OSCILLOMETRY

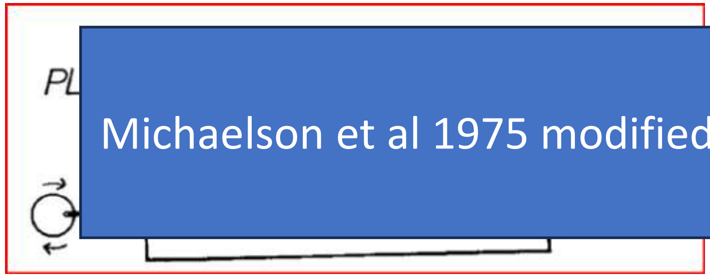
Gunda Jaya Hareesh

09-11-2024

- History and physiology
- Spirometry vs oscillometry
- Machine, Technique
- FOT vs IOT
- Parameters
- Uses

History and Physiology

- FOT and IOS capture the effect of frequency on respiratory mechanics



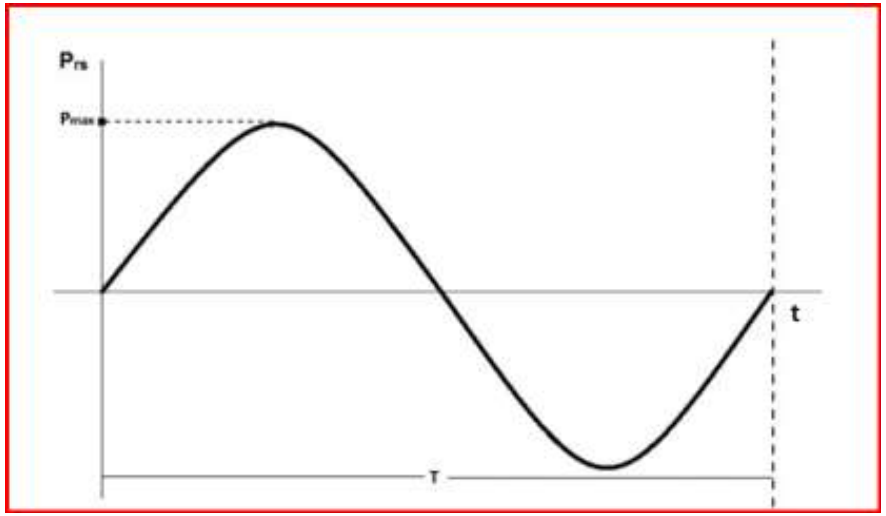
Michaelson et al 1975 modified this technique using multiple frequencies

Application of sinusoidal pressure waves 2-18 Hz to the surface of the body and flow recorded at airway opening
Based on changing transthoracic pressure
Measures impedance of the whole system
Impedance = Trans thoracic pressure/Flow recorded

Application of sinusoidal pressure waves at airway opening and flow is also recorded from here
Based on trans respiratory pressure
Impedance = Trans respiratory pressure/Flow

Du Bois et al JAP 1956

Physiology

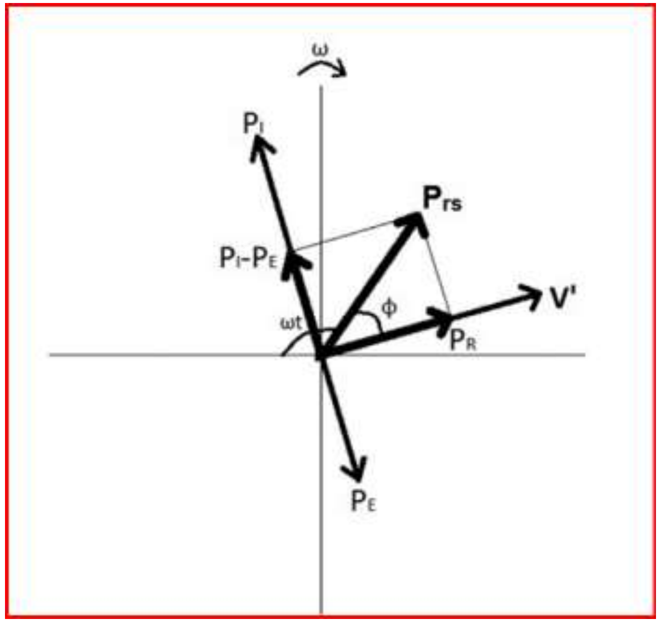


$P_{rs} = P_E + P_R + P_I$

P_E = Total respiratory system elastance * Volume

P_R = Total respiratory system resistance * Flow

P_I = Coefficient of inertia of respiratory system * Acceleration



$P_{rs}(t) = P_{max} \sin(\omega t)$

$\omega = 2\pi f$ (frequency)

ωt = phase of pressure change

Andreas S. Lappas et al PNEUMON Number 4, Vol. 26, Oct –Dec 2013

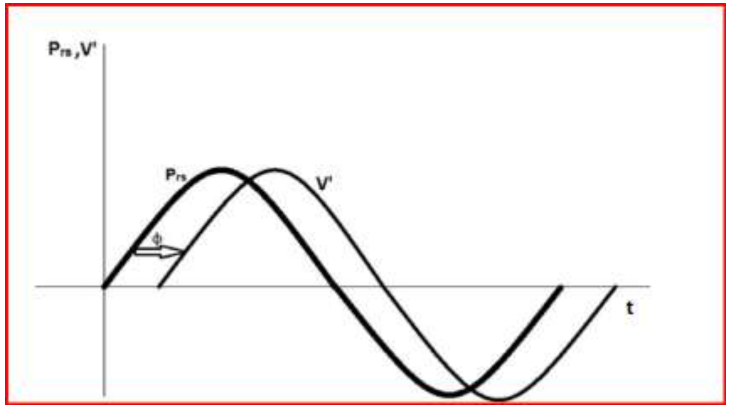
Physiology

- Impedance – 2 components
- Resistance (R) – Express pressure and flow amplitude relationship
- Reactance (X) – Time needed for pressure change to cause flow changes – in other words it is the phase difference
- Reactance
  1. Elastic properties of the respiratory system
  2. Inertia of both air column and tissue elements of the system

Physiology

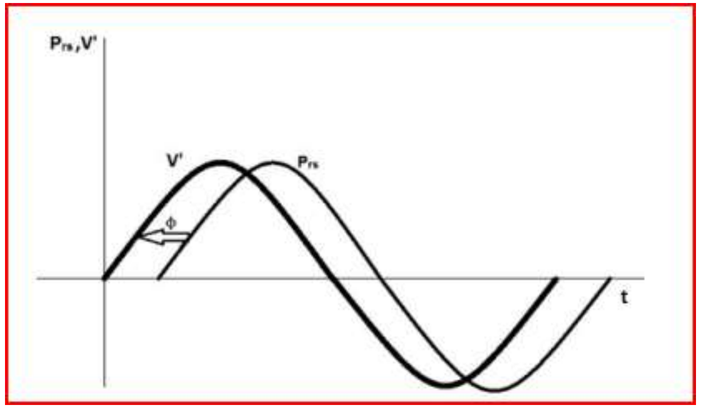
- Positive phase difference

To overcome inertial forces – Pressure change first resulting in flow change – positive phase change



- Negative phase difference

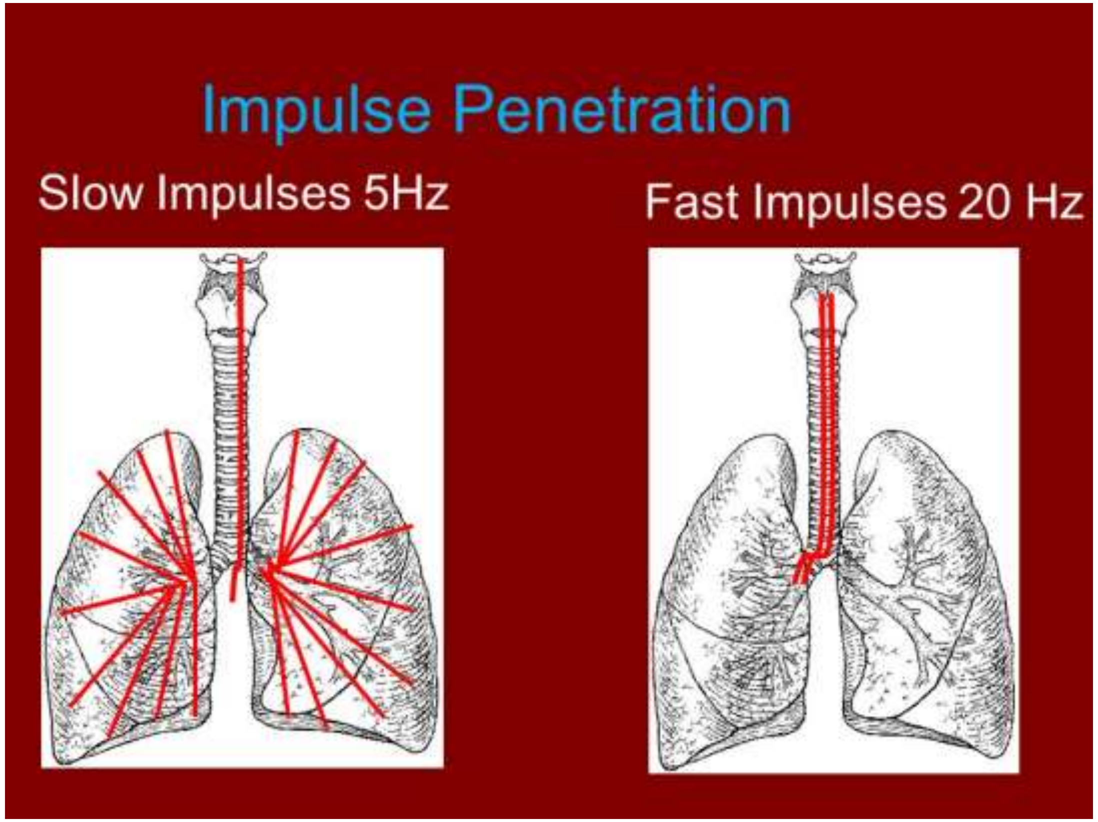
Forced oscillations on elastic elements – cause flow change which results in distension and subsequent pressure change in the form of elastic recoil pressure – negative phase change (pressure after flow change)



Andreas S. Lappas et al PNEUMON Number 4, Vol. 26, Oct – Dec 2013

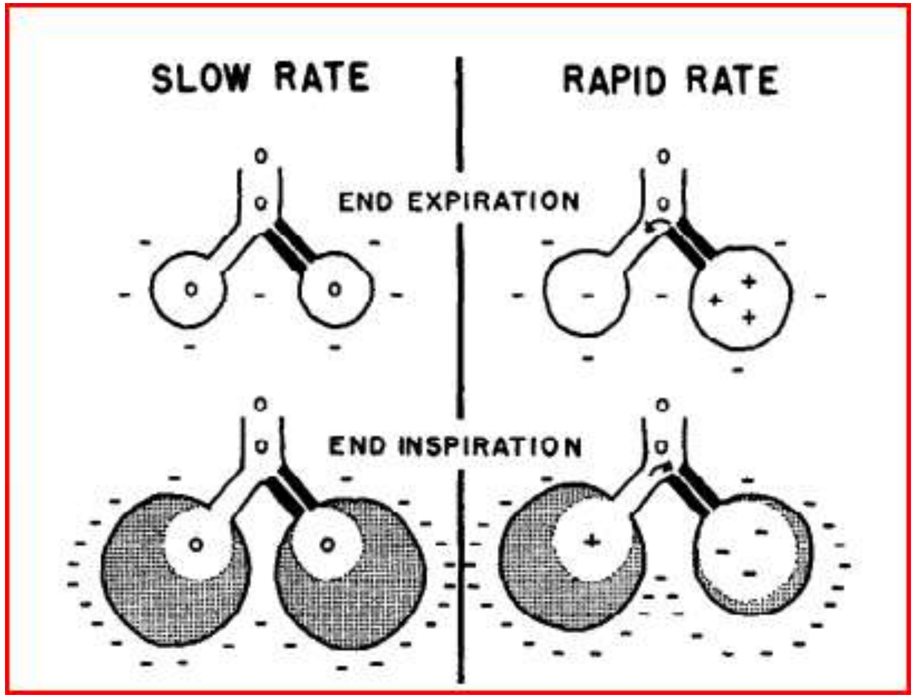
Physiology

- As at lower frequencies – elastic elements response predominate – total pressure changes follow flow change – the phase difference is negative – X values are negative
- At higher frequencies – inertial forces predominate due to extremely high values of acceleration and the development of adequate pressure is needed to overcome them and create flow – positive phase difference – X values are positive



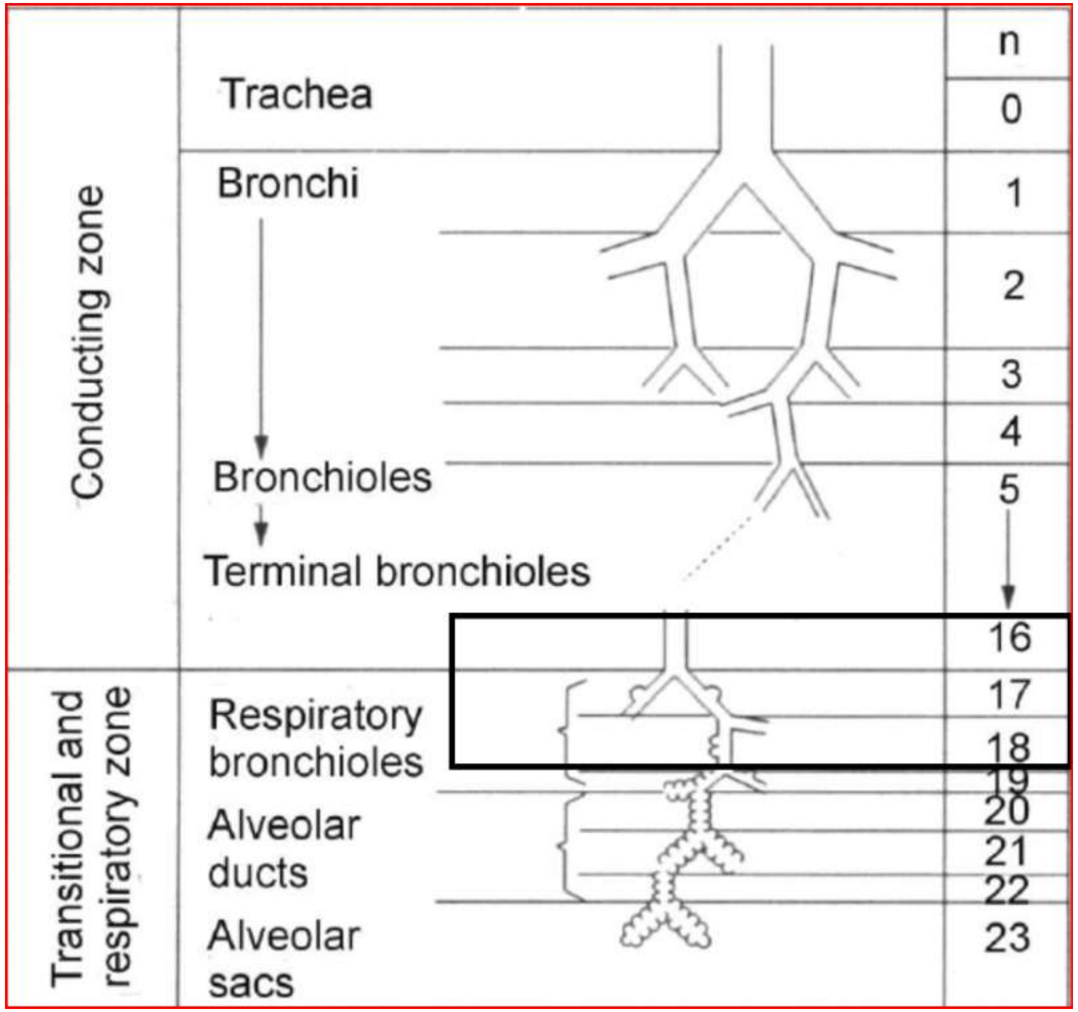
Heterogenous lung – Pendelluft phenomenon

- At lower rates and higher rates of respiration
- Effects flow changes in IOS



Otis et al JAP 1956

Unlocking silent zone



The quiet zone, a term coined by Jere Mead in 1970
Frequently involved early in the course of lung diseases with significant pathological changes demonstrable before the onset of symptoms/changes in spirometry/imaging

McNulty et al ECRJ 2014

Spirometry ----------> Oscillometry

- Relies on forced expiratory maneuver and requires patient co-operation – effort dependent (20% cannot perform and 40% recordings not acceptable)

Acute myocardial infarction within 1 wk
Systemic hypotension or severe hypertension
Significant atrial/ventricular arrhythmia
Noncompensated heart failure
Uncontrolled pulmonary hypertension
Acute cor pulmonale
Clinically unstable pulmonary embolism
History of syncope related to forced expiration/cough

Due to increases in intracranial/intraocular pressure
Cerebral aneurysm
Brain surgery within 4 wk
Recent concussion with continuing symptoms
Eye surgery within 1 wk

Due to increases in sinus and middle ear pressures
Sinus surgery or middle ear surgery or infection within 1 wk

Due to increases in intrathoracic and intraabdominal pressure
Presence of pneumothorax
Thoracic surgery within 4 wk
Abdominal surgery within 4 wk
Late-term pregnancy

Infection control issues
Active or suspected transmissible respiratory or systemic infection, including tuberculosis
Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding

Anyone who can breathe can do oscillometry
Children, old age, mentally and physically challenged

Clinically obstructive airway disease with normal spirometry
To determine level of obstruction (large airways vs small airways) – Role of ultra-fine particle inhaler therapy

Lung transplant rejection earlier than spirometry

Differences between Spirometry and IOS

Parameter	Spirometry	FOT/IOS
Main principle	Flow sensor/volume displacement helps measure flow rates and lung volumes	Forced oscillations of single frequency sound waves (FOT) or impulses of multiple frequency sound waves (IOS) are pushed into the lungs as pressure waves to measure respiratory resistance and reactance
Main parameters	Volumes: FEV_1, FVC	*Zrs*, *Rrs*, *Xrs*, *Fres*, *Ax*
	Flows: PEFR, $FEF_{25-75\%}$	
Patient co-operation required	+++	+
Type of breathing manoeuvre	Forced exhalation	Tidal breathing
Variability (intra-subject)	3–5%	5–15%
Sensitivity to airway location		
Central	+	+++
Peripheral	++	+++
Cut off for bronchodilator response	12–15% for FEV_1	40% for R_5 or X_5
Cut off for bronchoconstrictor response	20% for FEV_1	50% for R_5
Insight into lung mechanics	+	+++
Standardised methodology	+++	++
Availability of robust reference values	+++	+

Breathe March 2015 Volume 11 No1

Interpretation of spirometry

%predicted
LLN
Z-score

Why predicted not a fixed cut – off values ?

