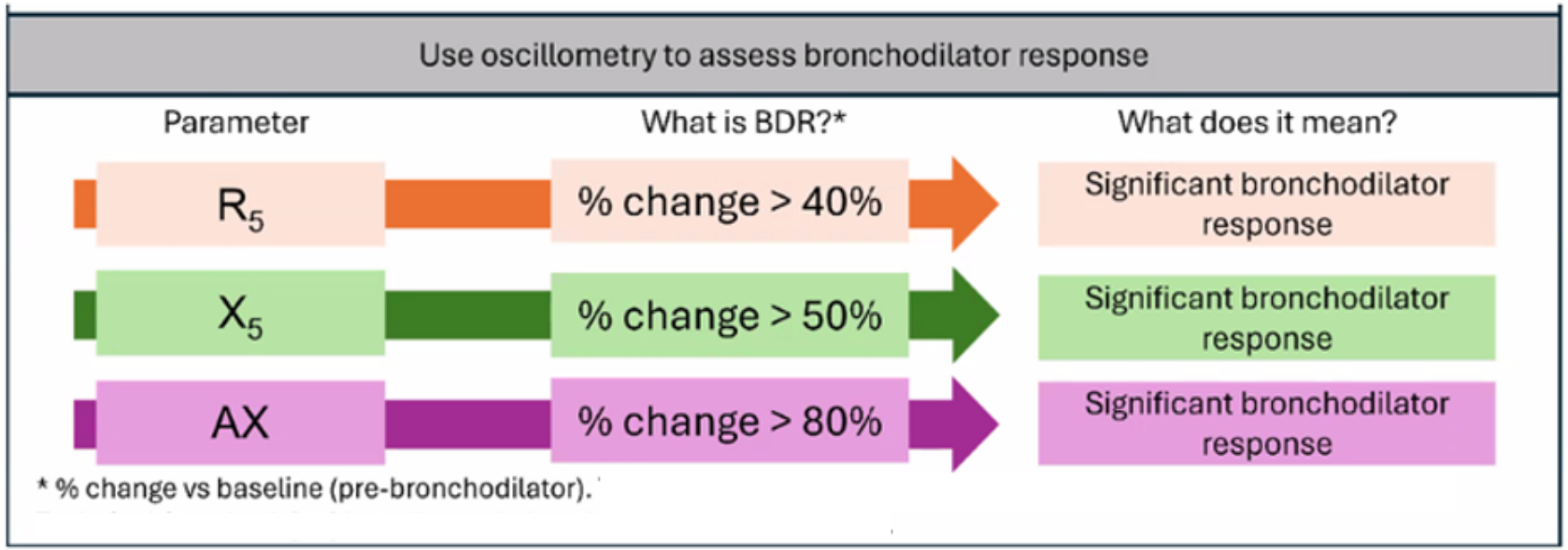
Discussion This international Delphi study combined evidence-based and expert opinion to inform clinicians in the interpretation of respiratory oscillometry. Focusing on a few key parameters of oscillometry will allow clinicians to become confident in its everyday use to assess abnormal lung function, grade severity of impairment, monitor progression over time and assess bronchodilator response.



Z-scores can be used to define the severity of abnormal lung function
(81% agreement)

- Mild: Z-score > 1.64 and ≤ 2.5
- Moderate: Z-score > 2.5 and ≤ 4
- Severe: Z-score > 4

ERJ Open Res 2025;11(6):00398-2025.



ERJ Open Res 2025;11(6):00398-2025.

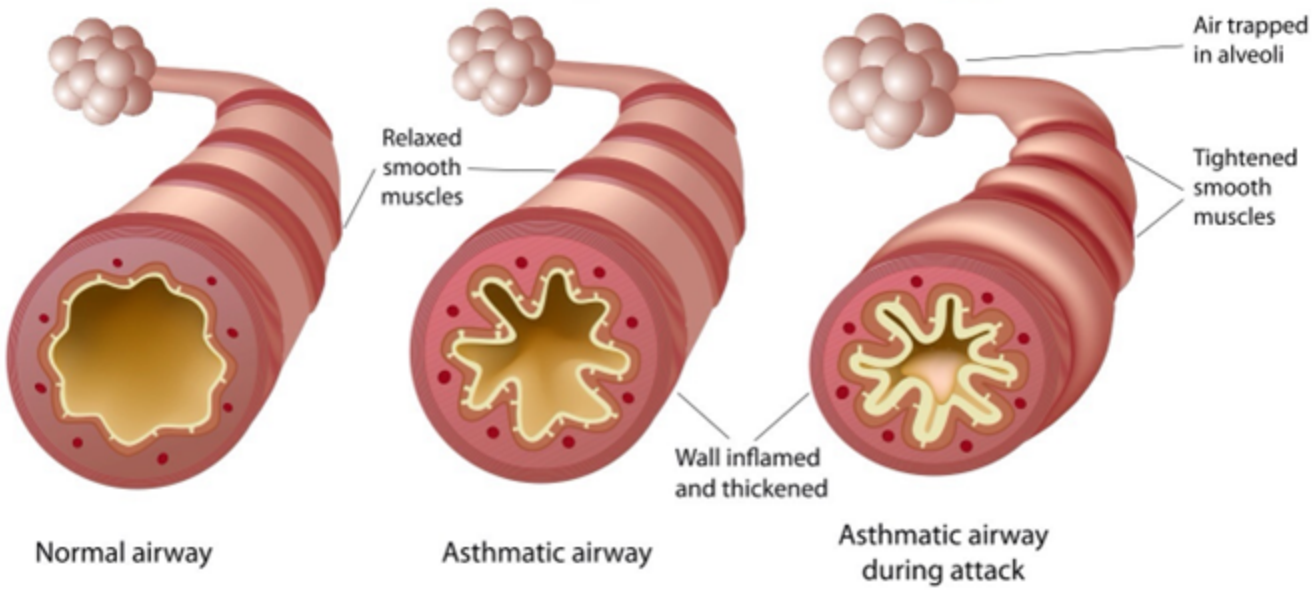
Parameter	Z-score cutoff	% change most common cutoff
R_5	> 0.5 (Neutral 48%)	> 25% (39% agreement)
X_5	> 1 (60% agreement)	> 30% (43% agreement)
AX	-	> 40% (45% agreement)
R_{5-20}	-	> 40% (67% agreement)

Lack of evidence for MCID (only 1 published study)[1]

1. Abdo M, et al. Eur Respir J. 2023;61

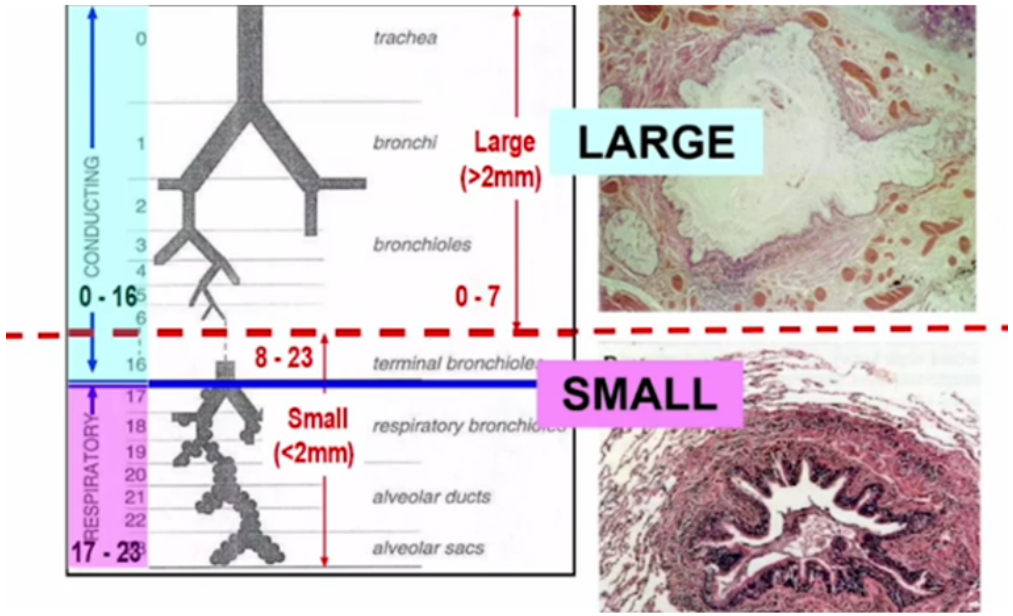
ERJ Open Res 2025;11(6):00398-2025.

Why is oscillometry an important tool in asthma?



Small airways disease is highly prevalent in asthma

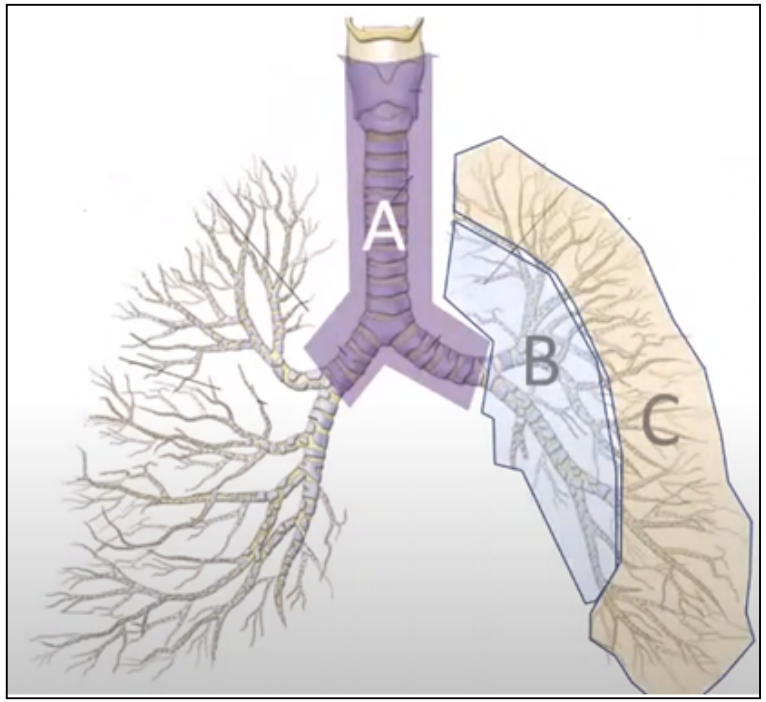
- Small airways dysfunction contribute significantly to the clinical impact of asthma.
- 2016 systematic literature review:
  - Using distinct techniques of small airways assessment
  - Small airways affected in > 50-60% of asthmatics
  - Small airway disease present across all asthma severities, with evidence of distal airway disease even in the absence of proximal airway obstruction



Respir Med. 2016;116:19-27.

SAD asthma

- Small-airway dysfunction (SAD) is associated with:
  - Exercise-induced asthma symptoms [OR 6.5 (3.6-11.4)]
  - Asthma-related night awakenings [OR 3.3 (1.8-6.2)]
  - Increased FeNO [OR: 2.0 (1.1-3.7)]
  - Female sex [OR 2.3 (1.3-4.1)]
  - Smoking [OR 3.1 (1.6-6.0)]
  - Older age [OR 3.1 (1.8-5.5)]
  - Overweight [OR 3.6 (2.0-6.8)]
- ***Though size matters, sometimes even small can outdo the big.***

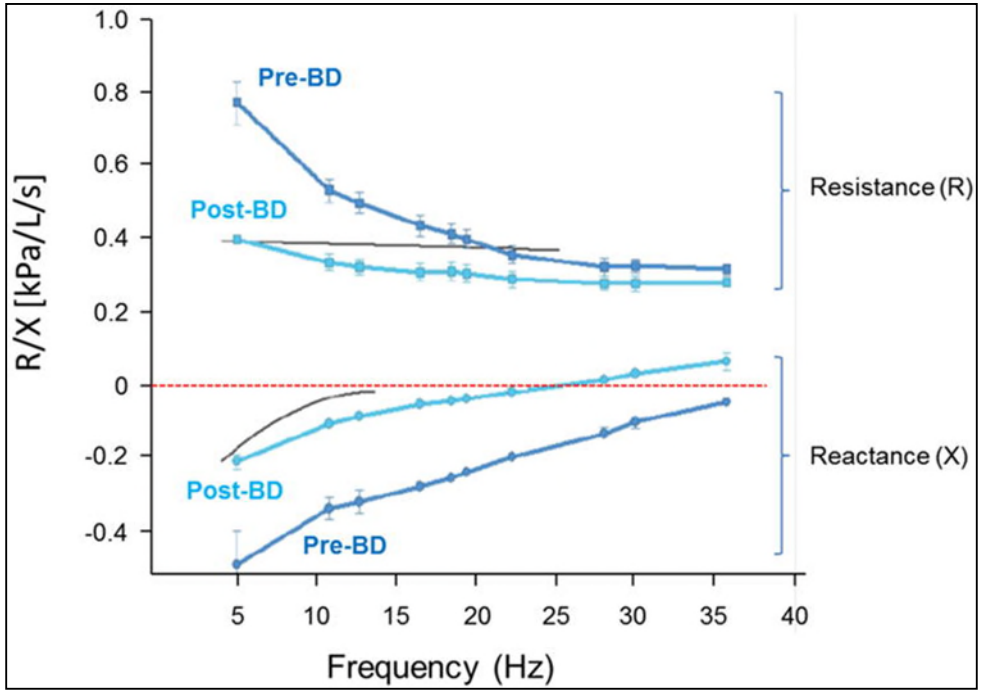


Primarily affects small airways
C >>> B > A

J Allergy Clin Immunol Pract. 2020;8(3):997-1004.
Lancet Respir Med. 2022;10(7):661-668.

AOS bronchodilator responsiveness in asthma

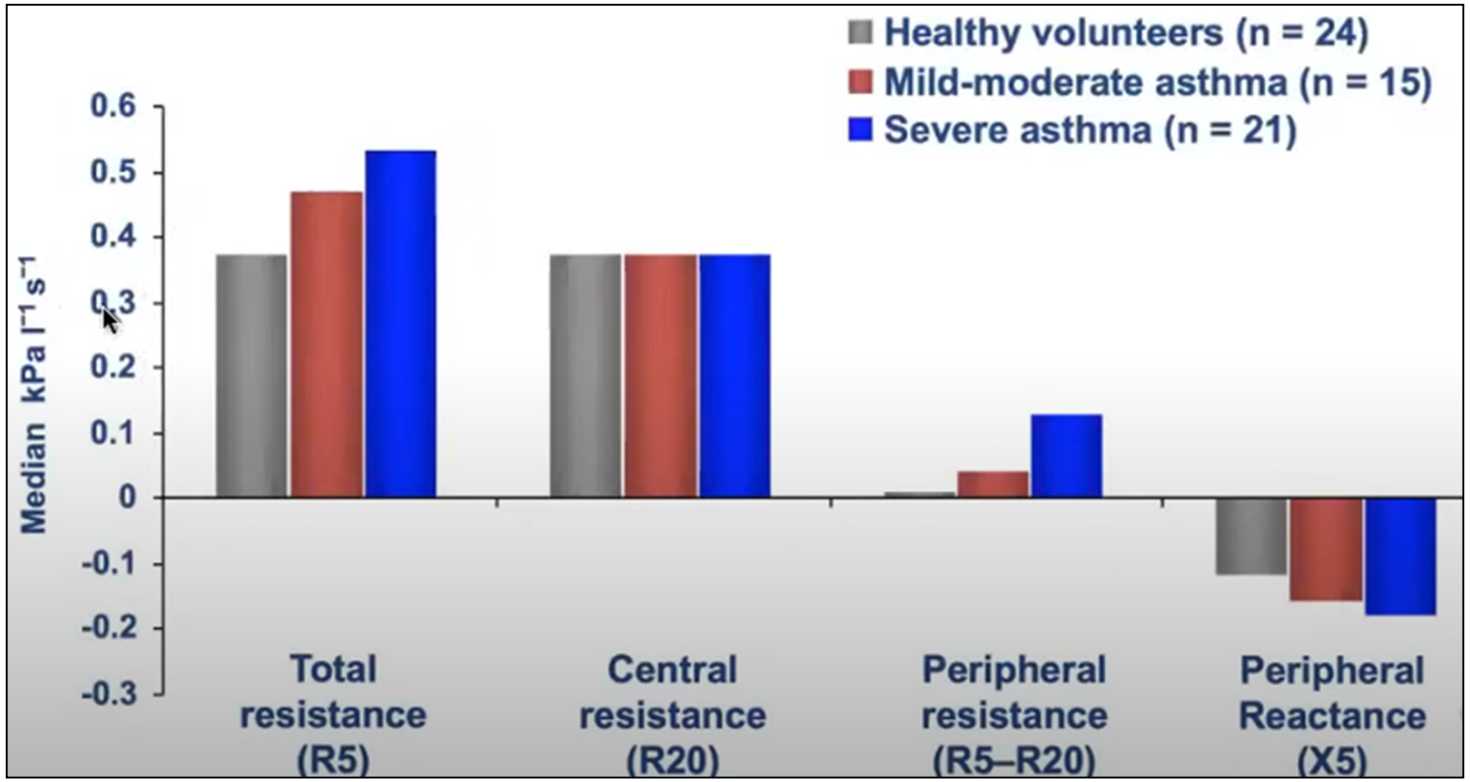
- AOS is more sensitive than spirometry for detecting BDR.
  - In one study, AOS detected BDR in ~20% of smokers without COPD, surpassing spirometry.
  - Another study reported AOS sensitivities ~70% for detecting significant BDR.



Ann Allergy Asthma Immunol. 2017;118(6):664-671.
J. Asthma Allergy. 2019;12:263-271
ERJ Open Res. 2021;7(4):00439-2021.
ERJ Open Res 2025;11(6):00398-2025.
ERJ 2022;31(163):210208

AOS and asthma severity

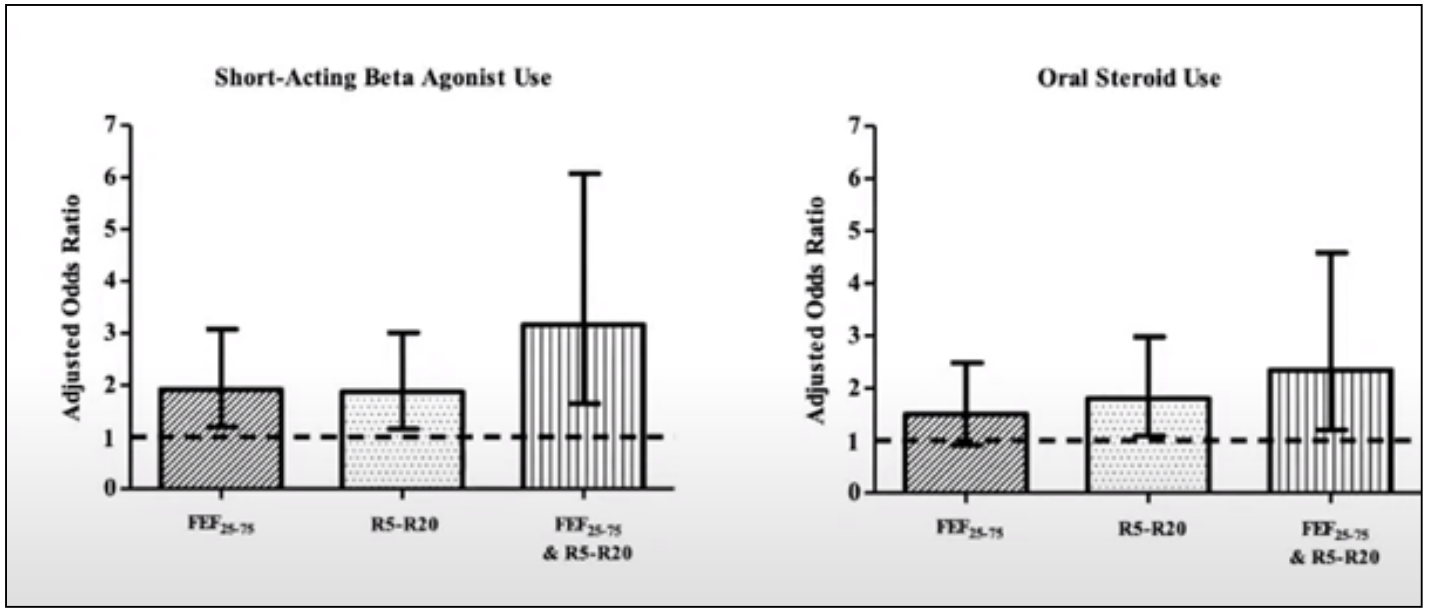
Except for central resistance, all parameters showed increased abnormality with increasing asthma severity.



