Annual Scientific Meetings 2003

Oscillometry

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Oscillometry consumes

15 – 30s

of Time for Tidal Breathing Recording

Why Oscillometry ?

Conventional Function Diagnostics seems to be
sensitive, objective, differentiated
and reproducible.

Prerequisites for use:

- ⇨ additional, relevant information
- ⇨ additional patient groups can be measured
- ⇨ easy operation and control (co-operation, instruction)

- ⇨ quick, low costs, reimbursement
- ⇨ combination with standard methods

Oscillometry - a Fashion?

1956
Du Bois

Musers
Goldman

1970
Smidt
Korn
Landser

1985
Van de
Woestijne

Zwaart
2000

Monofrequent

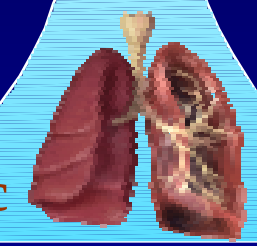
Multifrequent

Parameter Interpretation

Z, φ

Zrs

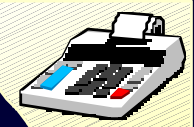
R5, X5



experimental
laboratory

routine !

Analytics
(FFT)



10 min

2 min

15 sec

0.001 sec

International Standards

Advantages of Oscillometry

Oscillometry complements conventional Function Diagnostics (Spirometry, Body Plethysmography, Occlusion, Diffusion, Compliance)

Oscillometry with proven Forced (Slow) Spirometry Application

Determination of

- static (VC, ERV, ...)
- dynamic (FEV1, FVC, FEF 50, ...)

Flow-Volume-Parameters

International Recommendations - Technology -

Apparatus - terminat. Res. < 0.1 kPa/l/s, test signal > 0.2 kPa, max. pressure <0.5 kPa, cmrr > 60 dB, CO2 < 0.5 %

Input Signal - [0.1 - 0.3 kPa], sine waves, random noise, pseudorandom noise/impulse

Frequencies - 2 - 48 Hz (0.01 Hz – 48 Hz)

Acceptance - coherence

Calibration - accuracy 10%, R-range 0 - 1 kPa/l/s, X-range -1 - 1 kPa/l/s reference impedance

Data Processing - time > FFT > frequency domain, 16 s min. measurement, Nyquist, analogue filters

International Recommendations - Clinical Standards -

- Recommendations for the measurement
  - → Patient well balanced and stress free
  - → Patient is sitting in upright position
  - → Head in neutral position or slight extension
  - → Nose clipped
  - → Cheeks supported with hands
  - → Lips firmly closed around mouthpiece

- Assessment of Quality
  - → Regularity of time trend and volume
  - → Z5-volume-graph without artifacts
  - → R5 and X5 in expected relation to prediction
  - → Coherence above 0.7

World-wide use of Oscillometry

1995 - 50 multifrequent oscillometric units in use
2003 - 1,500 devices in clinical practise
(majority IOS)

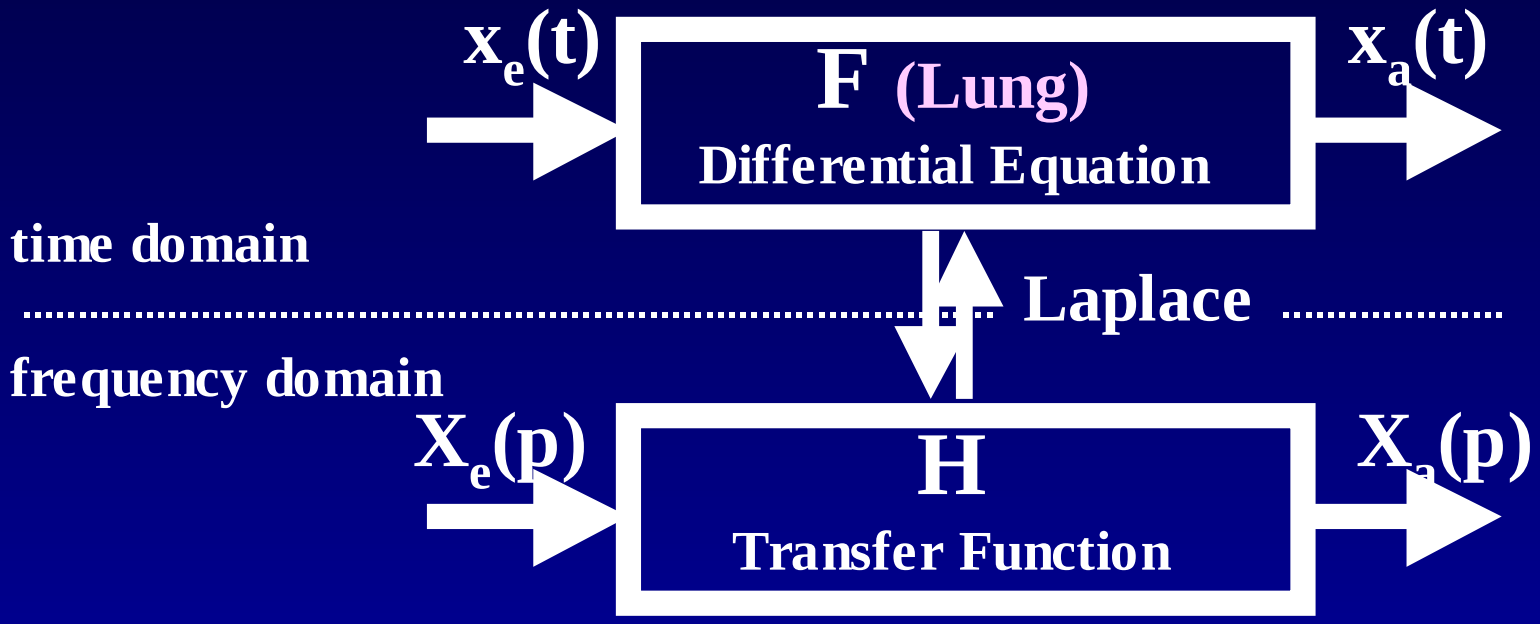
- ⇨ Scandinavia (Finland) 100 - standard resistance measurement
- ⇨ Germany / Austria 550 - already in clinical routine (paediatric, occupational m.)
- ⇨ Netherlands 100 - clinical routine
- ⇨ China 200 - validated method
- ⇨ USA 220 - clinical trials
- ⇨ Asia, South America, Canada 150
- ⇨ France 150 - paediatric medicine
- ⇨ UK 30 - paediatric medicine

General Aspects in the Determination of Breathing Mechanics

Advantages of Resistance Measurements

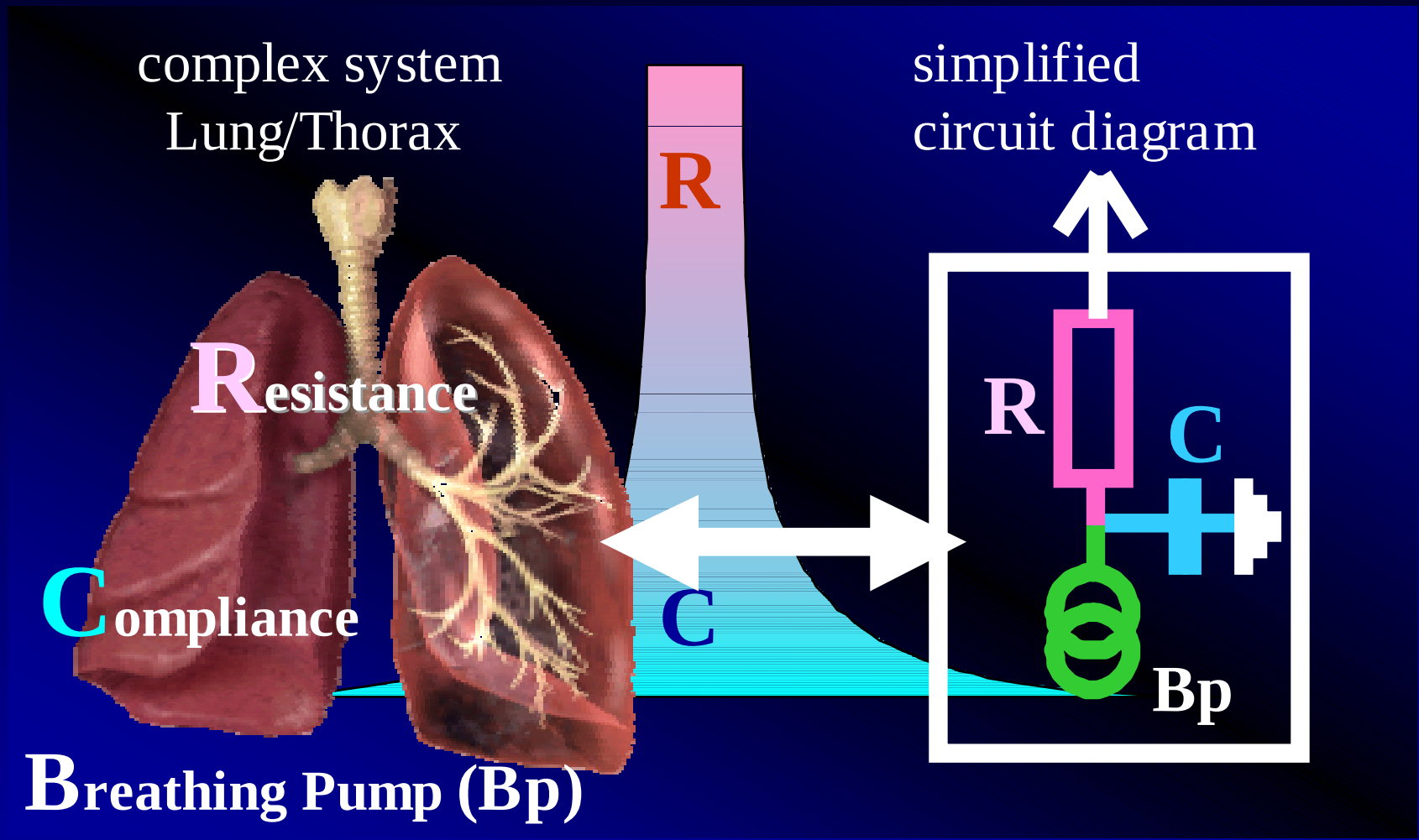
System Analysis (1)

The Transfer Function of a linear, time invariant system F is defined by the ratio of the output signal $x_a(t)$ to the input signal $x_e(t)$ and can be described by a linear differential equation.



System Analysis (2)

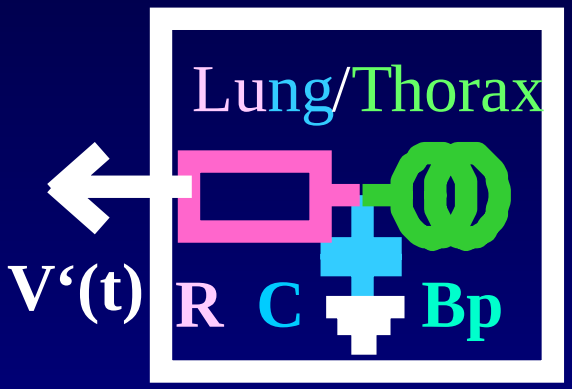
Target : Objectivization and Differentiation of the Lung/Thorax-System



Spirometric Methodology (1)

The pneumotachograph (Lilly) simply records V‘(t).

V(t) is without additional information!



$$V = \int V' dt$$

The determination of the respiratory tract based on only V‘(t) must be non-specific!

Spirometric Methodology (2)

Non-specific character of flow limitation

- Only little chance in the differentiation of functional or fixed stenoses in extra thoracic airways (in 98% of all existing cases not possible)

- Forced manoeuvre is different from spontaneous breathing (in 35% of all patients)

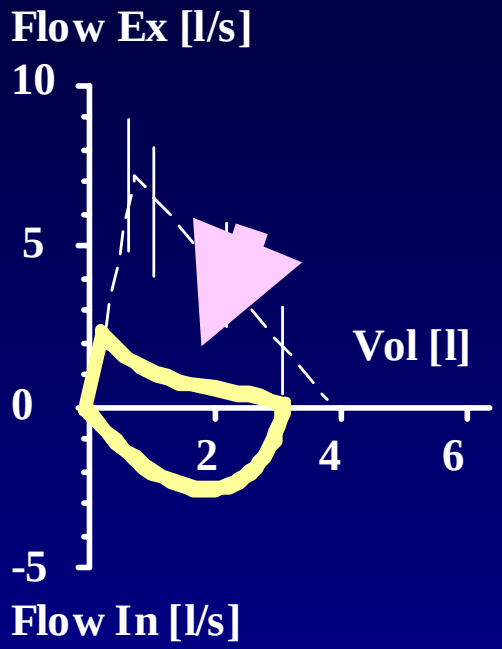
- Lung periphery is shadowed by central airways (especially in children)

Consequence

Over interpretation and possible wrong interpretation, even with highest quality of calibration, co-operation and instruction!

Forced Spirometry

Forced manoeuvre is non-physiological
Requires maximal effort (children?, elderly?, severe sick patients?)
Deep inspiration with broncho protective or dilating effect



Flow Limitation is non-specific and caused by

pulmonary components

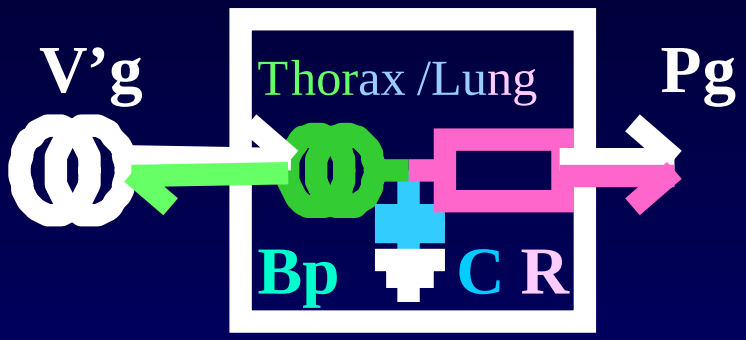
- ❑ unstable airways (collapse)
- ❑ proximal (central) obstruction
- ❑ distal (peripheral) obstruction
- ❑ loss of compliance of lung & thorax
- ❑ changes in lung volume

as well as undesirable factors

- ❑ functional or fixed stenoses
- ❑ breathing pump abnormality
- ❑ pain
- ! low co-operation

Oscillometric Methodology

objective: Impedance $\underline{Z}$ = transfer function of the lung



specific & differentiated:

$$\underline{Z} = \underline{Pg}/\underline{V'g}$$

- stenosis
- unstable bronchial system
- proximal obstruction
- distal obstruction
- lung capacity
- thorax

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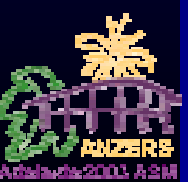
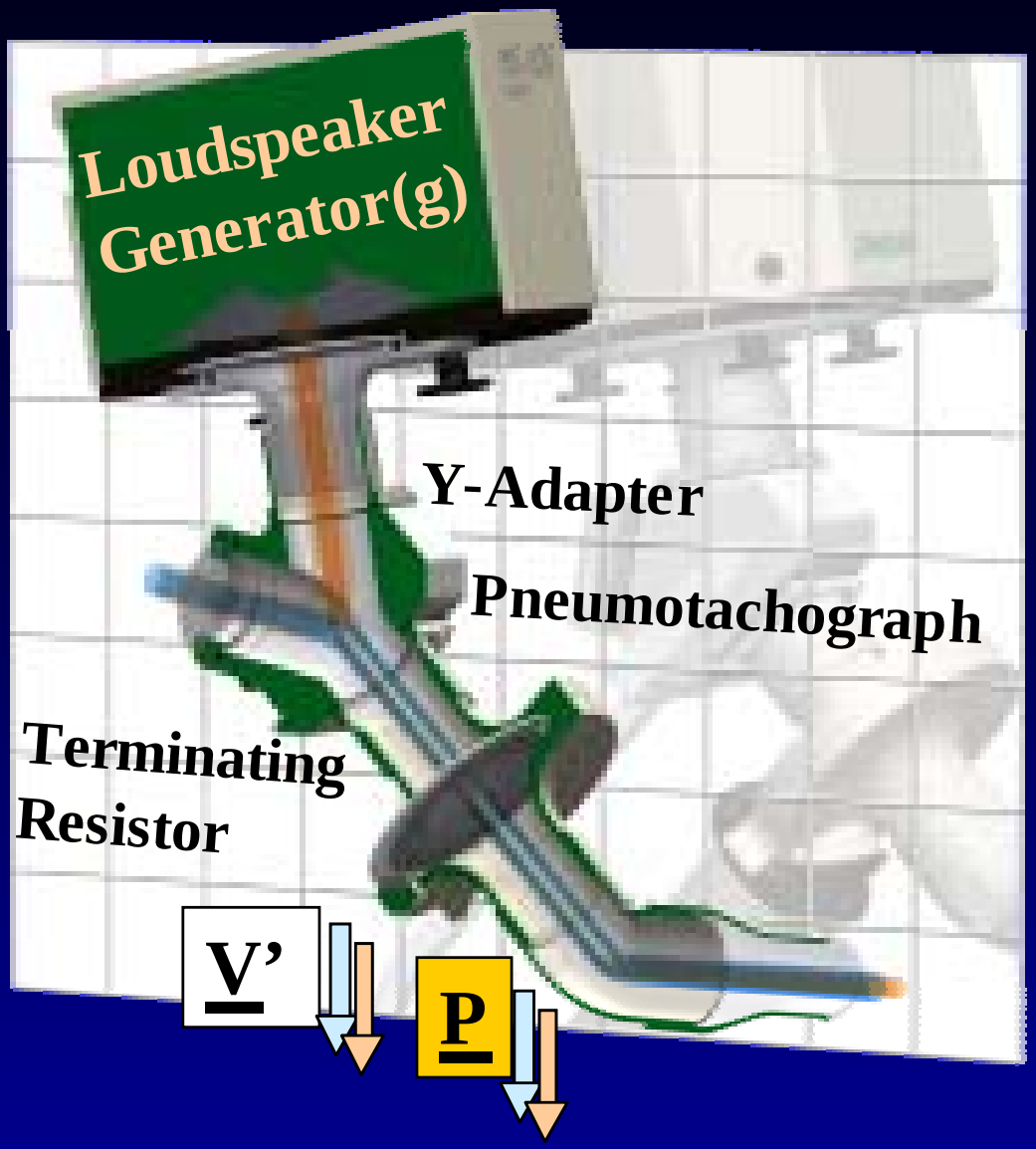
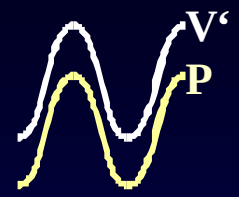
Methodology and Technology of Oscillometry