- Test is influenced by - Age, Gender, Ethnicity, Height, Weight

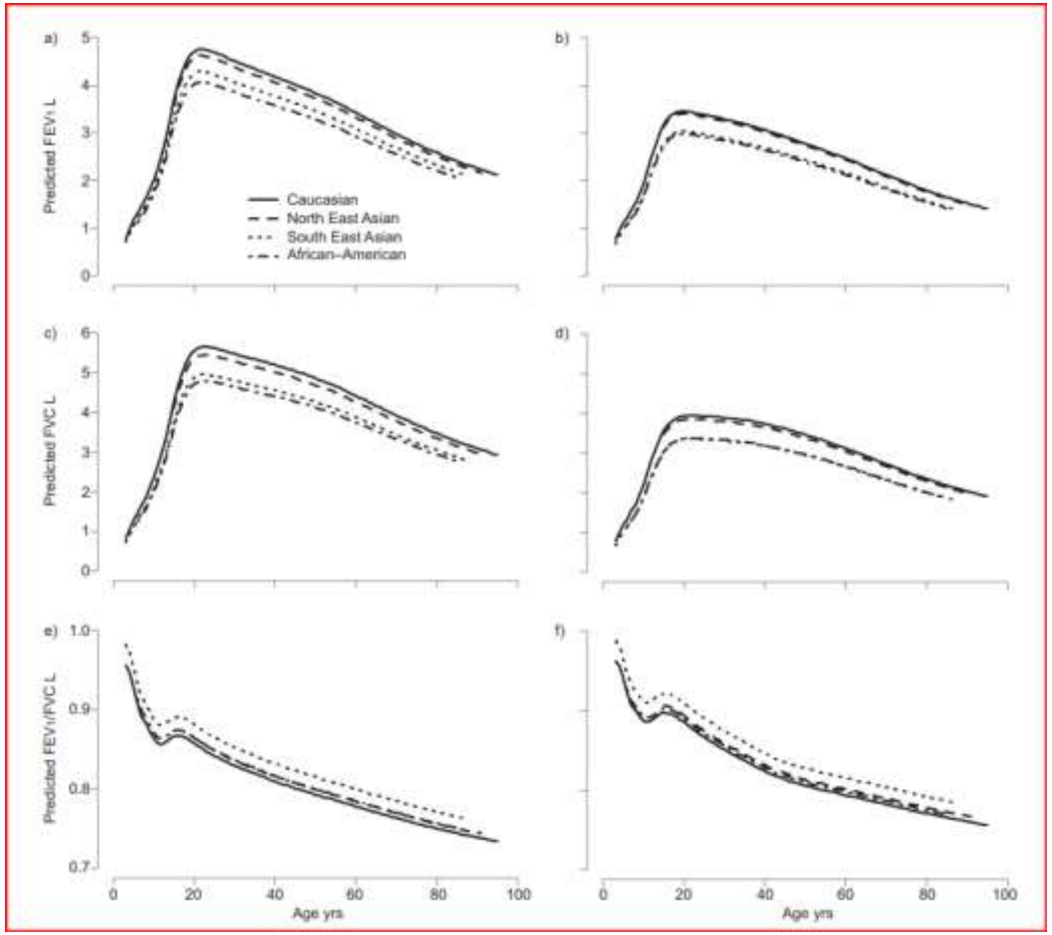
ERS TASK FORCE

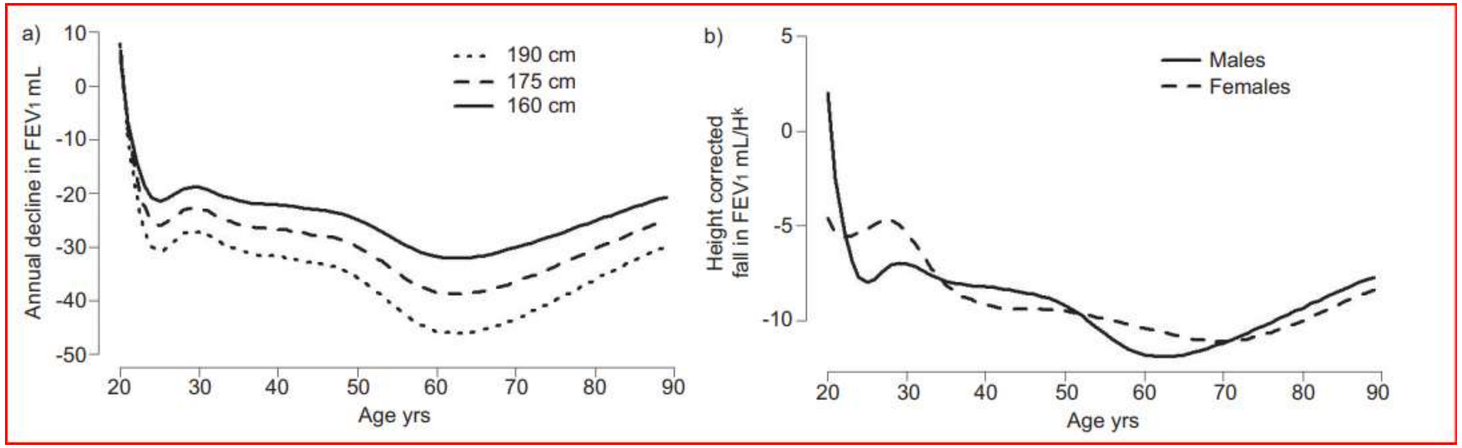
Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations

Philip H. Quanjer, Sanja Stanojevic, Tim J. Cole, Xaver Baur, Graham L. Hall, Bruce H. Culver, Paul L. Enright, John L. Hankinson, Mary S.M. Ip, Jinping Zheng, Janet Stocks and the ERS Global Lung Function Initiative

TABLE 1 Summary of datasets included in the initial analysis#

Group	Countries	Males		Females	
		N	Age range yrs	N	Age range yrs
African–American	1	1529	6–85	2029	6.1–87
India and Pakistan	2	2837	4–86	3003	3–79
Latin America	5	2337	6.7–89.4	2578	7.4–89.7
Mexican–American	1	1622	6.2–86	2282	6.5–87
Iran	1	3398	5–85	2739	5–80
Oman	1	638	6–65	618	6–65
North East Asia	2	2176	15.3–91	4526	15.5–90
South East Asia	4	4187	3.3–88	6371	3.1–92
North Africa	2	541	6–78	602	6–90
Caucasian	14	24229	2.5–95	28844	2.5–95
Other		199	6.2–93	474	5.8–91
Total	33	43693	2.5–95	54066	2.5–95





- Without correcting for age, height, gender, weight and ethnicity can lead 70-90% variability
- Thus predicted values are used

India - Heterogenous population

- Use of Caucasian prediction equations or a fixed percentage of their predicted values (e.g., 90% of predicted) are not suitable for Indians despite accounting for ethnic discounting
- Has multiple reference equations as per region-specific

Table 2 Comparison of spirometry interpretation by North Indian and other reference equations

	North Indian[6]		
	Normal	Obstruction	Restriction
South Indian[7]			
Normal	5830 (96.6)	203 (6.7)	967 (38.6)
Obstruction	204 (3.4)	2773 (91.5)	62 (2.5)
Restriction	—	55 (1.8)	1479 (59.0)
Total	6034	3031	2508
West Indian[8]			
Normal	13155 (99.5)	2971 (35.4)	2107 (36.6)
Obstruction	—	4514 (53.8)	—
Restriction	71 (0.5)	913 (10.9)	3652 (63.4)
Total	13226	8398	5759

%predicted

LLN

Z-score

Aggarwal AN et al Respirology 2007 Sep;12(5):763-8

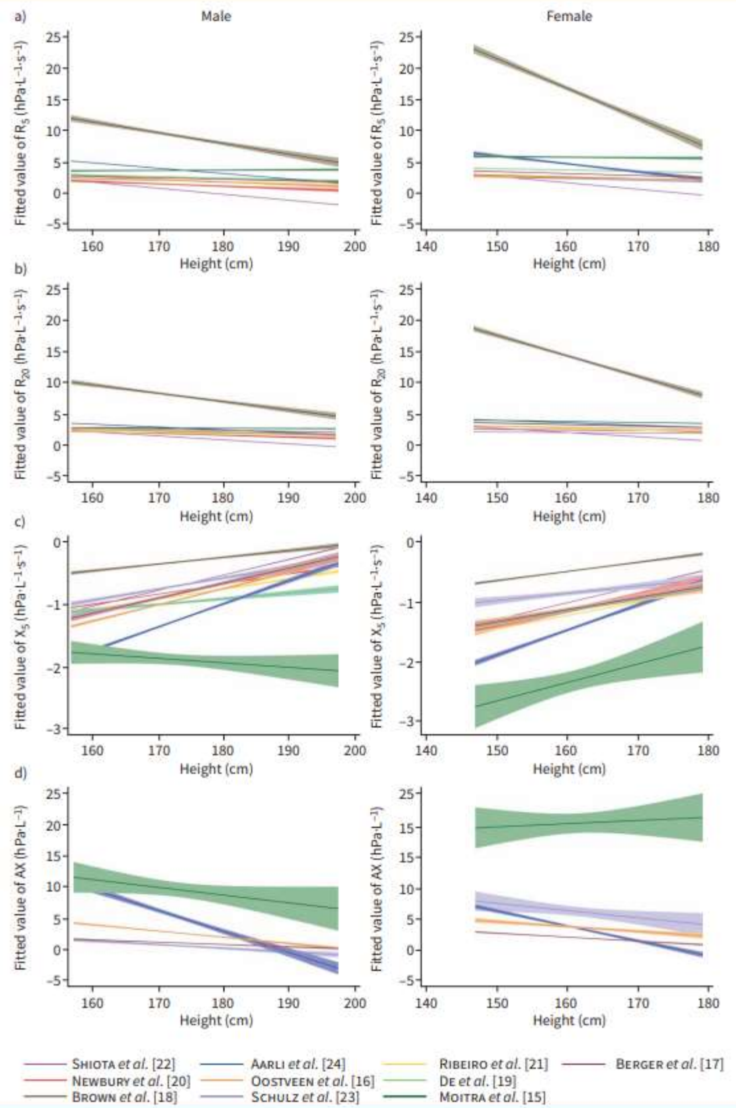
Interpretation of oscillometry

- Numerous reference equations exist globally, none has covered such a broad age range
- Not standardized for interpretation unlike spirometry
- Unlike spirometry, DL_{CO} no single equation gives limits – mainly because of smaller values and negative values

European Respiratory Review 2022; 31(165): 220021

Reference equations for oscillometry and their differences among populations: a systematic scoping review

EUROPEAN RESPIRATORY REVIEW
REVIEW
A. DEPRATO ET AL.

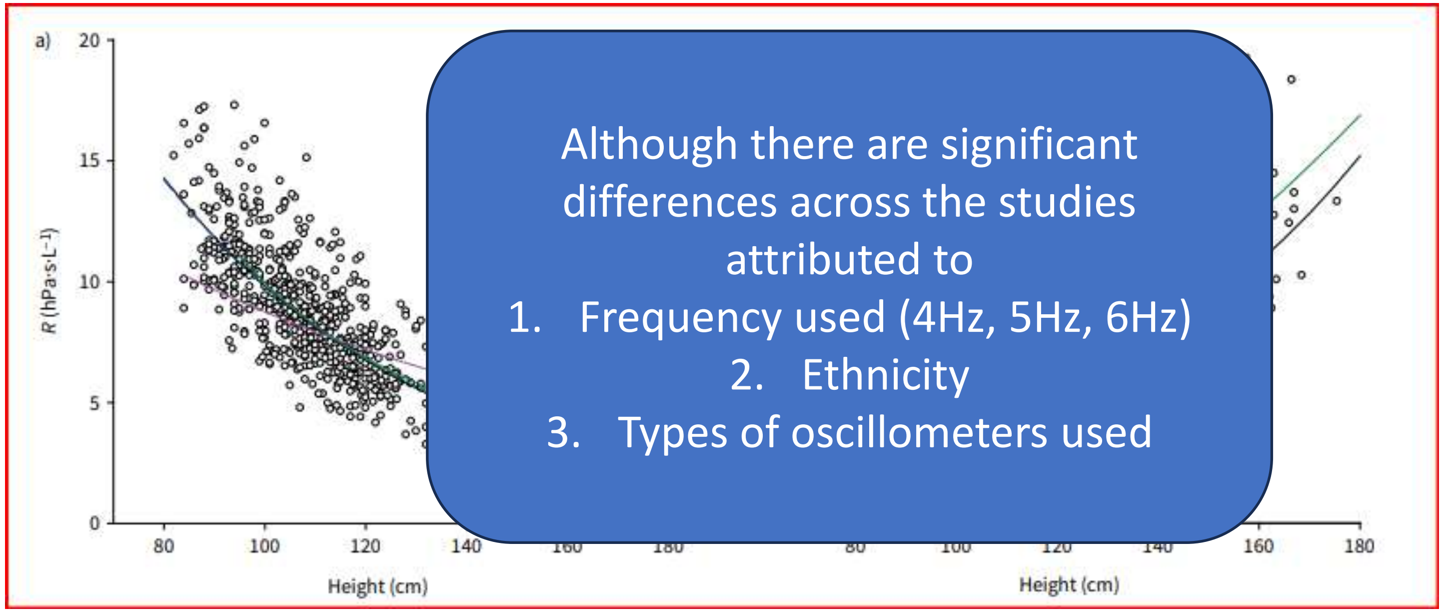


10 Studies
6 Caucasian
2 Indian

European Respiratory Review 2022; 31(165): 220021

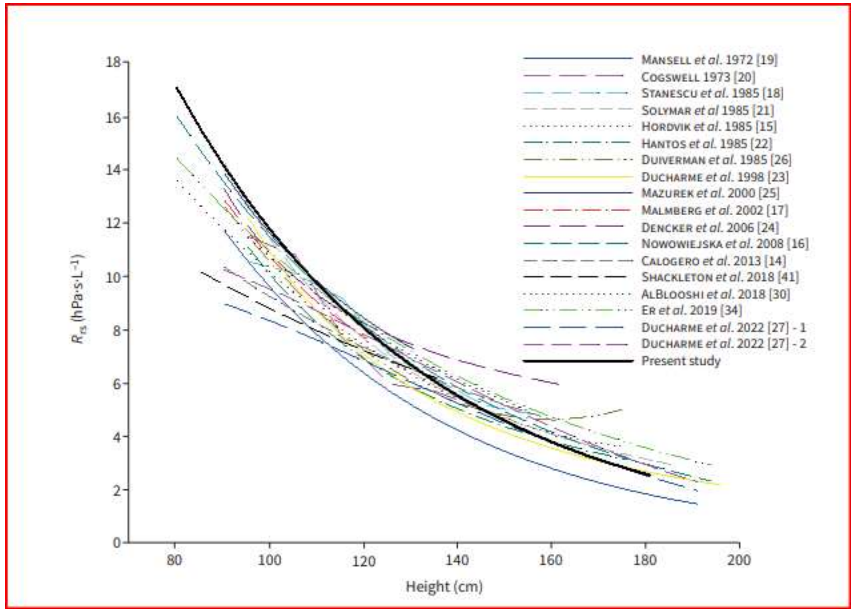
Variables determining cut-off for oscillometry

- Chaya et al 2023 conducted a study among 692 asymptomatic South African children and found that the only variable determining compliance and resistance is the height