Lung 2011;189(2):121-129.

AOS and asthma control

Odds ratio (95%CI) for asthma control over 2 years
N=302; FEV_1 = 97 percent predicted; on LABA/ICS

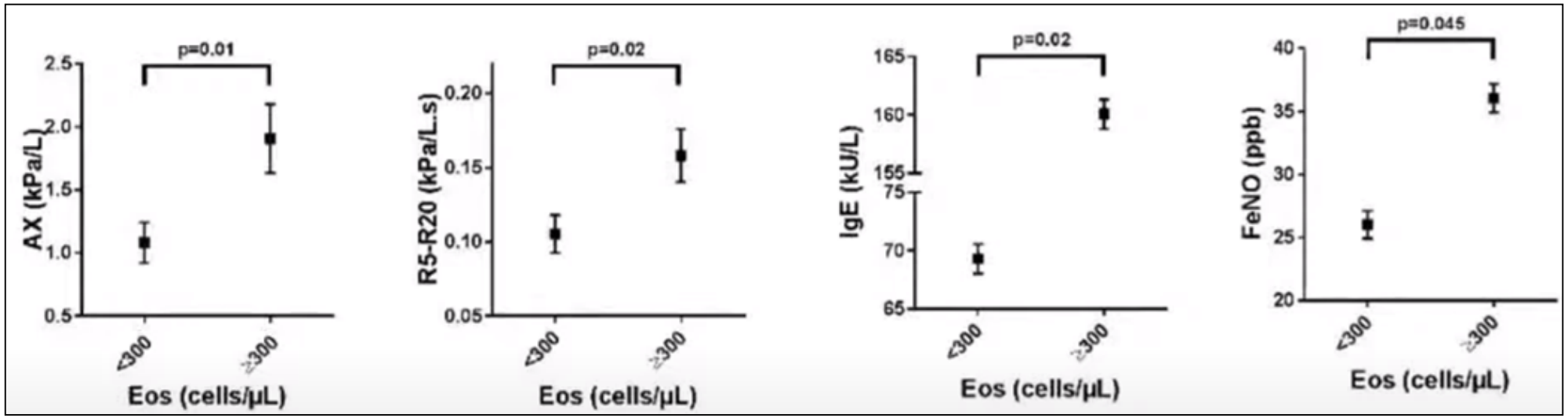


In asthmatics who have a preserved FEV_1, the presence of persistent small airway dysfunction (defined by $FEF_{25–75}$ and R_5-R_{20}) was associated with a significantly increased likelihood of worse long-term asthma control.

Eur Respir J. 2014;44(5):1353-1355.

AOS in relation to type 2 inflammation

113 persistent asthmatics; FEV_1 89%, ACQ 1.41; Mean ICS 644 mcg



Ann Allergy Asthma Immunol. 2018;121(5):631-632.

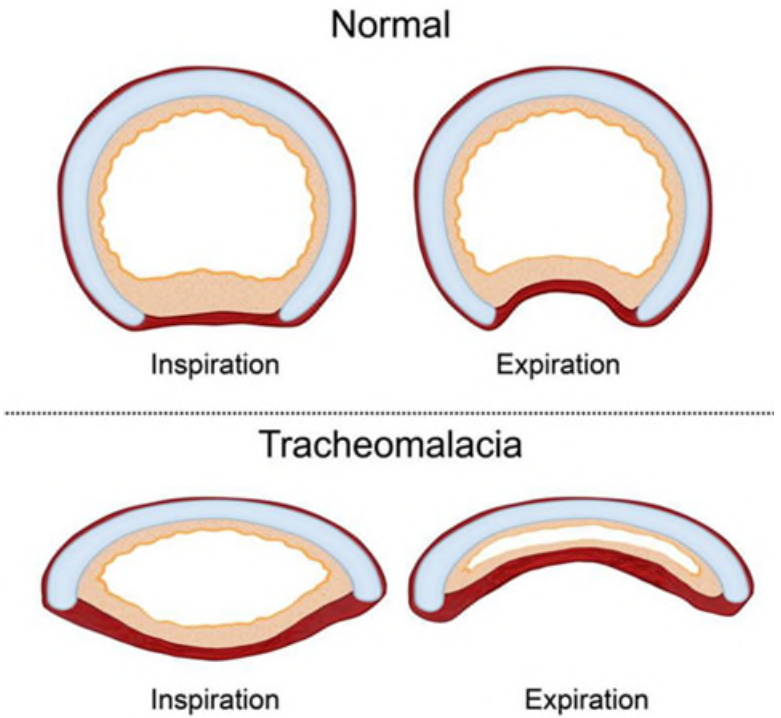
REVIEW | VOLUME 132, ISSUE 1, P21-29, JANUARY 2024

Adding oscillometry to spirometry in guidelines better identifies uncontrolled asthma, future exacerbations, and potential targeted therapy

Stanley P. Galant, MD • Tricia Morphew, MSc

Published: August 23, 2023 • DOI: https://doi.org/10.1016/j.anai.2023.08.011 •

Why is oscillometry an important tool in tracheobronchomalacia (TBM) / excessive dynamic airway collapse (EDAC) ?



AOS in TBM/EDAC

- 38 patients across 4 groups:
  - Controls (normal lung function, no EDAC)
  - Isolated EDAC with normal lung function
  - COPD without EDAC
  - COPD with EDAC
- EDAC definition: 75-100% expiratory airway closure at the carina or main bronchi on bronchoscopy
- EDAC associated with ↑X5, ↑AX, ↑resonant frequency and greater expiratory-inspiratory AOS differences vs controls. Resonant frequency best discriminated EDAC; AX ≥3.5 strongly predicted EDAC with normal lung function.
- COPD + EDAC showed greater AOS abnormalities than COPD alone.
- Clinical implication: AOS may detect EDAC even when spirometry is normal.

ERJ Open Res. 2018 Nov 12;4(4):00080-2018.

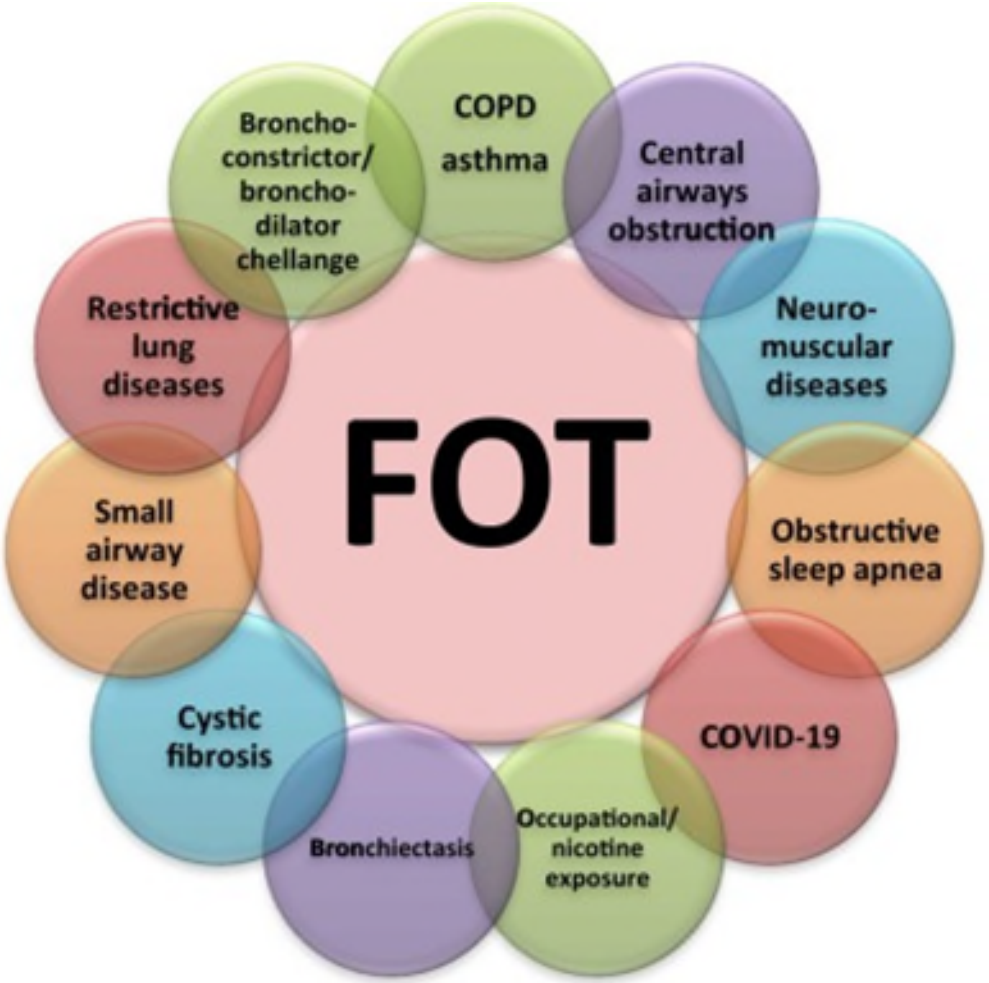
ELSEVIER

Respiratory Physiology & Neurobiology

Volume 316, October 2023, 104135

Window of opportunity for respiratory oscillometry: A review of recent research

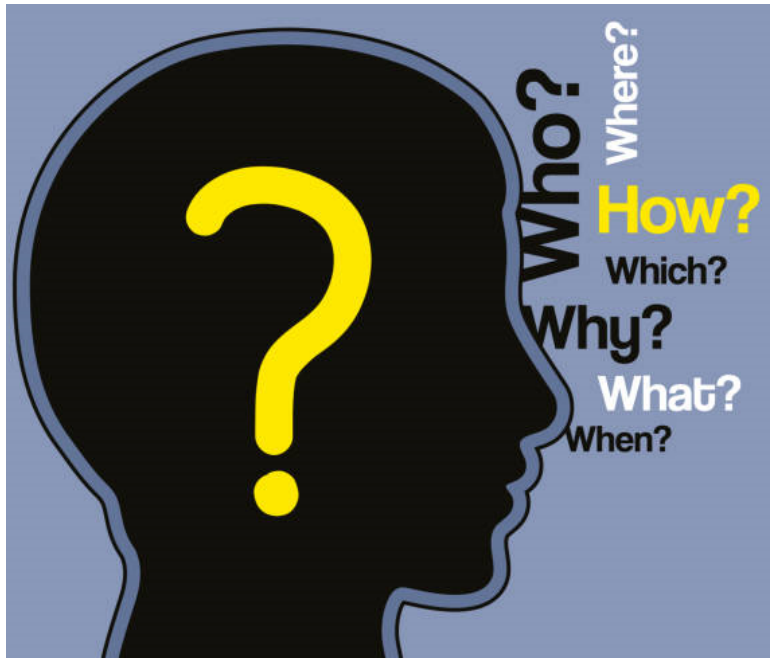
Sabina Kostorz-Nosal [a], Dariusz Jastrzębski [a], Anna Błach [b], Szymon Skoczyński [a]



FOT- Forced oscillation technique

Conclusions

- AOS is:
  - A young but very promising technology
  - An effort-independent rapid test
  - A portable user-friendly device
- AOS measures:
  - central/proximal and peripheral/distal airways, lung tissue, and chest wall resistance
  - reactance
- AOS detects subtle small airway changes, making it valuable for early diagnosis, disease monitoring, and assessing treatment response across respiratory conditions.
- AOS should be used in conjunction with spirometry to fully characterize physiology and pathophysiology.


Who?
Where?
How?
Which?
Why?
What?
When?


WORK
IN PROGRESS

What about children?

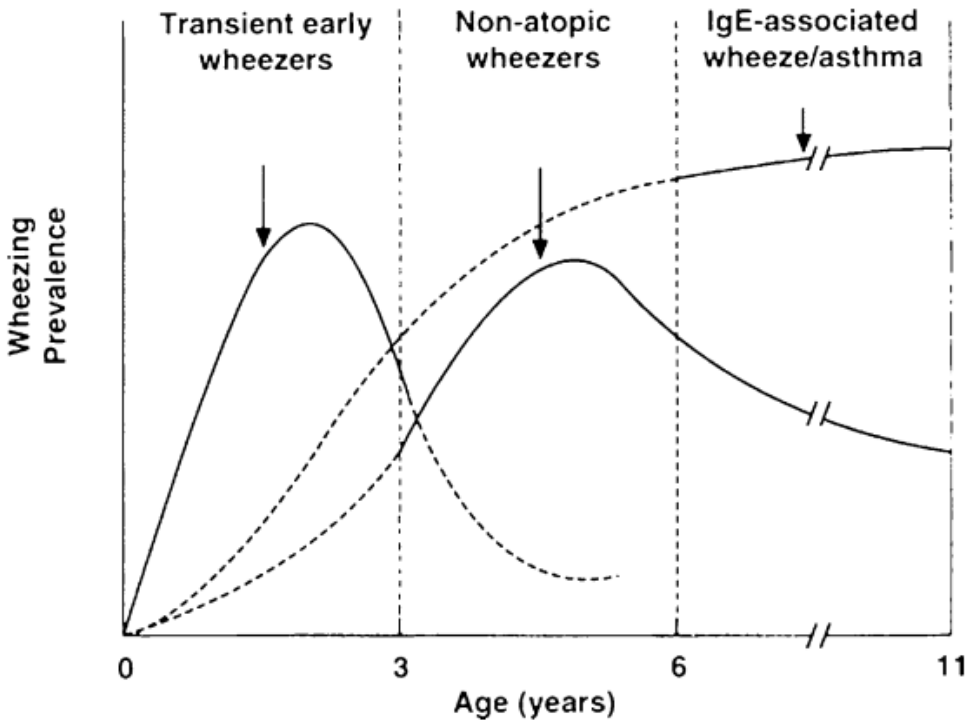
Peter P. Moschovis, MD, MPH
Massachusetts General Hospital
Pediatric Pulmonary Medicine

Outline

- Why oscillometry is needed in pediatric asthma
- How the test is performed in children
- Examples of tests and interpretation
- Applications in pediatric asthma
- Challenges and future opportunities

Why perform PFTs in young children?

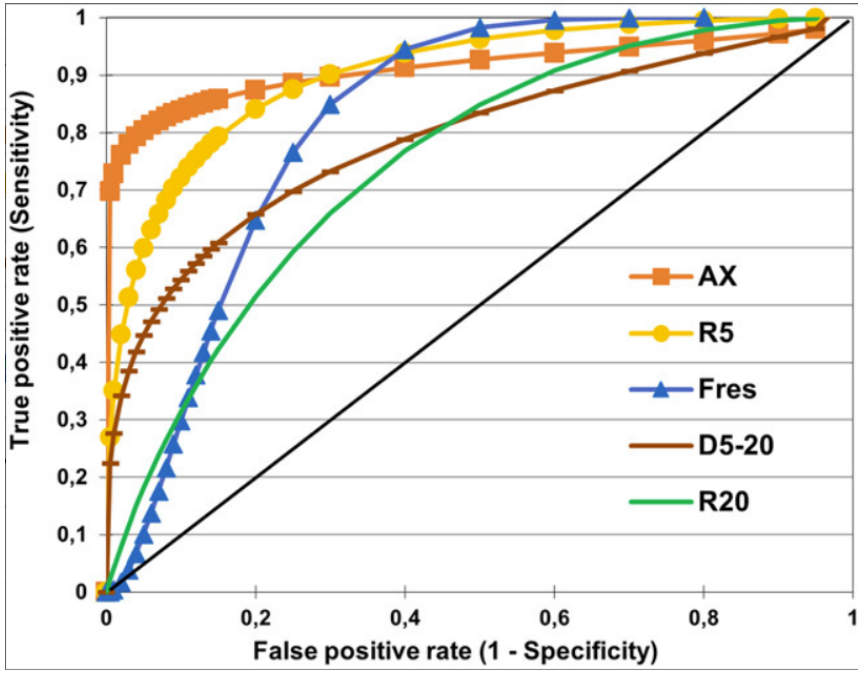
- Young children have a much greater prevalence of wheezing compared to older children and adults.
  - 1 in 3 children wheeze at least once before the age of 3 years; about 1/3 of those will continue to wheeze after age 6.
- It is difficult to determine response to treatment without objective data, and preschool children are difficult to test with spirometry:
  - ~50% spirometry success rate in children ≤5 years



Taussig LM et al. JACI 2003; PMID 12704342. Martinez FD. NEJM 1995; PMID 7800004
Stein RT and Martinez FD. Paediatr Respir Rev 2004. PMID 15135126.