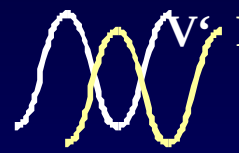


Head of Impulse Oscillometry



R 

- central resistance

X 

- peripheral resistance
  elastance
- inertance

Input Impedance

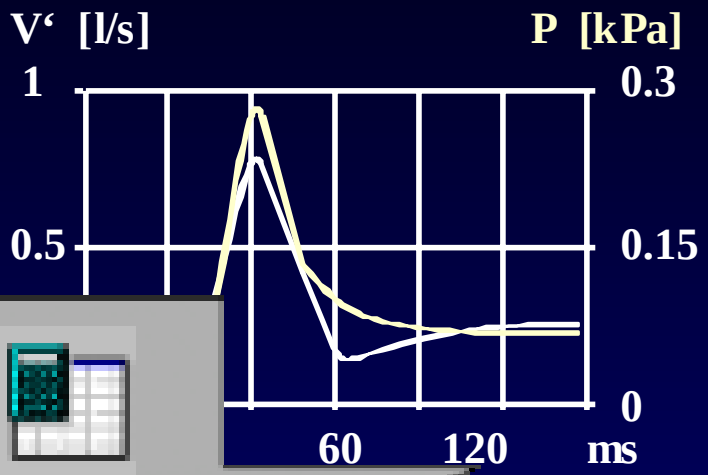
$\underline{Zrs} = \underline{Pg}/\underline{V'g} = R + jX$

respiratory and artificial signals superimposed

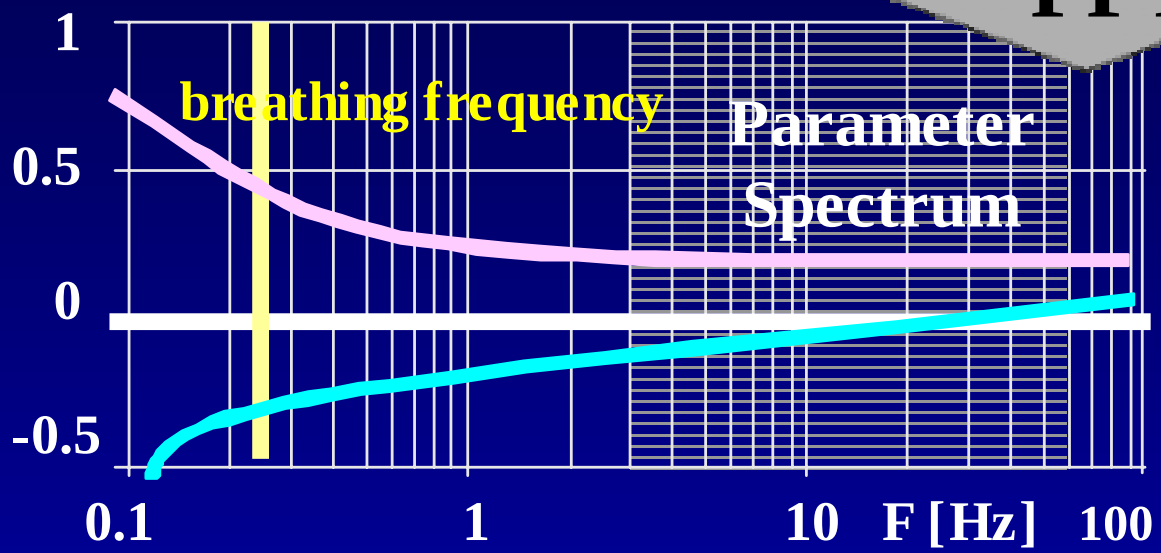
Impulse - Test Signal

Advantages of Test Signals

- reproducibility
- frequency range
- physical properties
- low co-operation

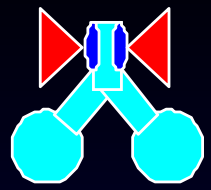


FFT

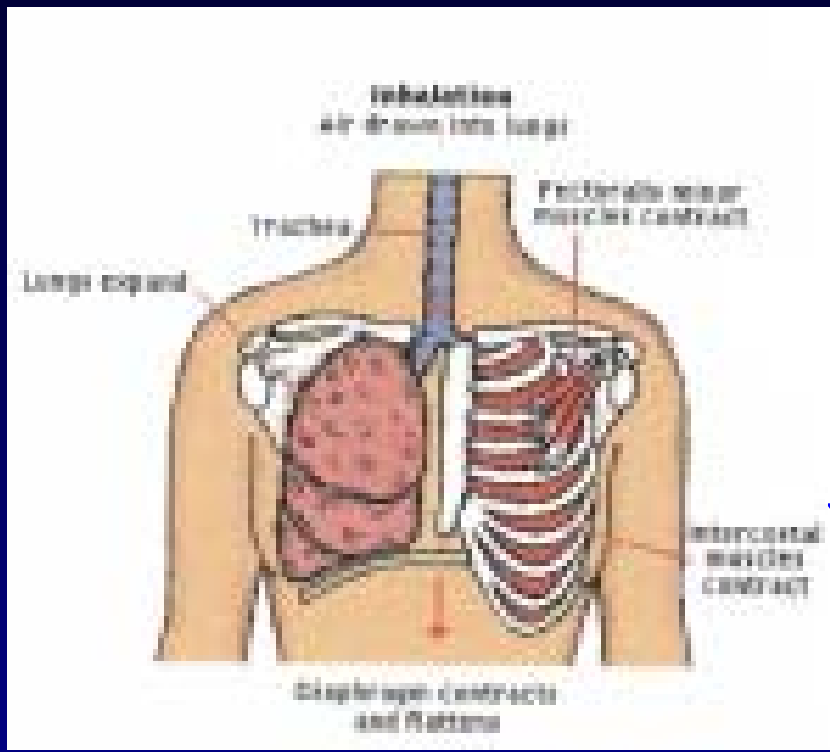


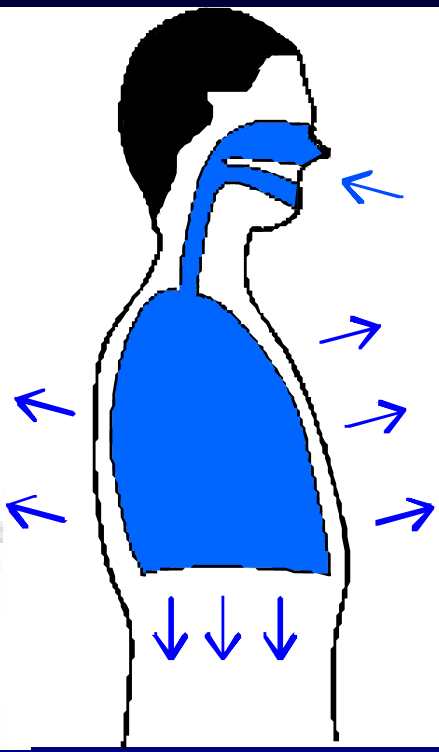
$$\left.\frac{\underline{P}}{\underline{V'}}\right|_{F=\omega} = R + jX$$

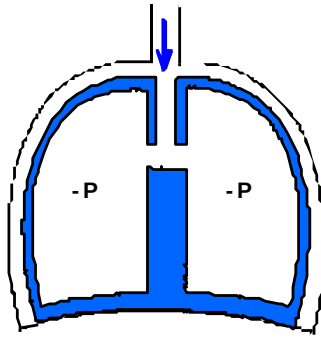
$0 < F < 100$ Hz



Inspiration

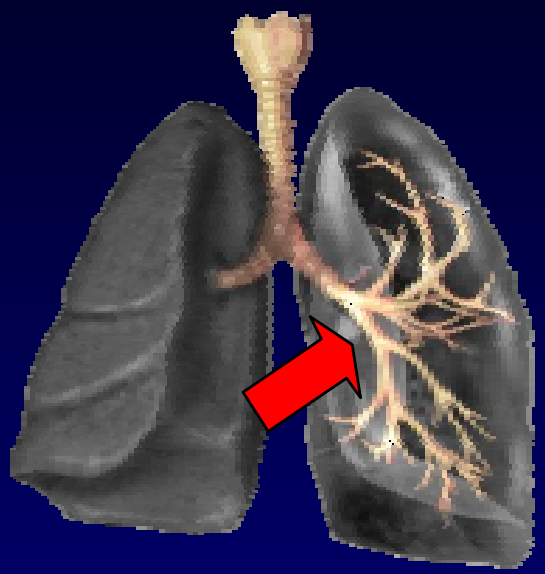


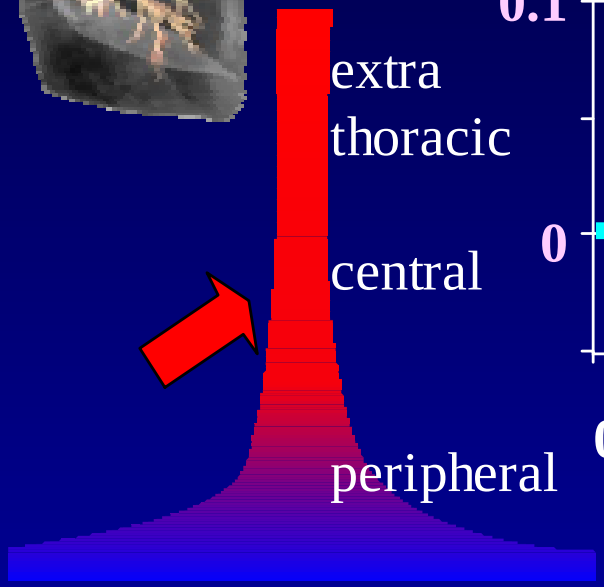




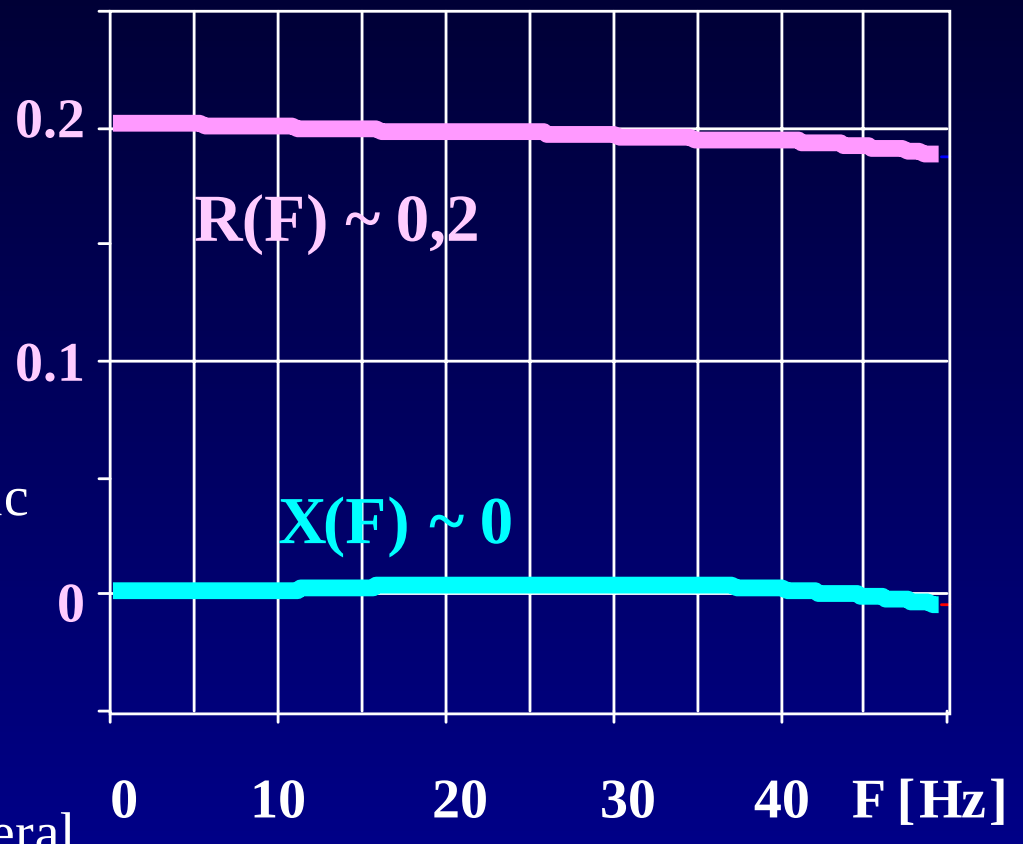
active !

Resistance Model (R)

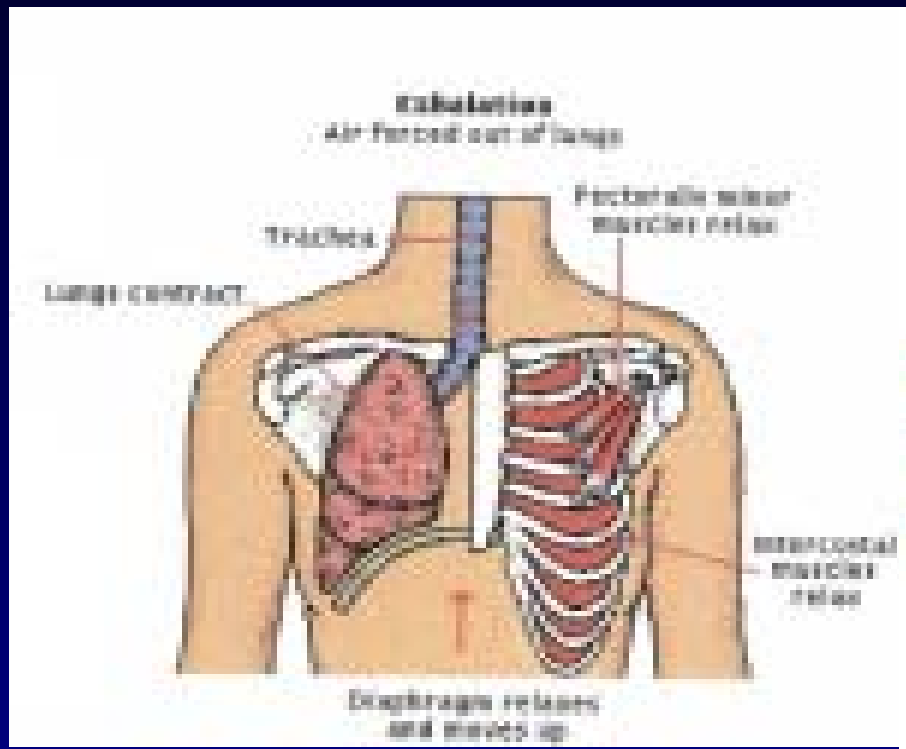


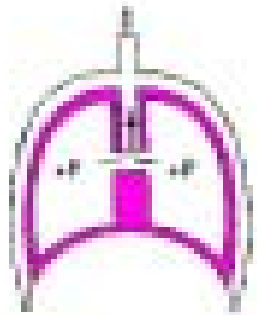


Weibels
trumpet
model



Expiration

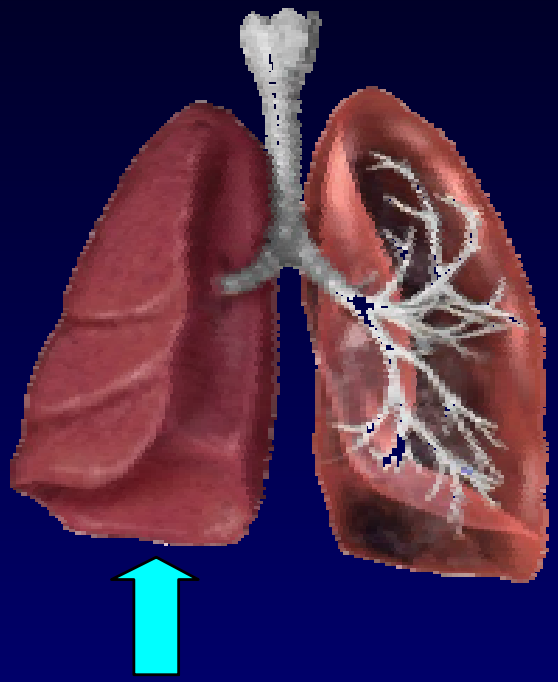


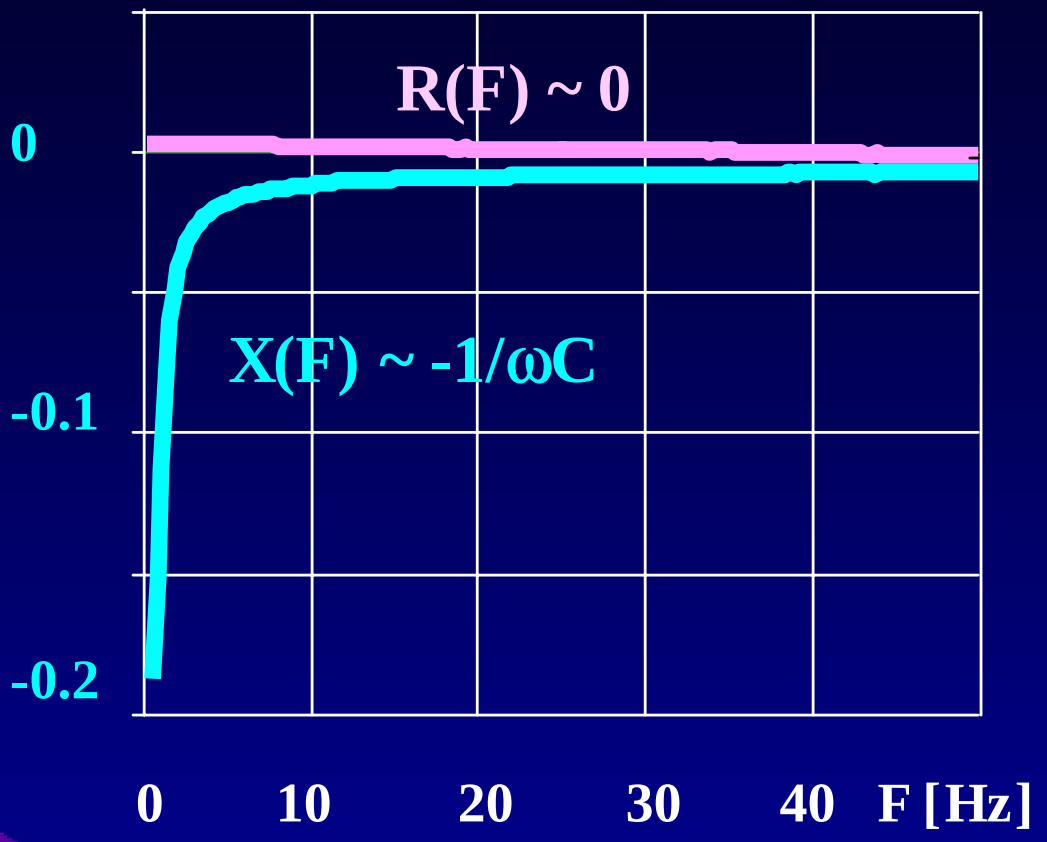


passive !