Although there are significant differences across the studies attributed to

1. Frequency used (4Hz, 5Hz, 6Hz)
2. Ethnicity
3. Types of oscillometers used



Chaya et al ERJ Open Res 2023; 9: 00371-2022

Reference equations using segmented regressions for impulse oscillometry in healthy subjects aged 2.7–90 years

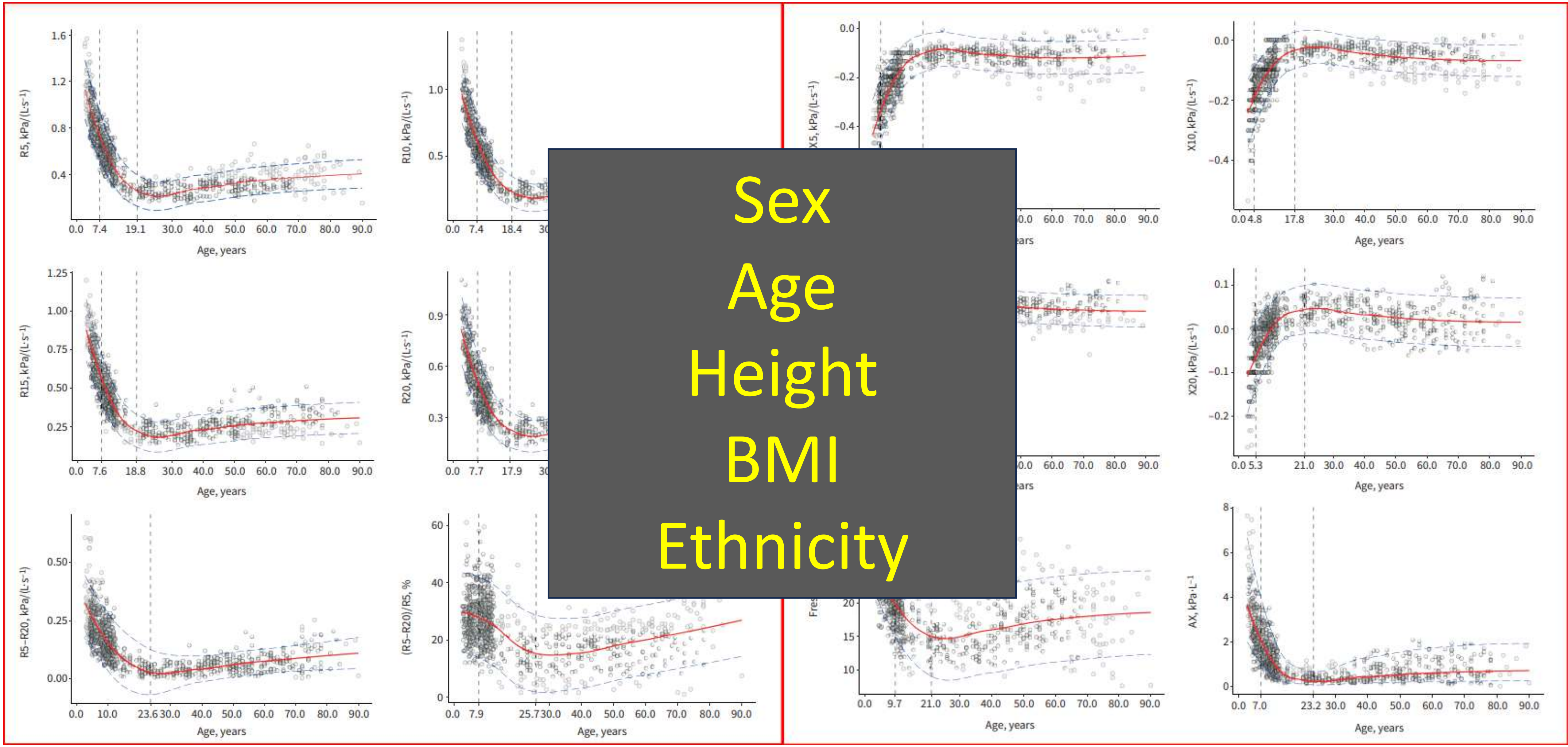
Laura Gochicoa-Rangel [1,2,7], David Martínez-Briseño [1,7], Selene Guerrero-Zúñiga [1], Jessica Contreras-Morales [3], Dulce Arias-Jiménez [4], Rodrigo Del-Río-Hidalgo [1], Federico Isaac Hernández-Rocha [5], Cecilio O. Ceballos-Zúñiga [5], Mónica Silva-Cerón [1], Uri De Jesús Mora-Romero [1], Luis Torre-Bouscoulet [2], Rosario Fernández-Plata [1], José E. Pérez-Nieto [6] and Mario H. Vargas [1]

TABLE 1 Characteristics of the study population (n=830) according to age groups

Age, years	Subjects, n (male:female)	Height, cm	Weight, kg	BMI, kg·m^{-2}
3.5 (2.7–4)	37 (17:20)	97 (86–108)	15 (13–19)	16.1 (13.9–19.3)
4.7 (>4–5)	44 (20:24)	106 (99–114)	18 (14–26)	15.9 (13.1–20.5)
5.5 (>5–6)	61 (29:32)	112 (101–127)	20 (15–37)	15.8 (13.1–24.3)
6.5 (>6–7)	41 (23:18)	118 (108–128)	22 (17–40)	15.7 (13.8–24.7)
7.6 (>7–8)	40 (20:20)	123 (111–135)	24 (19–42)	16.4 (13.2–22.7)
8.6 (>8–9)	57 (29:28)	128 (114–146)	28 (19–47)	16.9 (13.7–27.7)
9.6 (>9–10)	58 (21:37)	135 (121–150)	33 (23–57)	18.3 (14.9–27.2)
10.6 (>10–11)	56 (20:36)	140 (128–157)	34 (24–65)	18.4 (14.5–27.2)
11.6 (>11–12)	61 (32:29)	144 (131–161)	39 (28–66)	18.8 (14.6–26.9)
15 (>12–20)	56 (29:27)	158 (134–180)	54 (33–90)	20.7 (16.0–29.5)
24 (>20–30)	62 (28:34)	163 (150–185)	68 (46–94)	25.3 (17.6–29.8)
35 (>30–40)	54 (30:24)	164 (149–183)	70 (50–88)	26.1 (20.3–29.8)
45 (>40–50)	64 (25:39)	160 (146–185)	70 (52–96)	27.3 (19.4–31.6)
55 (>50–60)	56 (22:34)	155 (134–176)	66 (45–98)	26.9 (19.0–41.3)
65 (>60–70)	43 (20:23)	158 (142–175)	69 (51–89)	27.6 (20.4–31.0)
75.5 (>70–90)	40 (17:23)	158 (145–180)	68 (49–91)	28.3 (20.2–34.7)

830 Latin American people

Gochicoa-Rangel L et al ERJ Open Res. 2023 Dec 18;9(6):00503-2023



Gochicoa-Rangel L et al ERJ Open Res. 2023 Dec 18;9(6):00503-2023

Height seems to be the only variable that determines lung oscillometry indices

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CORRESPONDENCE
D. GHORPADE ET AL.

Letter to the editor Gochicoa-Rangel et al study

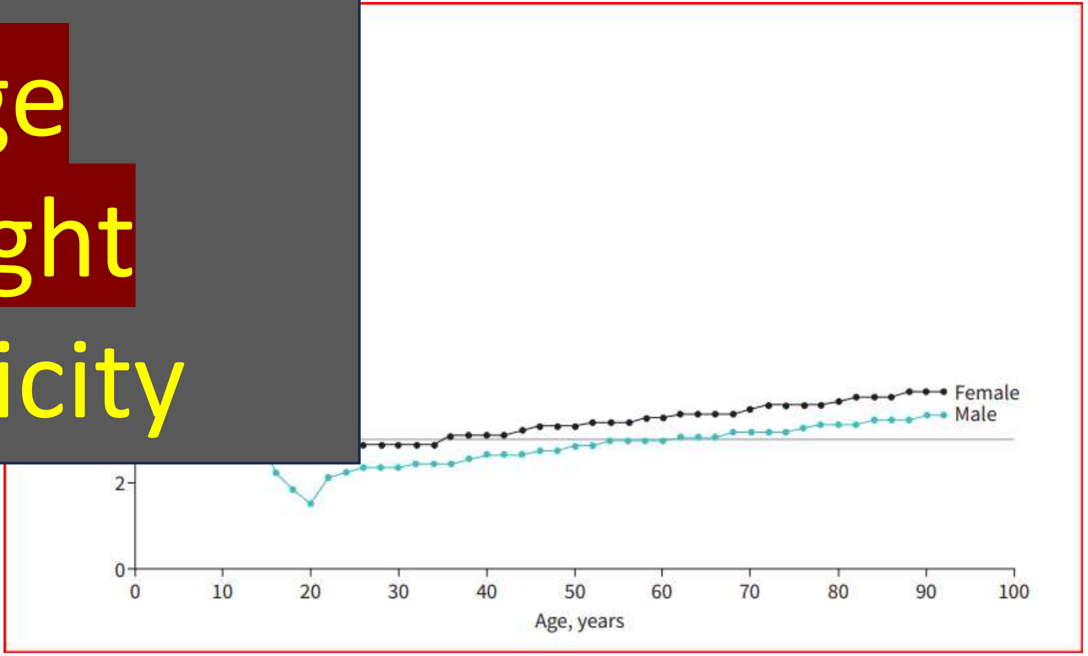
~~Sex~~

Age

Height

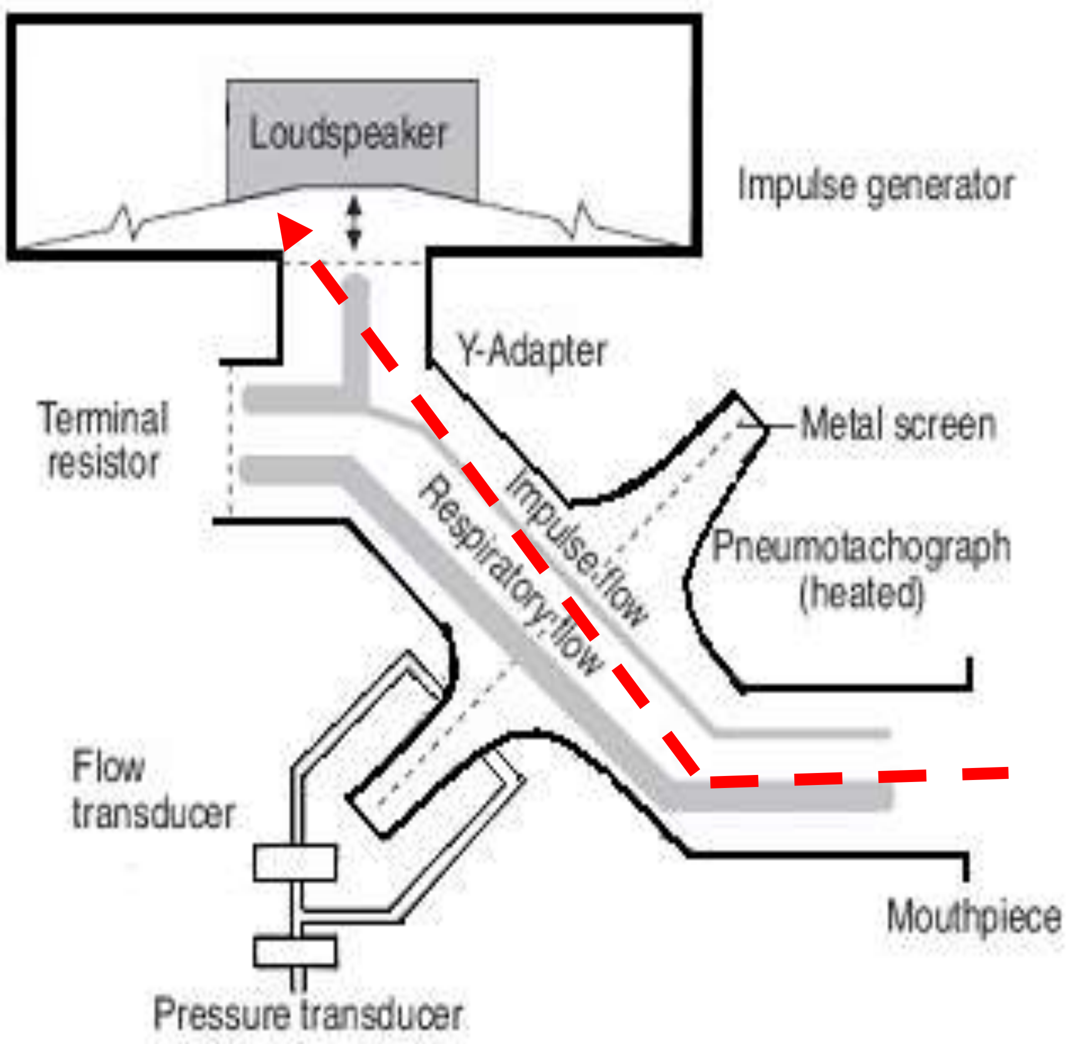
Ethnicity

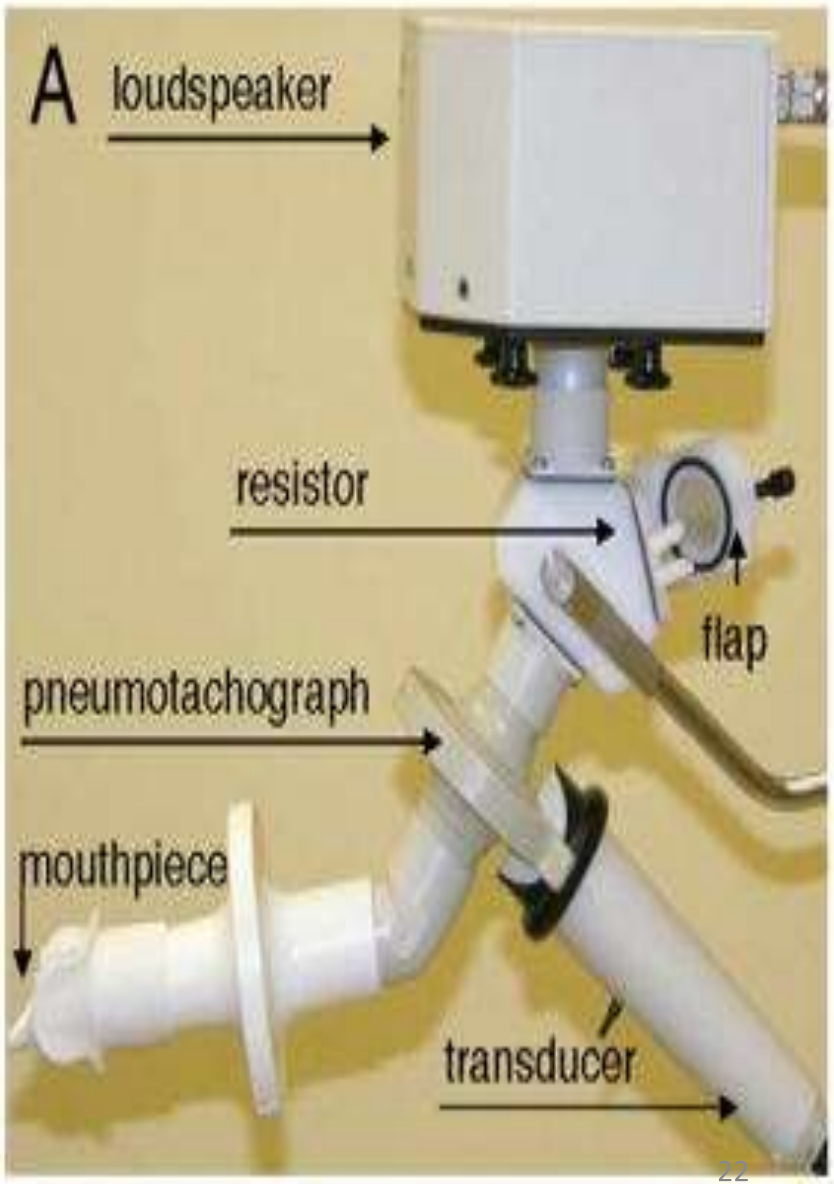
- They observed no difference betwee between boys and girls between 2.7
- After 19 yrs, remained relatively con females showing a consistently high males from 19 yrs to 90 yrs attribute differences
- Small increase in R5 in both males and females towards the latter ages



- Always do oscillometry first followed by spirometry

Components of IOS Equipment





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	Overall $N=84$		Asthma $N=59$		COPD $N=25$	
Age	54		50		65	
Gender F/M	46/38		[illegible]		12/13	
BMI	29		[illegible]		28	
Smoking status n/e/c	39/36/[illegible]		[illegible]		[illegible]/8/17	
Smoking pack year history	[illegible]		[illegible]		[illegible]	
SPT	[illegible]		[illegible]		[illegible]	
ICS (μg)	[illegible]		[illegible]		[illegible]	
LABA	[illegible]		[illegible]		[illegible]	
LAMA	26		[illegible]		[illegible]	
LTRA	20		[illegible]		0	
THEO	2		[illegible]		0	
OAH	25		24		1	
ACQ	–		1.60		–	
FEV_1 (% predicted)	81		88		64	
FEF_{25-75} (% predicted)	45		54		24	
FVC (% predicted)	101		102		99	
FEV1/FVC ratio	0.66		0.72		0.52	
	IOS	AOS	IOS	AOS	IOS	AOS
R5 (kPa/l.s)	0.52	0.50	0.50	0.49	0.58	0.53
R20(19) (kPa/l.s)	0.37	0.36	0.37	0.36	0.38	0.36
R5–R20(19) (kPa/l.s)	0.15	0.15	0.13	0.13	0.20	0.17
AX (kPa/l)	1.42	2.47	1.10	1.96	2.13	3.59
X5 (kPa/l.s)	– 0.23	– 0.29	– 0.20	– 0.24	– 0.29	– 0.40
Fres (Hz)	18.63	23.62	17.38	21.96	21.43	27.35

Resistance 10% difference IOS > AOS
Reactance 65% difference AOS > IOS

Kuo et al Lung (2019) 197:473–481

FOT vs IOS

- FOT – Sinusoidal wave – Vibrating mesh
- As a single frequency given each time – less discomfort, more time required, and higher precision control on flow, pressure, and volume
- Produce continuous sine waves which means continuous measurement is done over the whole time not only when the pulse appears – use prime numbers – so harmonics are avoided and the higher quality signal is present (covers all range of interest frequencies – avoid noise and discomfort)
- Power is controlled and the same for all frequencies

- IOS – Square waves – Loud speaker
- Made up of an almost infinite number of frequencies and many higher frequencies to get square morphology – a quick rise
- More discomfort to the patient and reduced time of testing
- 0.2 sec - Membrane moves out and in – 5 Hz – harmonics will be generated at multiples of 5 Hz leading to harmonic interference at multiples of 5
- Power spectrum is not controlled – power will be higher

Pseudorandom noise – randomly any frequency is delivered

Performing oscillometry

- Normal tidal breathing in a quiet room (prevent interference)
- Sitting uprig f legs
  (reduce extr per tongue
  position
- Cheek suppo
- Tidal breath
- Minimum of 3 readings (pre and post-BD each)

QUALITY OF TEST IS ONLY BY OBSERVING THE PROCEDURE
(unlike spirometry which has a graph)

Coherence -----→ Covariance

- CoV – to determine artifacts between flow and pressure (validity and quality of the test)
- CoV should be ≤10% in adults & ≤15% in children
- Because of improper technique, irregular breathing, glottis closure, and swallowing.