Oscillometry in pre-school children

- Feasible in preschool children, children with developmental delays, children with neuromuscular disease: success rates in preschool children ranging between 74-98%.
- Associated with asthma symptoms in standardized questionnaires
- Predicts later spirometry abnormalities among children with asthma
  - AUC for R5 (>1.07) and Ax (3.92) = 0.75 (95% CI 0.6, 0.9)



Medeiros D et al. Expert Rev Respir Med 2020. PMID 32852224
Vielkind ML et al. Pediatr Res 2022. PMID 34326475
Chaya S et al. Front Pediatr 2022. PMID 35769219
Grell AV et al. Pediatr Pulmonol 2023. PMID 36704870

Oscillometry in pre-school children

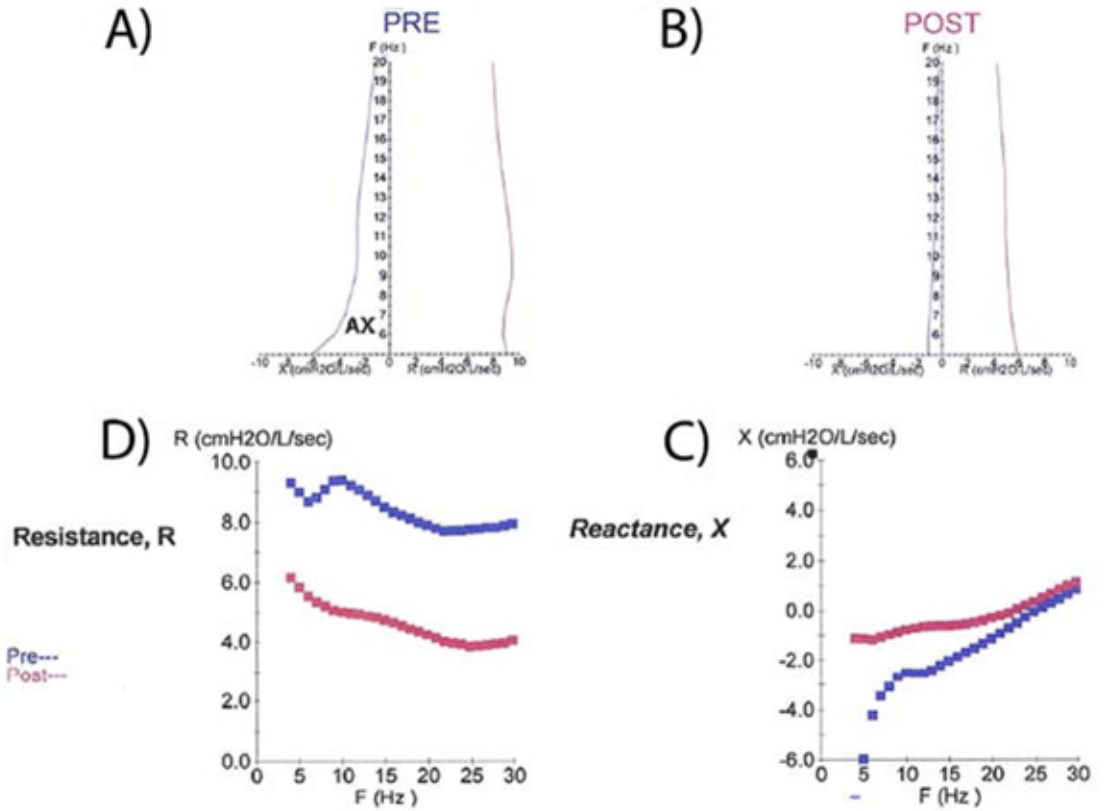
Vyaire IOS
https://intl.vyaire.com/products/ios-impulse-oscillometry

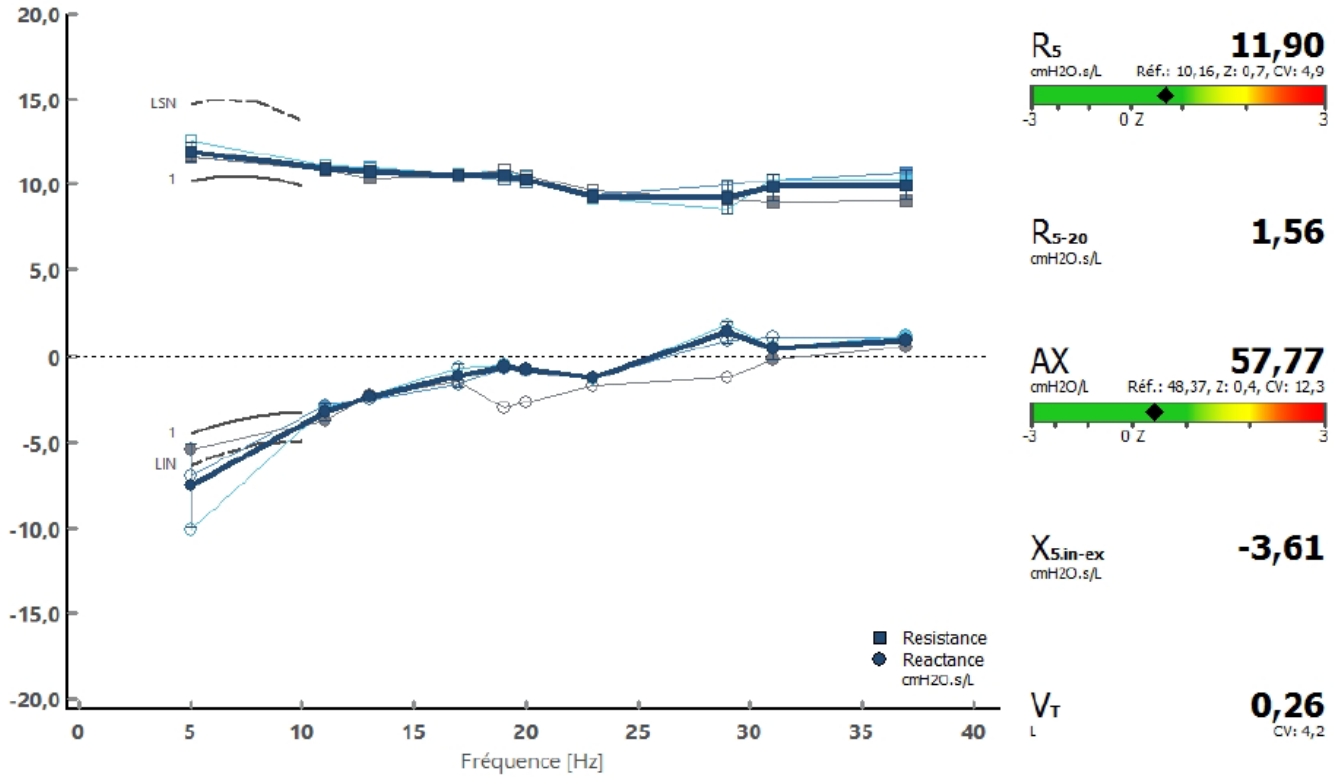
Thorasys Tremoflo C-100
(Image used with permission from child's family)

Performing the test

- Tell patients they will feel fluttering/vibration in their mouth (consider practice run)
- Instruct patients to breath normally
- Sit with upright posture, slight chin-up position
- Avoid swallowing, tongue relaxed, and below mouthpiece
- Teeth and lips need to have firm seal around mouthpiece
- Support cheeks and chin
- Nose clip

What the results look like (IOS, TremoFlo)





Komarow et al. Ann Allergy Asthma Immunol. 2011 Jan 6;106(3):191–199. doi: 10.1016/j.anai.2010.11.011

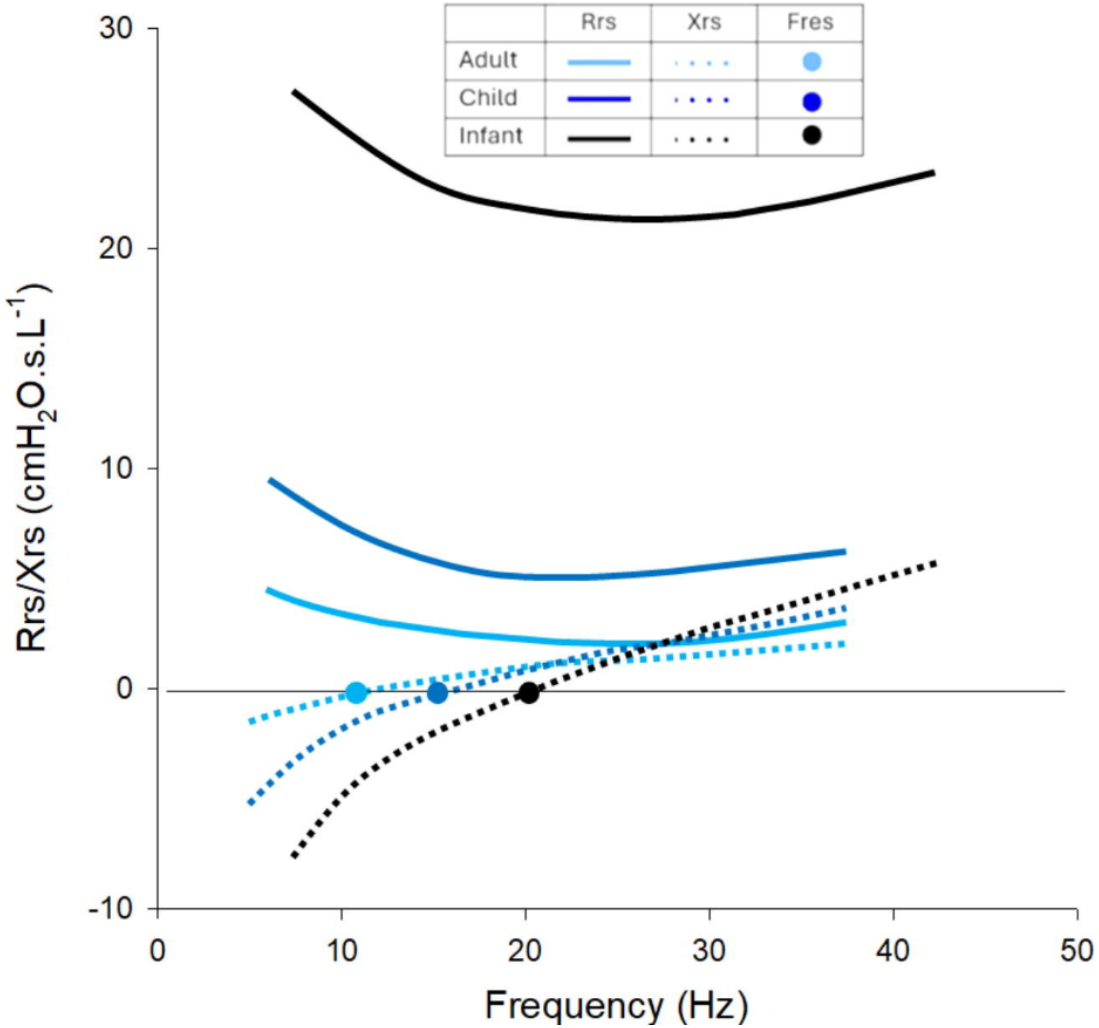
What makes an acceptable test?

- At least three artifact-free measurements (mean values are used across all measurements)
  - Visual inspection for leaks, cough, swallowing
  - Coefficient of variation ≤15% for children, ≤10% in adults
  - Automatic signal processing
- Minimum of 16-second acquisitions (children < 12 years) or 30-second acquisitions (older children and adults)
- Recording over at least three breaths
- *My addition*: A reasonable tidal volume (e.g., 4-10 cc/kg)
- Oscillometry should precede tests requiring deep breaths (e.g., spirometry, DLCO, lung volumes)
- Bronchodilator responsiveness is defined as -40% in R5, +50% in X5, and -80% in Ax.

King GG, Bates J, Berger KI, et al. Technical standards for respiratory oscillometry. Eur Respir J 2020; 55: 1900753 [https://doi.org/10.1183/13993003.00753-2019]

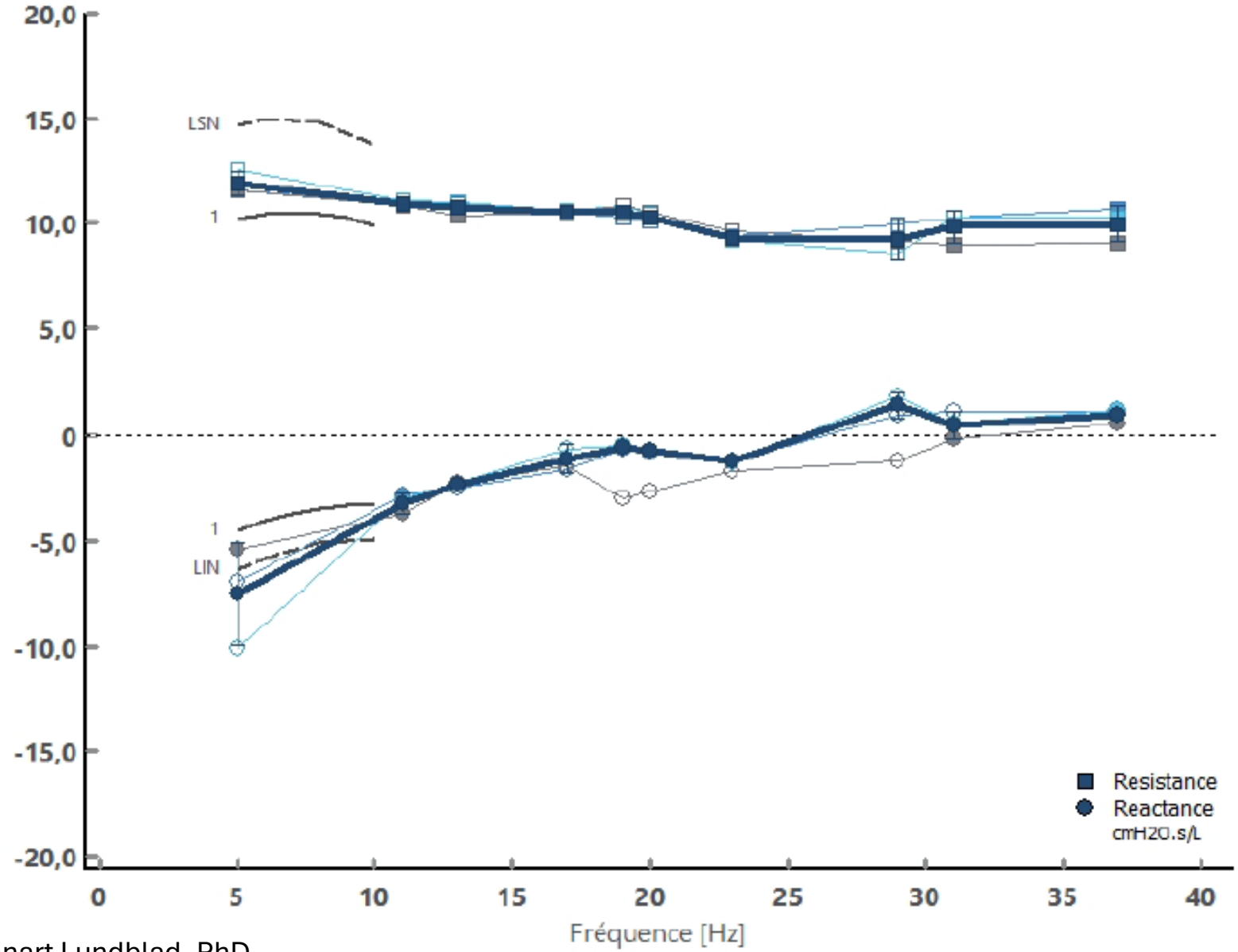
Examples: Interpretation and patterns of findings in health and disease

Normal developmental changes



Moschovis PP et al. Respiratory oscillometry in infants: present challenges and future opportunities. Pediatric Resp Review 2025.

SEXE	Femme	TEMPS	0 years	MODÈLE	Airwave Oscillometry
ÂGE	2,8 ans	TAILLE	91 cm	FORME	AOS 5-37
NÉ LE	29/05/2015	POIDS	11 kg	MÉDECIN	
AVANT MÉDICAMENT		ETHNIE	Caucasien	OPÉRATEUR	PLANETEMEDICALE



R_5 **11,90**
cmH2O.s/L Réf.: 10,16, Z: 0,7, CV: 4,9
-3 0 Z 3

R_{5-20} **1,56**
cmH2O.s/L

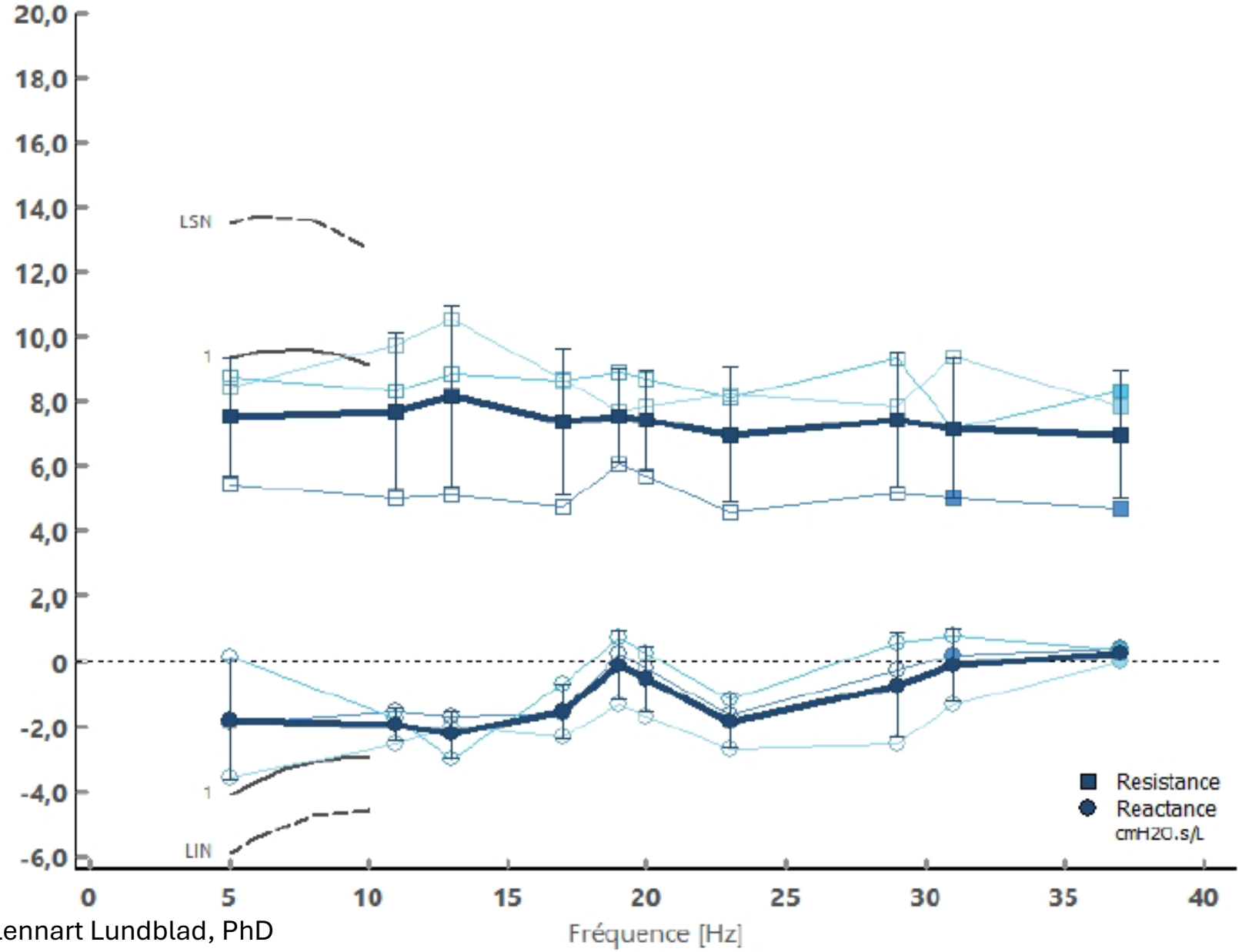
AX **57,77**
cmH2O/L Réf.: 48,37, Z: 0,4, CV: 12,3
-3 0 Z 3