Capacitance Model (Xc)

Negative Part of Reactance



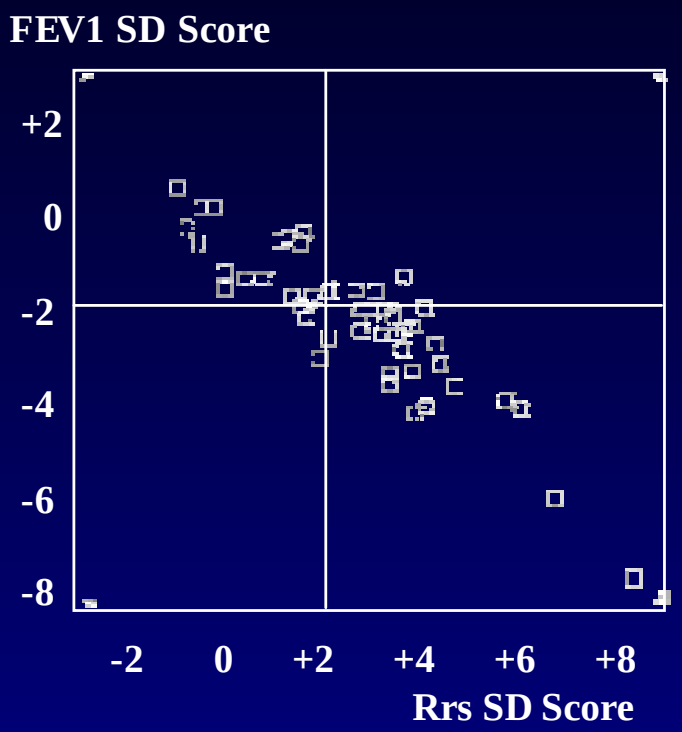


Weibels trumpet model

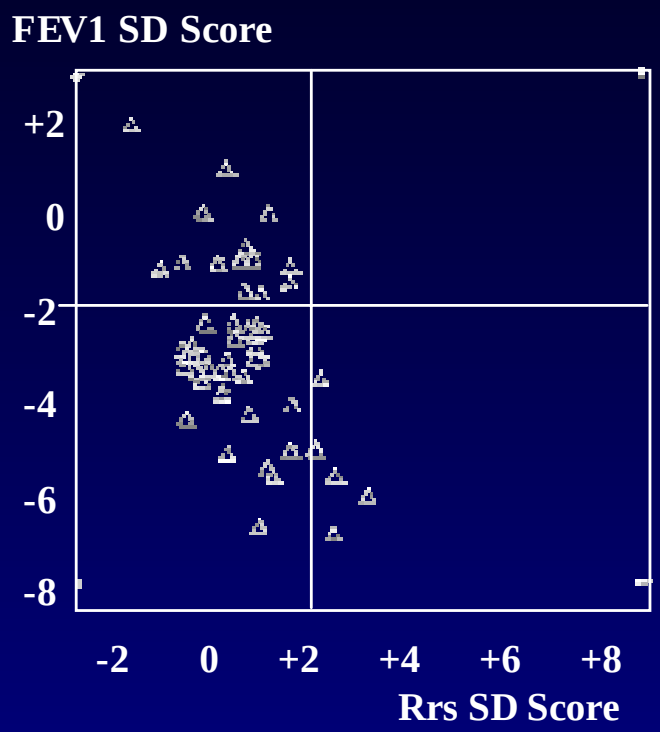
tissue/thorax elastance
peripheral obstruction

Clinical Relevance of Reactance

Asthma (45)



Cystic Fibrosis (45)



Diagnostics of peripheral airways

using

Oscillometry

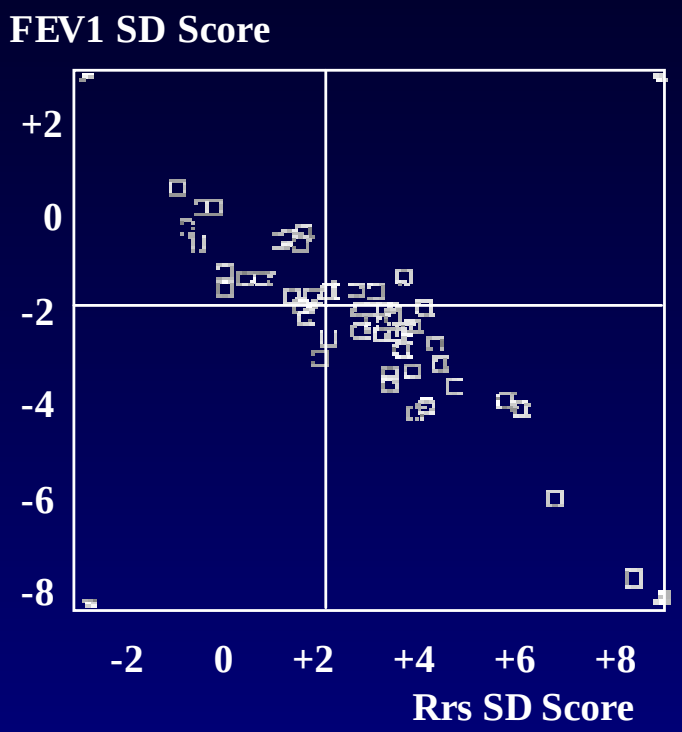
?

No correlation !!

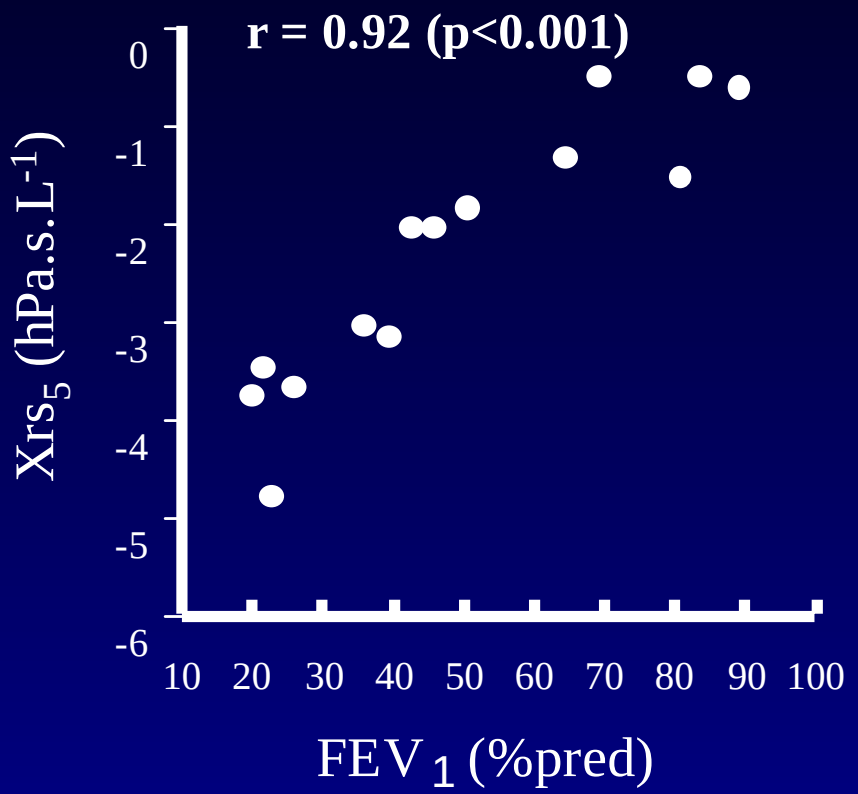
P. Lebecque, D. Stanescu, „Respiratory resistance by oscillation technique in asthmatic children and cystic fibrosis patients“, Eur. Respir. J. 1997, 10, 891-895

Clinical Relevance of Reactance

Asthma (45)



Cystic Fibrosis (45)

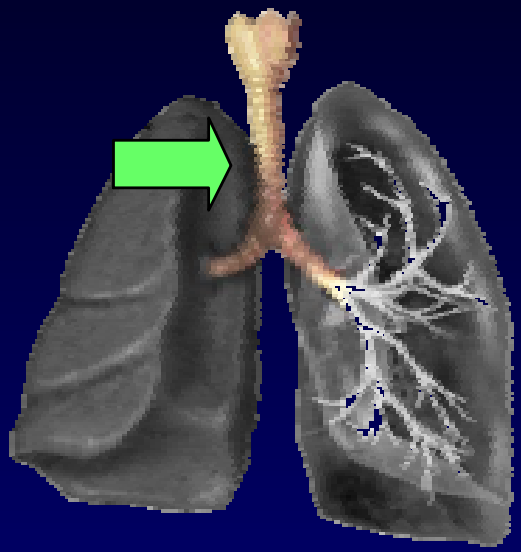


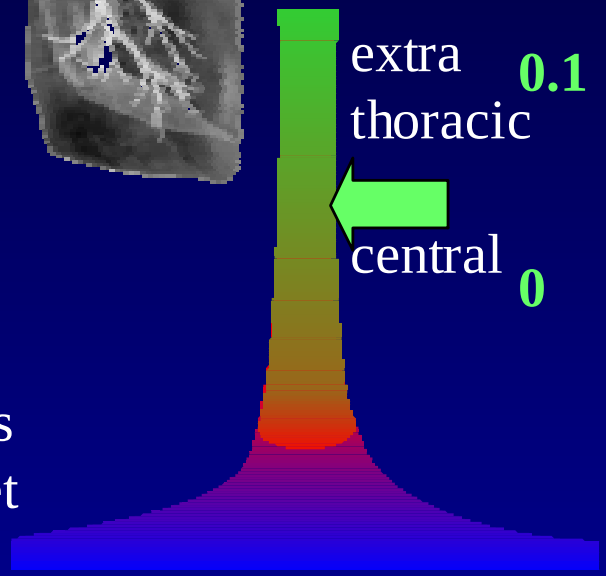
P. Lebecque, D. Stanescu, „Respiratory resistance by oscillation technique in asthmatic children and cystic fibrosis patients“, Eur. Respir. J. 1997, 10, 891-895

A. Van Muylem, C. Knoop, D. Baran „Use of forced oscillation technique in cystic fibrosis exacerbation“, ERS poster presentation , Florence 2000

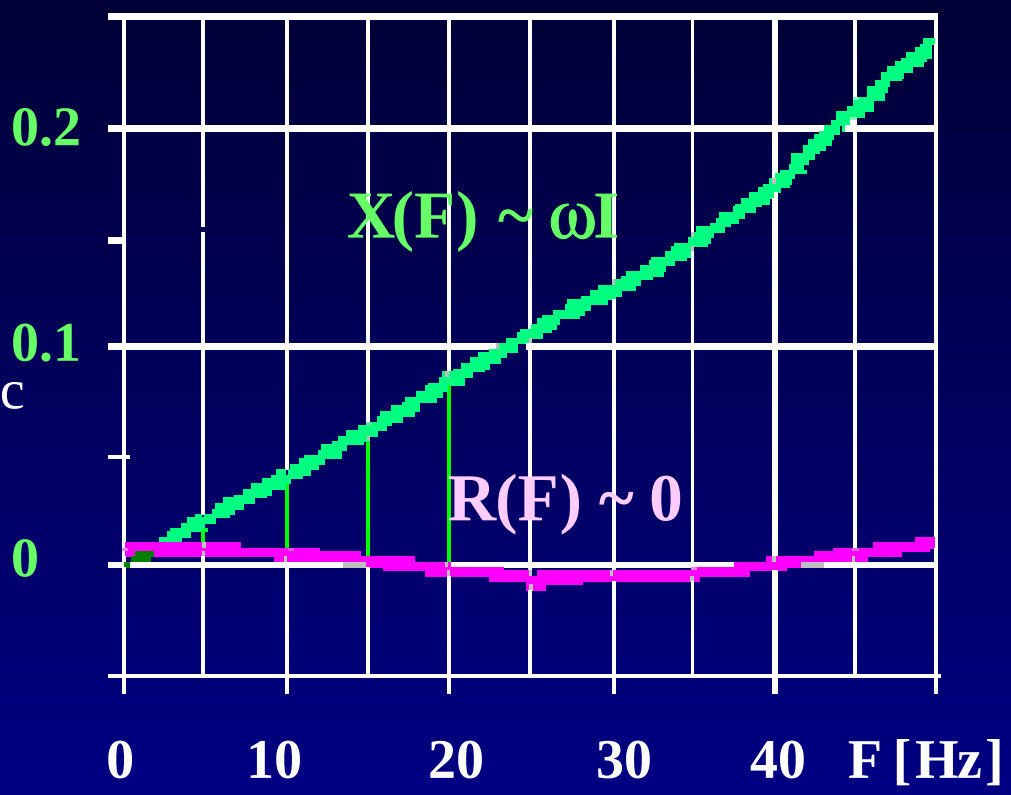
Inertance Model (X_I)

Positive Part of Reactance





Weibels
Trumpet
Model

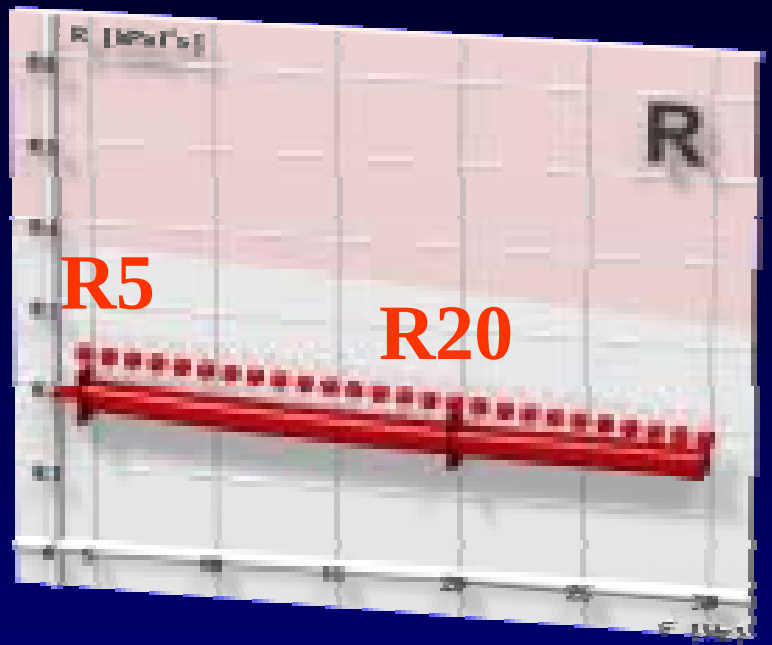


Limited clinical relevance because of R !

Important Parameters

Resistance R(F)

-Energy Consumption-



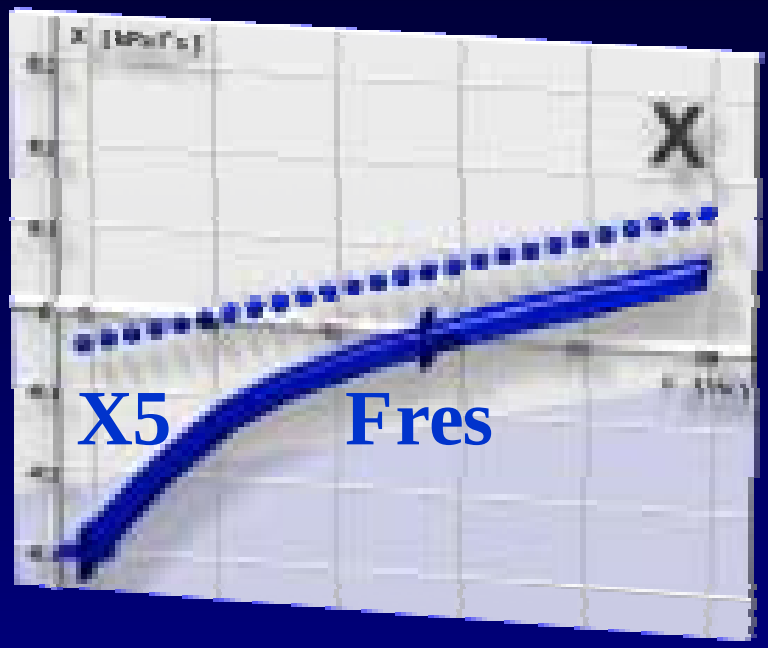
R5 Total Resistance
R20 Proximal Resistance