Parameters in oscillogram

Respiratory impedance(Zrs)

Dependent on flow

Resistance (Rrs)

Reactance (Xrs)

Dependent on volume changes

Capacitance: elastic properties of the lung and of the chest wall, mobility of the ribcage, lung compliance

Capacitance

Inertance (I)

Inertance: mass-inertia of the moving air columns, due to the physical properties of inhaled air

Elastance (E)

Compliance

Parameters in spirometry

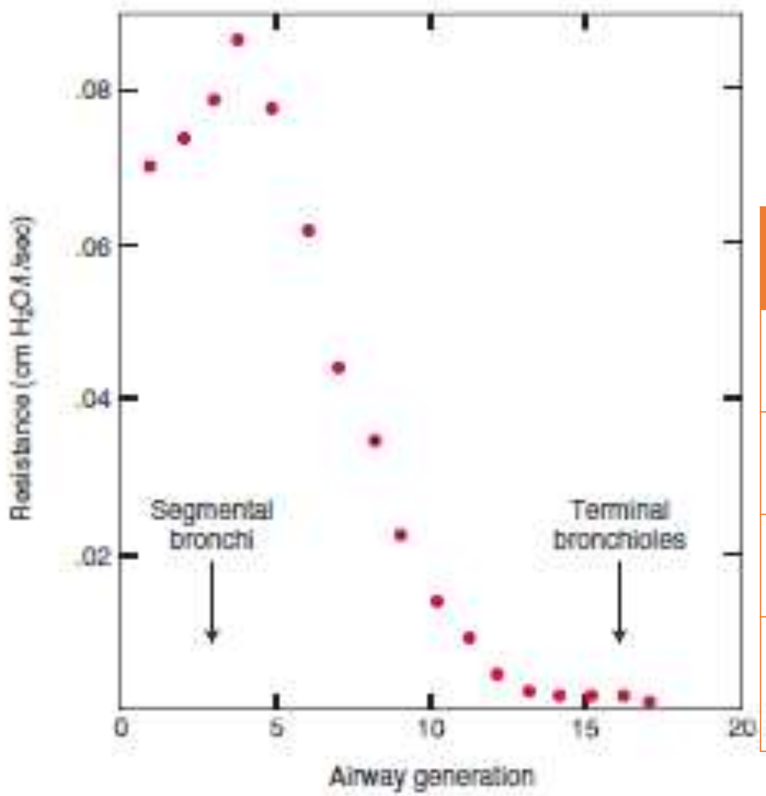
1. **<u>Resistance (Rrs) – Energy required to propagate pressure wave</u>**

- Reflects opposition to changes in flow- in phase with flow and increased resistance will decrease flow for a given pressure input
- Resistance due to central airways, peripheral airways, lung tissue, and chest wall, although the latter two are usually negligible
- Depends on airway caliber and length -

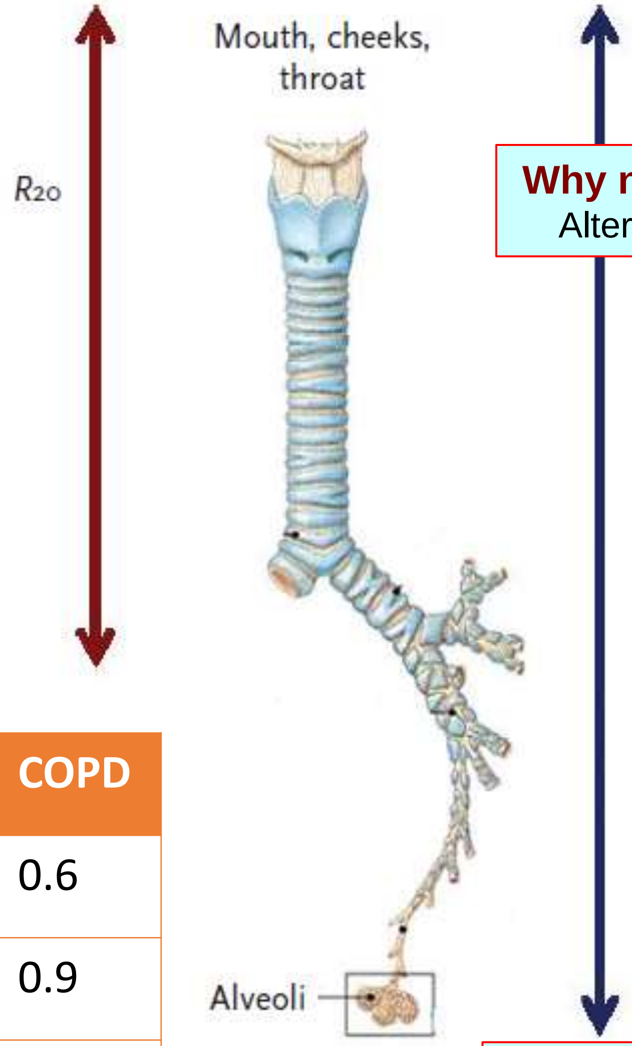
$$\text{Resistance} = \frac{8 \times \text{Tube length} \times \text{Gas viscosity}}{\pi \times \text{Tube radius}^4}$$

Resistance

- 80% by central airways and only 20% by small airways (<2 mm diameter) in adults



Location	Normal	COPD
Pharynx-Larynx	0.6	0.6
Airways> 2mm	0.6	0.9
Airways<2mm	**0.3**	**3.5**
Total Airway Resistance	1.5	5.0

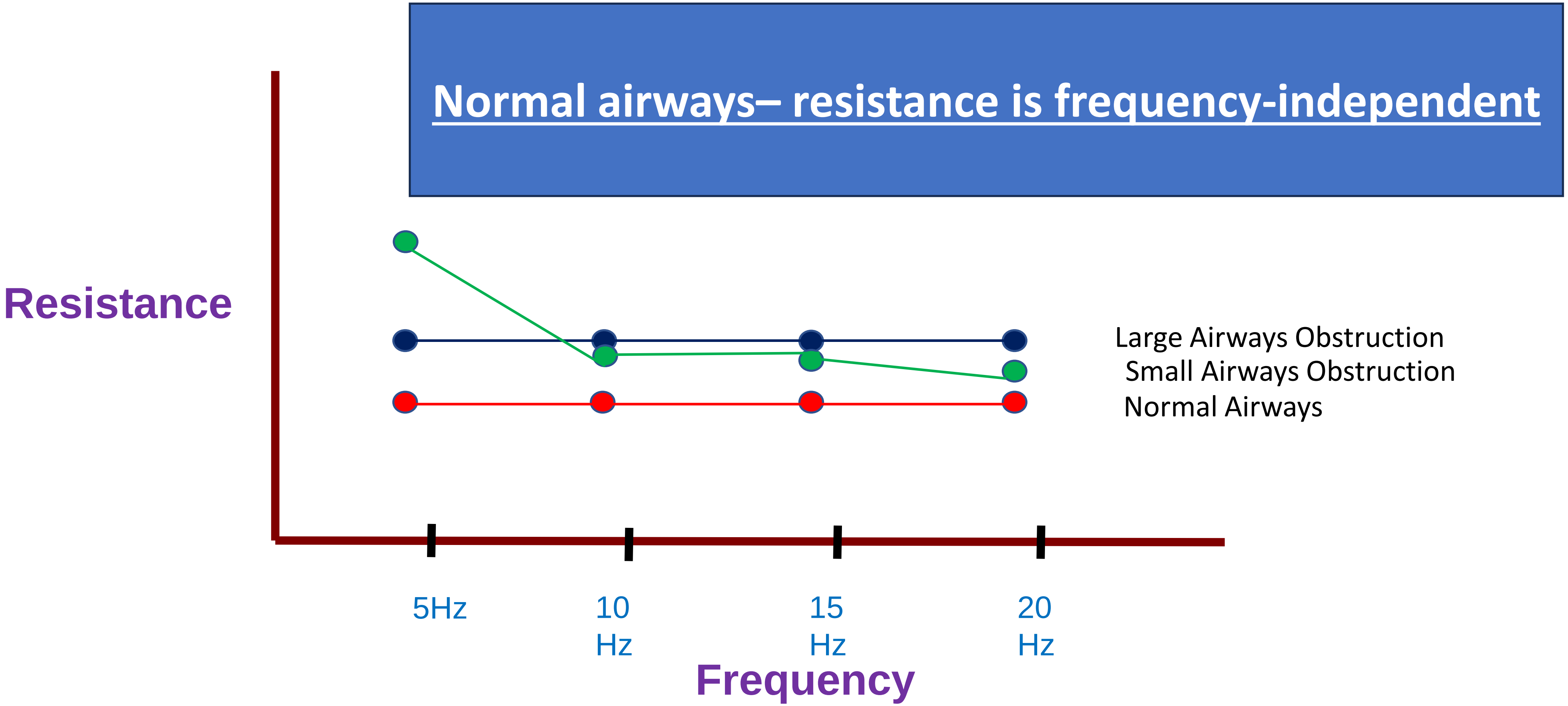


Why not less than 5 Hz?
Alters breathe dynamics

Why not more than 30 Hz?
Causes discomfort to the patient

J. B. West, Respiratory Physiology, 9/e, 2012

Frequency dependency of resistance In airway obstruction



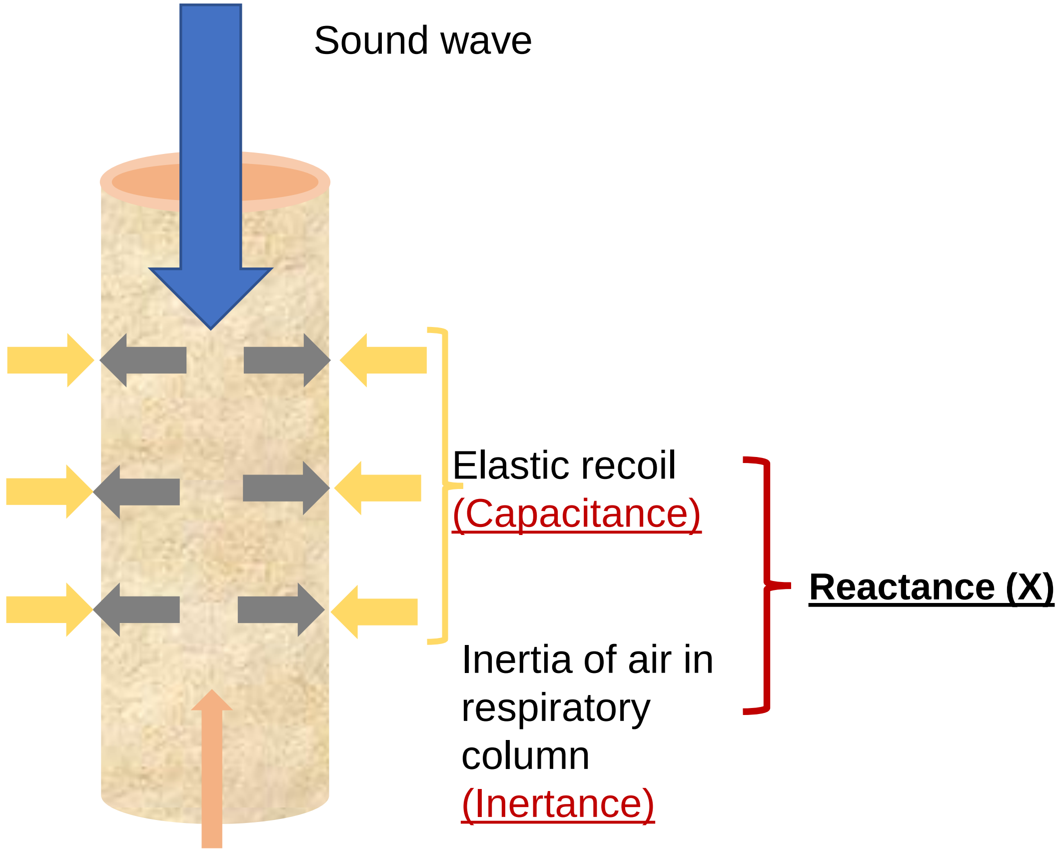
R5: increased in both large and small airway obstruction
R20: increased in central airway obstruction
R5-R20: increased in small airway obstruction

Reactance (X)

1. Inertance in the large, central airways – Positive phase difference
2. Elastic properties of lung tissue (capacitance) – Negative phase difference

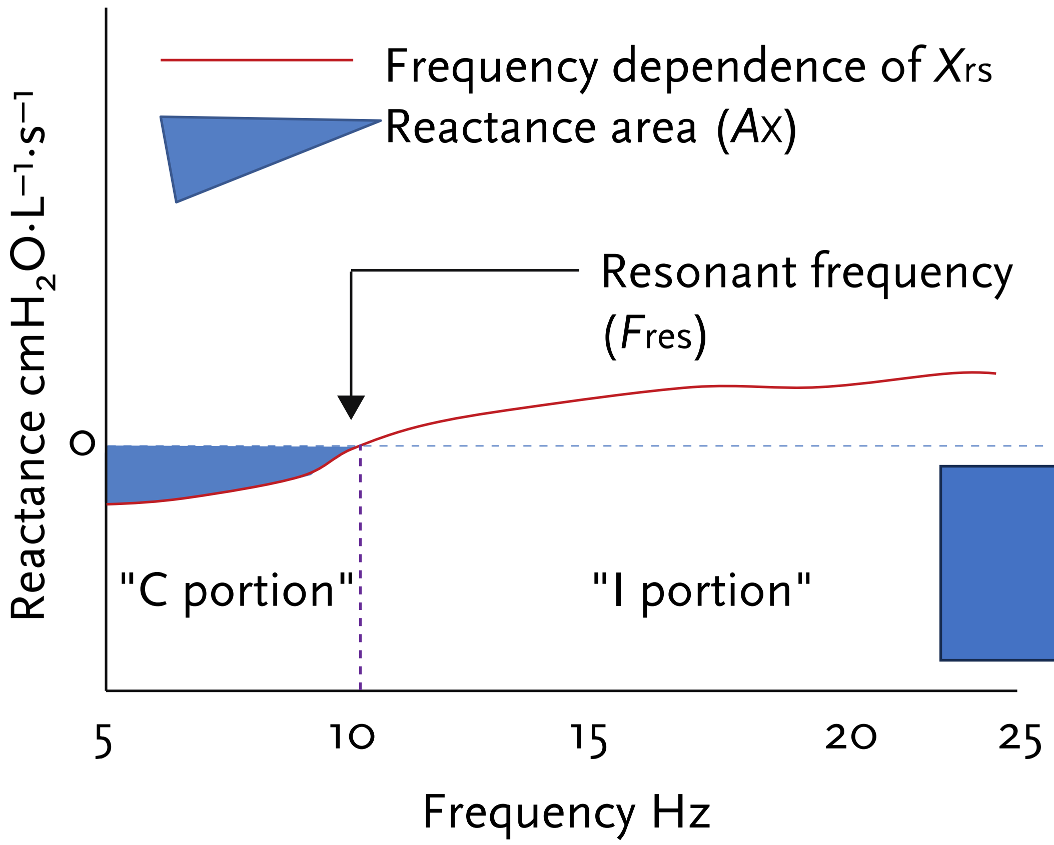
- **Reactance is more frequency-dependent than resistance**
- Ers, which is 1/compliance, measures the elastance and stiffness of the entire system (chest wall, lungs, and airway walls)