$X_{5.in-ex}$ **-3,61**
c

V_T **0,26**
L CV: 4,2

Credit: Lennart Lundblad, PhD

SEXE	Homme	TEMPS	0 years	MODÈLE	Airwave Oscillometry
ÂGE	2,3 ans	TAILLE	95 cm	FORME	AOS 5-37
NÉ LE	21/11/2015	POIDS	16 kg	MÉDECIN	
AVANT MÉDICAMENT		ETHNIE	Caucasien	OPÉRATEUR	PLANETEMEDICALE



R_5 **7,51**
cmH2O.s/L Réf.: 9,34, Z: -1,0, CV: 24,3
-3 0 Z 3

R_{5-20} **0,11**
cmH2O.s/L

AX **35,23**
cmH2O/L Réf.: 40,99, Z: -0,3, CV: 77,5
-3 0 Z 3

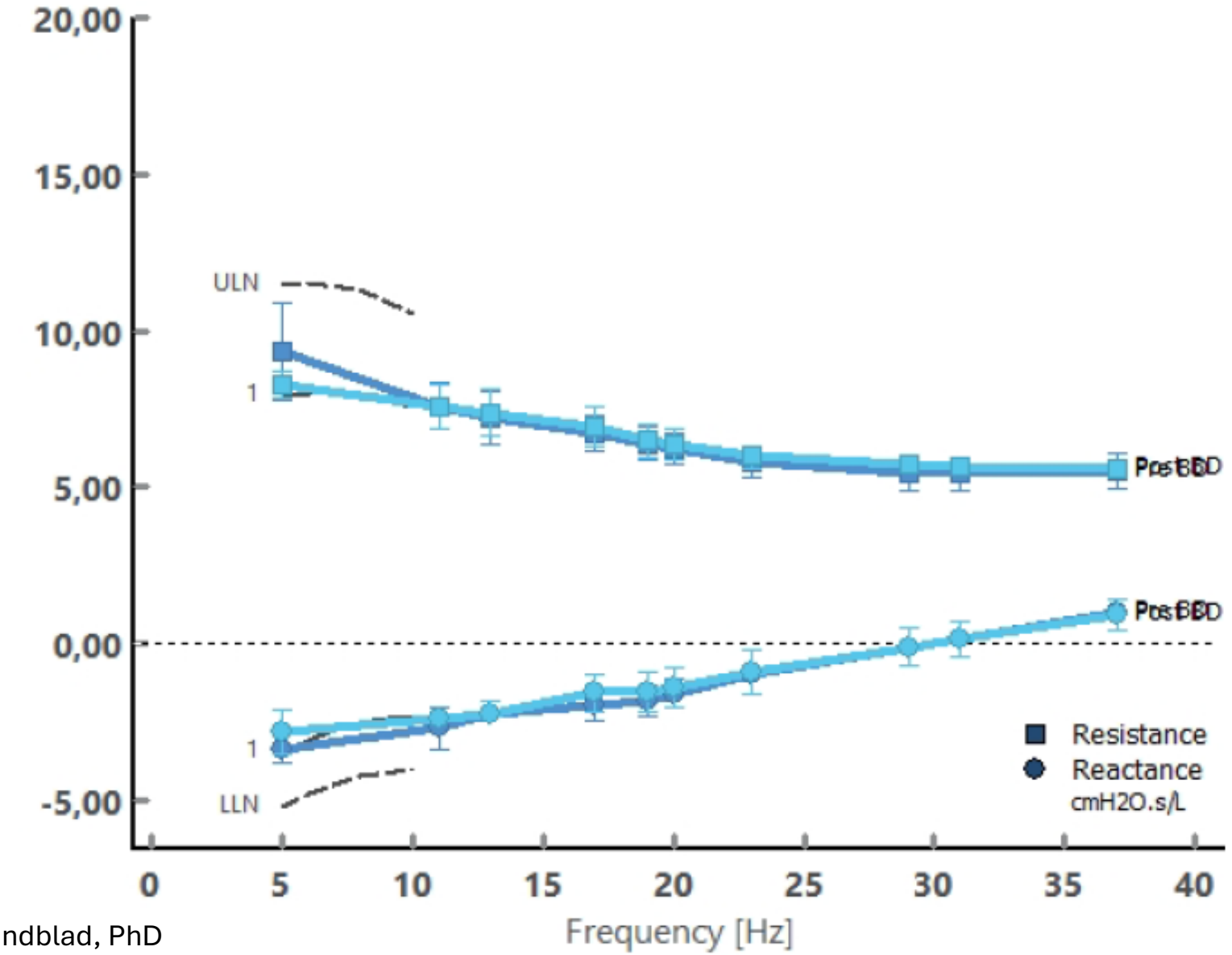
$X_{5.in-ex}$ **-1,23**
cmH2O.s/L

V_T **0,17**
L CV: 8,5

Credit: Lennart Lundblad, PhD

SEX	Male	HOW LON		LATE	Airwave Oscillometry
AGE	5,7 yrs	HEIGHT		FORM	AOS 5-37
DOB	31/01/2012	WEIGHT	18,0 kg	PHYSICIAN	
PRIOR MED		ETHNICITY	Caucasian	OPERATOR	PLANETE

DOSE	200
ADMINISTERED	15:40:19
OPERATOR COMMENTS	



R_5 ▼ **-11%**
cmH2O.s/L Pre: 9,33, Post: 8,27, Δ -1,06

R_{5-20} ▼ **-39%**
cmH2O.s/L Pre: 3,10, Post: 1,90, Δ -1,20

AX ▼ **-10%**
cmH2O/L Pre: 44,27, Post: 39,77, Δ -4,50

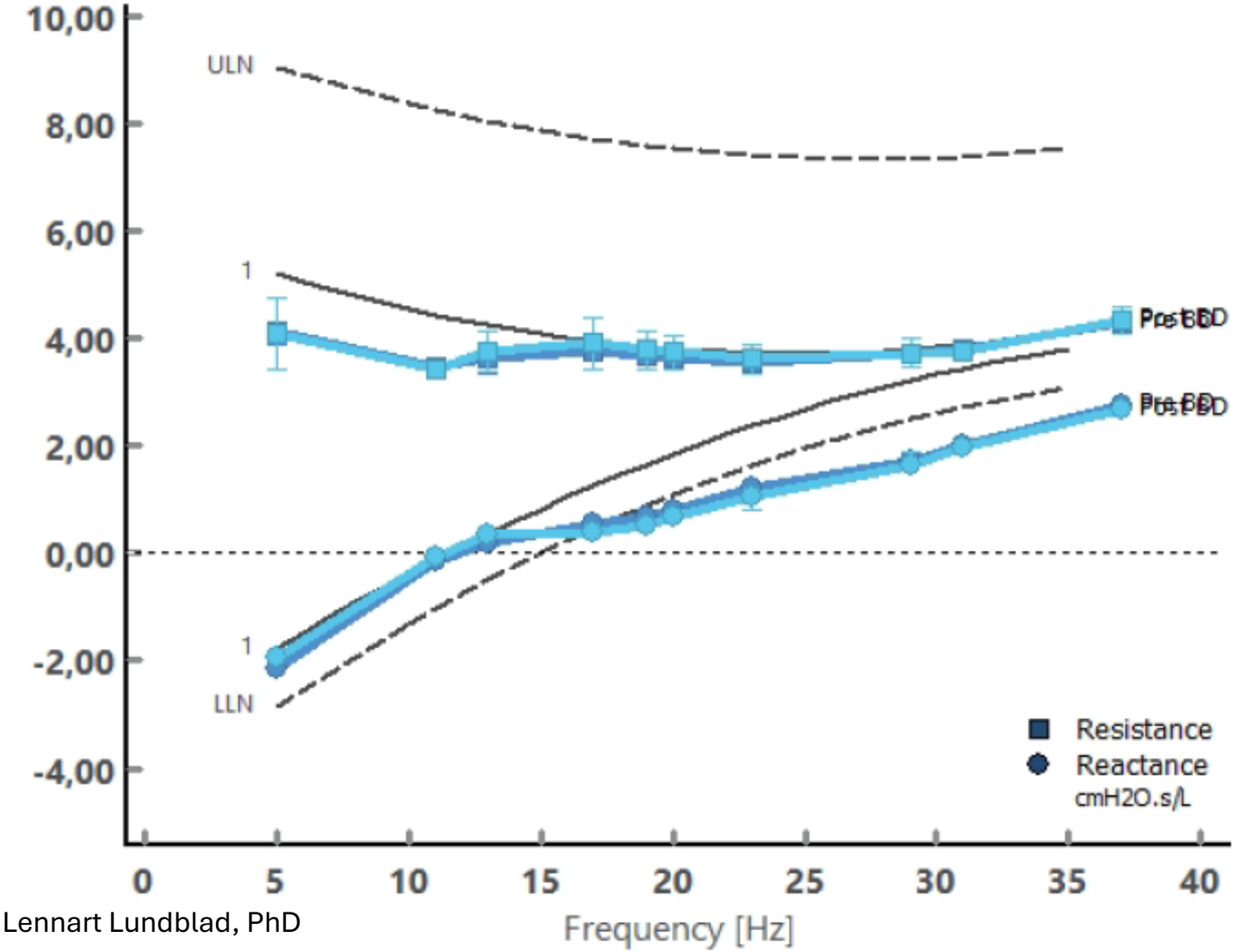
$X_{5.in-ex}$ ▼ **-4%**
cmH2O.s/L Pre: -1,67, Post: -1,73, Δ -0,06

f_{res} ▼ **-1%**
Hz Pre: 29,70, Post: 29,52, Δ -0,18

V_T ▲ **11%**
L Pre: 0,47, Post: 0,53, Δ 0,05

Credit: Lennart Lundblad, PhD

SEX	Male	HOW LONG	0 years	TEMPLATE	Airwave Oscillometry	DOSE	200
AGE	14,0 yrs	HEIGHT	147 cm		-37	ADMINISTERED	14:06:23
DOB	18/09/2003	WEIGHT	40,1 kg			OPERATOR COMMENTS	
PRIOR MED.		ETHNICITY	Caucasian	OPERATOR	PLANETE		



R_5 ▼ 0%
cmH2O.s/L Pre: 4,12, Post: 4,10, Δ -0,02
0 Z 3

R_{5-20} ▼ -26%
cmH2O.s/L Pre: 0,48, Post: 0,36, Δ -0,12
-3 0 Z 3

AX ▼ -15%
cmH2O/L Pre: 7,05, Post: 5,98, Δ -1,07

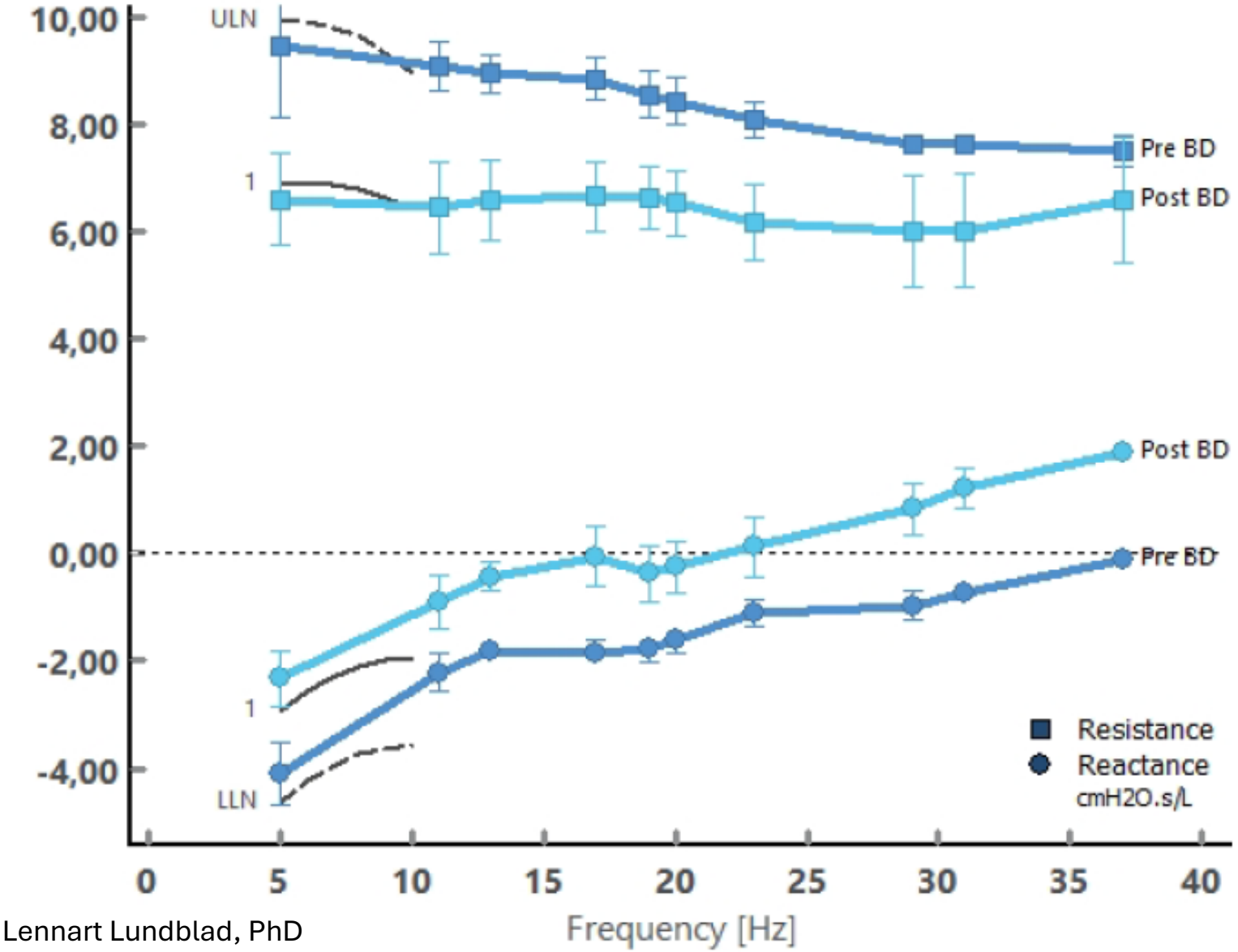
$X_{5.in-ex}$ ▼ -12%
Δ -0,07

f_{res} ▼ -4%
Hz Pre: 11,63, Post: 11,19, Δ -0,43

V_T ▲ 24%
L Pre: 0,54, Post: 0,66, Δ 0,13

Credit: Lennart Lundblad, PhD

SEX	Male	HOW LONG	0 years	TEMPLATE	Airwave Oscillometry	DOSE	200
AGE	8,7 yrs	HEIGHT	123 cm	WAVEFORM	AOS 5-37	ADMINISTERED	15:10:12
DOB	31/01/2009	WEIGHT	22,7 kg	PHYSICIAN		OPERATOR COMMENTS	
PRIOR MED.		ETHNICITY	Unspecified	OPERATOR	PLANETE		



R_5 ▼ -30%
cmH2O.s/L Pre: 9,45, Post: 6,60, Δ -2,85
-3 0 Z 3

R_{5-20} ▼ -92%
cmH2O.s/L Pre: 1,02, Post: 0,08, Δ -0,94

AX ▼ -73%
cmH2O/L Pre: 50,21, Post: 13,60, Δ -36,61
-3 0 Z 3

$X_{5.in-ex}$ ▼ -95%
cmH2O.s/L Pre: -0,41, Post: -0,79, Δ -0,39

f_{res} ▼ -50%
Hz Pre: 36,38, Post: 18,36, Δ -18,02

V_T ▲ 9%
L Pre: 0,44, Post: 0,48, Δ 0,04

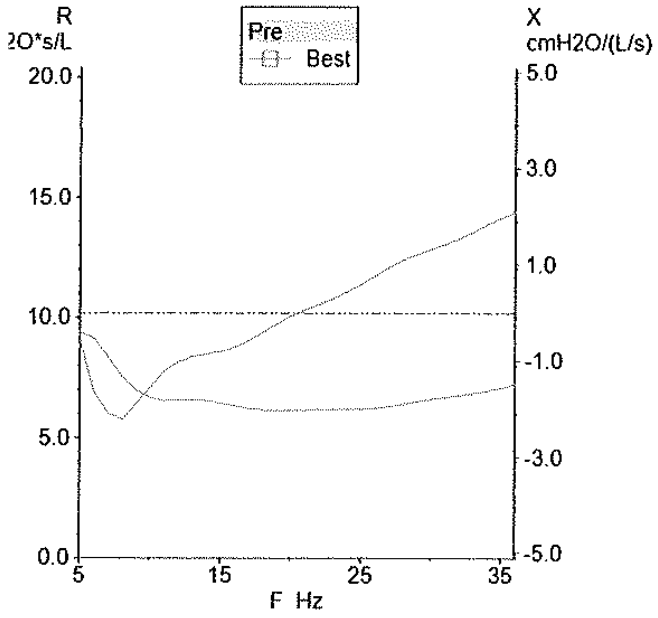
Credit: Lennart Lundblad, PhD

Height:	43.00 cm	Weight:	21.30 kg	BMI:	115 kg/m²
Ref. Physician:				Attending:	
Technician:					
Diagnosis:					

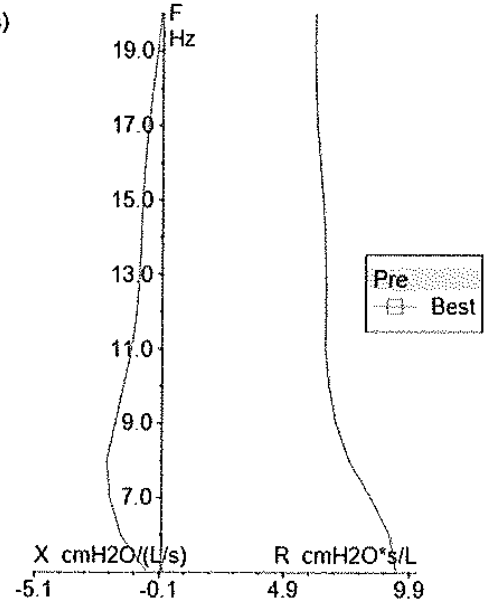
Impulse Oscillometry

		Pred	LLN	ULN	PRE	%PRED	Z-Score Pred
R5Hz	cmH2O/(L/s)	100.93	97.78		9.40	9	
R20Hz	cmH2O/(L/s)	83.44	80.78	86.11	6.13	7	
X5Hz	cmH2O/(L/s)	-30.11	-31.62	-28.60	-0.56	2	
Fres.	1/s		62.65		3.37	5	
AX	cmH2O/L						
D5-20%	%				34.75		
VT	L	0.04	0.03	0.07	5.12	11466	