Z = R + jX Impedance

-Complex Respiratory Resistance-

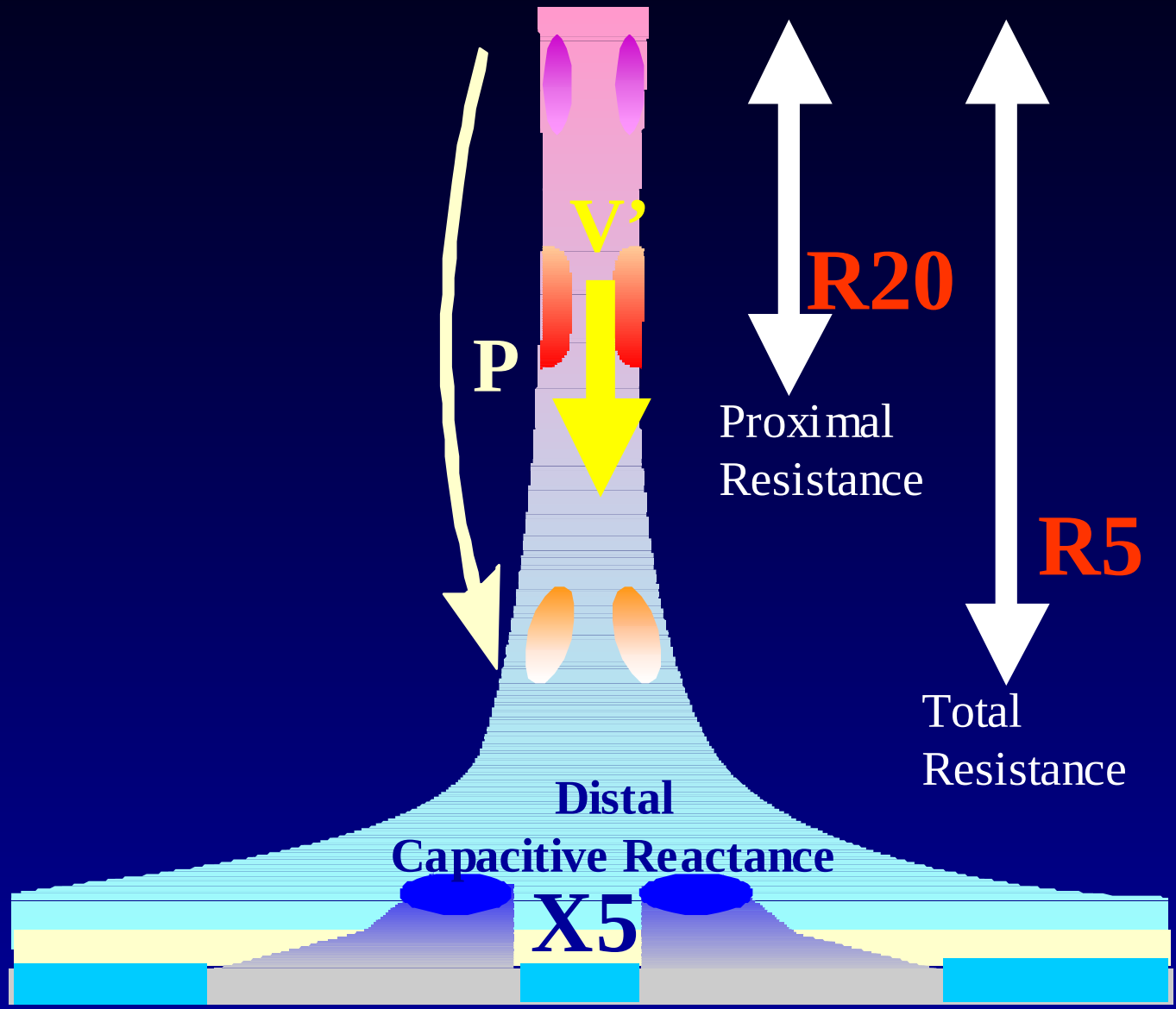
Reactance X(F)

-Energy Storage-



X5 Distal Capacitive Reactance
Fres Resonant Frequency

Relationship to Lung Physiology



extra thoracic

central

peripheral

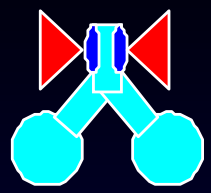
pulmonary

Clinical Interpretation of Oscillometry in Routine Use

Clinical Questions on Oscillometry

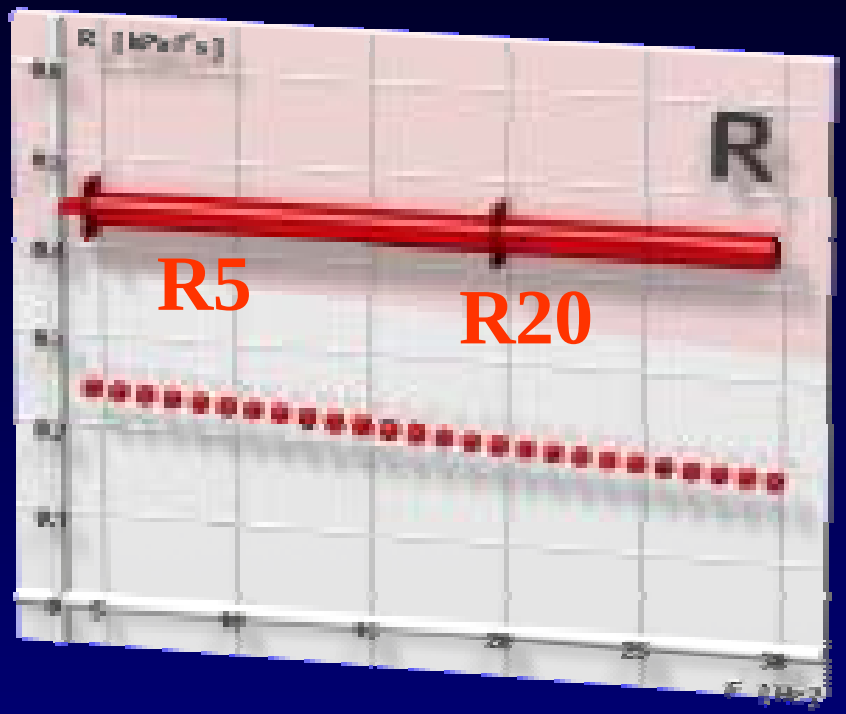
- Analysis of **spontaneous breathing** – low co-operation
- Determination of **degree of disability**
- Comprehensive **differential diagnostics**
- **Pre-, post-measurement** of both, provocation and spasmolysis independent of co-operation (also in combination with spirometry).
- **Trend analysis**, using the low intra individual variability of different parameters
- Prognosis
- Occupational reports

Complementary and specific information to improve the interpretation of spirometry



Proximal Obstruction

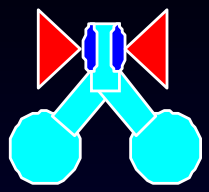
- Functional Differentiation -



R5 abnormal (> 150 % pred)

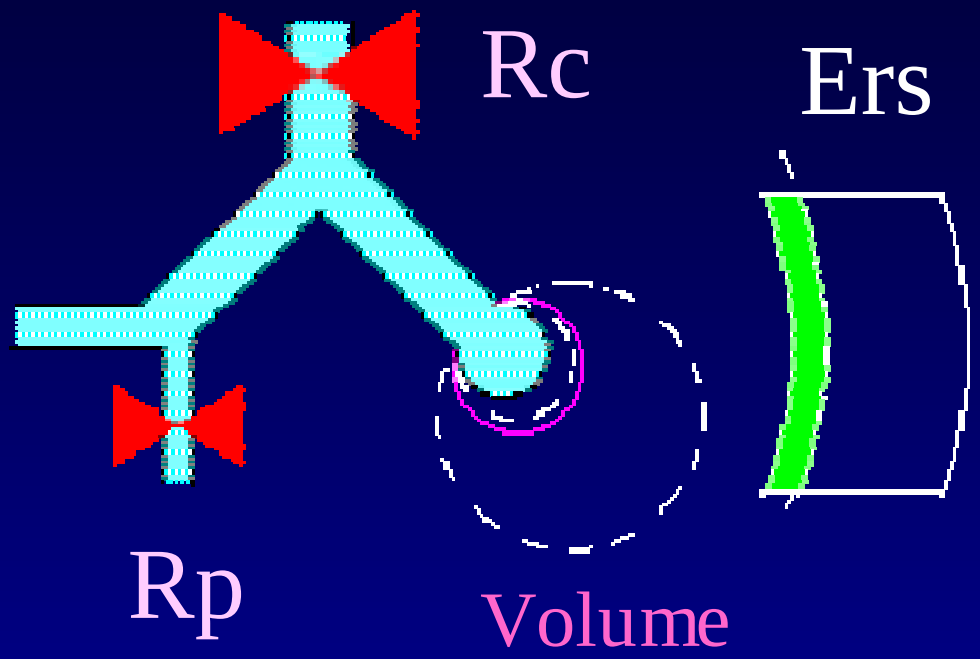
ΔR5-R20 < 10 % frequency independent

X5 normal



Proximal Obstruction

- Interpretation Graph – according to Mead (Vogel)

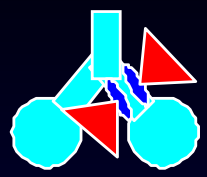


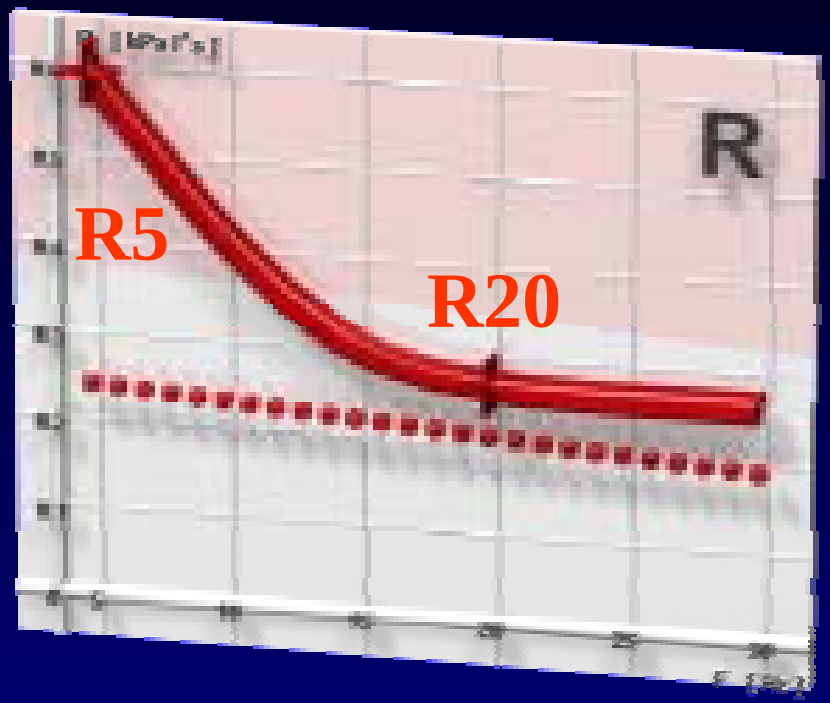
proximal (Rc)↑
> = distal (Rp)
airway resistance

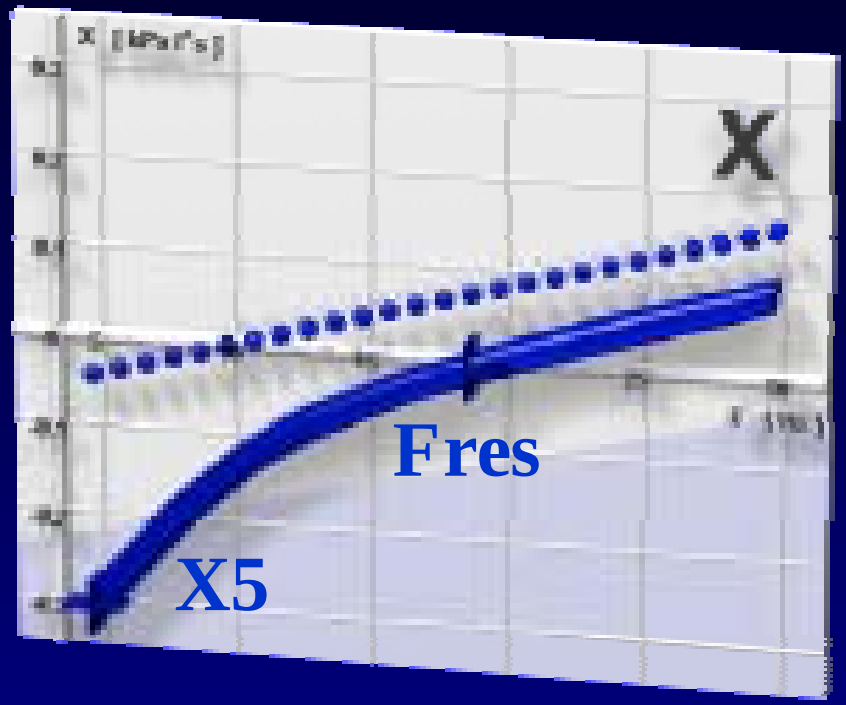
elasticity (Ers) of lung & thorax

Distal Obstruction

- Functional Differentiation -







R5 abnormal (> 150% pred)

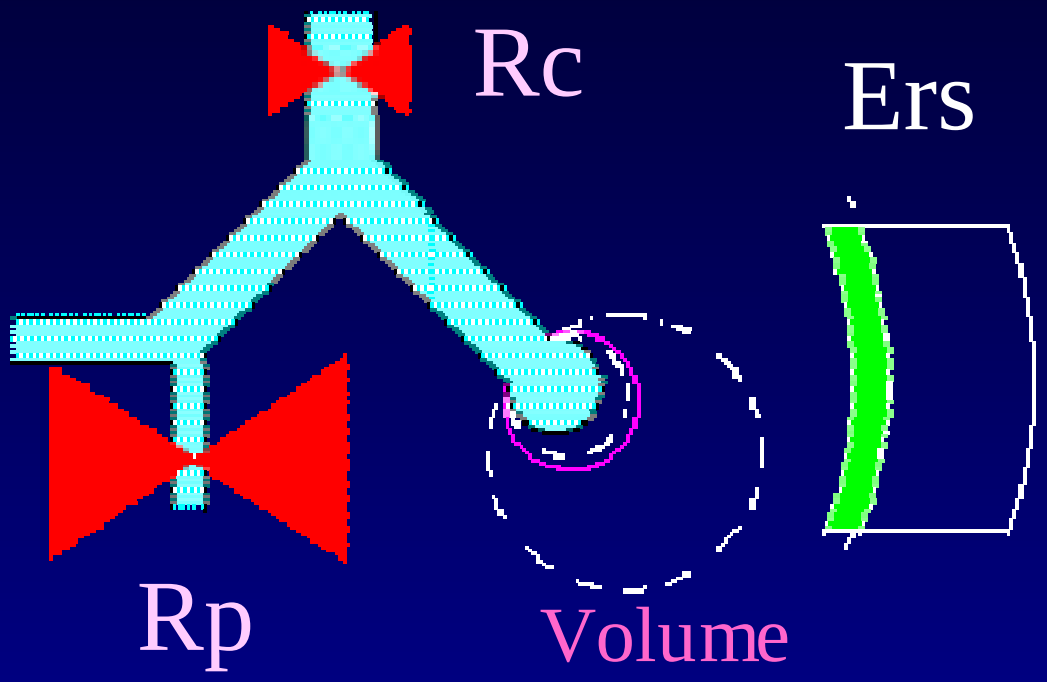
ΔR5-R20 > 10 % frequency independent

X5 abnormal

< X5pred – 0.15 kPa/l/s

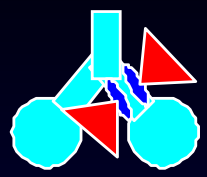
Distal Obstruction

- Interpretation Graph –



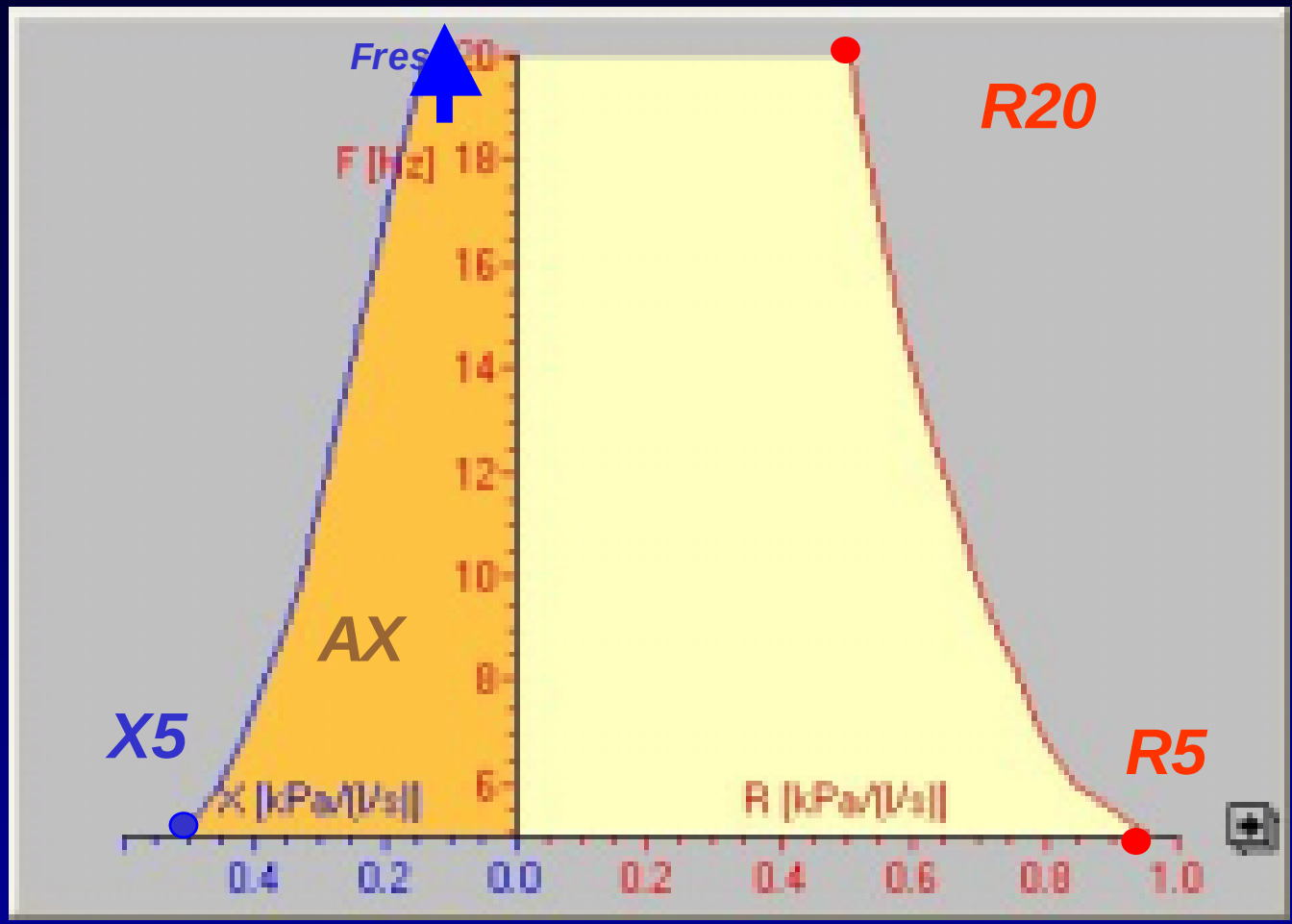
distal (Rp)↑ > proximal (Rc) airway resistance