In either fibrosis, emphysema or small airway disease, the reactance at lower frequencies would change in the same direction, i.e., become even more negative



Reactance (X)= Capacitance + Inertance

Frequency dependency of reactance



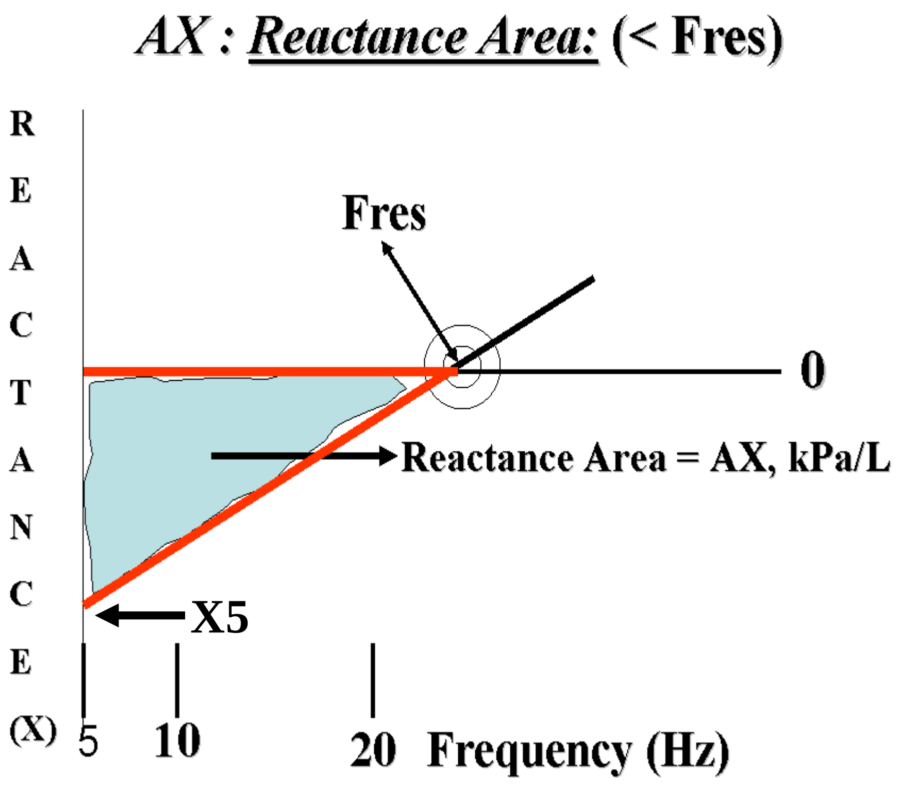
Normal airways– reactance is frequency-dependent

Area of reactance (AX)- Goldman triangle

- Area under the curve between the reactance values for 5Hz and the resonance frequency

- It includes the total area dominated by the capacitance and reflects the elastic properties of the lung

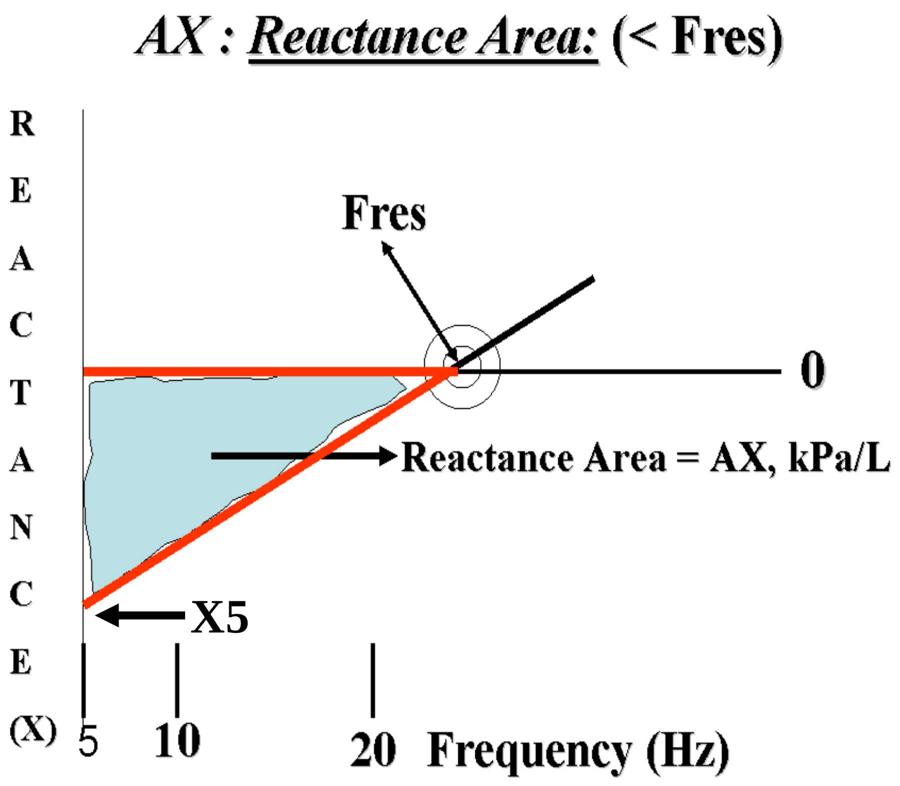
- Increases in any disease of lung periphery



Resonant Frequency (fres)

- Resonant frequency (fres) is defined as the frequency at which the inertial properties of the airway and the capacitance of the lung periphery are equal

- The frequency at which total reactance is zero



In both obstructive and restrictive lung diseases, *fres* is increased above normal

Parameters

- R5 – Total respiratory resistance
- R20 – Large airway resistance

R5 – R19 vs R5 – R20 – harmonic distortions

- R5 – R20 – Small airway resistance
- X5 – Small airway obstruction, Lung elastance and stiffness, Lung heterogeneity
- Fres – Airflow obstruction, Lung restriction
- AX – What is happening in the distal portion of the lungs, both – small airways and lung parenchyma
- X5 inspiratory more than X5e – restrictive
- X5 expiration more than X5i - obstructive
- Delta X5

Clinical application of oscillometry in respiratory diseases: an impulse oscillometry registry

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ORIGINAL RESEARCH ARTICLE

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- Multi centre study – in 20 hospitals in China 2016 – 2018

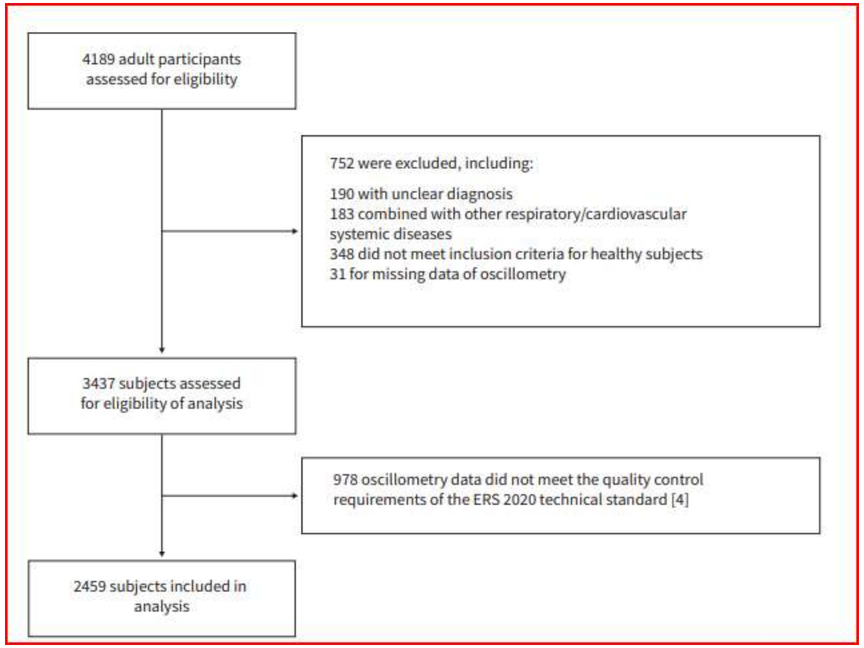
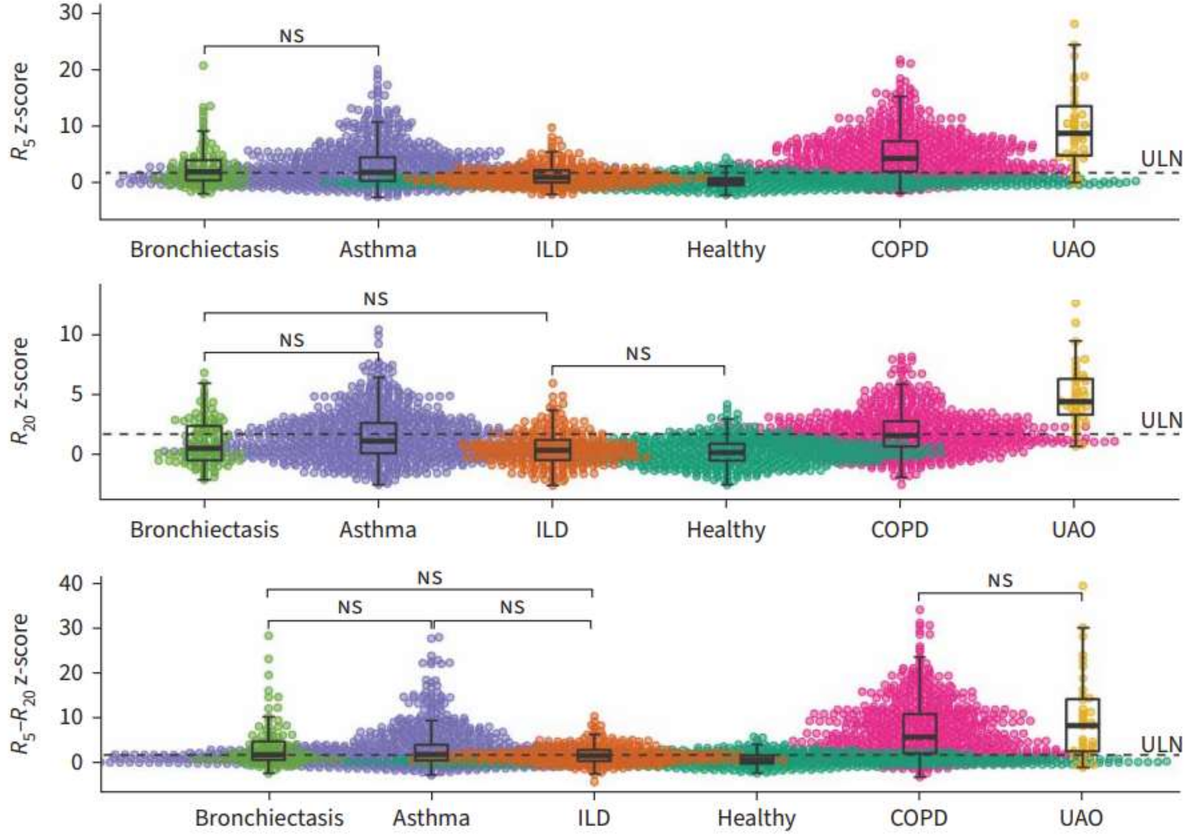


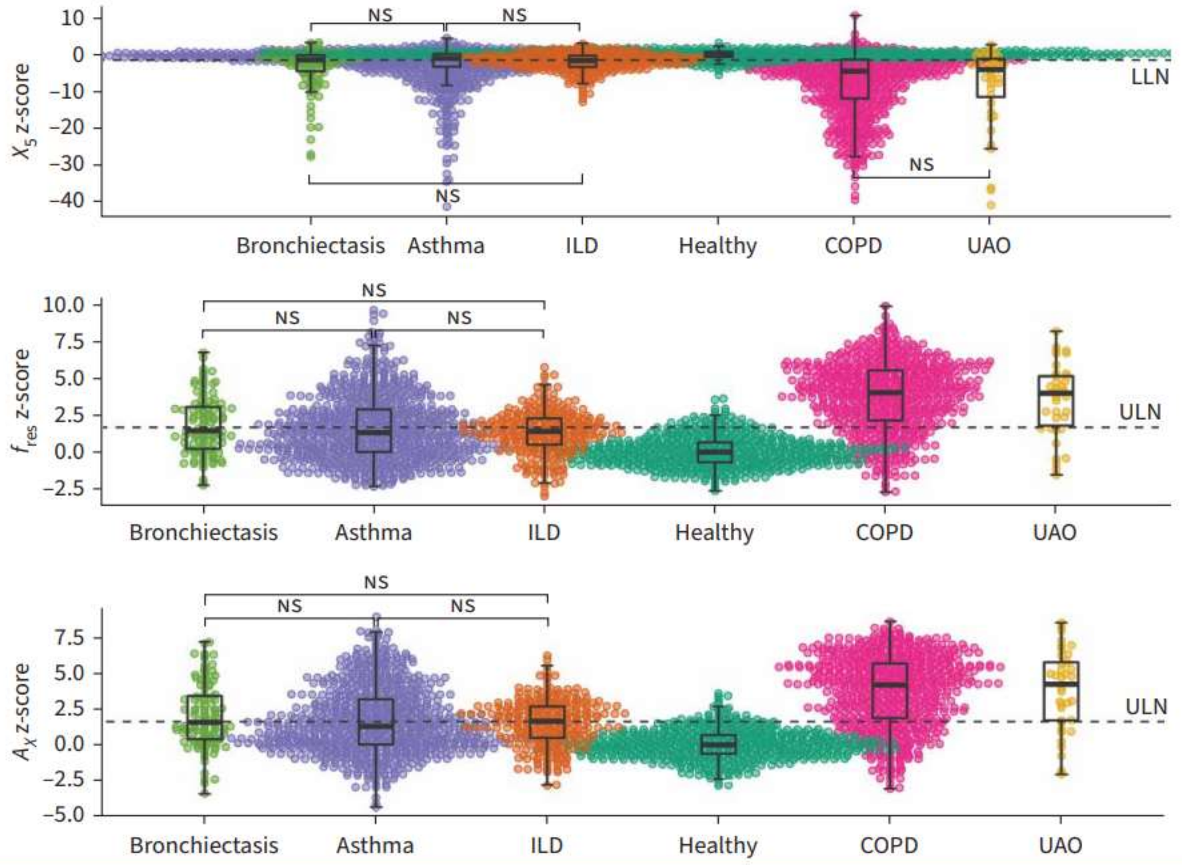
TABLE 1 Anthropometrics and spirometric parameters of the analysed population

	Healthy	ILD	Asthma	COPD	Bronchiectasis	UAO
Subjects, N	567	274	781	688	109	40
Females, n (%)	300 (52.9)	124 (45.3)	441 (56.5)	58 (8.4)	66 (60.6)	19 (47.5)
Age, years	38.3±14.3	57.4±11.6	45.9±12.9	63.2±8.6	52.9±11.1	54.5±14.9
Height, cm	164.3±8.3	161.6±8.0	162.2±8.2	165.2±7.0	160.0±8.4	160.7±7.5
Weight, kg	62.9±11.1	64.8±10.9	63.7±12.5	62.7±11.5	58.0±12.1	61.7±10.7
BMI, $kg \cdot m^{-2}$	23.2±3.1	24.7±3.3	24.1±3.7	22.9±3.6	22.5±3.7	23.8±3.3
FEV_1, L[#]	3.32±0.72	2.15±0.64	2.39±0.83	1.5±0.64	1.93±0.74	2.11±0.85
FEV_1 z-score[#]	0.291±0.914	−1.766±1.664	−1.784±1.902	−4.12±1.796	−2.506±1.942	−2.034±2.34
FVC, L[#]	3.96±0.87	2.71±0.84	3.52±0.95	3.02±0.80	2.84±0.86	3.22±0.84
FVC z-score[#]	0.310±0.978	−1.800±1.753	−0.225±1.442	−1.517±1.690	−1.363±1.482	−0.407±1.526
FEV_1/FVC[#]	83.8±5.5	80.1±8.7	67.2±13.0	48.5±12.8	67.2±14.1	64.2±16.0
FEV_1/FVC z-score[#]	−0.047±0.791	0.01±1.507	−2.572±2.16	−4.849±2.047	−2.329±2.382	−2.882±2.948
MMEF, $L \cdot s^{-1}$[¶]	3.45±1.06	1.89±0.88	1.63±0.97	0.59±0.39	1.21±0.89	1.76±0.82
MMEF z-score[¶]	0.153±0.993	−0.904±1.347	−1.917±1.172	−2.901±0.552	−2.094±1.304	−1.399±1.067
PEF, $L \cdot s^{-1}$[#]	8.02±1.93	5.12±2.19	6.08±1.98	4.00±2.21	7.03±1.94	4.08±2.27
PEF z-score[#]	0.378±0.995	−1.212±1.537	−2.653±1.311	−0.233±1.349	−1.623±1.464	−2.658±1.661