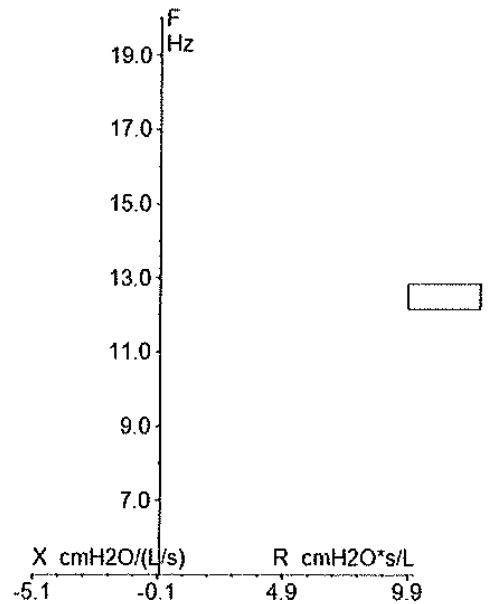
Resistance & Reactance Spectra



PRE



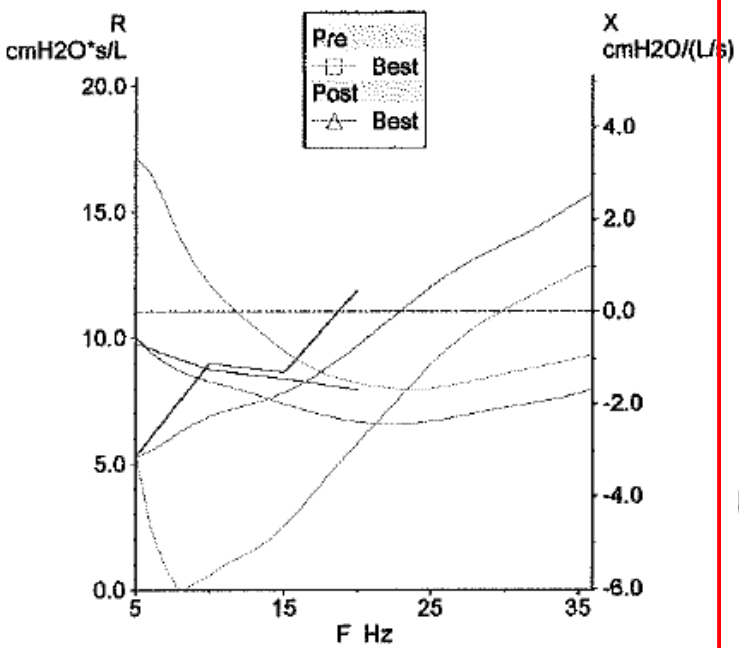
POST

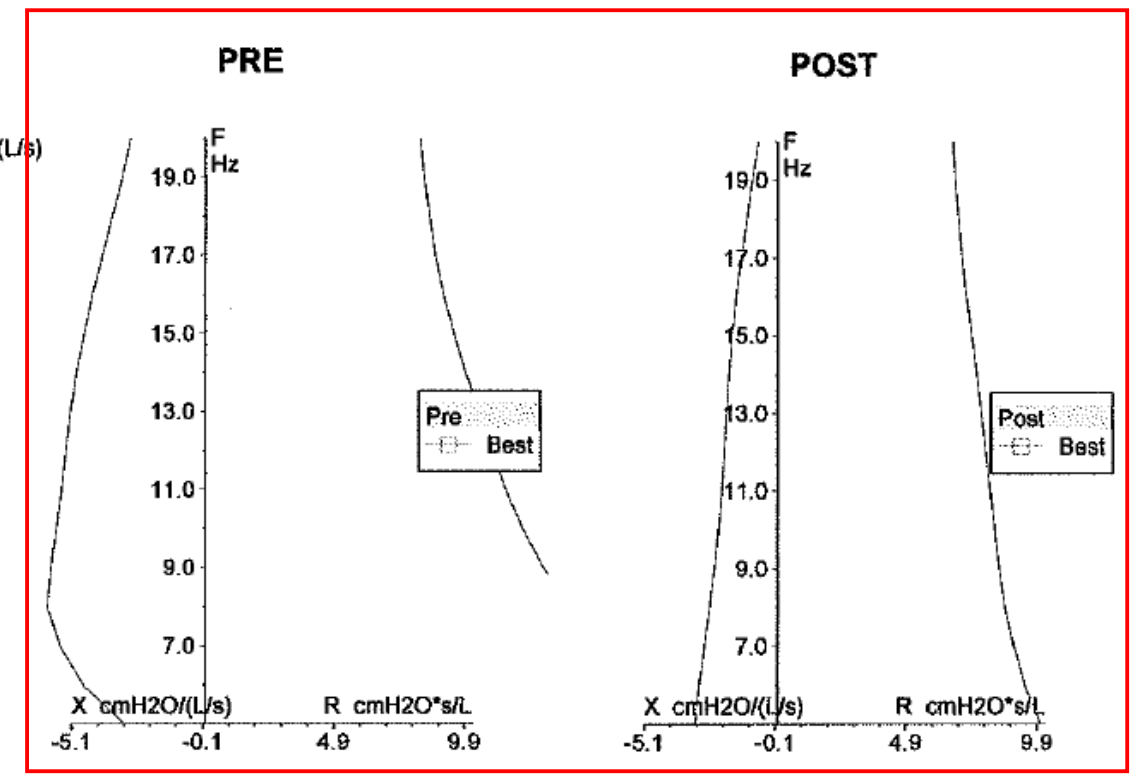


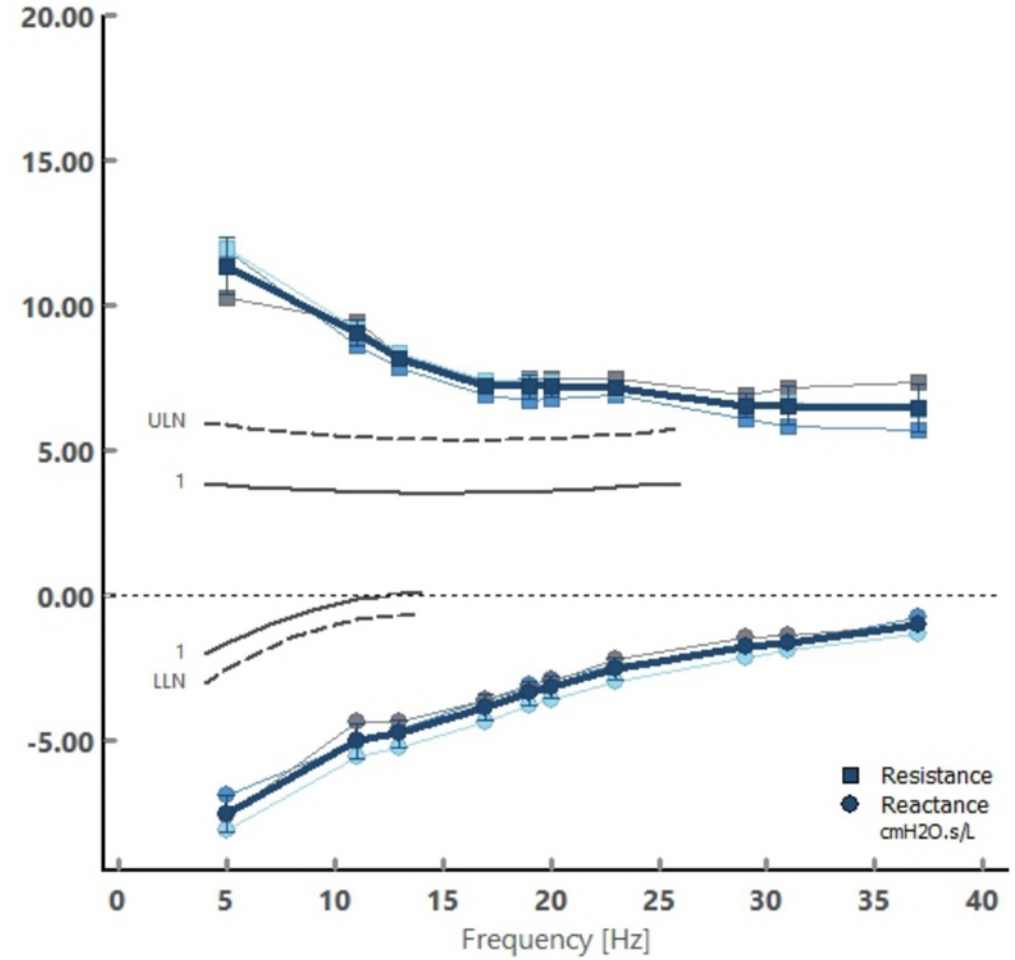
Impulse Oscillometry

		Pred	LLN	ULN	PRE	%PRED	POST	%PRED	%CH	Z-Score
R5Hz	cmH2O/(L/s)	9.79	6.63	12.94	18.31	187	10.05	103	-45	
R20Hz	cmH2O/(L/s)	7.93	5.26	10.60	9.15	115	6.68	84	-27	
X5Hz	cmH2O/(L/s)	-3.14	-4.65	-1.63	-5.85	186	-3.15	100	-46	
Fres.	1/s	17.12	10.82	23.42	29.67	173	22.85	133	-23	
AX	cmH2O/L				93.85		31.33		-67	
D5-20%	%				50.01		33.57		-33	
VT	L	0.24	0.16	0.37	0.73	300	0.40	164	-45	

Resistance & Reactance Spectra







R_5 **11.36**
cmH2O.s/L Ref.: 3.76, Z: 4.2, CV: 8.6
-3 0 Z 3

R_{20} **7.19**
cmH2O.s/L Ref.: 3.70, Z: 2.7, CV: 5.0
-3 0 Z 3

R_{5-20} **4.17**
cmH2O.s/L Ref.: 0.07, Z: 11.1
-3 0 Z 3

AX **108.40**
cmH2O/L Ref.: 4.77, Z: 4.5, CV: 11.2
-3 0 Z 3

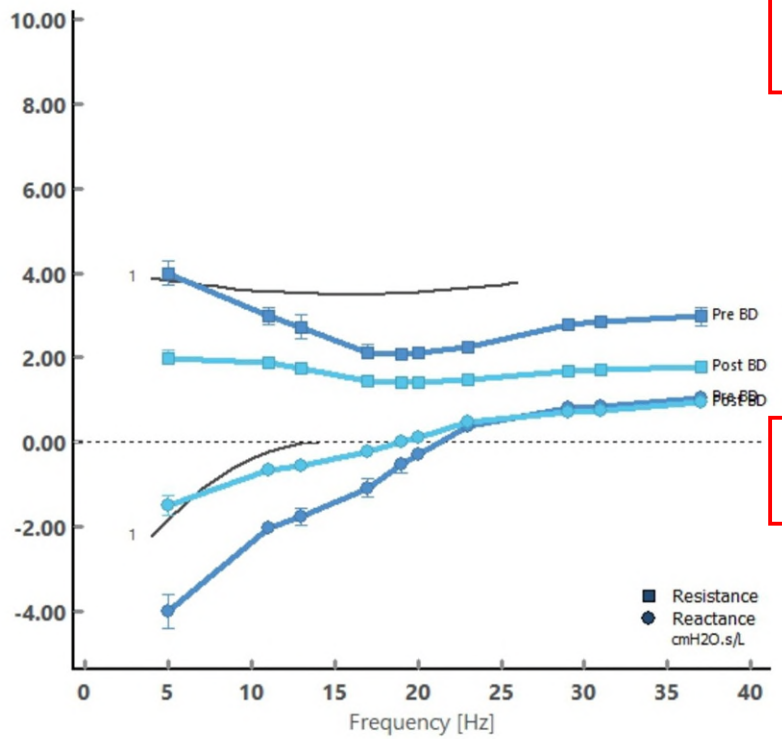
X_5 **-7.55**
cmH2O.s/L Ref.: -1.63, Z: -8.7
-3 0 Z 3

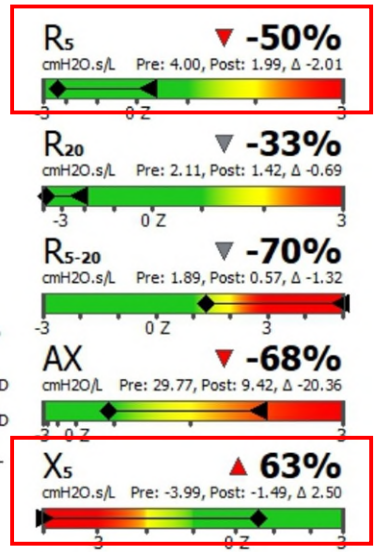
V_T **0.48**
L CV: 12.3

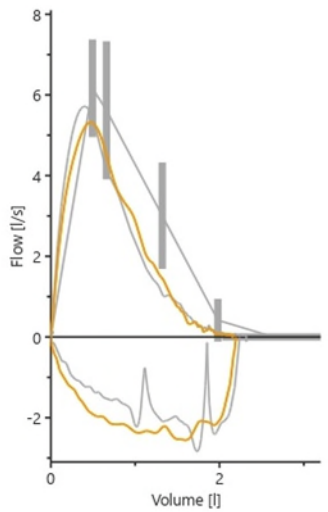
RR **24.05**
/min CV: 9.4

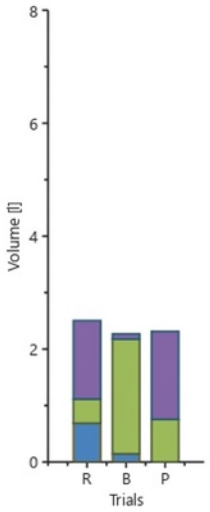
		Reference	Test Average	SD	CV %	Z Score	Abs. Diff.	% Pred.	M1	M3	M4
R5	cmH2O.s/L	3.765	11.357	0.9774	8.606	4.156	7.592	301.7	11.910	10.228	11.932
R20	cmH2O.s/L	3.696	7.186	0.362	5.038	2.695	3.489	194.4	6.772	7.442	7.343
R5-20	cmH2O.s/L	0.068	4.171			11.1			5.139	2.786	4.589
AX	cmH2O/L	4.772	108.402	12.13	11.19	4.499	103.6	2272	103.025	99.890	122.291
X5	cmH2O.s/L	-1.628	-7.550	0.6315		-8.745	-5.922		-6.879	-7.637	-8.133

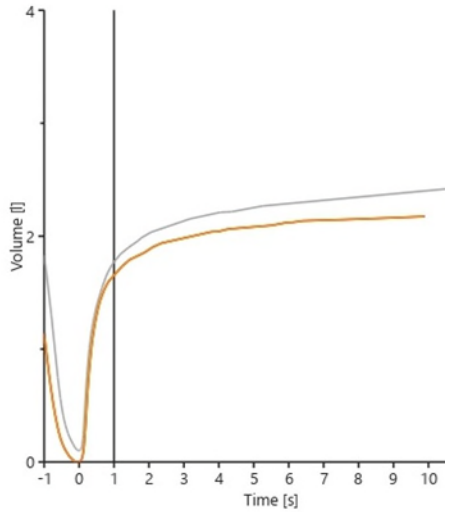
Credit: Lennart Lundblad, PhD







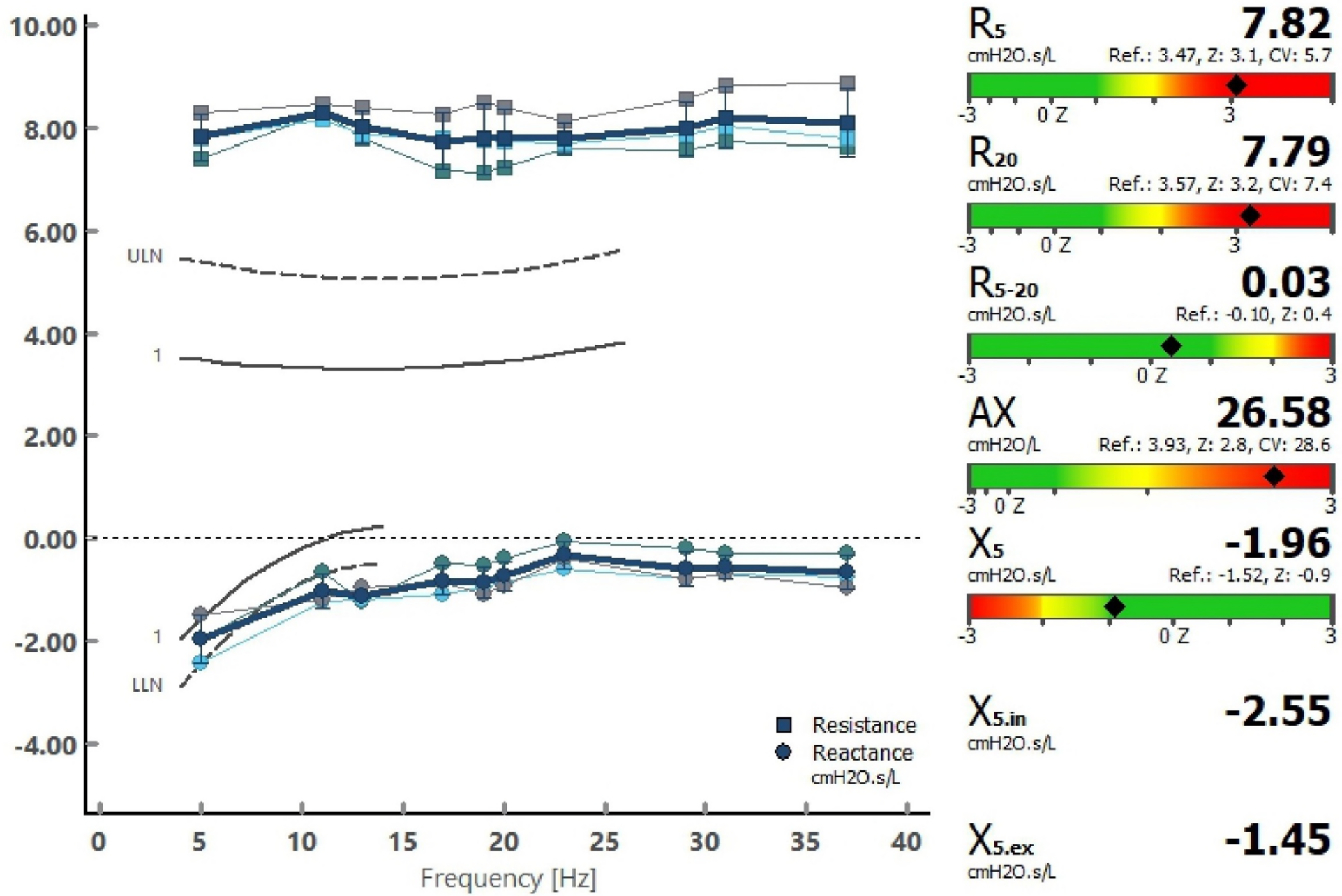




		Reference	Z Score Pre BD	Z Score Post BD	Pre BD	Post BD	Post BD Mean Diff	Post BD % Diff.
R5	cmH2O.s/L	3.740	0.255	-2.371	4.002	1.992	-2.010	-50.227
R20	cmH2O.s/L	3.669	-2.242	-3.836	2.110	1.424	-0.686	-32.518
R5-20	cmH2O.s/L	0.071	4.925	1.345	1.892	0.568	-1.324	-69.982
AX	cmH2O/L	5.156	2.526	0.8675	29.774	9.416	-20.358	-68.375
X5	cmH2O.s/L	-1.766	-3.964	0.592	-3.992	-1.491	2.501	