elasticity (Ers) of lung & thorax



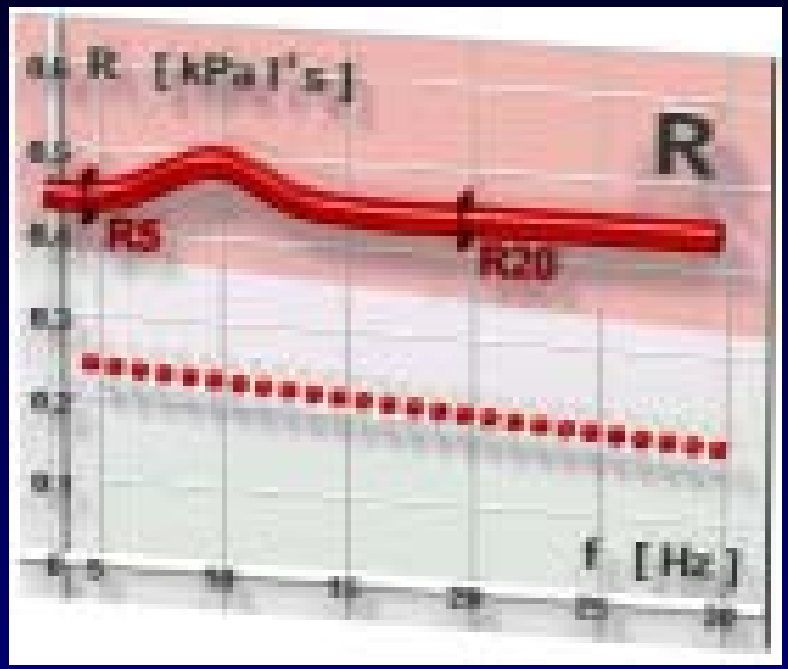
Distal Obstruction

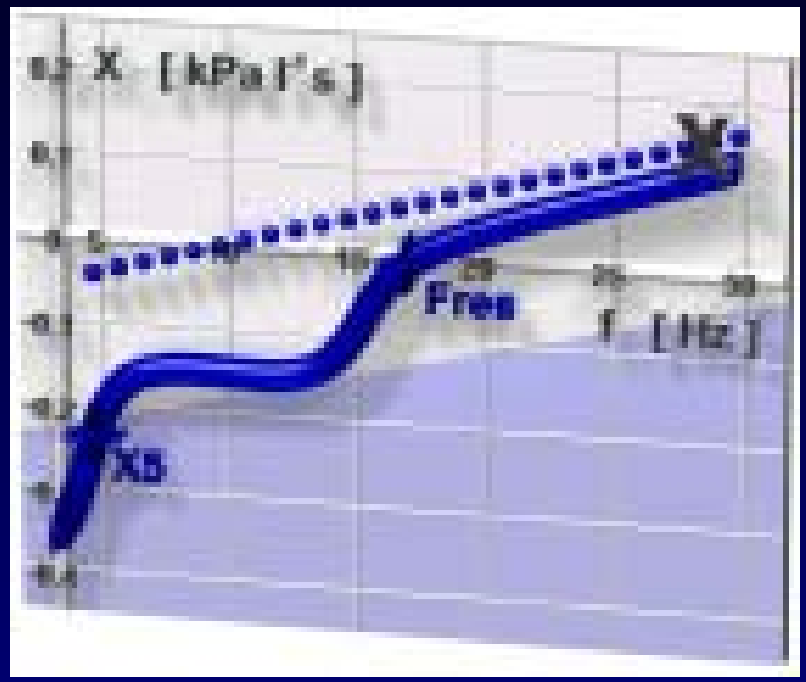
- Asthma Intelligence – according to Goldman



Extra Thoracic Obstruction

- Functional Differentiation -





Plateau in reactance course

Comparison of oscillometry and spirometry

Definition of Abnormality

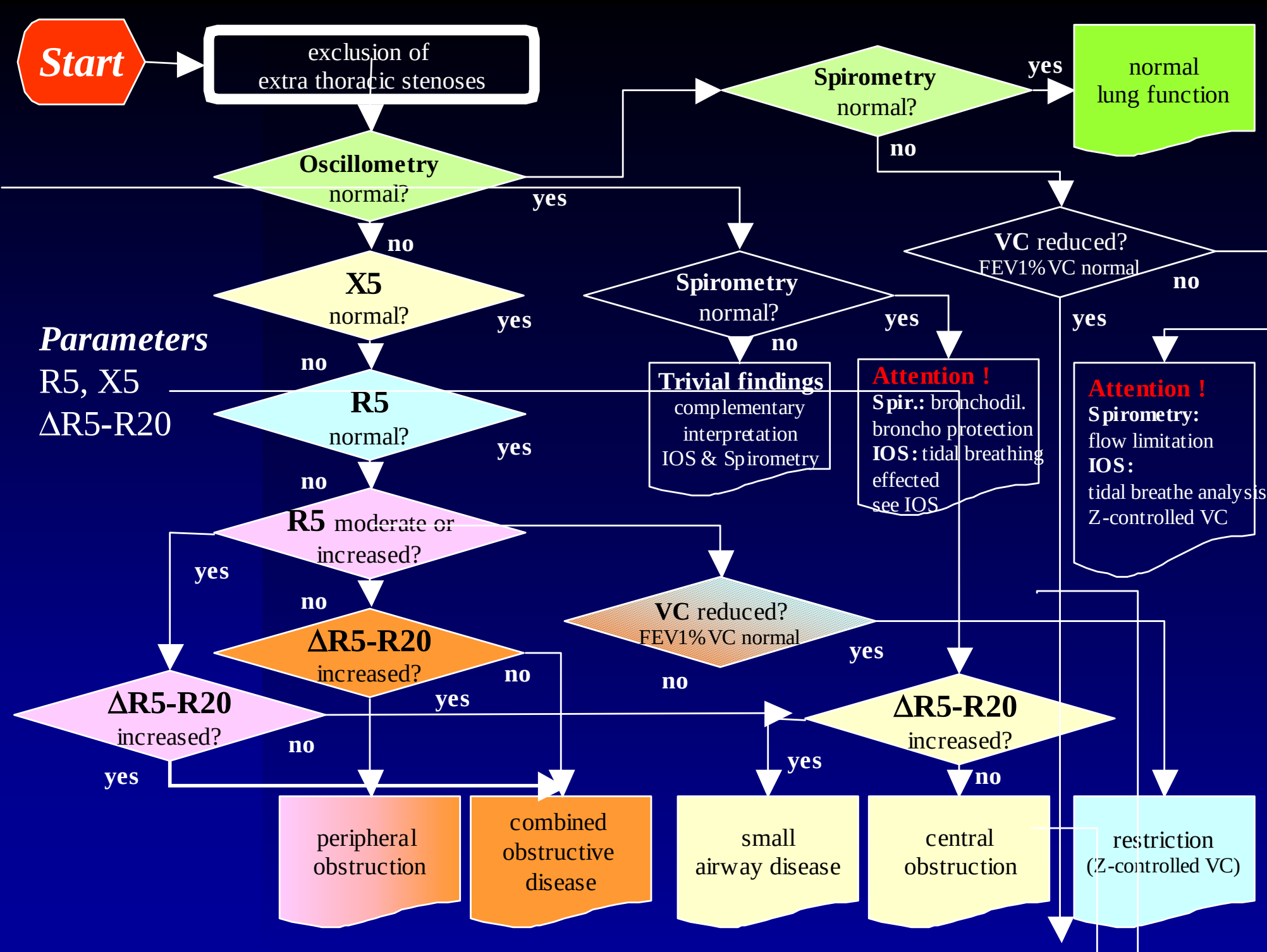
R5 *Total Respiratory Resistance* - abnormal, if above 150 % predicted

X5 *Distal Capacitive Reactance* - abnormal, if below X5 predicted – 0,15 kPa/(l/s)

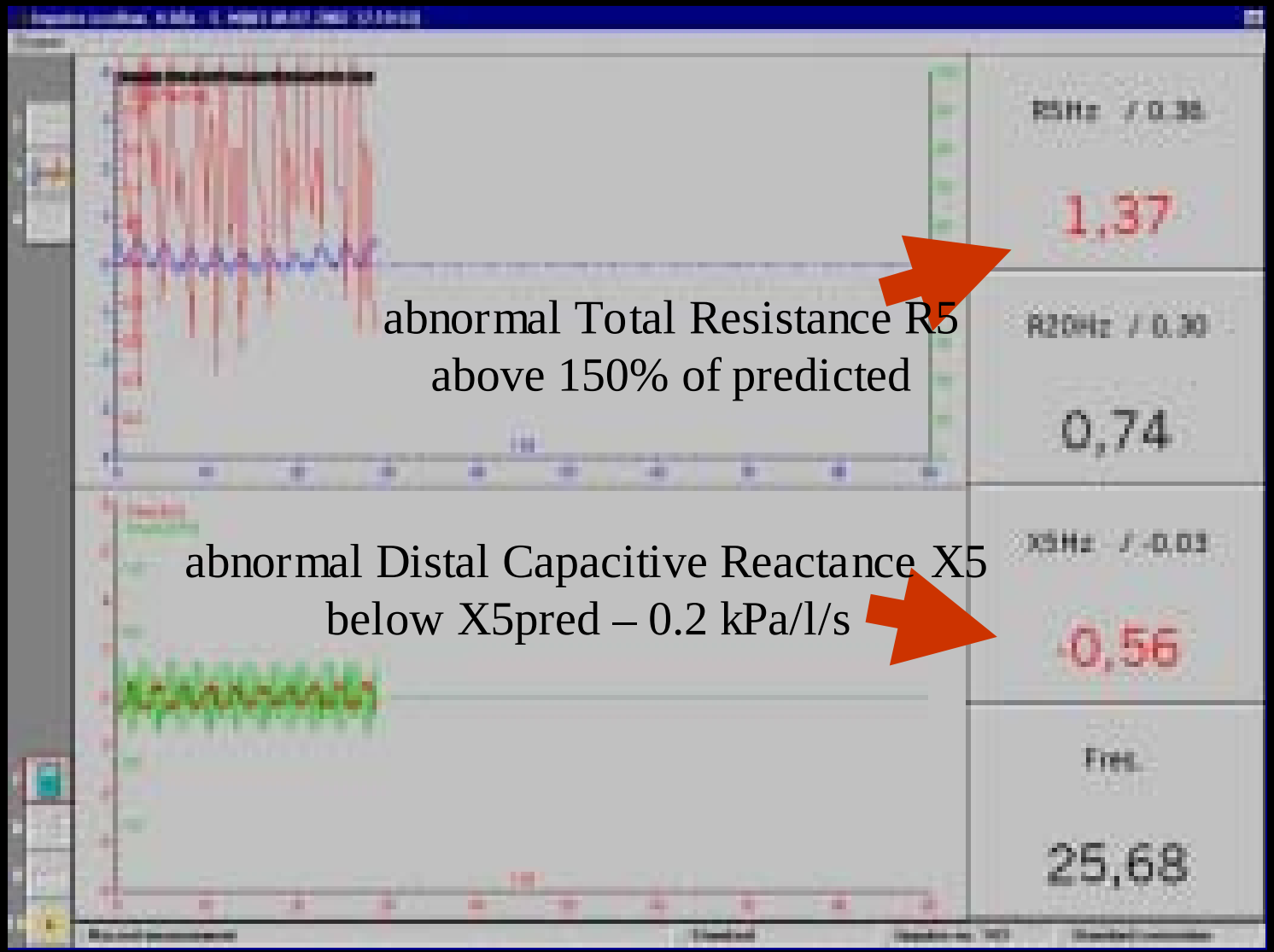
The Lung Function is abnormal, if either R5 or X5 or both Parameters are within the abnormal area. R5 and X5 are invoked together for the determination of the degree of severity of a disease.

Resistance specifications in [kPa/(l/s)]	X5 > X5predicted - 0,15	X5predicted - 0,15 ≥ X5 > X5Predicted - 0,3	X5predicted - 0,3 ≥ X5 > X5Predicted - 0,6	X5 ≤ X5predicted-0,6
R5 < 150%predicted	normal	I (slight)	II (moderate)	III (severe)
150% ≤ R5 < 200%predicted	I (slight)	II (moderate)	III (severe)	III (severe)
200% ≤ R5 < 300%predicted	II (moderate)	III (severe)	III (severe)	III (severe)
R5 ≥ 300%predicted	III (severe)	III (severe)	III (severe)	III (severe)

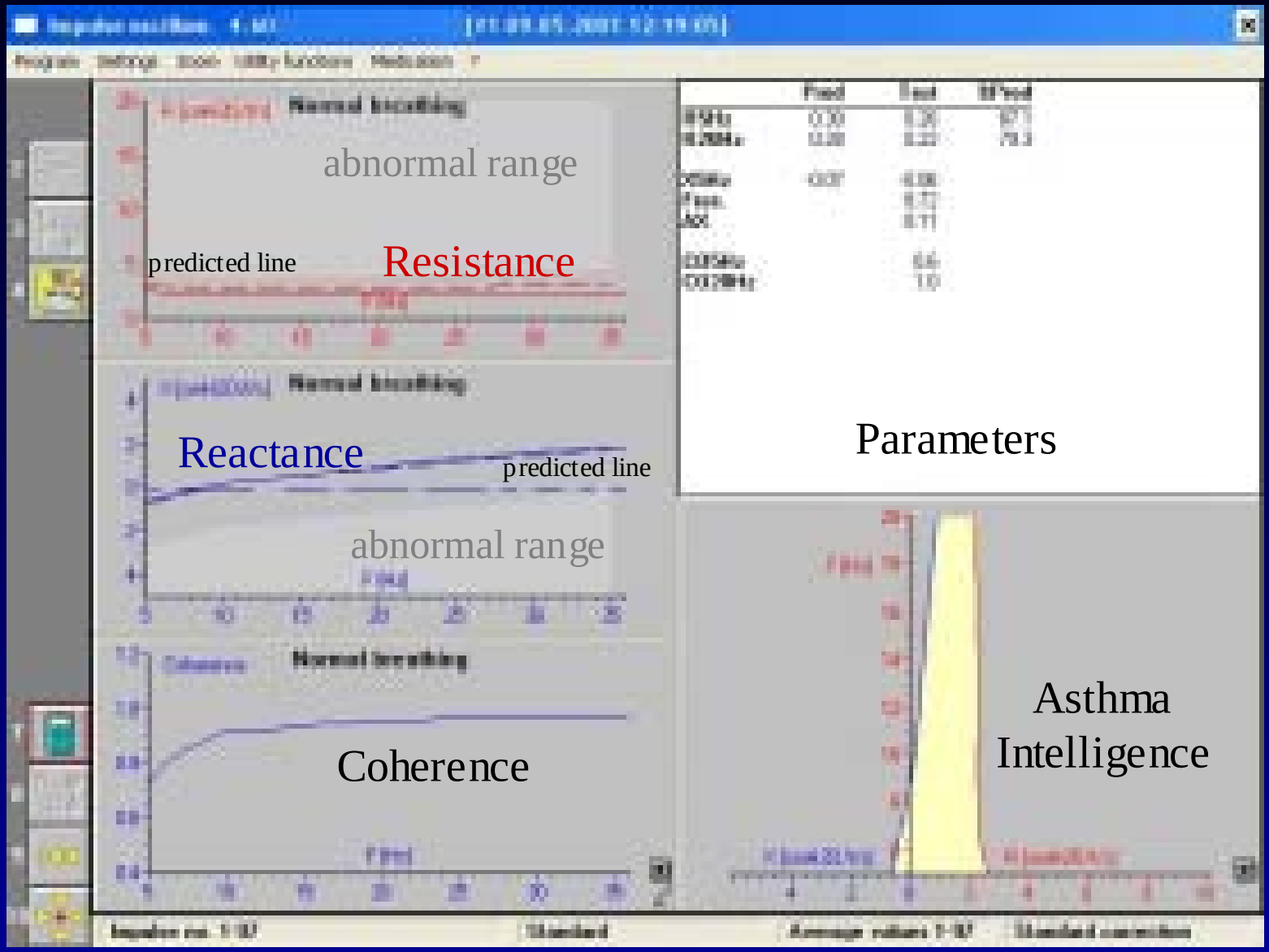
Combination of Oscillometry and Spirometry: the maximum step is defined as test result, regardless whether it occured in Oscillometry or Spirometry.