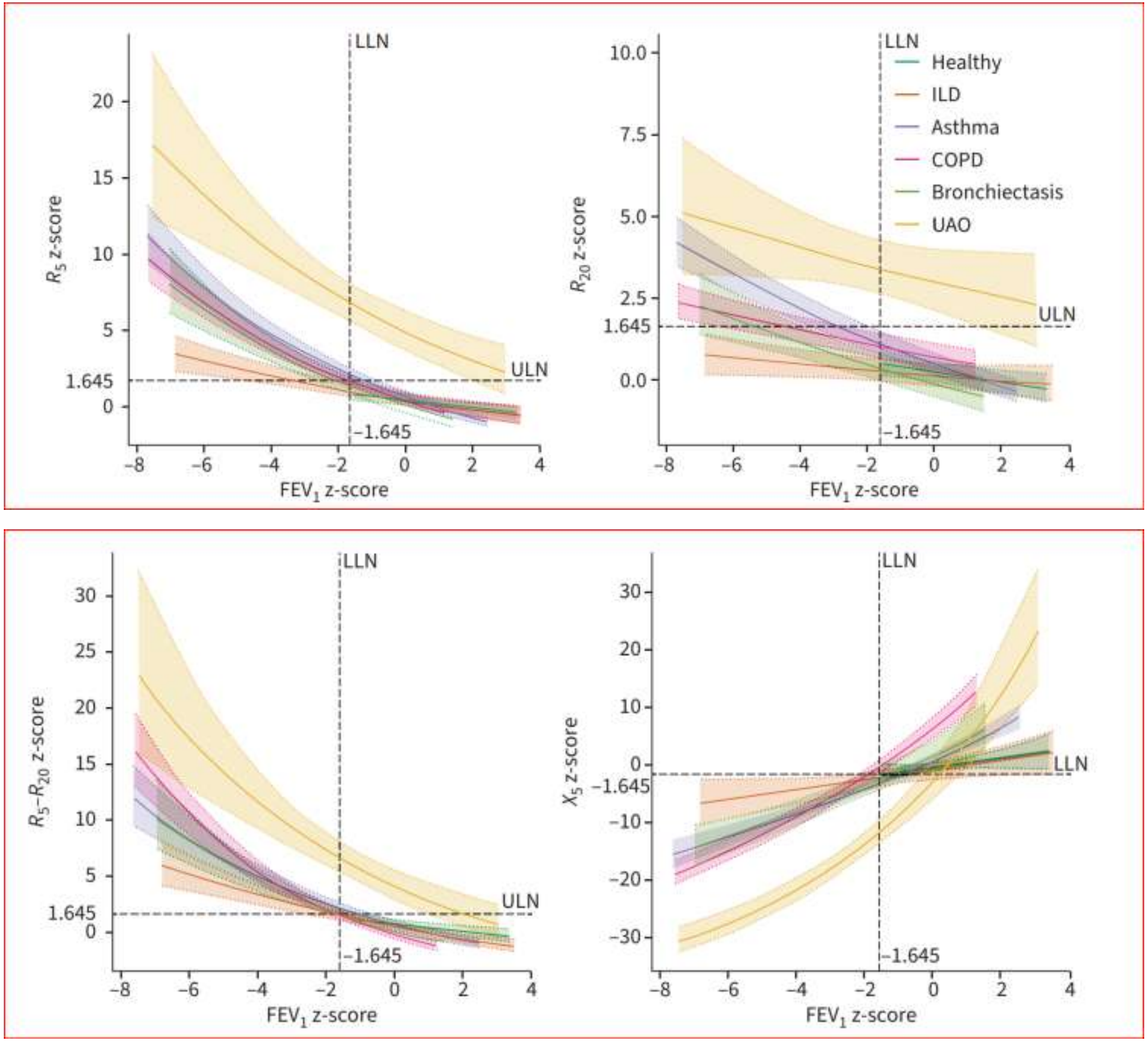
Data are presented as mean±SD unless otherwise stated. ILD: interstitial lung disease; UAO: upper airway obstruction; BMI: body mass index; FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; MMEF: maximum mid-expiratory flow; PEF: peak expiratory flow. #: 11 data were missing from this analysis; ¶: 177 data were missing from this analysis.



R_5 z-score
R_{20} z-score
R_5–R_{20} z-score
NS
ULN
Bronchiectasis
Asthma
ILD
Healthy
COPD
UAO



X_5 z-score
f_{res} z-score
A_X z-score
NS
LLN
ULN
Bronchiectasis
Asthma
ILD
Healthy
COPD
UAO



For the same FEV1

- R5 and R20 were higher for asthma
- R5-R20 higher for COPD

ILD –

- R5 exceed ULN if FEV1 < -3.5
- R5-R20 > ULN
- X5 < LLN

- When compared to FEV1 and FEV1/FVC, oscillometry parameters had lowest diagnostic value

	Variable	AUC (95% CI)	P	Cut-off	Sensitivity	Specificity
UAO	R_{20} z-score	0.895 (0.852, 0.938)	<0.01	>2.300	87.5	79.0
COPD	f_{res} z-score	0.807 (0.789, 0.826)	<0.01	>2.590	70.6	50.7
Asthma	R_{20}	0.620 (0.596, 0.645)	<0.01	>0.346	39.7	80.6
ILD	R_5	0.580 (0.549, 0.612)	<0.01	≤0.450	88.0	30.4
Bronchiectasis	R_5	0.536 (0.482, 0.590)	0.148	>0.335	67. 9	43.7

TABLE 3 Comparisons of the diagnostic values between R_5 and spirometric parameters

	AUC (95% CI)	p-value	Cut-off	Sensitivity	Specificity
Respiratory diseases					
R_5 z-score	0.807 (0.790–0.824)	<0.01	>1.426	62.4%	90.3%
FEV_1 z-score	0.900 (0.888–0.912)	<0.01	⩽ −1.112	74.0%	95.4%
FEV_1/FVC z-score	0.861 (0.847–0.875)	<0.01	⩽ −1.410	70.5%	97.4%
Obstructive airway diseases					
R_5 z-score	0.788 (0.770–0.806)	<0.01	>1.426	66.7%	81.5%
FEV_1 z-score	0.820 (0.803–0.837)	<0.01	⩽ −1.069	76.2%	75.2%
FEV_1/FVC z-score	0.922 (0.912–0.933)	<0.01	⩽ −1.401	80.72%	94.5%
UAO					
R_{20} z-score	0.895 (0.852–0.938)	<0.01	>2.300	87.5%	79.0%
FEV_1 z-score	0.509 (0.420–0.598)	0.84	⩽ −0.230	82.1%	26.6%
	0.557 (0.473–0.640)	0.18	⩽ −0.595	87.2%	32.2%
PEF z-score	0.728 (0.657–0.799)	<0.01	⩽−0.835	89.47%	47.87%

Cut – offs

- Z- scores –
  i. Not normally distributed
  ii. although anthropometric factors impact impulse oscillometry indices, their impact is not as large as that of spirometric indices (the highest determination coefficient of the predictive equation is ∼**0.20** vs 0.8)
- Fixed cut-off
- % predicted - ≥ 140% predicted

Interpreting lung oscillometry results: Z-scores or fixed cut-off values?

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S. SALVI ET AL.

- For Indian adults (n=1200), found age, height and weight – 10-20% contribution to variability

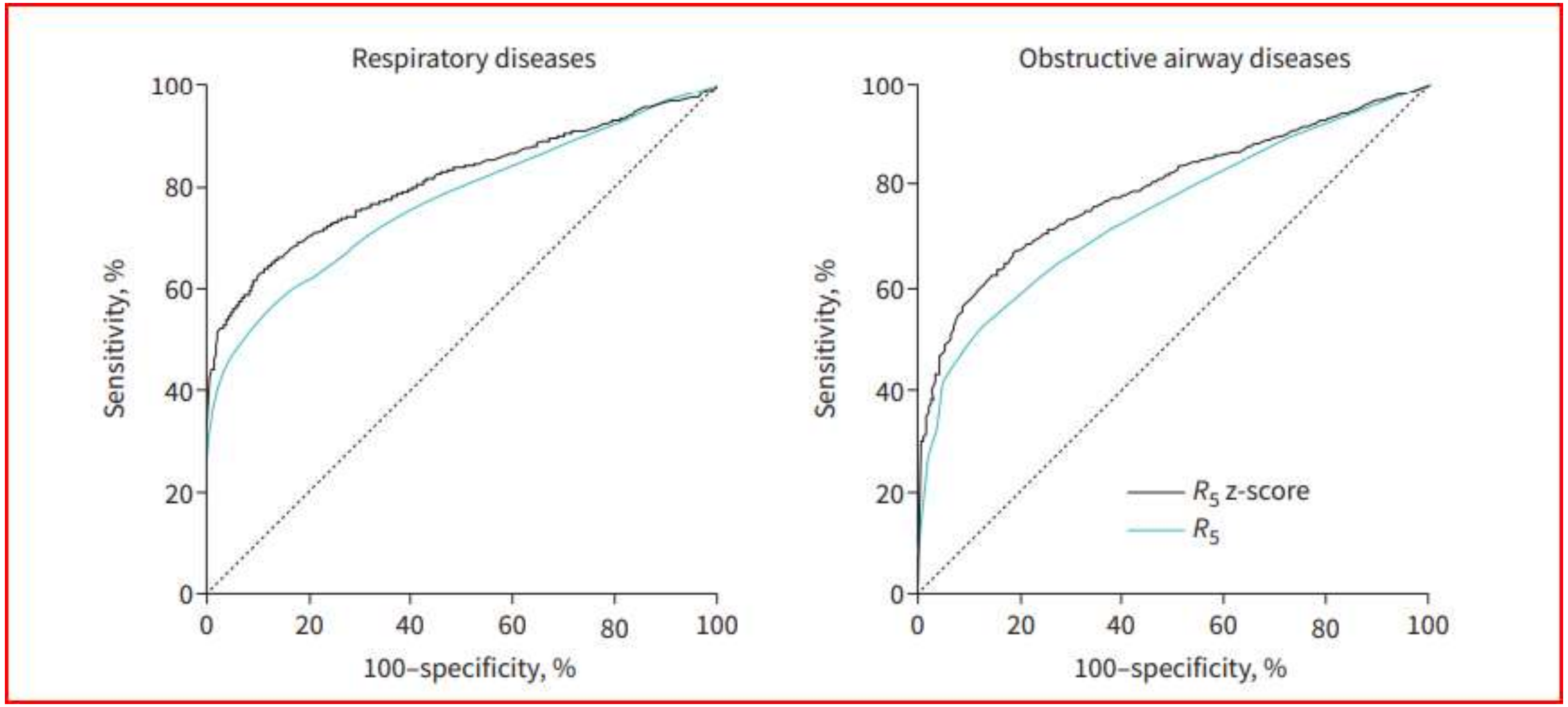
TABLE 1 Sensitivity, specificity and area under the curve (AUC) for fixed cut-off values to differentiate between healthy and obstructive airway disease (OAD)

Parameter	Cut off, $cmH_2O \cdot s \cdot L^{-1}$	OAD			
		Sensitivity	Specificity	Overall accuracy	AUC (95% CI)
R_5	⩾4.07	0.82	0.62	78.5%	0.81 (0.69–0.94)
R_{20}	⩾3.05	0.61	0.69	62.4%	0.75 (0.62–0.87)
$R_5–R_{20}$	⩾1.01	0.83	0.62	78.5%	0.76 (0.63–0.89)
X_5	⩽−1.01	0.89	0.50	82.8%	0.84 (0.74–0.93)
A_X	⩾4.07	0.83	0.625	78.1%	0.74 (0.58–0.88)

R_5: resistance measured at 5 Hz; R_{20}: resistance measured at 20 Hz; X_5: reactance measured at 5 Hz; A_X: area of reactance.

Fres – 12 Hz

Comparison between fixed values and z-scores



Z-scores performed better than fixed values
diagnosing respiratory diseases (area under the curve (AUC) 0.81 versus 0.77, p<0.01)
obstructive airway diseases (AUC 0.79 versus 0.75, p<0.01)

Liang et al ERJ Open Research 2023; 9(2): 00718-2022;

Reversibility testing

	Prebronchodilator	Postbronchodilator	Subjects With Significant BDR[a]
Spirometry			
FEV_1, L	2.04 ± 0.80	2.20 ± 0.83	13 (25%)[b]
FEV_1, % predicted	70 ± 19	75 ± 19	
FVC, L	3.01 ± 0.96	3.18 ± 0.98	6 (12%)[b]
FVC, % predicted	86 ± 17	89 ± 18	
FEV_1/FVC, %	66 ± 13	69 ± 13	
FOT			
R5, $cmH_2O \cdot s/L$	5.50 ± 1.80	4.89 ± 1.87	10 (19%)
R5, % predicted	164 ± 66	143 ± 62	
X5, $cmH_2O \cdot s/L$	−3.59 ± 2.79	−2.76 ± 2.15	21 (40%)
X5, % predicted	270 ± 182	203 ± 133	
AX, cmH_2O/L	35.67 ± 33.10	24.75 ± 26.24	27 (52%)
AX, % predicted	971 ± 978	665 ± 820	

- Spirometry vs FOT
- 52 asthma patients
- BDR – Spirometry – ≥200 ml and ≥12% FEV1 and/or FVC
- BDR – FOT - absolute change in R5 ≥ –1.40 cm H_2O.s/L, X5 ≥ 0.55 cmH_2O s/L, or AX ≥ –3.98 cmH2O/L
- 1 subject had BDR based on FVC alone
- BDR – more frequently by oscillometry (54%) vs 27% in spirometry
- 15 met BDR by elastance but not spirometry
- Only 2 met BDR by spirometry but no oscillometry
- Elastance more sensitive for poor asthma control than spirometry

Cottee et al 157#6 CHEST JUNE 2020

Reversibility testing

Multicentre, multidevice study among 368 adults

	R_4 $hPa \cdot s \cdot L^{-1}$	R_5 $hPa \cdot s \cdot L^{-1}$	R_6 $hPa \cdot s \cdot L^{-1}$	R_{10} $hPa \cdot s \cdot L^{-1}$	X_4 $hPa \cdot s \cdot L^{-1}$	X_5 $hPa \cdot s \cdot L^{-1}$	X_6 $hPa \cdot s \cdot L^{-1}$	AX_4 $hPa \cdot L^{-1}$	AX_5 $hPa \cdot L^{-1}$	FEV_1 L
Short-term repeatability										
CR absolute	1.03	0.94	0.90	0.83	0.67	0.49	0.48	5.30	4.79	0.22
CR relative %	18.4	17.4	16.8	17.0	33.6	36.7	69.5	55.3	71.5	6.8
Bronchodilator response										
Absolute change	-1.41	-1.37	-1.26	-1.21	0.67#	0.55#	0.46#	-4.43	-3.90	0.34
Relative change %	-32.8	-31.5	-31.6	-31.2	-33.8	-43.5	-67.8	-56.0	-65.4	10.7

LUNG FUNCTION | E. OOSTVEEN ET AL

Bronchodilator – Reversibility on IOS parameters

Table E3. Threshold values for bronchodilator response derived from healthy adults.

Study	n*	Drug (dose)	Cut-off
Houghton 2004 (salbutamol 800μg) [56]	12	Salbutamol (800 μg)	Rrs5: -16%, Xrs5: +27%
Houghton 2005 (ipratropium) [57]	12	Ipratropium (200 μg)	Rrs5: -23%, Xrs5: +19%
Oostveen 2013 [50]	368	Salbutamol (400 μg)	Rrs5: -32%, Xrs: +44%, AX: -65%

STILL EVOLVING

King GG et al, Eur Respir J 2020

Do all oscillometers have similar cut-offs?