		Pred	Pre	Pre % Pred	Post	% Pred	Z-Score	% Change
VC IN	[L]	2.23	2.21	99 %	2.20	99 %	-0.1	-1 %
FVC	[L]	2.64	2.31	88 %	2.21	84 %	-1.5	-4 %
FEV 1	[L]	2.02	1.71	85 %	1.76	87 %	-1.1	3 %
FEV1%VCin	[%]	72.81	77.25	106 %	80.06	110 %	0.3	4 %
FEF 25	[L/s]	5.62	4.80	85 %	5.22	93 %	-0.2	9 %
FEV1%FVC	[%]	76.81	73.89	96 %	79.55	104 %	0.2	8 %
FEF 50	[L/s]	3.01	1.61	54 %	2.33	78 %	-0.5	45 %
FEF 75	[L/s]	0.41	0.35	83 %	0.34	81 %	-0.4	-2 %
FEF 25-75	[L/s]	1.54	1.20	78 %	1.54	100 %	0.0	28 %
PEF	[L/s]	6.17	5.72	93 %	5.32	86 %	-0.7	-7 %
BEV	[L]	-	0.07	-	0.09	-		25 %
FIV 1	[L]	-	1.49	-	1.83	-		23 %

Credit: Lennart Lundblad, PhD



R_5 **7.82**
cmH2O.s/L Ref.: 3.47, Z: 3.1, CV: 5.7
-3 0 Z 3

R_{20} **7.79**
cmH2O.s/L Ref.: 3.57, Z: 3.2, CV: 7.4
-3 0 Z 3

R_{5-20} **0.03**
cmH2O.s/L Ref.: -0.10, Z: 0.4
-3 0 Z 3

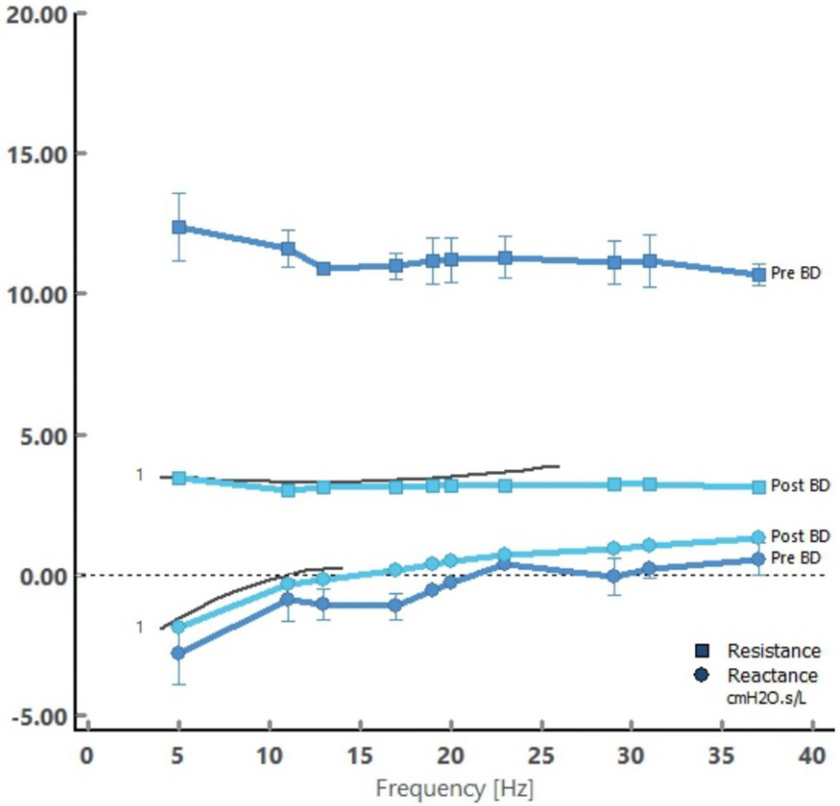
AX **26.58**
cmH2O/L Ref.: 3.93, Z: 2.8, CV: 28.6
-3 0 Z 3

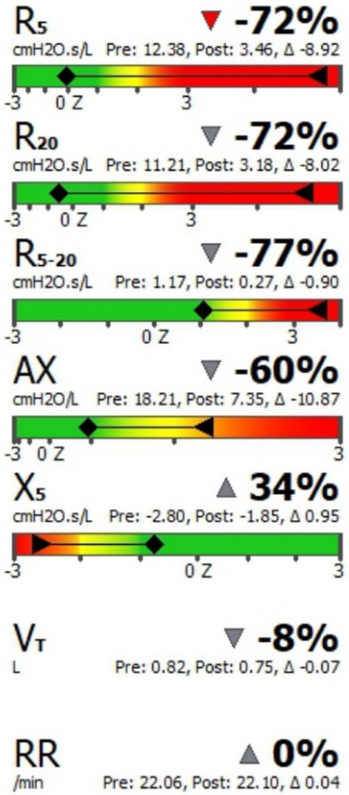
X_5 **-1.96**
cmH2O.s/L Ref.: -1.52, Z: -0.9
-3 0 Z 3

$X_{5.in}$ **-2.55**
cmH2O.s/L

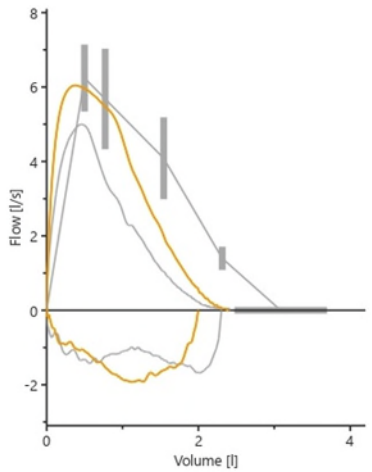
$X_{5.ex}$ **-1.45**
cmH2O.s/L

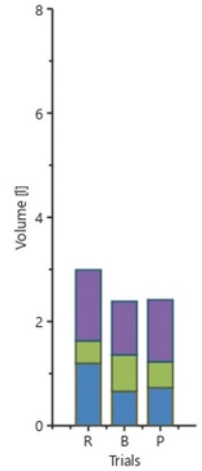
Credit: Lennart Lundblad, PhD

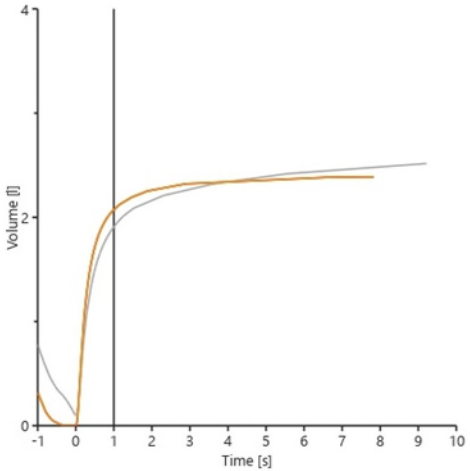




		Reference	Z Score Pre BD	Z Score Post BD	Pre BD	Post BD	Post BD Mean Diff	Post BD % Diff.
R5	cmH2O.s/L	3.489	4.766	-0.03594	12.380	3.456	-8.924	-72.082
R20	cmH2O.s/L	3.611	4.591	-0.5118	11.207	3.183	-8.025	-71.600
R5-20	cmH2O.s/L	-0.122	3.5	1.069	1.172	0.273	-0.899	-76.694
AX	cmH2O/L	3.864	2.233	0.9254	18.212	7.346	-10.866	-59.662
X5	cmH2O.s/L	-1.491	-2.595	-0.7623	-2.801	-1.848	0.953	

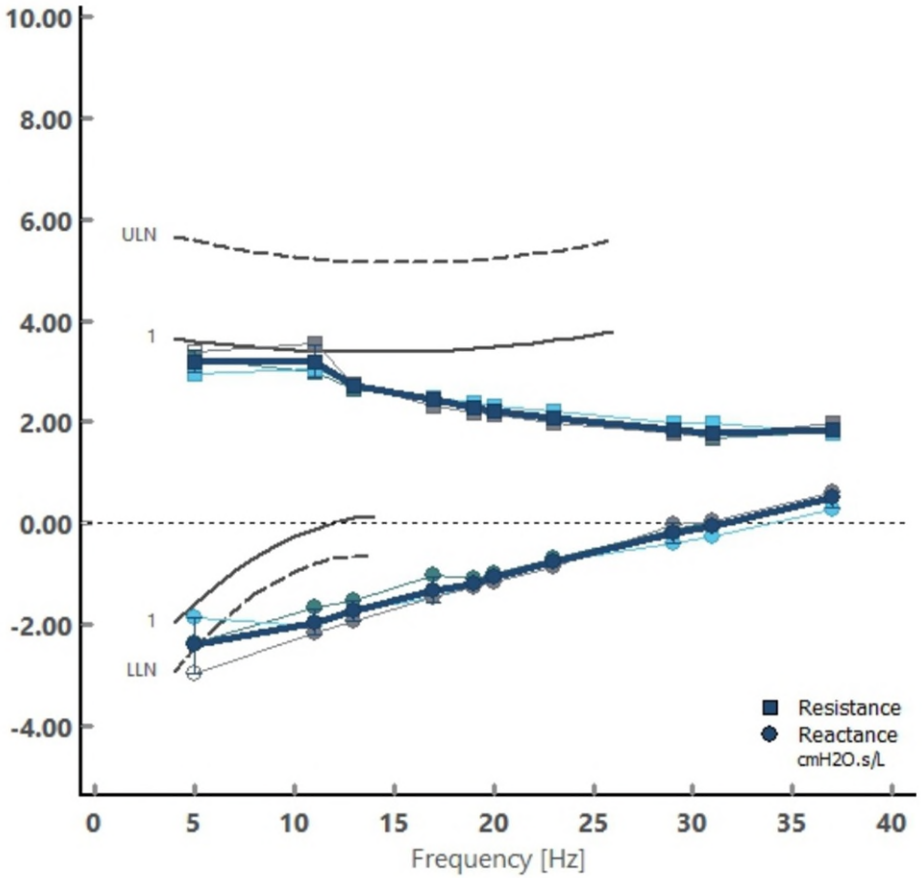






		Pred	Pre	Pre % Pred	Post	% Pred	Z-Score	% Change
VC IN	[L]	2.66	2.29	86 %	2.00	75 %	-1.6	-13 %
FVC	[L]	3.08	2.42	78 %	2.39	77 %	-2.2	-1 %
FEV 1	[L]	2.67	1.83	69 %	2.09	78 %	-1.8	14 %
FEV1%VCin	[%]	83.40	80.06	96 %	104.49	125 %	3.2	31 %
FEF 25	[L/s]	5.68	4.57	81 %	5.84	103 %	0.1	28 %
FEV1%FVC	[%]	86.50	75.94	88 %	87.39	101 %	0.2	15 %
FEF 50	[L/s]	4.09	2.06	50 %	3.53	87 %	-0.5	72 %
FEF 75	[L/s]	1.40	0.49	35 %	1.14	81 %	-0.6	132 %
FEF 25-75	[L/s]	2.95	1.46	50 %	2.81	95 %	-0.2	92 %
PEF	[L/s]	6.24	5.00	80 %	6.05	97 %	-0.2	21 %
BEV	[L]	-	0.07	-	0.05	-		-34 %
FIV 1	[L]	-	1.15	-	1.27	-		11 %

Credit: Lennart Lundblad, PhD



R_5 **3.20** cmH2O.s/L Ref.: 3.58, Z: -0.4, CV: 7.0

R_{20} **2.23** cmH2O.s/L Ref.: 3.58, Z: -1.9, CV: 4.4

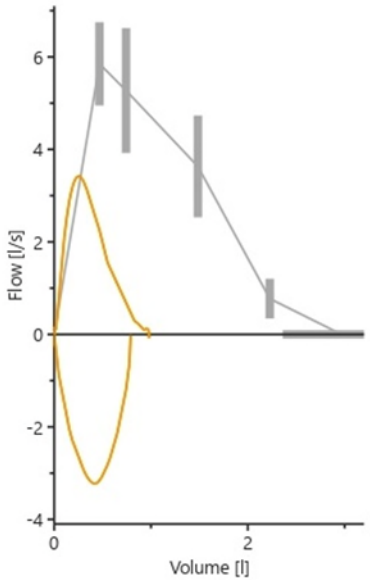
R_{5-20} **0.97** cmH2O.s/L Ref.: 0.00, Z: 2.6

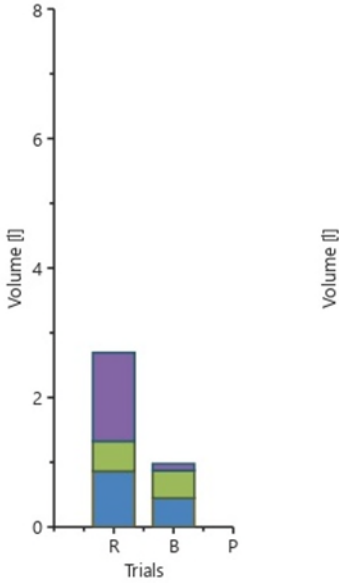
AX **32.35** cmH2O/L Ref.: 4.23, Z: 2.9, CV: 11.4

X_5 **-2.40** cmH2O.s/L Ref.: -1.55, Z: -1.7

V_T **0.34** L CV: 15.1

RR **59.30** /min CV: 1.3





		Reference	Test Average	SD	CV %	Z Score	Abs. Diff.	% Pred.	M5	M7	M8
R5	cmH2O.s/L	3.584	3.198	0.2234	6.986	-0.429	-0.386	89.23	3.240	2.956	3.397
R20	cmH2O.s/L	3.583	2.227	0.09798	4.399	-1.927	-1.356	62.16	2.220	2.329	2.133
R5-20	cmH2O.s/L	0.001	0.970			2.623			1.020	0.627	1.264
AX	cmH2O/L	4.235	32.346	3.673	11.36	2.929	28.11	763.8	28.448	32.846	35.743
X5	cmH2O.s/L	-1.548	-2.400	0.5495		-1.73	-0.8511		-2.359	-1.871	-2.968

		Pred	Pre	% Pred	Z-Score
VC IN	[L]	2.40	0.78	33 %	-3.8
FVC	[L]	2.97	0.98	33 %	-6.2
FEV 1	[L]	2.40	0.90	37 %	-4.4
FEV1%VCin	[%]	78.84	114.24	145 %	5.9
FEF 25	[L/s]	5.27	3.41	65 %	-1.4
FEV1%FVC	[%]	81.11	91.59	113 %	2.1
FEF 50	[L/s]	3.63	2.16	59 %	-1.3
FEF 75	[L/s]	0.77	0.67	87 %	-0.3
FEF 25-75	[L/s]	2.22	1.66	75 %	-0.9
PEF	[L/s]	5.85	3.42	59 %	-2.7
BEV	[L]	-	0.06	-	
FIV 1	[L]	-	-	-	

Credit: Lennart Lundblad, PhD

Oscillometry in pediatric asthma

Diagnosis

- 2017 systematic review (Dos Santos et al):
  - Area under the curve (AUC) for asthma diagnosis with BDR or bronchoprovocation for FEV1 or FEV1/FVC ~0.80, Xrs5 0.65-0.79 and AX 0.64-0.81
- Limitation: BDR cutoffs likely too conservative; currently cutoffs are likely good for ruling in rather than ruling out (high specificity, lower sensitivity)

Dos Santos, K et al. Impulse oscillometry in the assessment of asthmatic children and adolescents: from a narrative to a systematic review. Paediatr Respir Rev. 2017; 23:61-67

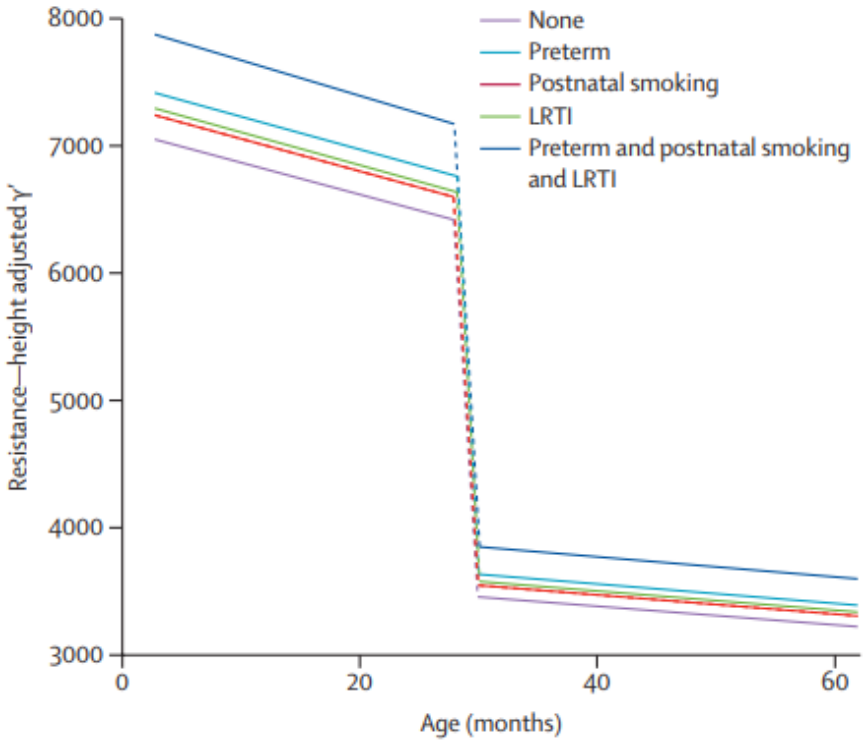
Control of asthma

- More sensitive than spirometry (FEV1, FEV1/FVC, and FEF25-75) for detection of small airway disease
- 2021 systematic review/meta-analysis (Ling et al): R5, Fres, and Ax predicted subsequent asthma exacerbation or loss of asthma control
- In our clinical practice:
  - Under age 5: oscillometry
  - Age 5+: oscillometry +/- spirometry + FENO

Ducharme FM et al. Oscillometry in the diagnosis, assessment, and monitoring of asthma in children and adults. Annals of Allergy, Asthma & Immunology 2024, 134(2)135 – 143
Ling Y et al. The predictive value of impulse oscillometry for asthma exacerbations in childhood: a systematic review and meta-analyses. Pediatr Pulmonol. 2021; 56(7):1850-1856

Predicting future lung function

- In birth cohort, early life LRTI and prenatal smoking associated with increased resistance, decreased compliance in infancy and in age 4-5 lung function testing.
- In pregnancy cohort, R5 at age 4 predicted decreased lung function at 5-8 years and active asthma at 8 years
- In infants with bronchiolitis, R5 and more negative X5 at 5-7 years associated with irreversible airway obstruction at 10-13 years.