Start
exclusion of extra thoracic stenoses
Spirometry normal?
yes
normal lung function
no
Oscillometry normal?
yes
no
VC reduced? FEV1%VC normal
no
yes
X5 normal?
yes
no
Spirometry normal?
yes
no
Parameters
R5, X5
ΔR5-R20
Trivial findings
complementary interpretation IOS & Spirometry
Attention !
Spir.: bronchodil. broncho protection
IOS: tidal breathing effected see IOS
Attention !
Spirometry: flow limitation
IOS: tidal breathe analysis Z-controlled VC
R5 normal?
yes
no
R5 moderate or increased?
yes
no
VC reduced? FEV1%VC normal
yes
no
ΔR5-R20 increased?
no
yes
ΔR5-R20 increased?
no
yes
ΔR5-R20 increased?
yes
no
peripheral obstruction
combined obstructive disease
small airway disease
central obstruction
restriction (Z-controlled VC)

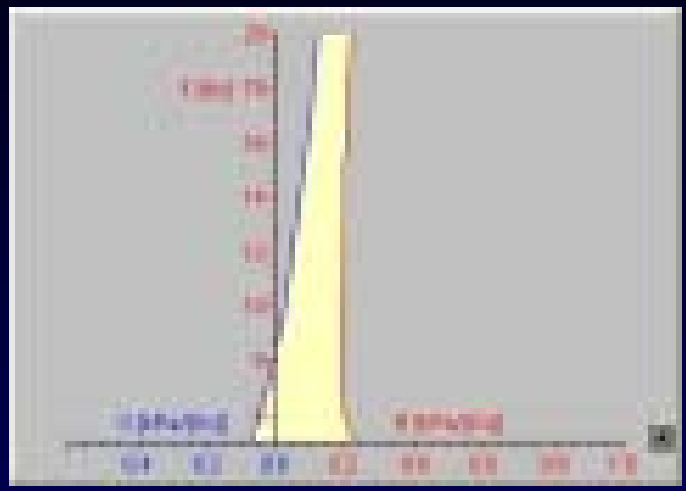
On-line Data Acquisition with Indication of Abnormal Range



Normal Lung Function



Normal Lung Function

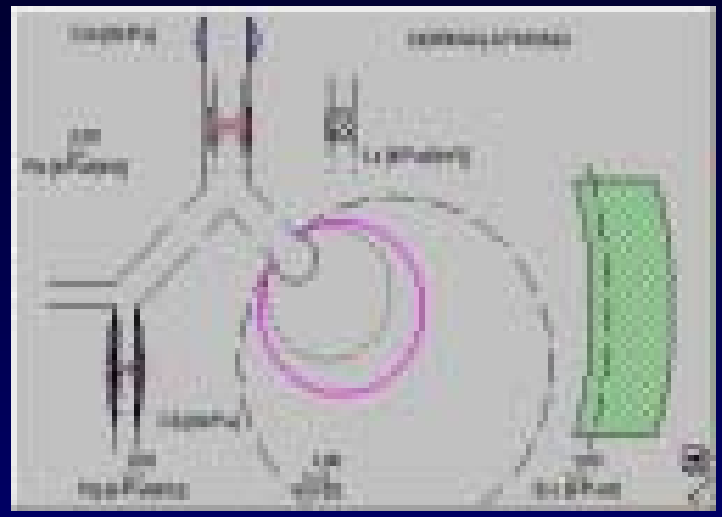


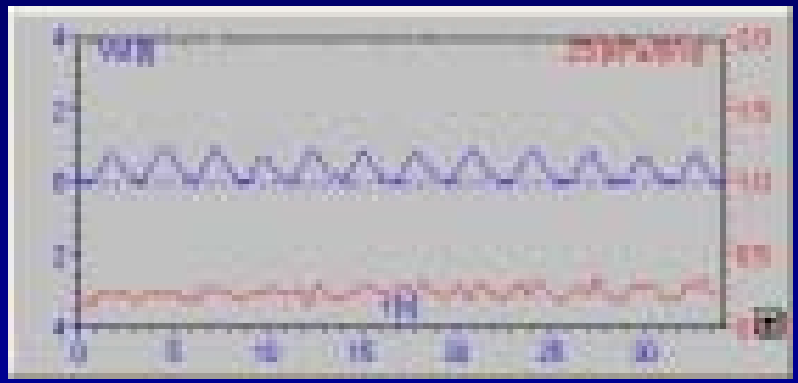
Impedance Interpretation

-Degree of severity, Pre-, Post measurement

Interpretation Model

- from 7 years upwards



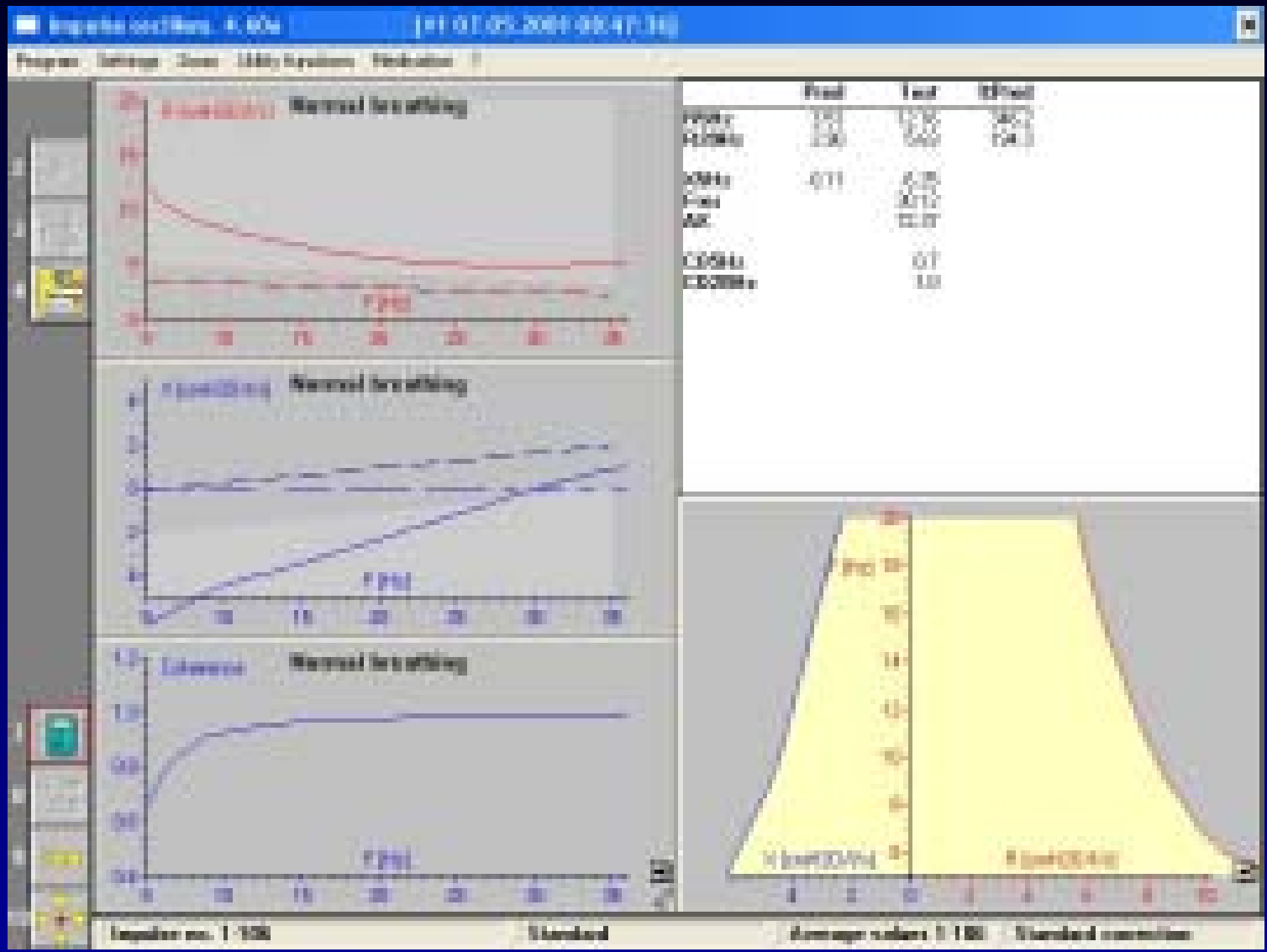


On-line!

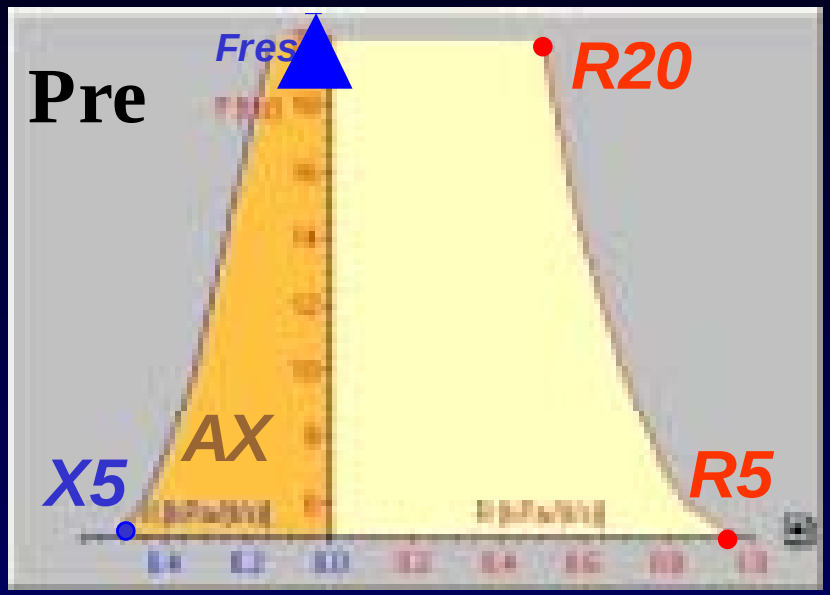
Time trends of Z5 & V

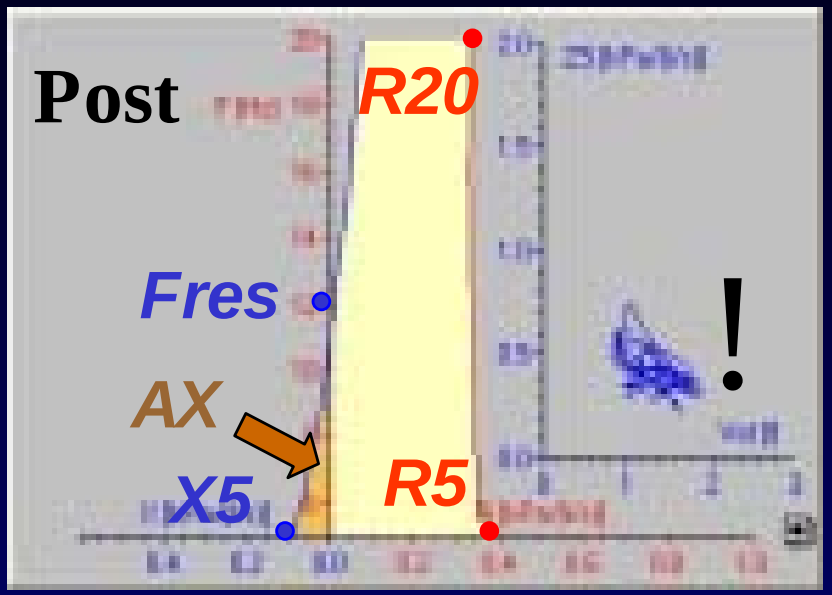
- controlled data acquisition

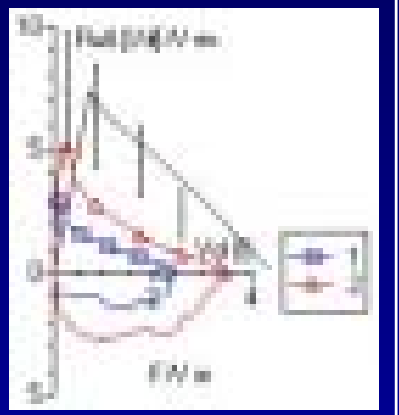
Peripheral Obstruction (Asthma)



Peripheral Obstruction (Asthma)

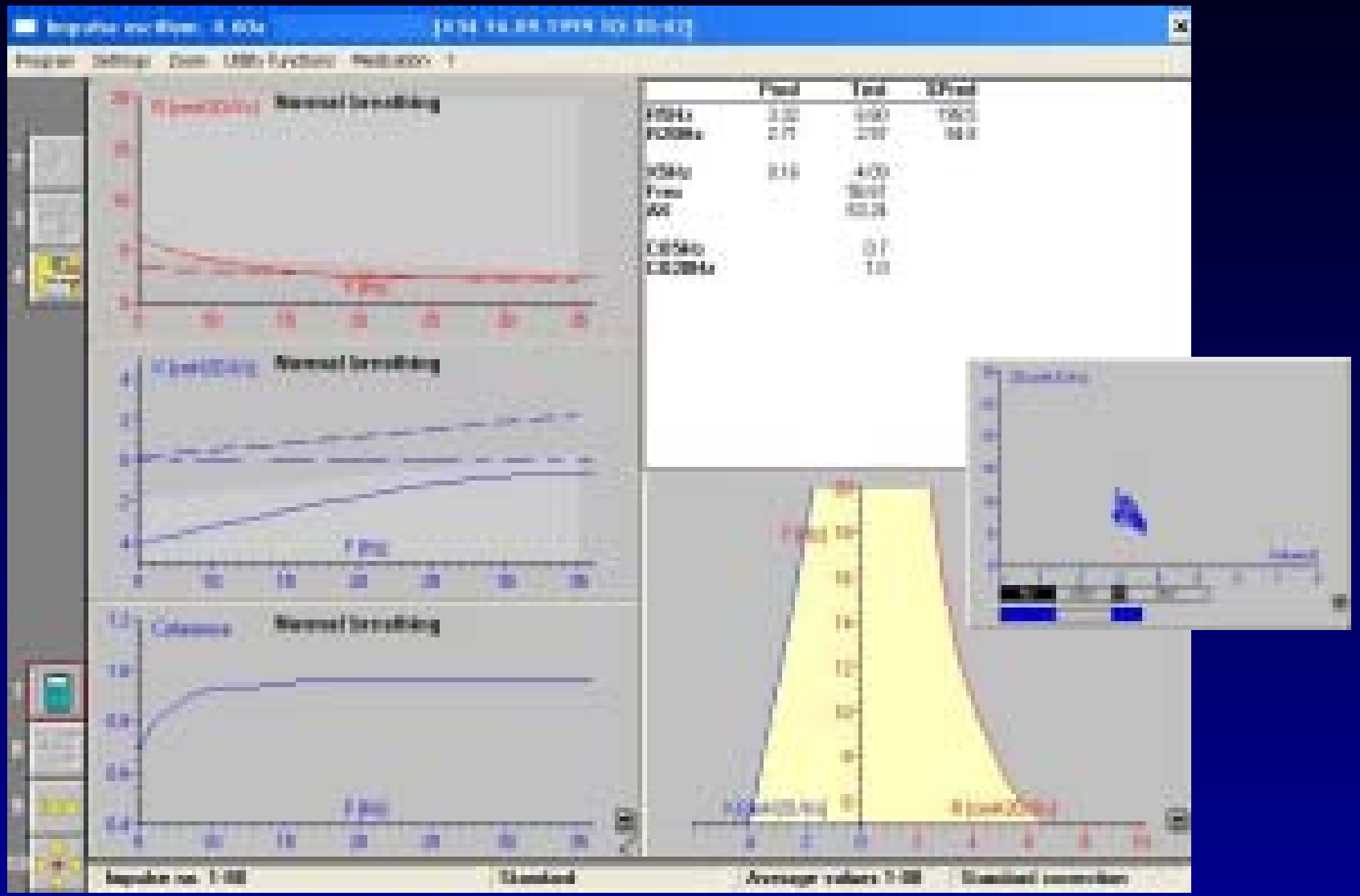




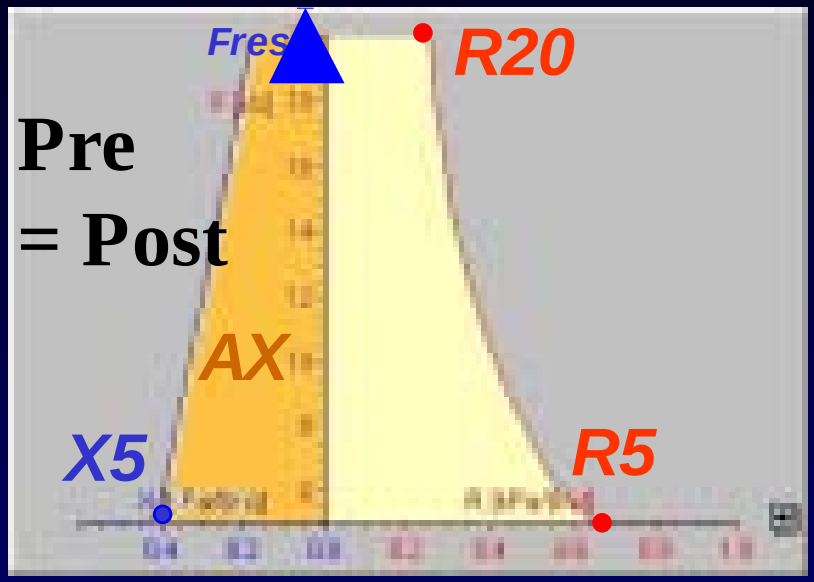


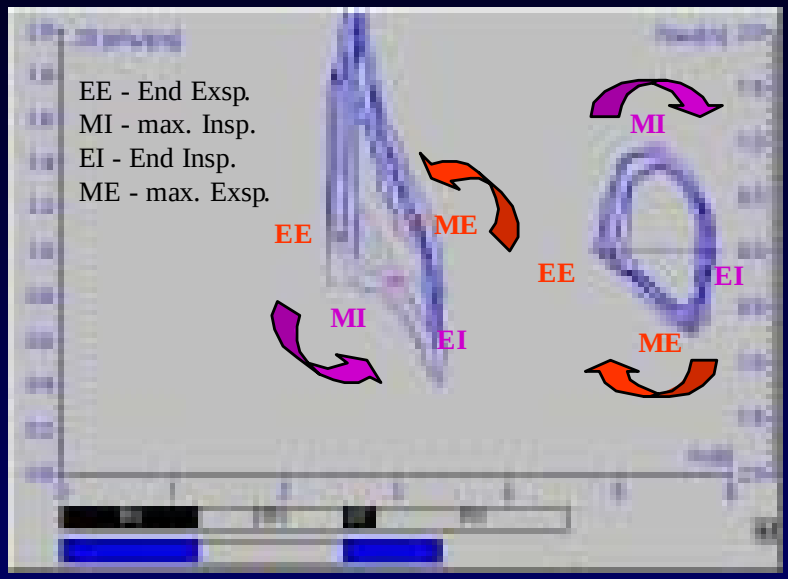
- ***Pre: peripheral airway obstruction***
  - - Abnormal values of **R5** (n▲), **X5** (▼), **Fres** ▲, **AX** ▲
  - - Elevated frequency dependence of R-spectrum **ΔR5-R20** ▲
- ***Post: Normal lung function at tidal breathing***
  - - BUT high variability of **Z5-Vol-Diagram** even at tidal breathing
  - - Spirometry represents border situation

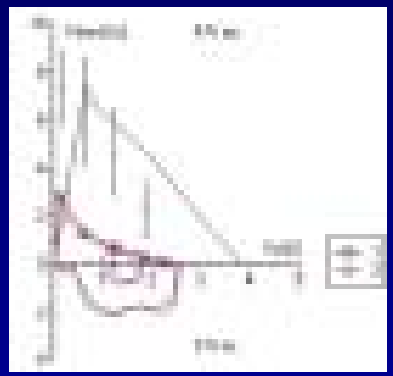
COPD


Normal breathing
Normal breathing
Coherence
Normal breathing

COPD







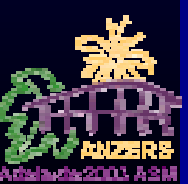
Pre measurement:peripheral airway obstruction