Standardization of oscillometers

- Why is it necessary?
- Different devices provide different values
- Difference is higher with higher test loads
- One device cannot be compared with another device
- Each device must have its own cut-off value
- Need for standardization of devices

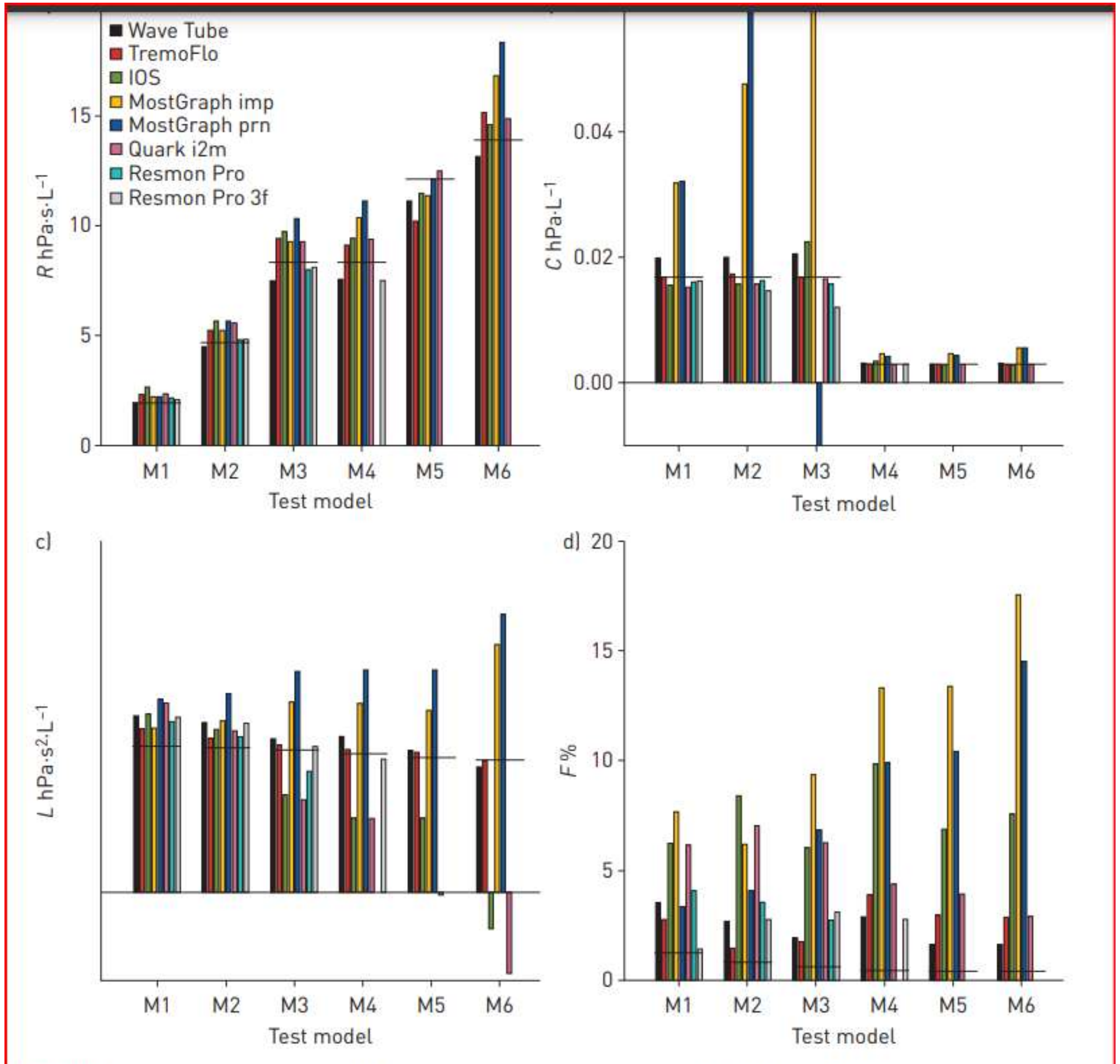


FIGURE 4 Values of a) resistance (R), b) compliance (C), c) inertance (L) and d) the fitting error (F) obtained from model fitting to impedance data measured in the mechanical test loads M1–M6, with the different devices and modes. Horizontal lines indicate values from fitting to calculated impedances. #: $C>0.06\ L\cdot hPa^{-1}$.

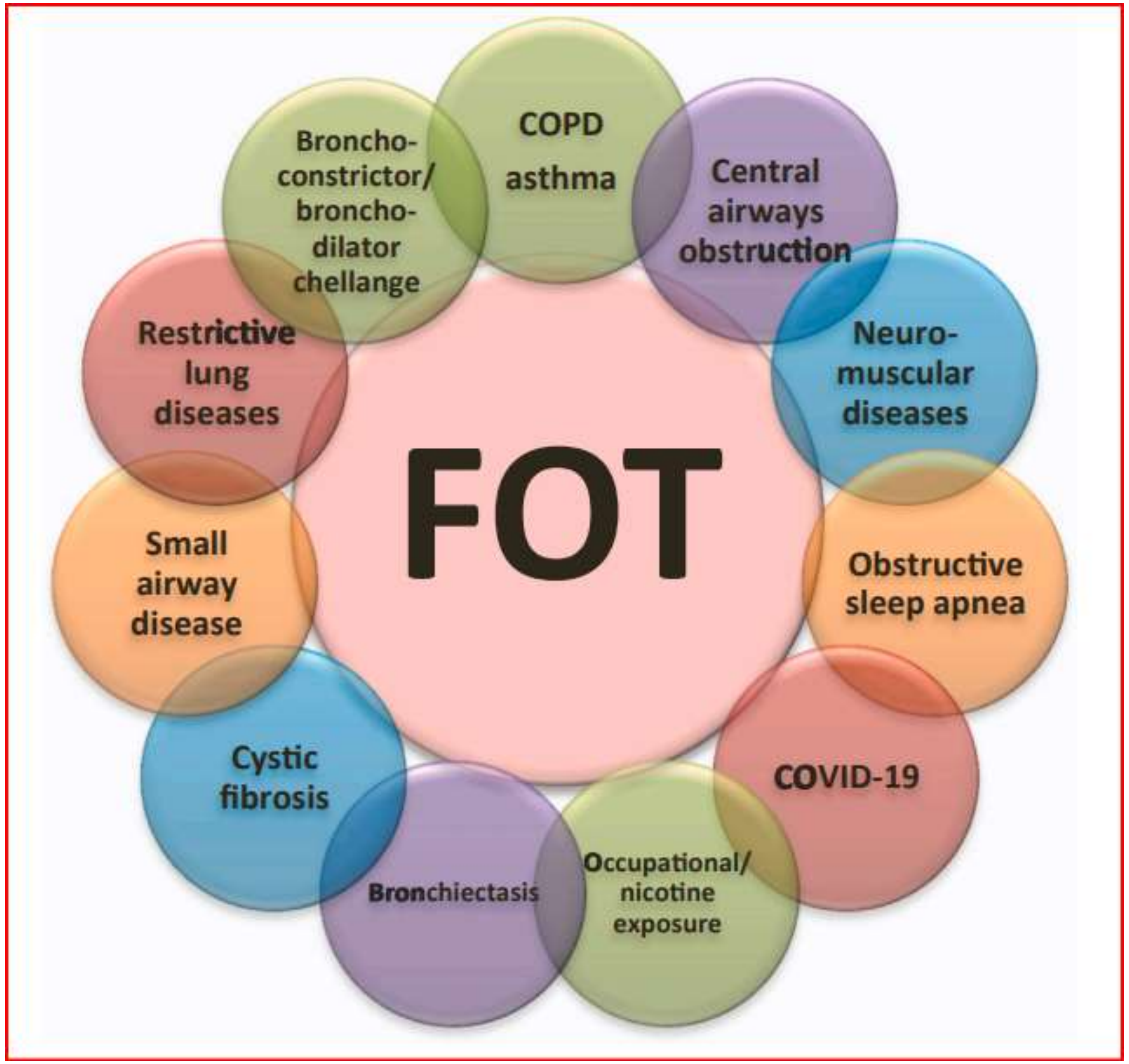
Ronald et al, ERJ Open Research 2019; 5(4): 00160-2019

Standardization of oscillometers

- By test loads - Dynamic test load that simulates patient breathing and a static load that includes elastic and inertive components
- Must cover most of the acceptable tolerance range
- It is recommended that test loads for adult testing be ∼15 $hPa \cdot s \cdot L^{-1}$ and for children ∼40 $hPa \cdot s \cdot L^{-1}$

King GG et al, Eur Respir J 2020

Uses



S. Kostorz-Nosal et al.Respiratory Physiology & Neurobiology 316 (2023) 104135

Small airway COPD phenotype

- Hyperinflation – increased TLC, increased residual volume and decreased FVC due to gas trapping
- Higher peripheral resistance (high R5-R20) and lower X5 and high Ax
- HRCT showing increased low attenuation areas

Respiratory system impedance with impulse oscillometry in healthy and COPD subjects: ECLIPSE baseline results

Courtney Crim [a], Bartolome Celli [b], Lisa D. Edwards [a], Emiel Wouters [c], Harvey O. Coxson [d], Ruth Tal-Singer [e], Peter M.A. Calverley [f,*], on behalf of the ECLIPSE investigators

Table 1 Baseline demogra

Age, years
Male gender No. (%)
BMI (kg/m^2)
Current smokers No. (%)
Pack-years
Lung function: FEV_1 (L)
FEV_1 (% predicted)
FEV_1/FVC (×100)
% reversibility
LAA% on CT

Table 2 Baseline IOS (impulse oscillometry) impedance parameters in ECLIPSE subjects.

	NSC[a] (n = 233)	CS (n = 322)	COPD (n = 2054)	GOLD 2 (n = 915)	GOLD 3 (n = 861)	GOLD 4 (n = 278)
R_5 (kPa/L/s)	0.33 (0.10)	0.31 (0.10)	0.49 (0.16)[b]	0.45 (0.14)	0.51 (0.16)[c]	0.55 (0.19)[d]
R_{20} (kPa/L/s)	0.26 (0.07)	0.25 (0.07)[e]	0.30 (0.08)[b]	0.29 (0.07)	0.31 (0.08)[c]	0.31 (0.09)[f]
$R_5 - R_{20}$ (kPa/L/s)	0.07 (0.05)	0.06 (0.05)	0.19 (0.10)[b]	0.15 (0.09)	0.20 (0.10)[c]	0.24 (0.12)[d]
X_5 (kPa/L/s)	−0.10 (0.06)	−0.09 (0.05)	−0.29 (0.17)[b]	−0.21 (0.13)	−0.32 (0.16)[c]	−0.44 (0.18)[d]
AX (Hz·kPa/L/s)	0.38 (0.40)	0.34 (0.35)	1.99 (1.46)[b]	1.37 (1.08)	2.25 (1.36)[c]	3.23 (1.79)[d]
F_{Res} (Hz)	12.4 (3.4)	12.1 (3.2)	20.7 (5.2)[b]	18.3 (4.3)	21.8 (4.7)[c]	25.3 (5.5)[d]

Data expressed as mean (SD) unless otherwise specified; Impedance parameters are post-bronchodilator. NSC = non-smoker controls; CS = control smokers; COPD = chronic ... disease; GOLD = Global Initiative for Chronic Obstructive Lung Disease; R_5 = respiratory resistance ... Hz; $R_5 - R_{20}$ = difference in respiratory resistance at 5 Hz and 20 Hz; X_5 ... nce; F_{Res} = resonant frequency.

[a] 11 (5%) of N...
[b] $p < 0.001$ ...
[c] $p \leq 0.001$ ...
[d] $p \leq 0.001$ c...
[e] $p = 0.041$ com...
[f] $p = 0.002$ compared ... for age and gender.

% difference GOLD 4 vs GOLD 2
Ax = 136%
R5 - R20 = 60%

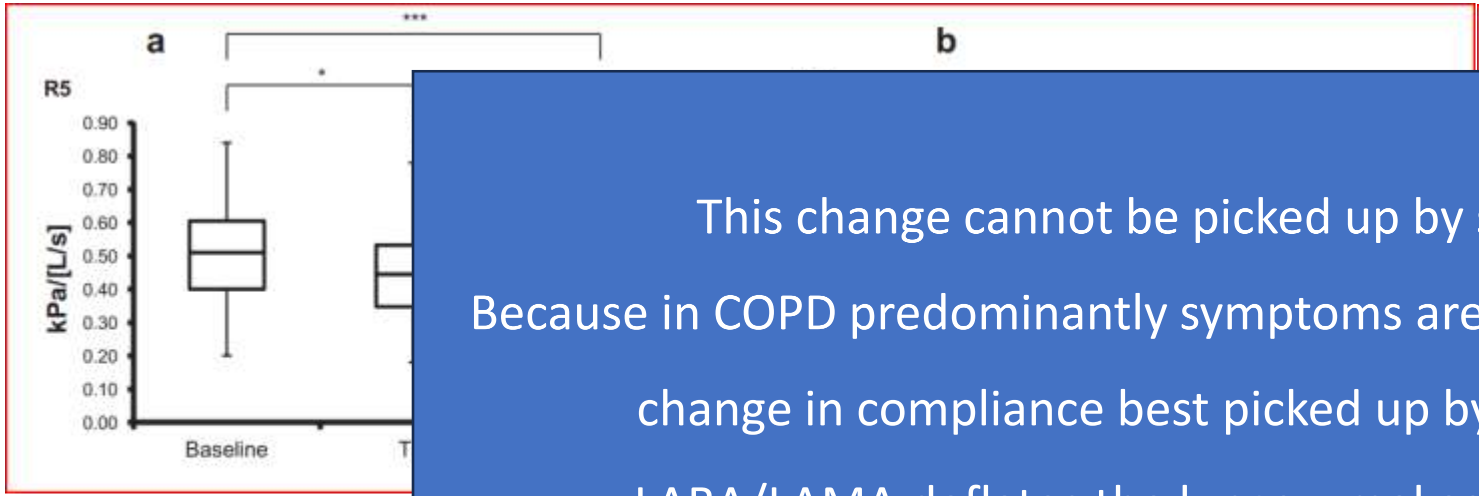
Intra breath ΔXrs

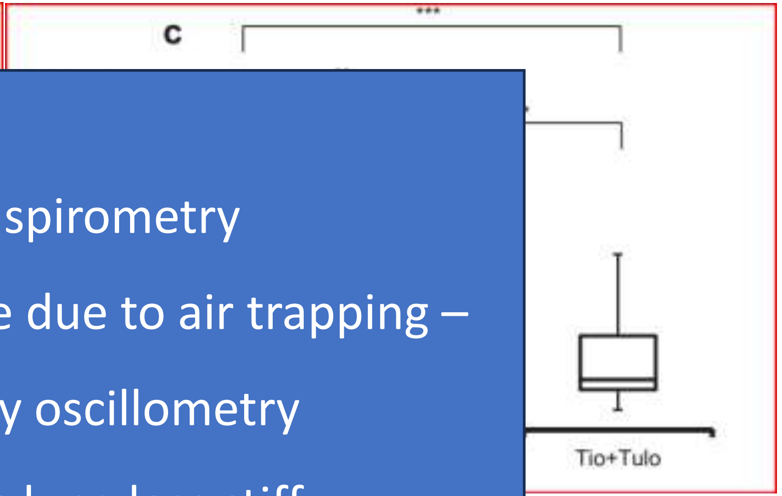
- Differences between inspiratory and expiratory phases of respiratory reactance - expiratory flow limitation (EFL) – a characteristic feature of patients with moderate-to-severe COPD
- High EFL index (>0.55 cmH2O/L/s) - independently predicts emphysema score, peripheral airway obstruction ($FEF_{25\%-75\%}$ of forced vital capacity), hyperinflation (functional residual capacity), and airway caliber (whole-breath Rrs at 5 Hz)

Dellaca et al European Respiratory Journal 2004; 23(2): 232-240

Mikamo et al. BMC Pulmonary Medicine 2014, 14:23

LAMA and LABA in COPD

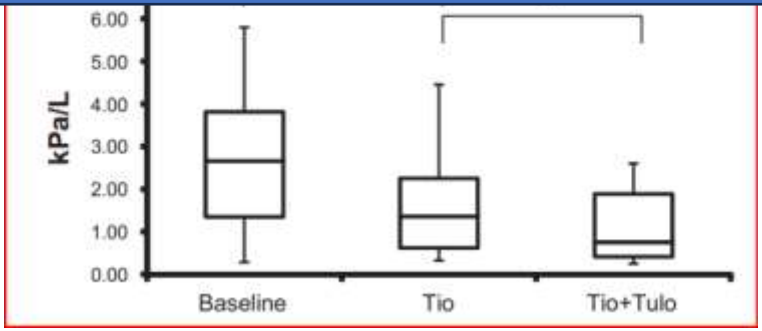




This change cannot be picked up by spirometry

Because in COPD predominantly symptoms are due to air trapping – change in compliance best picked up by oscillometry

LABA/LAMA deflates the lungs – makes lung less stiff



T. Abe et al. Pulmonary Pharmacology & Therapeutics 24 (2011) 617e624

Asthma

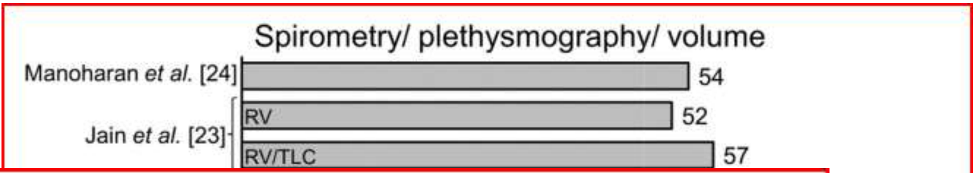


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Table 2
Comparisons of extra-fine particle solution formulation of inhaled corticosteroid (ICS) vs standard particle size (suspension CFC/HFA, or dry powder formulation) ICS outcomes at step 2

Anderson et al Ann Allergy Asthma Immunol 109 (2012) 185–189

Variable	Extra-fine ICS ($n = 67$)	Standard ICS ($n = 125$)	*P*-Value
ICS dose (μg/day)	279 (249, 309)	406 (364, 447)	**<.0001**
FEV_1 (% predicted)	88.9 (84.8, 92.9)	90.3 (87.5, 93.1)	.56
FEF_{25-75} (% predicted)	63.7 (57.5, 69.8)	67.1 (62.7, 71.5)	.38
R5[a] (% predicted)	124.1 (113.5, 135.8)	138.3 (130.0, 147.0)	**<.05**
R20[a] (% predicted)	126.0 (117.0, 135.8)	136.7 (130.0, 143.9)	.07
R5-R20[a] (kPa/L/s)	0.069 (0.05, 0.088)	0.088 (0.071, 0.105)	.18
F_{res}[a] (kPa/L/s)	13.9 (12.6, 15.2)	14.6 (13.6, 15.7)	.36
FeNO[a] (ppb)	31.4 (24.9, 39.5)	25.3 (21.9, 29.2)	.11