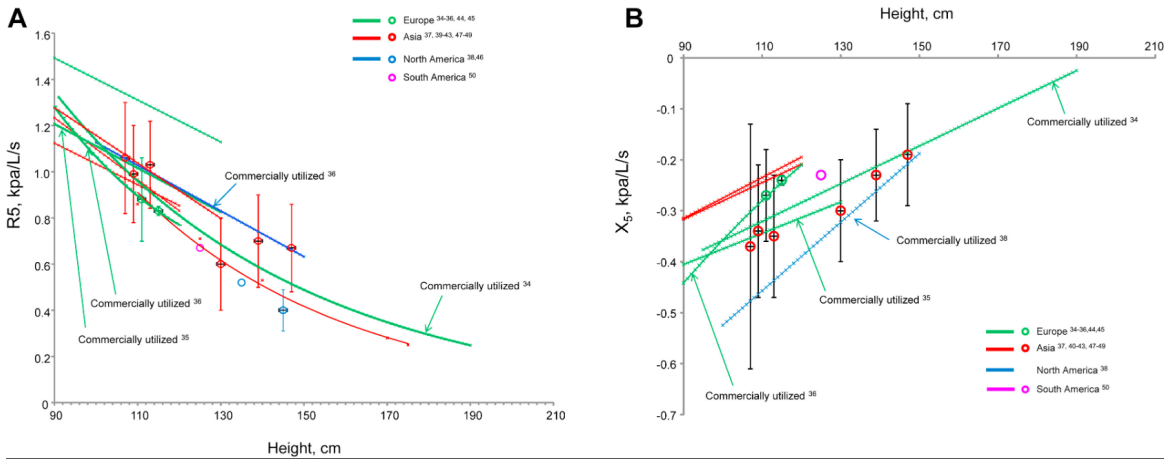


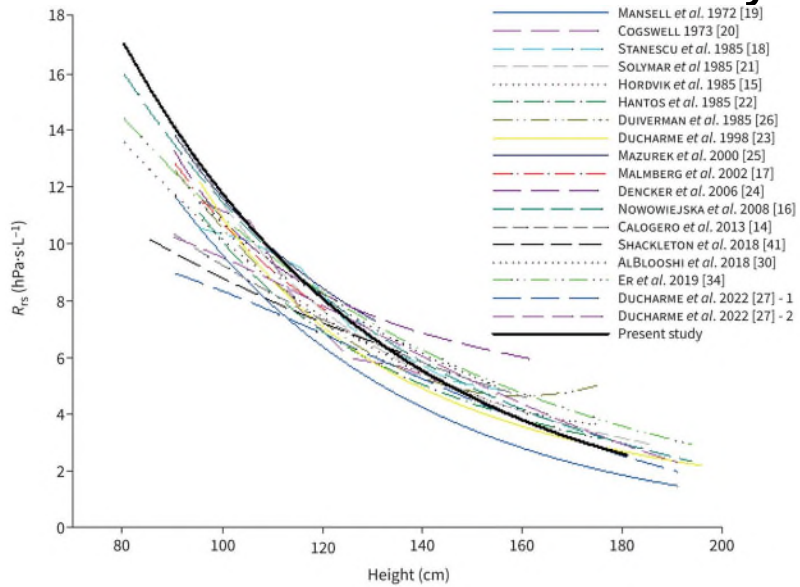
McCready C, et al. Determinants of lung function development from birth to age 5 years: an interrupted time series analysis of a South African birth cohort. Lancet Child Adolesc Health, 8 (2024), pp. 400-412.
Ducharme FM et al. Oscillometry in the diagnosis, assessment, and monitoring of asthma in children and adults. Annals of Allergy, Asthma & Immunology 2024, 134(2)135 – 143
Knihtilä HM et al. Preschool impulse oscillometry predicts active asthma and impaired lung function at school age. J Allergy Clin Immunol. 2024; 154(1):94-100.e13
Riikonen R et al. Risk factors for irreversible airway obstruction after infant bronchiolitis. Respir Med. 2021; 187, 106545

Challenges and future directions in pediatric oscillometry

Challenges: reference ranges

- There is currently a lack of standardized prediction equations across all devices and ethnic groups; this is even more the case in pediatrics
  - No GLI database exists for oscillometry; unclear effect of race/ethnicity





Galant SP et al. Ann Allergy Asthma Immunol 2017. PMID 28583260
Chaya S. ERJ Open Res 2023. PMID 37057080

Challenges: differences among platforms

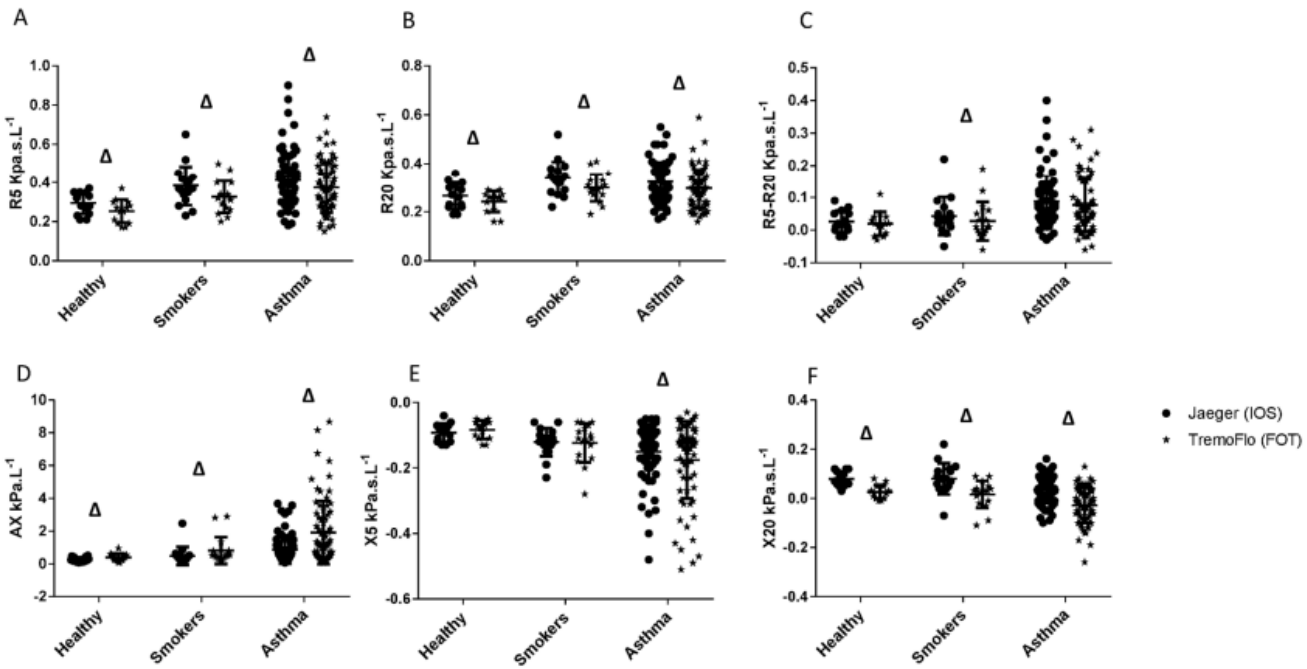
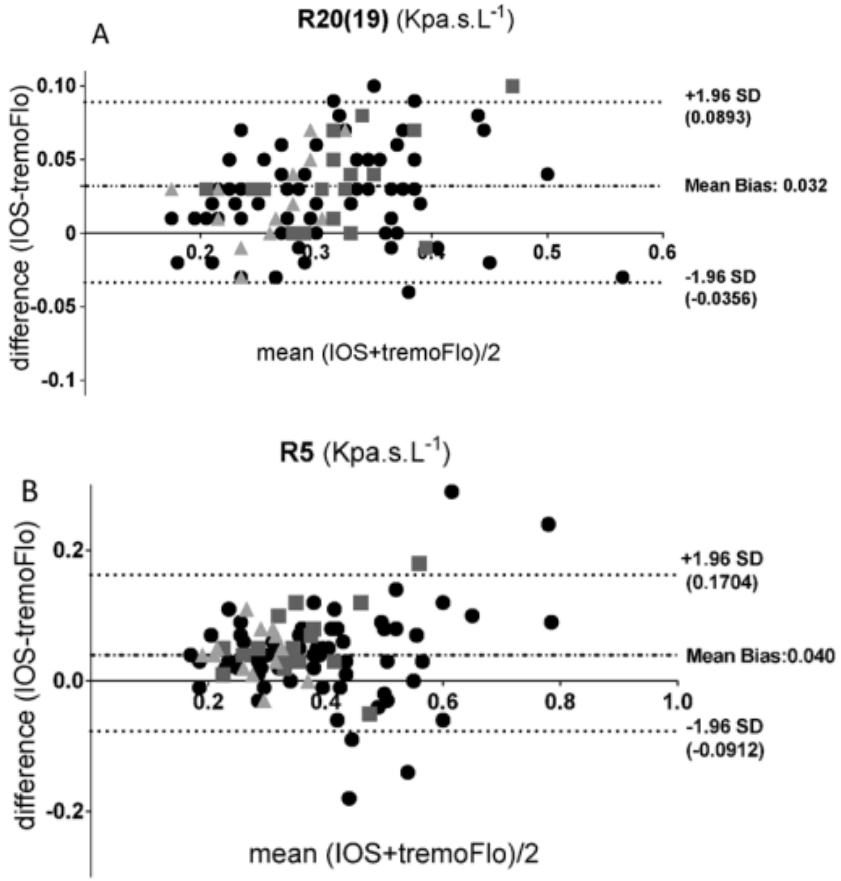


Figure 1. Dot plots of Resistance (**A,B,C**) and Reactance (**D,E,F**) for Jaeger (IOS) (dots) and TremoFlo (stars) devices in the three clinical populations. $^{\Delta}p < 0.05$ for within group comparison of IOS and TremoFlo values.



Soares M et al. Sci Rep 2019. PMID 30765757.

Challenges: differences among platforms

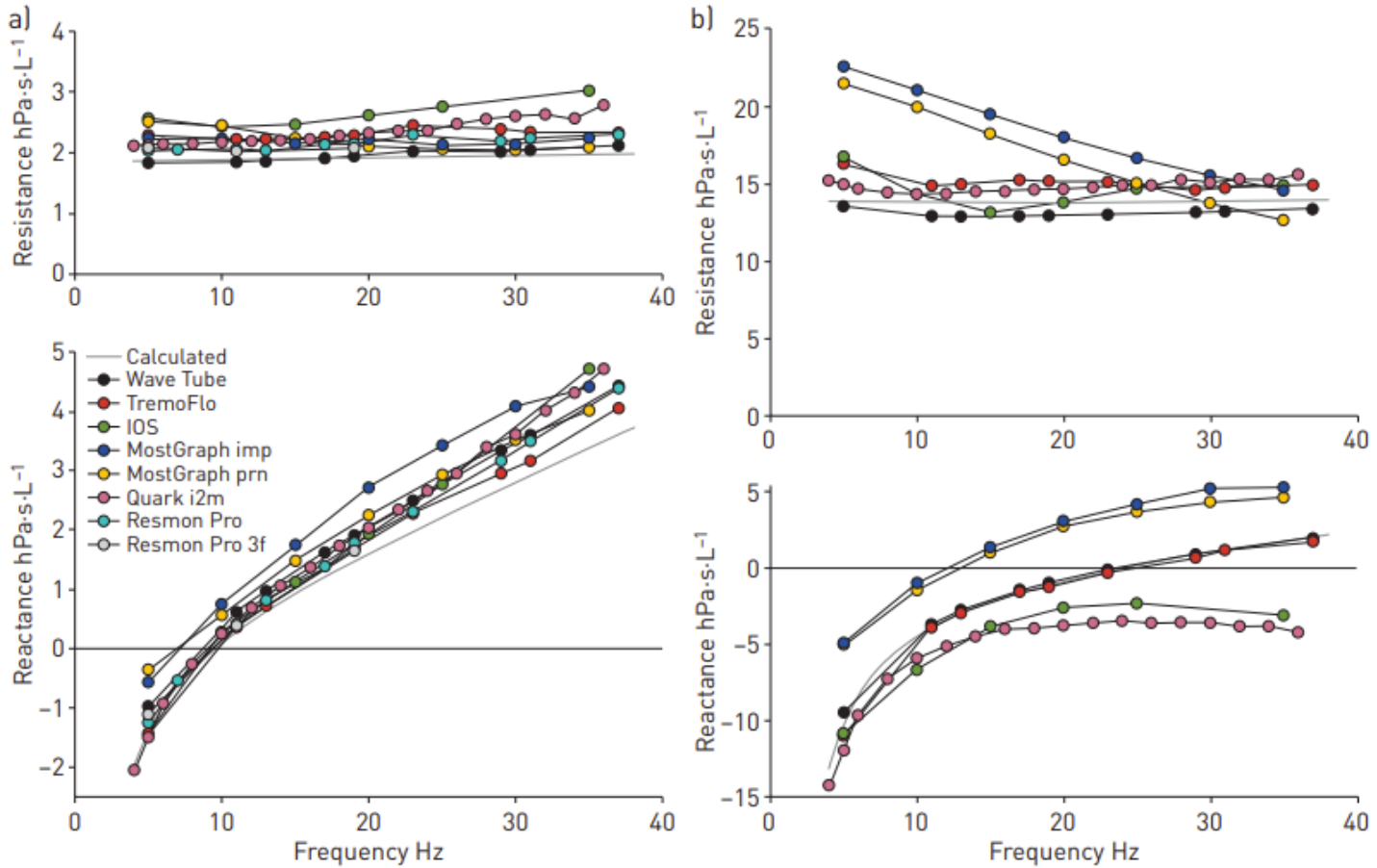
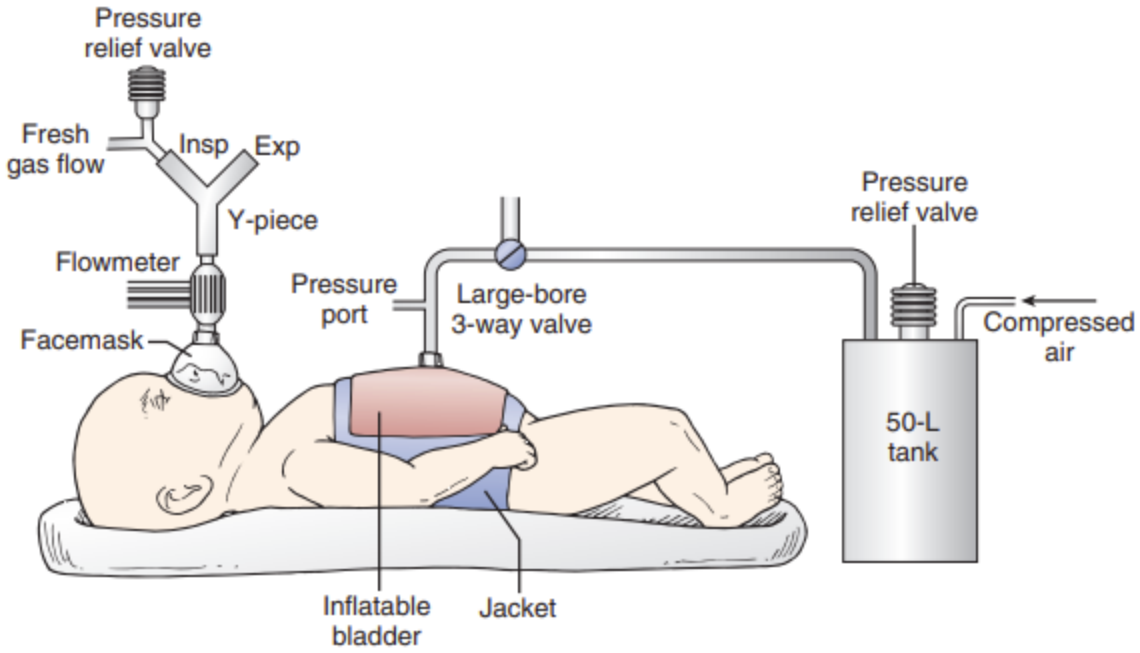


FIGURE 3 Impedance measurements in the mechanical test loads a) M1 and b) M6.

Dandurand RJ et al. ERJ Open Res 2019. PMID 31886158

Challenges: testing in children under 3 years

- Below age 3, traditional oscillometry is difficult
- Options for lung function testing:
  - Tidal breathing analysis
  - Raised volume rapid thoracoabdominal compression
  - Multiple-breath gas washout
- Problems: specialized equipment, sedation, lack of normative values



Czovek D. Pulmonary Function Tests in Infants and Children In: Kendig's Disorders of the Respiratory Tract in Children. Elsevier; 2019

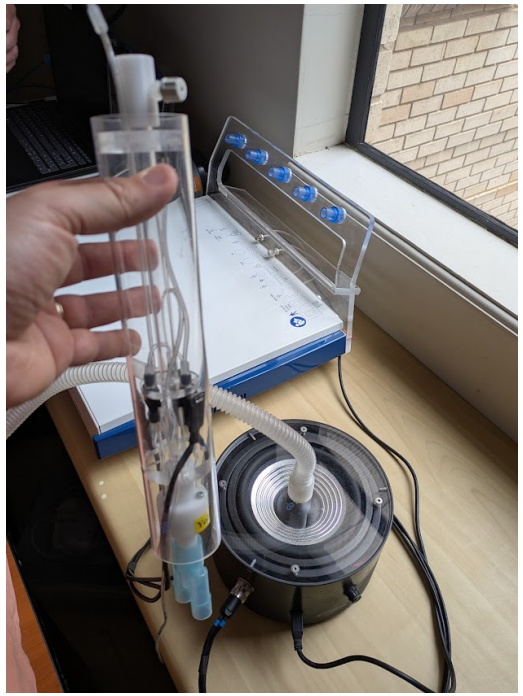
Current options for pulmonary function testing under age 2

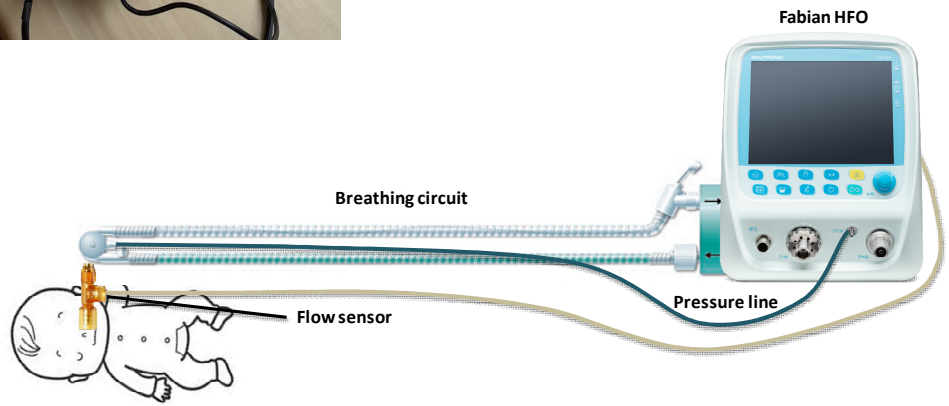
Technique	No need for sedation	No need for complex breathing maneuvers	Short test duration	Portable, available at bedside	Detects airway obstruction	Assesses peripheral airways
Tidal breathing analysis	✓	✓	✓	× / ✓	✓	×
Raised volume rapid thoracoabdominal compression	×	×	×	×	✓	×
Multiple-breath inert gas washout	✓	✓	×	×	✓	✓
Single-breath occlusion technique/ Interrupter resistance technique	✓	✓	✓	✓	✓	×
Oscillometry	✓	✓	✓	✓	✓	✓