- Abnormal values of: **R5** (n▲), **X5** (▼), **Fres** (▲), **AX** (▲)
- Elevated frequency dependence of R-spectrum **ΔR5-R20** (▲)
- **Z5-vol-diagram** shows strict synchronity, window visible

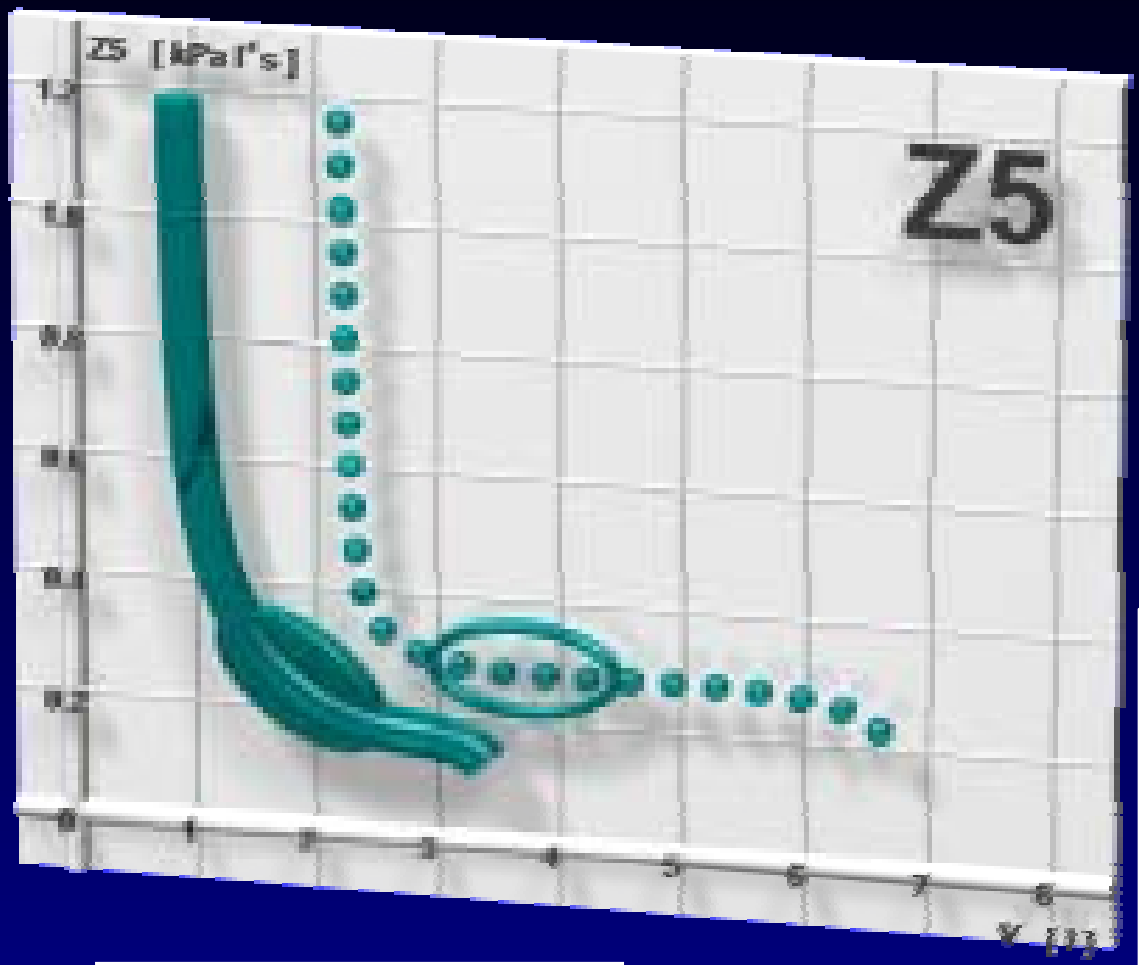
Pre-, Post measurement WITHOUT relevant improvement

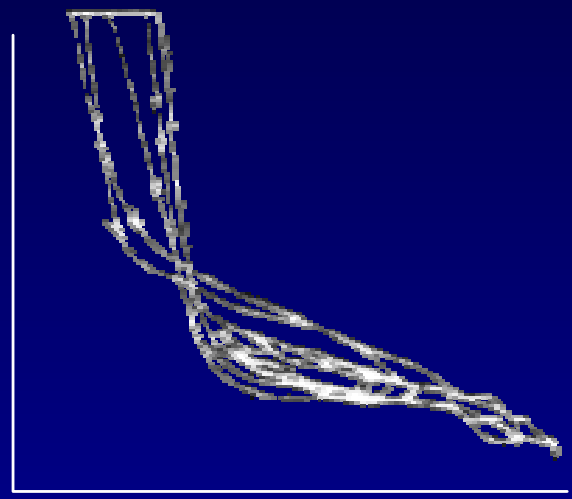
coherence for trustworthy results > 0,7

Differentiated Analysis for Improved Clinical Interpretation and Scientific Questions



VC-Manoeuvre (Restriction)

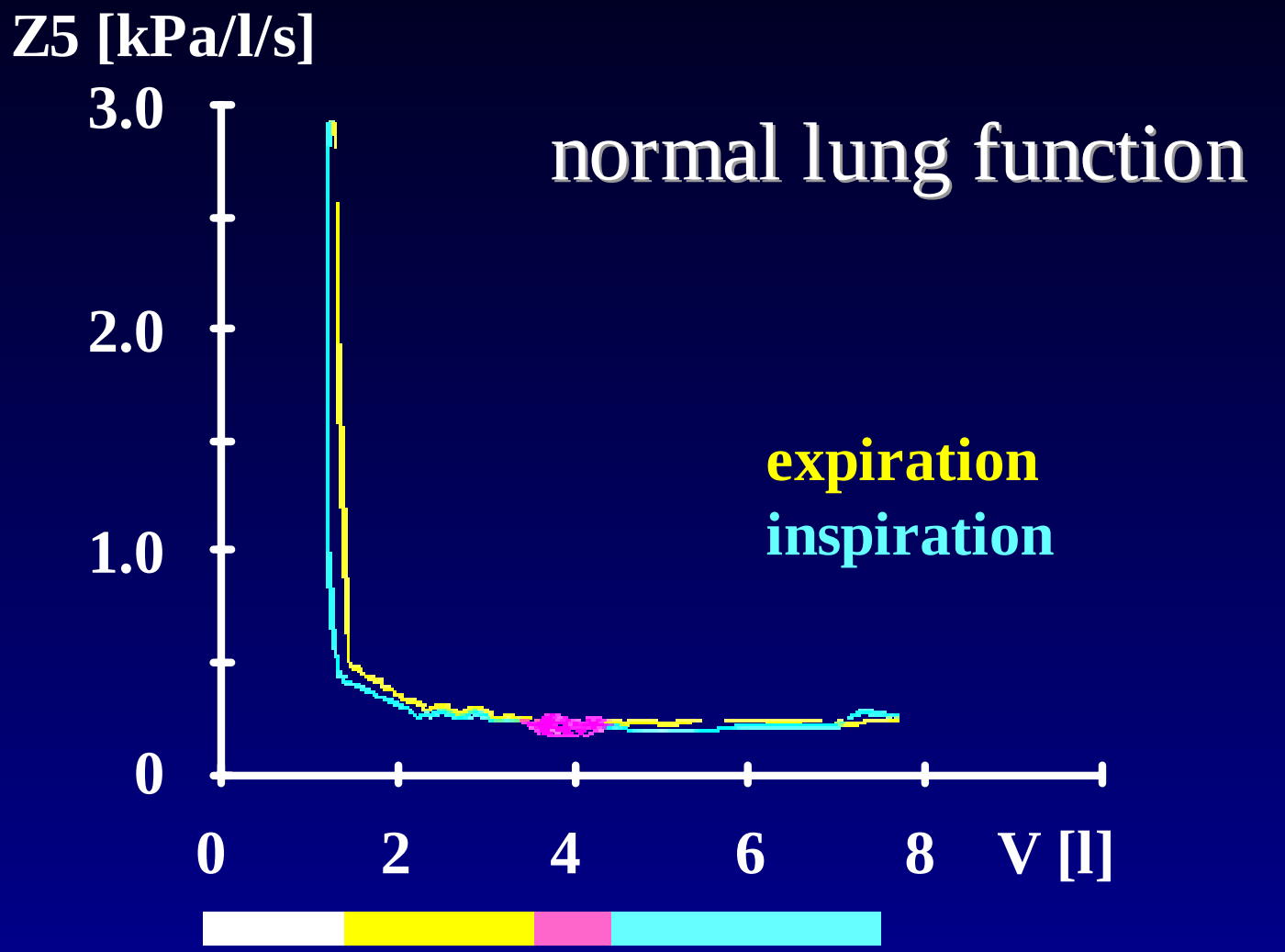




VC abnormal

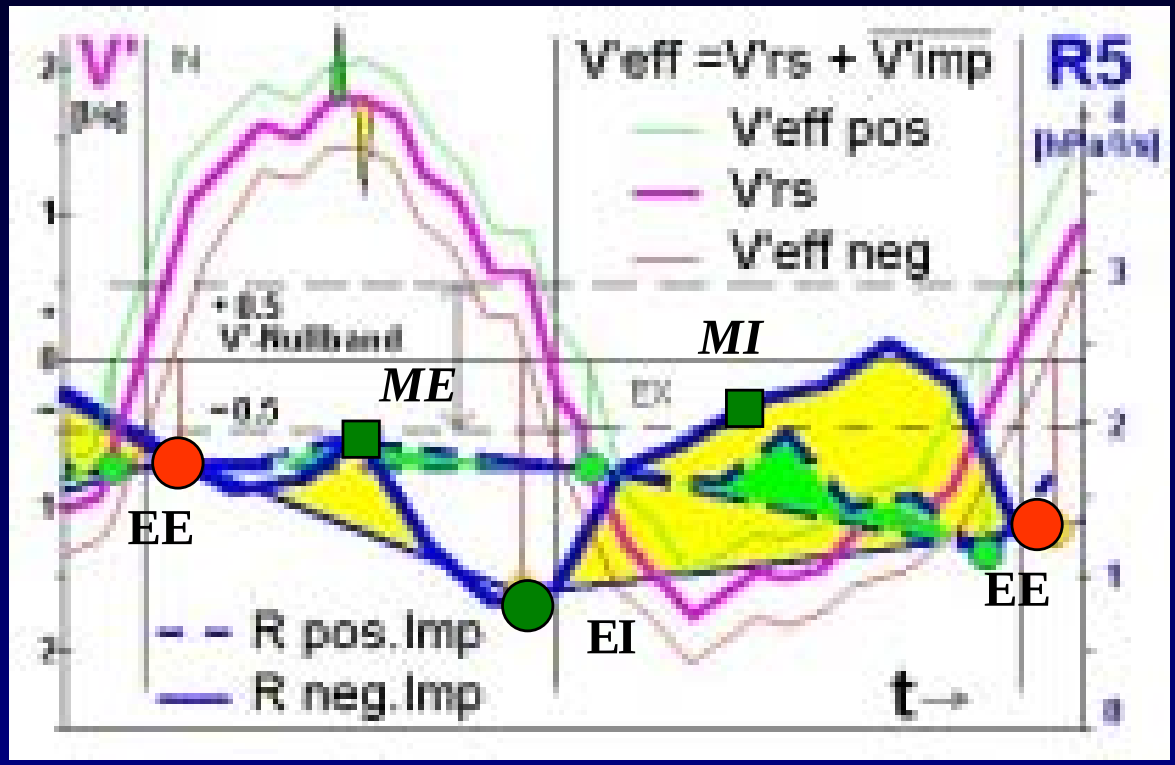
Schnellbächer (***ErgoMed*** 1982)

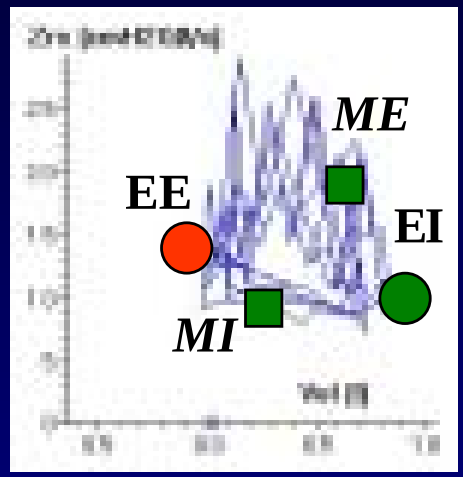
Impedance-Volume Graph from VC-Manoeuvre



Flow-Volume Dependence in Spontaneous Breathing

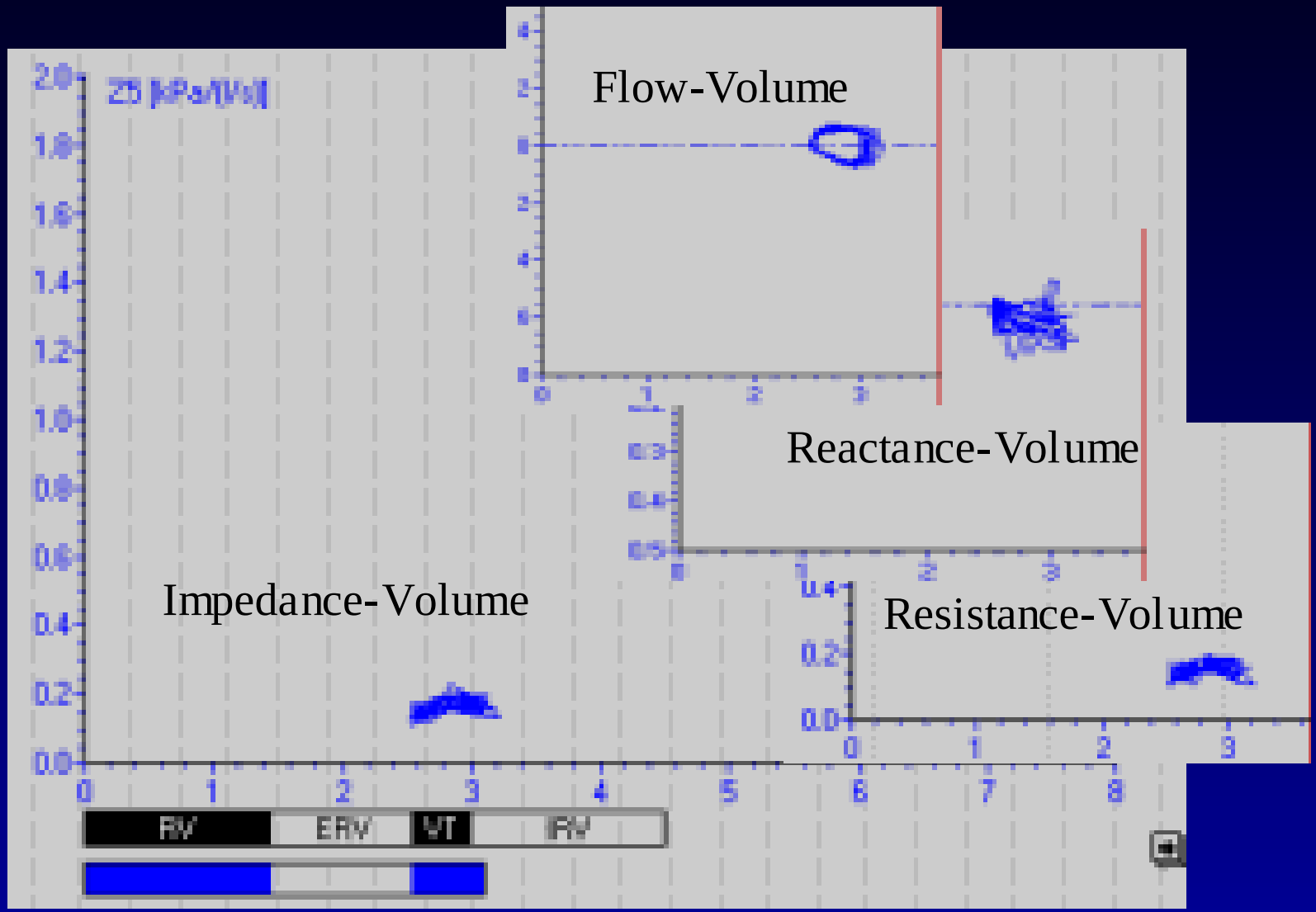
Breathing Cycle of 4 Phases





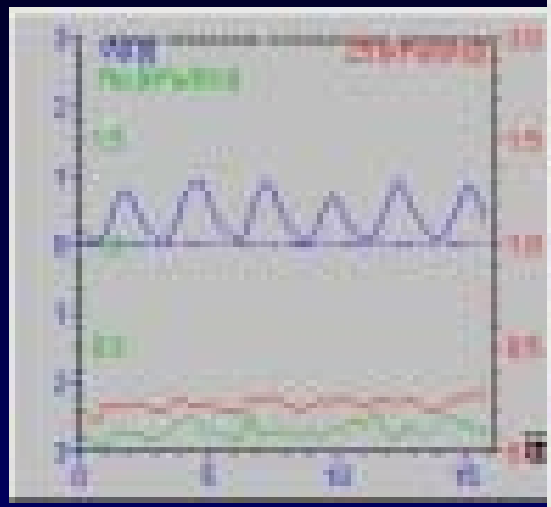
- MI Maximal Inspiration (V‘)
- EI End-Inspiration (V)
- ME Maximal Expiration (V‘)
- EE End-Expiration (V)