O.S. Usmani et al. / Respiratory Medicine 116 (2016) 19e27
Cottini et al JACI 2020;8:997-1004

Asthma

Prevalence and features of IOS-defined small airway disease across asthma severities

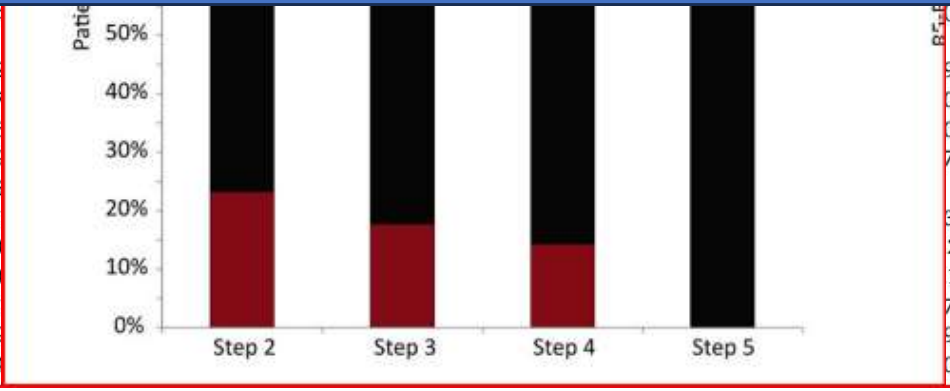
Marcello Cottini [a,**], Anita Licini [a], Carlo Lombardi [b], Alvise Berti [c,*]

Patient Characteristics	Total (n = 400)	GINA Classification Steps				p value[a]
		Step 2 (n = 84)	Step 3 (n = 212)	Step 4 (n = 90)	Step 5 (n = 14)	
Clinical features and treatment						

SAD asthma is associated with a higher risk of exacerbations (65.9% versus 25.0%)

cottini et al Respiratory Medicine 209 (2023) 107154 2023

FEF25-75 < 60%, n(%)	1[illegible]	[illegible]92.9)	<0.0001
Spirometry values, *mean (SD)*			
FEV1, *(% predicted)*	92	[illegible]9 (13.3)	<0.0001
FEV1/FVC ratio, (x100)	77	[illegible] (12.3)	<0.0001
FEV1/FVC ratio, *(% predicted)*	86	[illegible] (8.8)	<0.0001
FEF25-75, *(% predicted)*	69	[illegible]7 (12.3)	<0.0001
Impulse oscillometry values, kPa/l/s, median [25%			
R5-R20	0.	[illegible]3 [0.15, 0.30]	0.0007
X5	–	[illegible]23 [-0.34,	0.0002
	–	[illegible]12]	
Ax	1.	[illegible]7 [1.39, 4.25]	0.0002
F_{Res}	19	[illegible]94 [18.74,	0.0001
	24	[illegible]03]	



Respiratory Medicine 176 (2021) 106243

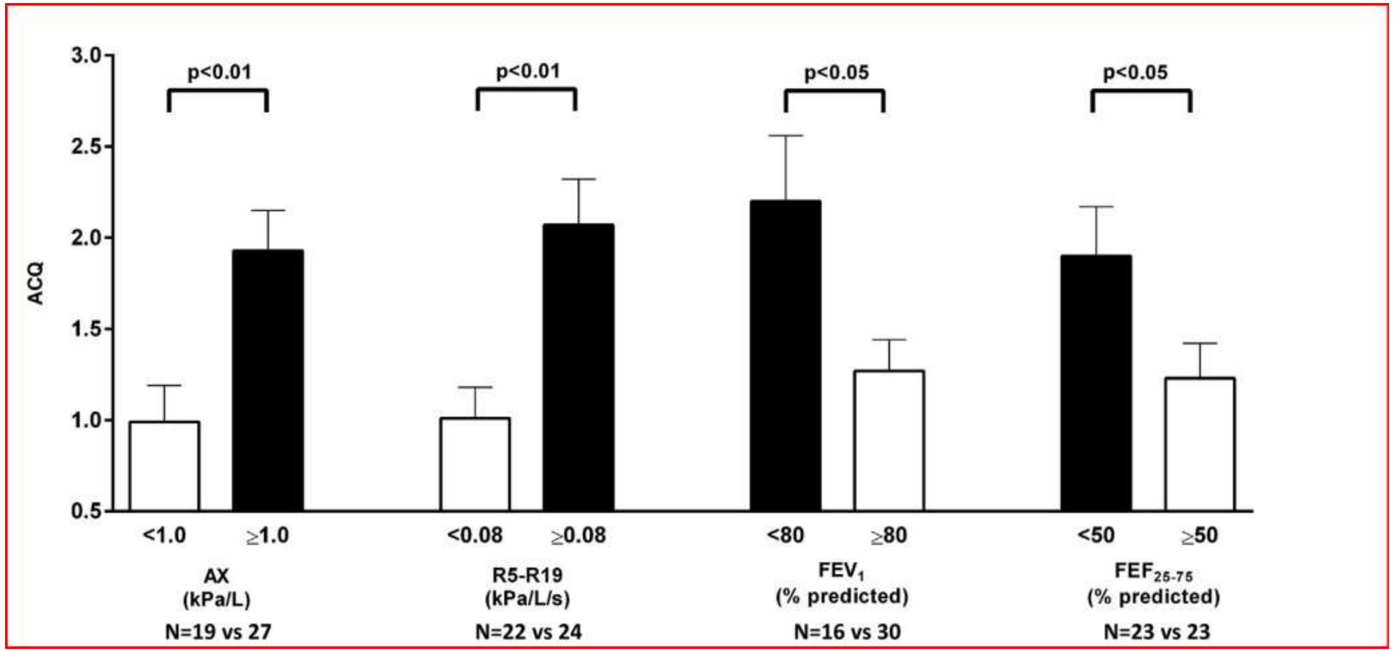
Small airway dysfunction among preserved FEV1

- 302 (68%) out of 442 asthmatics had a preserved FEV1 (>80% pred)
- In such patients 135 (45%) had abnormal R5-R20 indicating small airway dysfunction
- 157 patients (51.9%) had abnormal $FEF_{25\%-75\%}$

	Adjusted	
	OR (95% CI)	p-value
$FEF_{25-75\%}$ <70% (n=157) *versus* $FEF_{25-75\%}$ >70% (n=145)		
Oral steroid use	1.50 (0.91–2.48)	0.11
SABA use	1.91 (1.19–3.07)	0.007
FEV_1/FVC <0.80 (n=167) *versus* FEV_1/FVC >0.80 (n=135)		
Oral steroid use	1.85 (1.10–3.12)	0.02
SABA use	1.54 (0.95–2.51)	0.08
R_5-R_{20} >0.07 $kPa \cdot L^{-1} \cdot s$ (n=135) *versus* R_5-R_{20} <0.07 $kPa \cdot L^{-1} \cdot s$ (n=167)		
Oral steroid use	1.80 (1.09–2.98)	0.02
SABA use	1.87 (1.15–3.01)	0.01
$FEF_{25-75\%}$ <70% and R_5-R_{20} >0.07 $kPa \cdot L^{-1} \cdot s$ (n=83) *versus* $FEF_{25-75\%}$ >70% and R_5-R_{20} <0.07 $kPa \cdot L^{-1} \cdot s$ (n=93)		
Oral steroid use	2.34 (1.20–4.58)	0.01
SABA use	3.16 (1.64–6.07)	0.001

Patient outcomes – asthma control

- In a study with n=46, mean FEV1 = 87%, ICS 620 mcg (mild - moderate)



Asthma

- In pre-school children where spirometry is difficult to perform for diagnosis and follow-up
- BDR
- Changes in FOT precede spirometry changes predominantly in milder forms of asthma (SAD)

  (Abdo et al 2023)
- Useful in home based monitoring (Wang et al AJRCCM 2019)

Reversibility in asthma and COPD

% reversibility to salbutamol 400 mcg:

- In a study of 84 patients (asthma – 59 and COPD – 25), reversibility using FEV1 was found to be asthma (8.14%) and COPD (8.40%), while for AX the degree of reversibility was more pronounced in asthma than COPD with AOS: 40% versus 24% (p=0.05)

Kuo et al Lung (2019) 197:473–481

Characteristics of inspiratory and expiratory reactance in interstitial lung disease

A. Sugiyama, N. Hattori*, Y. Haruta, I. Nakamura,
M. Nakagawa, S. Miyamoto, Y. Onari, H. Iwamoto,
N. Ishikawa, K. Fujitaka, H. Murai, N. Kohno

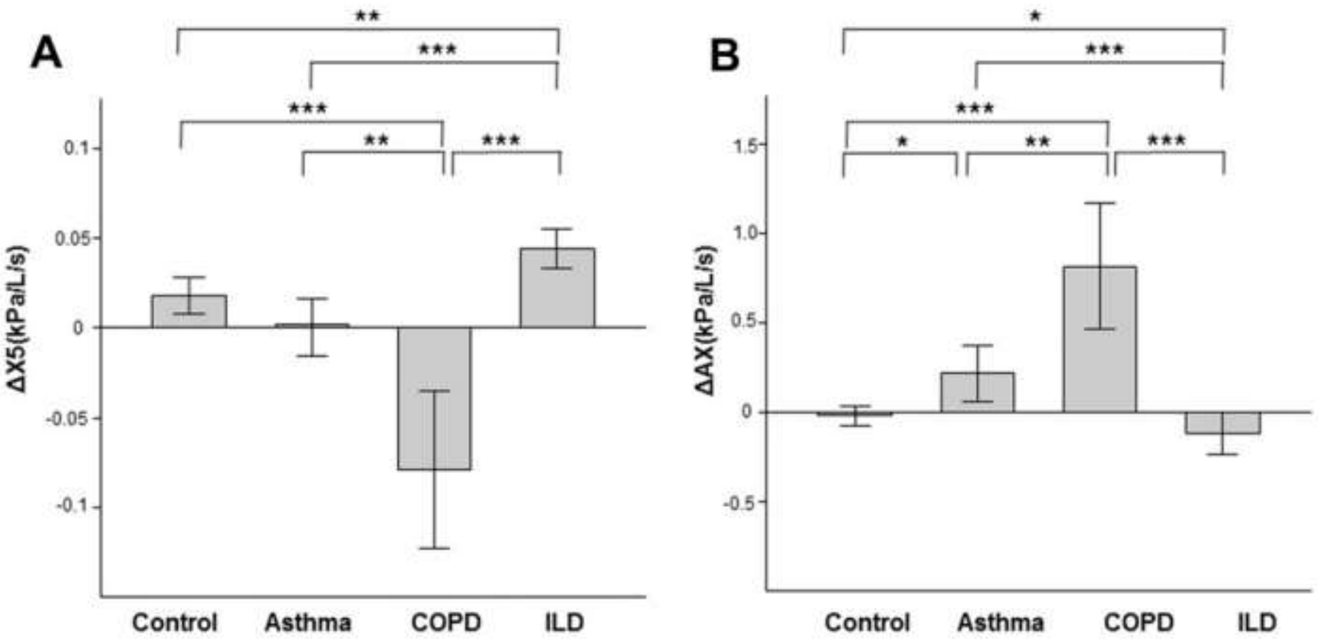


Figure 2 Comparison of the mean values for ΔX5 (expiratory—inspiratory values of the reactance at 5 Hz) (A) and ΔAX (expiratory—inspiratory values of the reactance area) (B) in the control group (n = 29), patients with asthma (n = 54), patients with chronic obstructive pulmonary disease (COPD) (n = 49), and patients with interstitial lung disease (ILD) (n = 64). Error bars indicate standard errors of the mean. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.0001$.

Restrictive lung diseases

Correlation of respiratory oscillometry with CT image analysis in a prospective cohort of idiopathic pulmonary fibrosis

Table 3 Patient demographics and oscillometry parameters according to the GAP score

	GAP I (n=48)	Gap II (n=21)	Gap III (n=5)	P value
Sex (M/F)	31/17	15/6	5/0	0.26
Age (yrs)	71.2±8.8	70.5±4.9	70.7±8.4	0.94
BMI (kg/m^2)	27.2±4.0	27.7±3.6	21.2±3.9	**0.004**
Smoking status				
Never smoked	17	6	2	**<0.001***
Ex-smoker <20 pk years	19	5	2	**<0.001***
Ex-smoker ≥20 pk years	12	10	1	**<0.001***
6MW distance (% predicted)	111±17$^{\alpha}$	98±25$^{\beta}$	86±20	**0.005**
R5 (cm H_2O s/L)	3.8±1.2	3.8±1.3	2.7±0.7	0.15
R5-19 (cm H_2O s/L)	0.8±0.7	0.7±0.6	0.8±0.5	0.76
X5 (cm H_2O s/L)	−2.1±1.1	−2.2±0.7	−2.2±0.3	0.93
X5in (cm H_2O s/L)	−2.1±1.0	−2.3±0.8	−2.5±0.5	0.67
X5ex (cm H_2O s/L)	−2.1±1.3	−2.1±0.9	−2.0±0.3	0.98
ΔX5 (cm H_2O s/L)	−0.0±0.9	−0.2±0.7	−0.5±0.5	0.48
AX (cm H_2O/L)	14.6±10.8	15.0±7.8	14.9±4.6	0.99
Fres (Hz)	20.1±4.6	20.9±3.5	21.3±3.1	0.68
ReE-ReI (cm H_2O s/L)	0.8±0.6	1.0±0.7	0.4±0.2	0.20
XeE (cm H_2O s/L)	−0.4±0.8	−0.4±0.6	−0.5±0.4	0.89
XeI (cm H_2O s/L)	−0.6±0.4	−0.8±0.5	−1.1±0.4	**0.004**
XeE-XeI (cm H_2O s/L)	0.2±0.7	0.4±0.6	0.6±0.6	0.24

Figure 1 Example
intrabreath oscillom
and open circles, re
XeE and XeI, respec
of inspiration and d

OTHERS

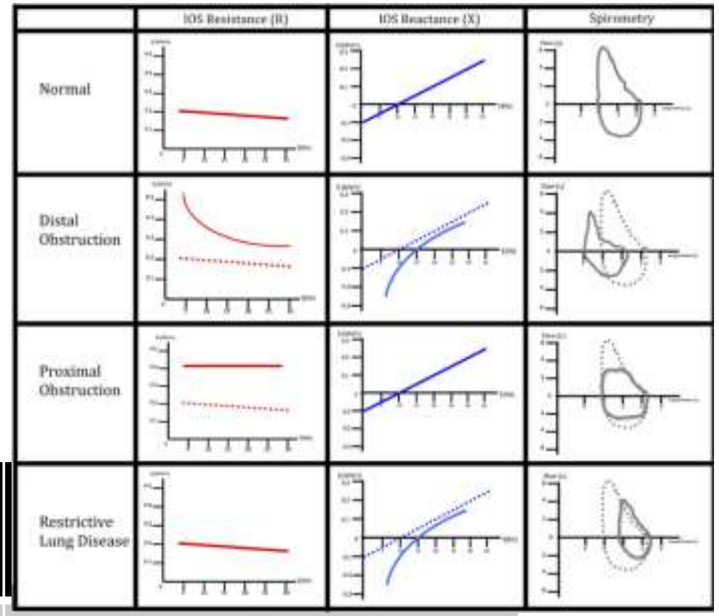
- Fujii et al (n=93) CPI best correlates with Fres in patients with restrictive lung diseases
- In post-lung transplant patients – differentiate between BOS and RAS (Verleden et al JTD 2017 Aug;9(8):2650-2659)
- In immediate post-transplant patients where spirometry is difficult to perform
- OSA – Central airway resistance (correlates with AHI index) (Ravi Dosi et al, IJSM 13-25)
- OHS – Severity based on compliance
- Cannot be used for pre-op because does not give lung volumes

Summary - Asthma vs COPD

- SAD vs Large airway
- Large airway predominantly
- Resistance at all frequencies increase – R5, R20 and R5 and R20 difference mild
- BDR reversible and R20 more decreased
- Ax and R5-R20 closely relate to asthma control and T2 inflammation

- Small airway predominant
- R20 – normal and R5 increase and R5 – R20 increase
- Reactance shifts more compared to resistance
- Partial reversible
- Ax is more sensitive than R5 in COPD

Interpretation of IOS Parameters



R5	R20	R5-20	X5	AX	Fres	
↑↑	↑↑	N	N	N	N	Central airway obstruction
↑↑↑	N	↑↑	More Negative	↑↑	↑↑	Peripheral Airway obstruction
↑↑↑	↑↑	↑	More Negative	↑↑	↑↑	Total Airway obstruction
N	N	N	More Negative	↑↑	↑↑	Restrictive lung disease

THANK YOU