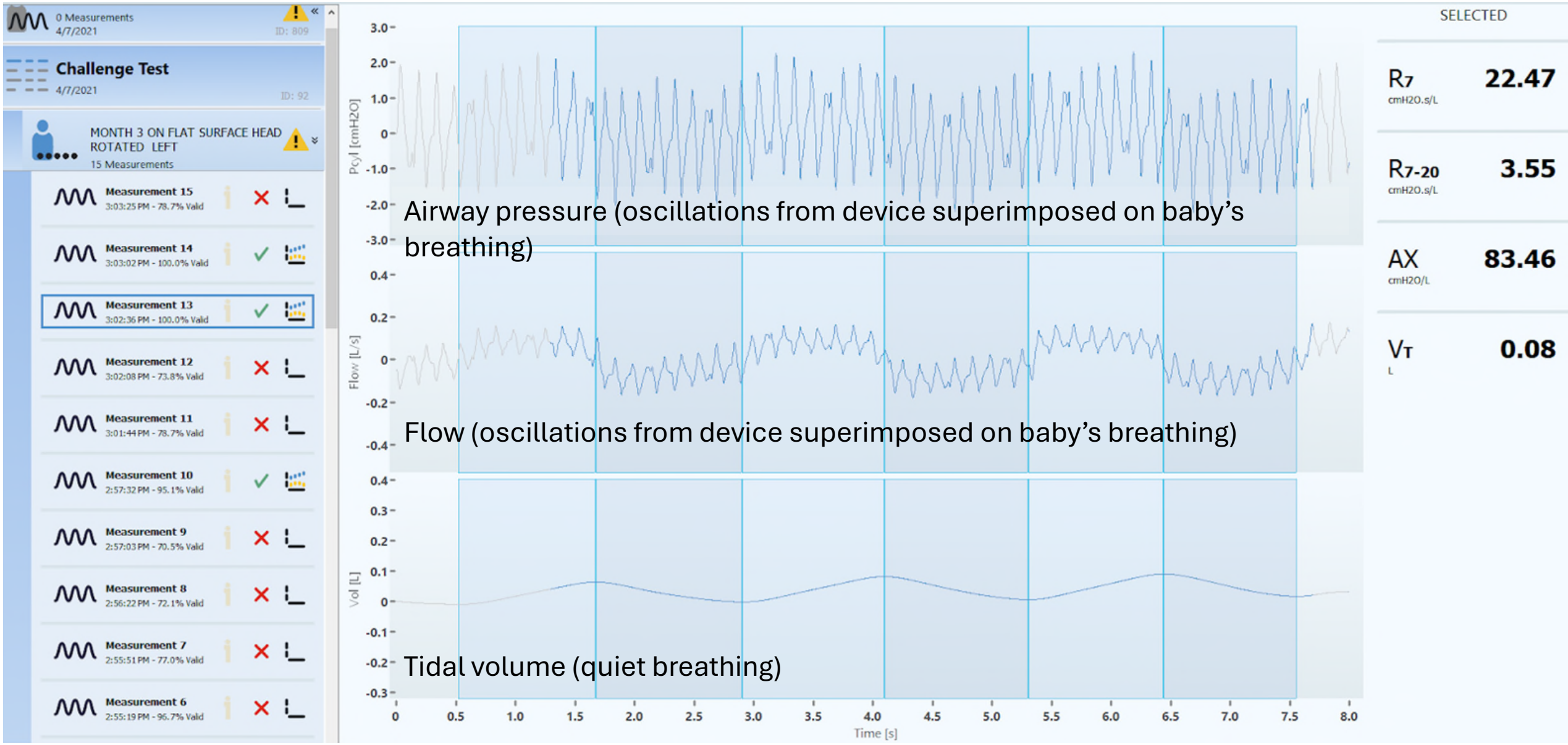
Moschovis PP et al. Respiratory oscillometry in infants: present challenges and future opportunities. Ped Resp Review, 2025.

Infant oscillometry

- Infants have smaller airway diameters and increased elastance compared to older children and adults
- Also have increased upper airway resistance
- Testing usually performed via facemask
- Three options for infant testing:
  - Wave tube
  - Tremoflo N-100
  - Ventilator-integrated devices






0 Measurements
4/7/2021
ID: 809
Challenge Test
4/7/2021
ID: 92
MONTH 3 ON FLAT SURFACE HEAD ROTATED LEFT
15 Measurements
Measurement 15
3:03:25 PM - 78.7% Valid
Measurement 14
3:03:02 PM - 100.0% Valid
Measurement 13
3:02:36 PM - 100.0% Valid
Measurement 12
3:02:08 PM - 73.8% Valid
Measurement 11
3:01:44 PM - 78.7% Valid
Measurement 10
2:57:32 PM - 95.1% Valid
Measurement 9
2:57:03 PM - 70.5% Valid
Measurement 8
2:56:22 PM - 72.1% Valid
Measurement 7
2:55:51 PM - 77.0% Valid
Measurement 6
2:55:19 PM - 96.7% Valid
Pcyl [cmH2O]
Flow [L/s]
Vol [L]
Time [s]
Airway pressure (oscillations from device superimposed on baby's breathing)
Flow (oscillations from device superimposed on baby's breathing)
Tidal volume (quiet breathing)
SELECTED
R7 22.47 cmH2O.s/L
R7-20 3.55 cmH2O.s/L
AX 83.46 cmH2O/L
VT 0.08 L

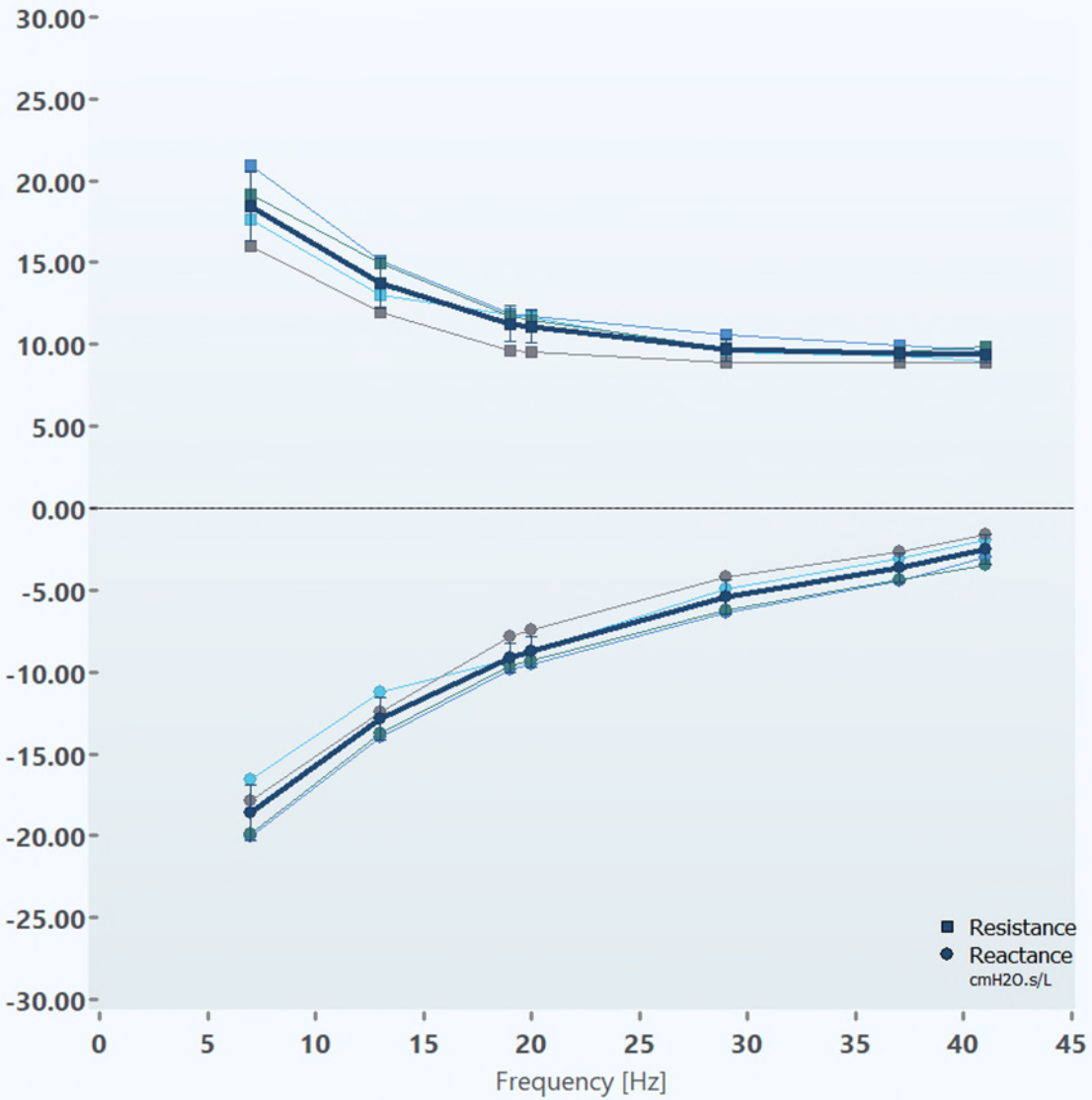
Standard Test
0 Measurements
7/12/2020
ID: 883

Standard Test
4 Measurements
3/5/2020
ID: 847

Standard Test
0 Measurements
3/5/2020
ID: 846

Standard Test
7 Measurements
3/5/2020
ID: 845

- **Measurement 7** 3:46:59 AM - 27.2% Val
- **Measurement 6** 3:43:35 AM - 98.8% Val
- **Measurement 5** 3:42:27 AM - 23.5% Val
- **Measurement 4** 3:28:34 AM - 90.5% Val
- **Measurement 3** 3:27:48 AM - 37.0% Val
- **Measurement 2** 3:26:39 AM - 90.1% Val
- **Measurement 1** 3:25:35 AM



TEST RESULTS

R16

V_T L — **n/a**

AOS 7-41 Short

R_7 cmH2O.s/L — **18.44** CV: 11.4

R_{7-20} cmH2O.s/L — **7.32**

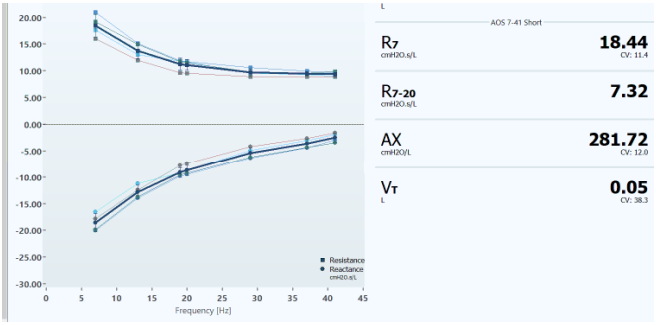
AX cmH2O/L — **281.72** CV: 12.0

V_T L — **0.05** CV: 38.3

Challenges with infant oscillometry

- Software and hardware are still under development
- High variability due to
  - Short tests
  - Moving/non-cooperative infant
  - Lung/airway disease?
- Need for standardized QC/interpretation guidelines (i.e., reproducibility, acceptability)
- Need for reference values
- When to transition from infant to regular oscillometry

Pediatric Lungs in Uganda Study-2 (PLUS-2): 205 tests among 34 children interpreted by at least 2 readers

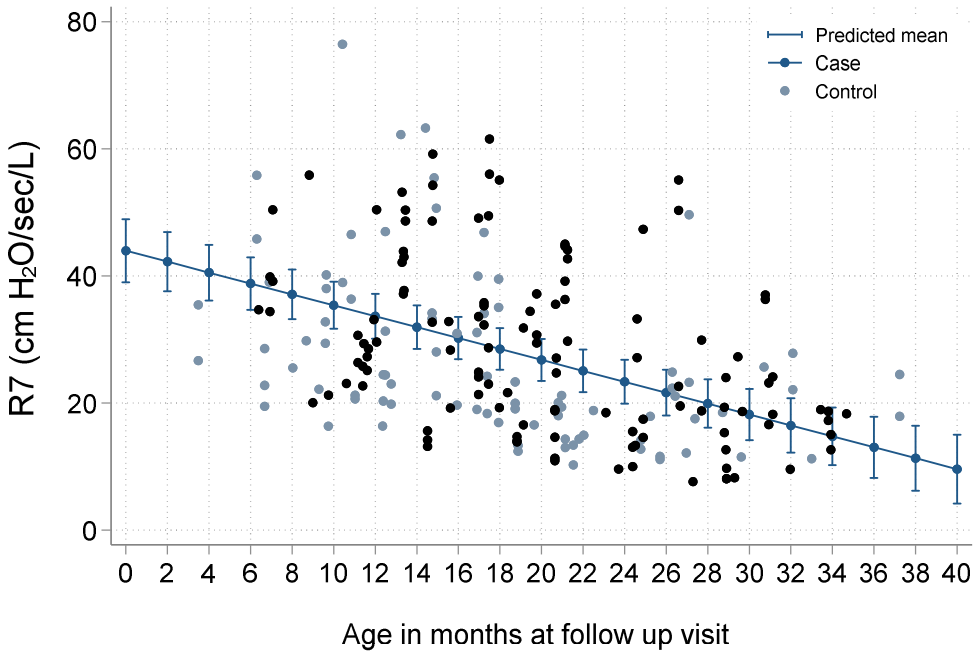


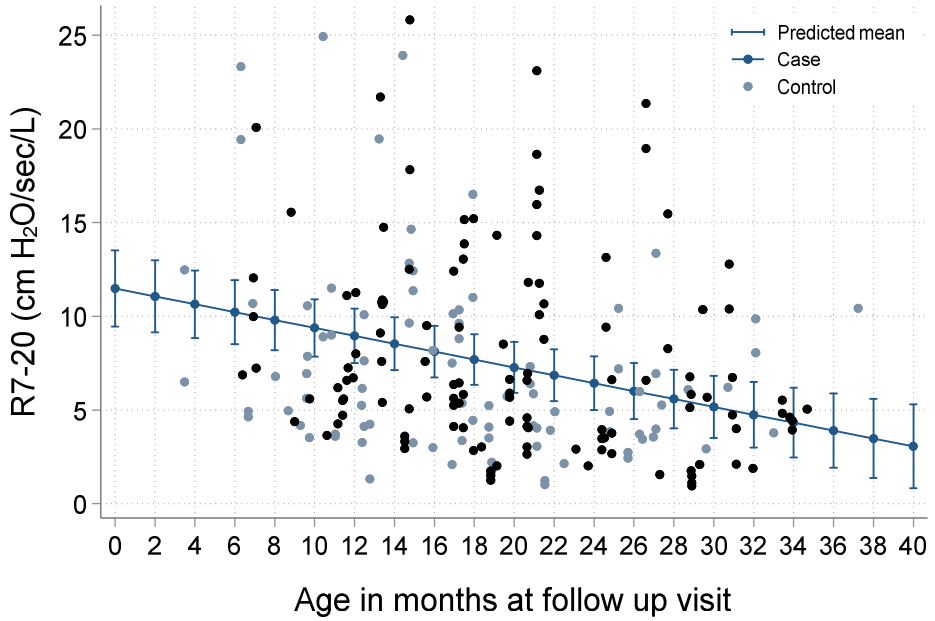
	R7	p	R7-20	p	Ax	p
Age (per month)	-0.84 (-0.95, -0.72)	<0.001	-0.24 (-0.28, -0.19)	<0.001	-10.89 (-14.72, -7.05)	<0.001
Sex (M vs. F)	-0.92 (-5.84, 4.00)	0.72	-0.01 (-1.98, 1.95)	0.99	21.98 (-116.95, 160.90)	0.76
Weight (per kg)	-4.24 (-4.97, -3.51)	<0.001	-1.24 (-1.51, -0.96)	<0.001	-48.54 (-58.31, -38.78)	<0.001
Length (per cm)	-1.13 (-1.31, -0.97)	<0.001	-0.33 (-0.38, -0.26)	<0.001	-13.28 (-15.56, -11.00)	<0.001
Chest circumference (per cm)	-2.04 (-2.64, -1.43)	<0.001	-0.58 (-0.80, -0.36)	<0.001	-24.73 (-32.69, -16.78)	<0.001
Case vs. control	-1.67 (-6.50, 3.15)	0.50	-0.80 (-2.72, 1.12)	0.42	-72.62 (-207.57, 62.32)	0.29

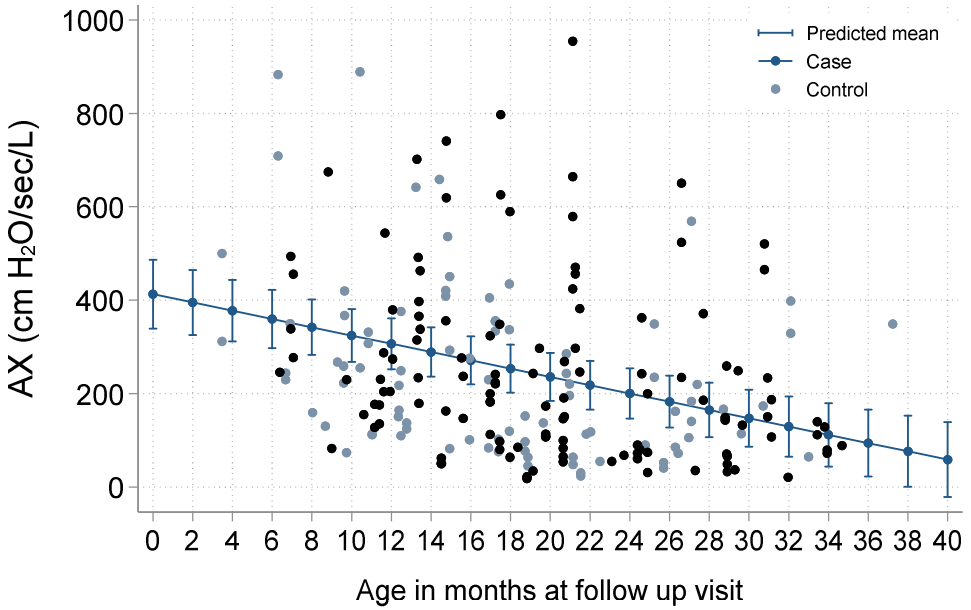
Linear mixed effects model, with participant and reader as random effects

Moschovis PP et al. Chest 2024; 166:4, A5102 - A5103

R7, R7-20, Ax by age







Predicted probabilities with 95% CI from linear mixed effects model, with participant as random effect

Moschovis PP et al. Chest 2024; 166:4, A5102 - A5103

Conclusions

- Oscillometry is a useful tool for measuring airway physiology in young children and infants.
- Like spirometry, it provides longitudinal data in the developing child and can be used to measure response to treatment.
- Infant oscillometry may identify signs of impaired lung development, early determinants of asthma, and markers of other respiratory diseases.

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THANK
YOU