Advanced Volume-Dependence Graph

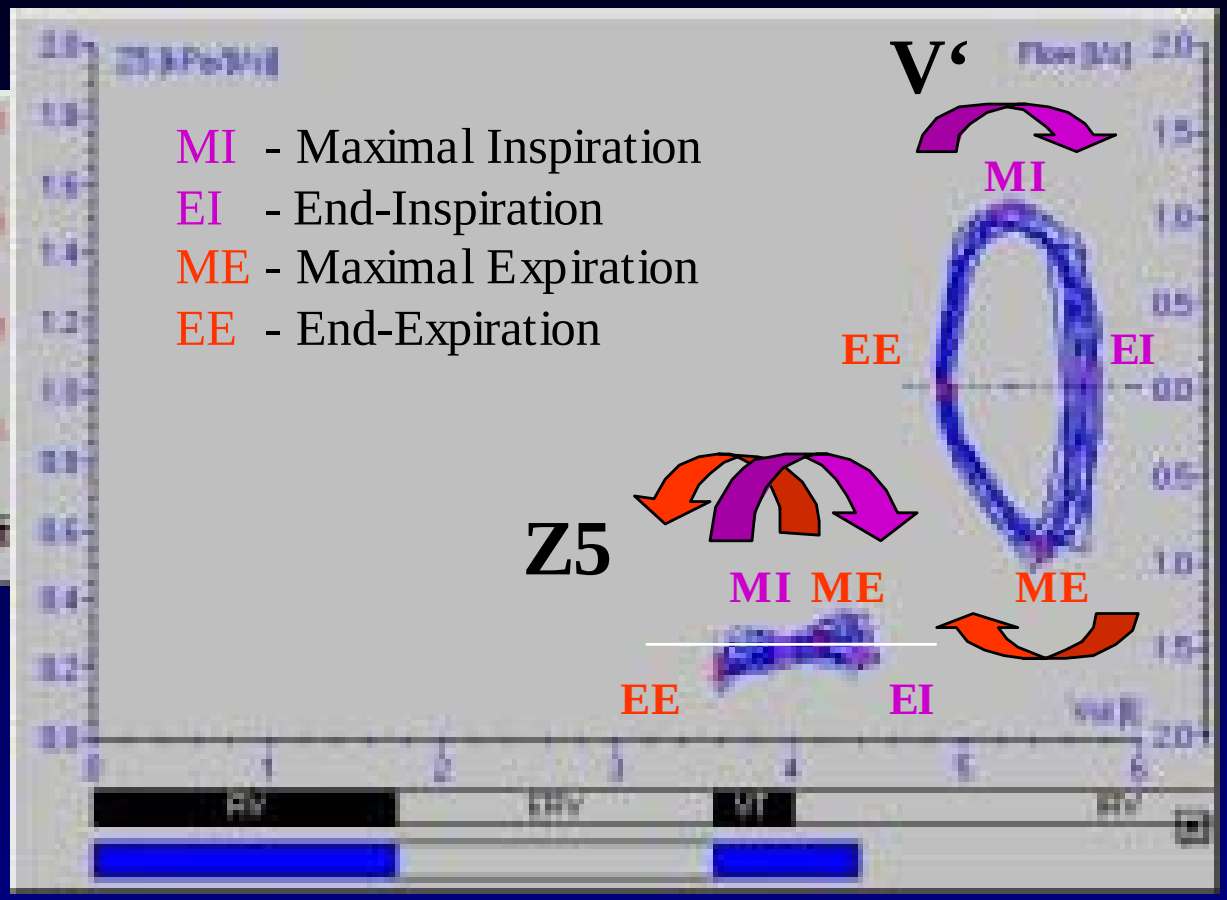


Normal Lung Function

Timetrend

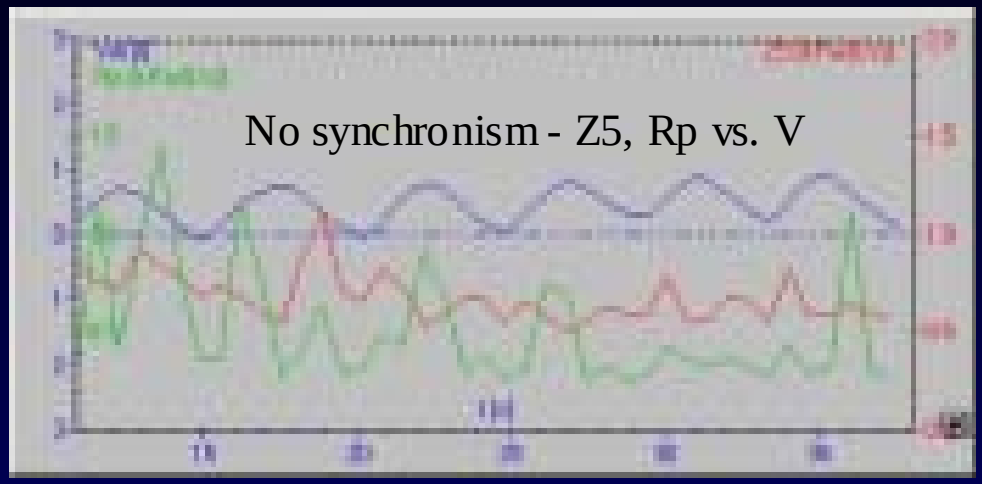


Volume dependence of Z5 and V‘

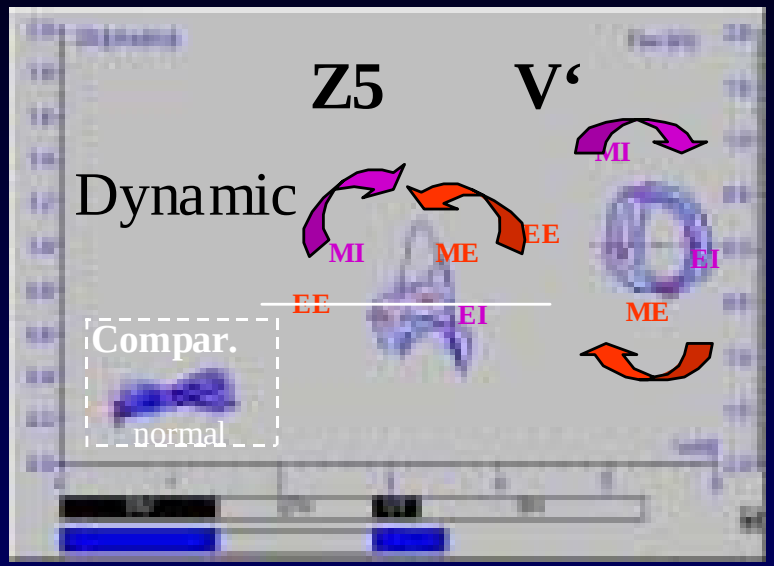


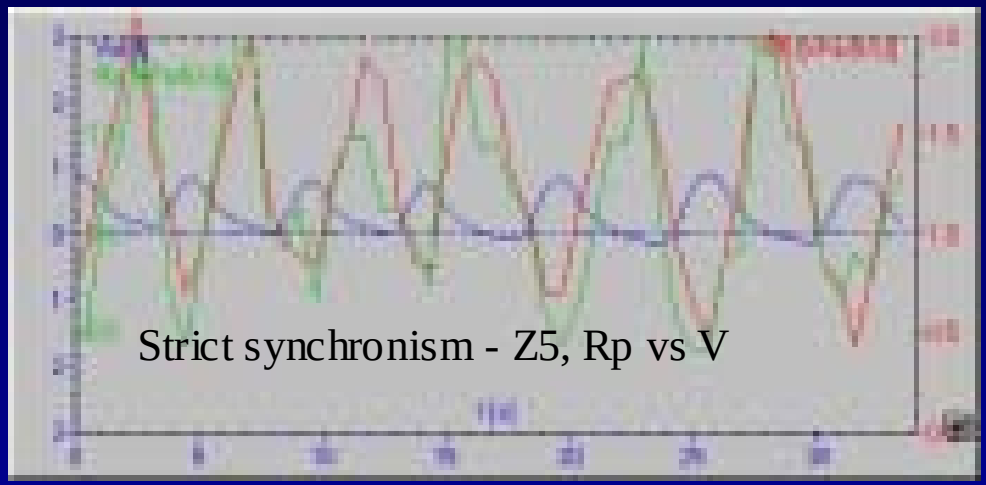
Single Breaths

Intra-Breath Information

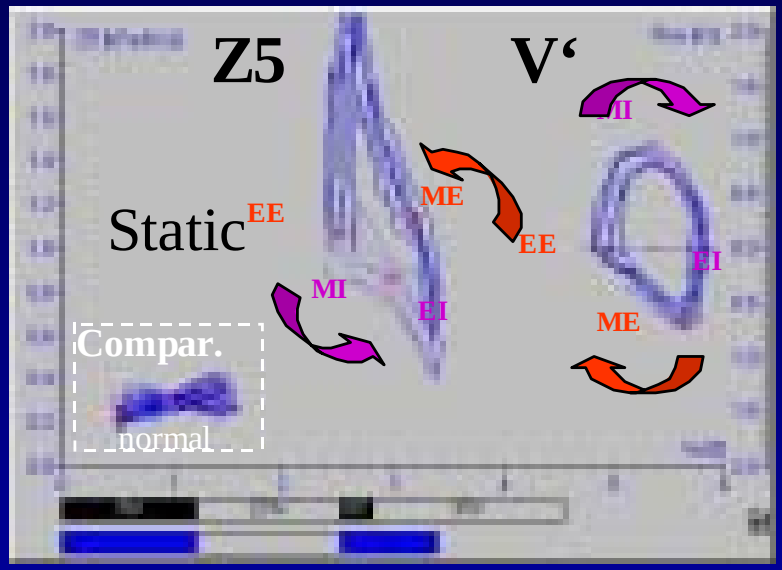


Asthma male, 18 years, 168 cm, 61 kg

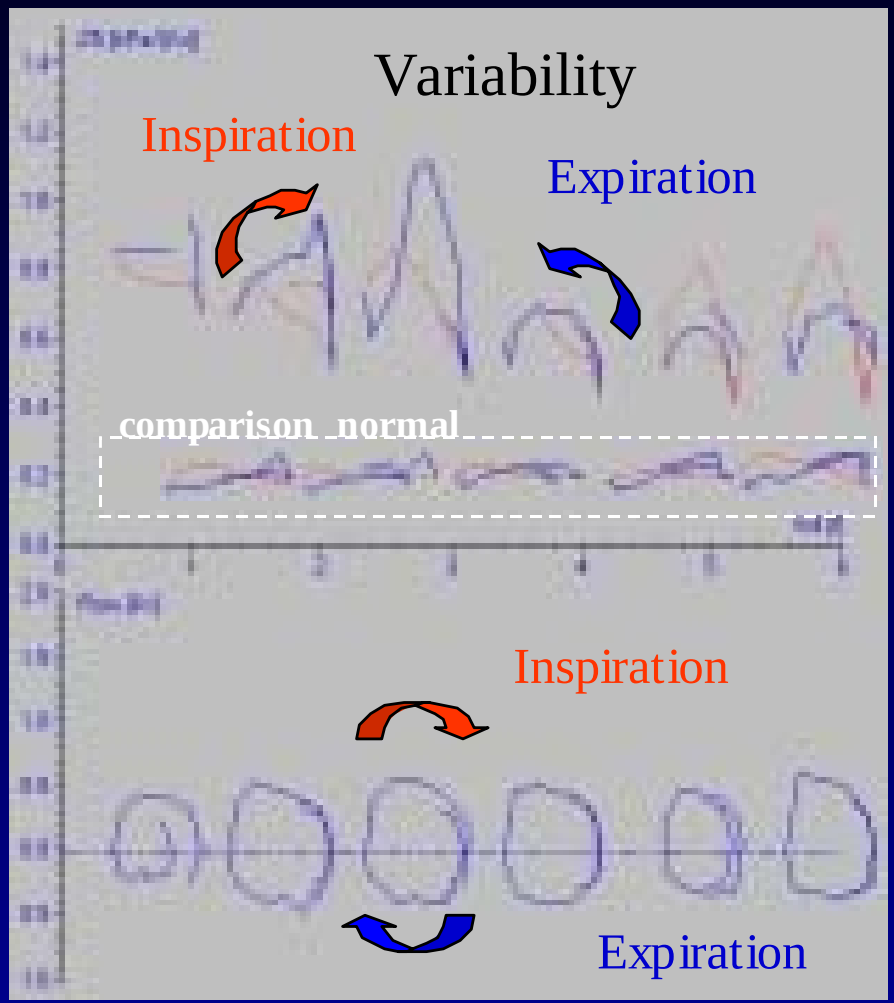




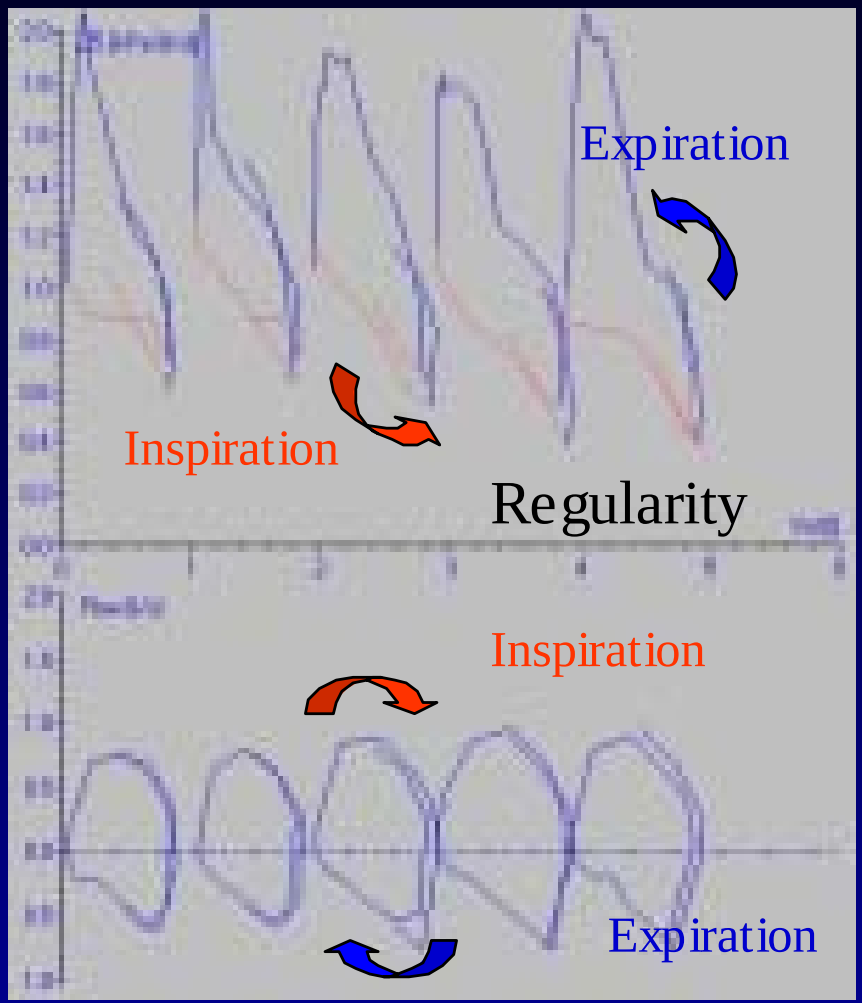
COPD male, 26 years, 156 cm, 44 kg



Intra-Breath Information

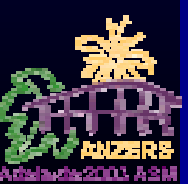


Asthma



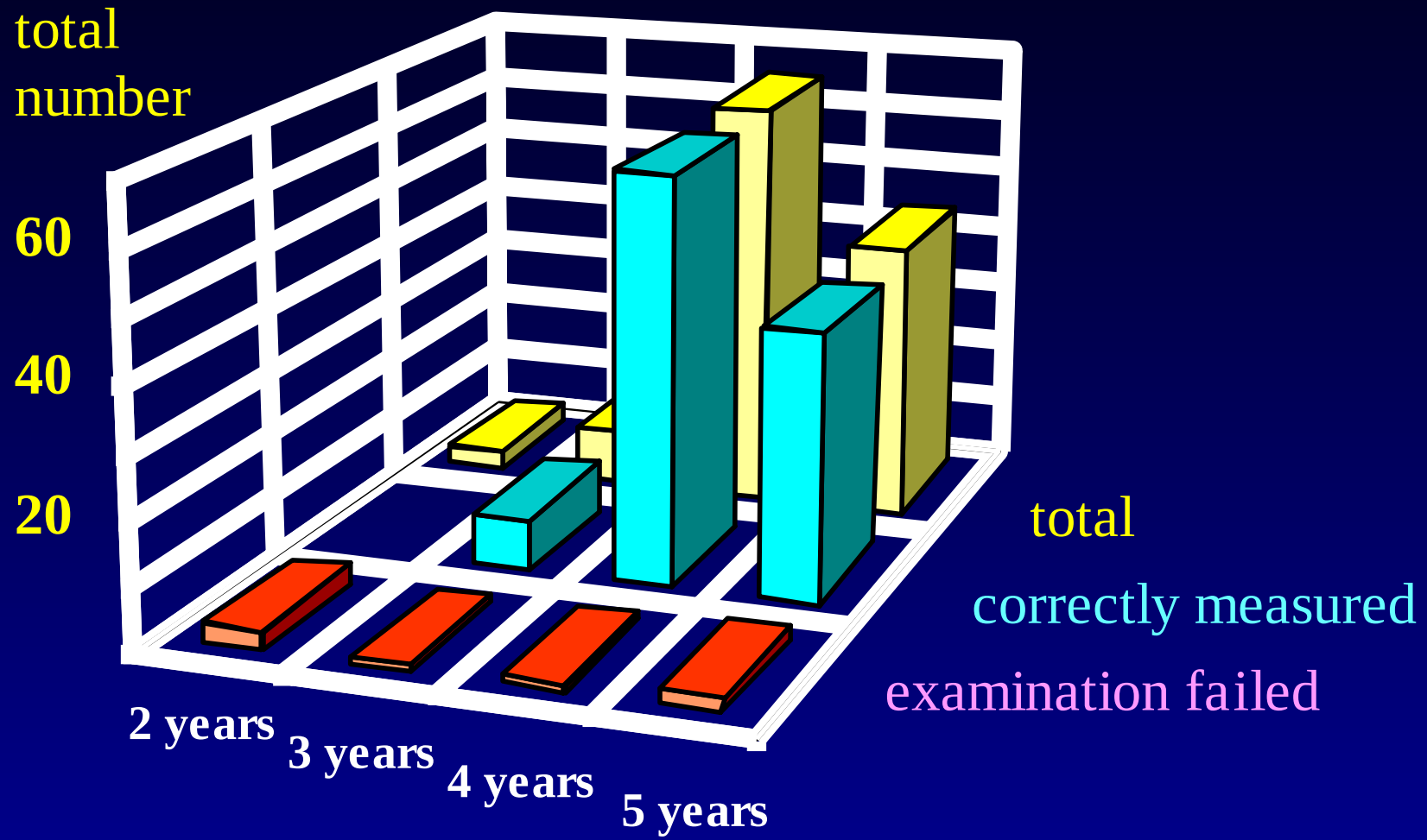
COPD

Clinical Application of Oscillometry



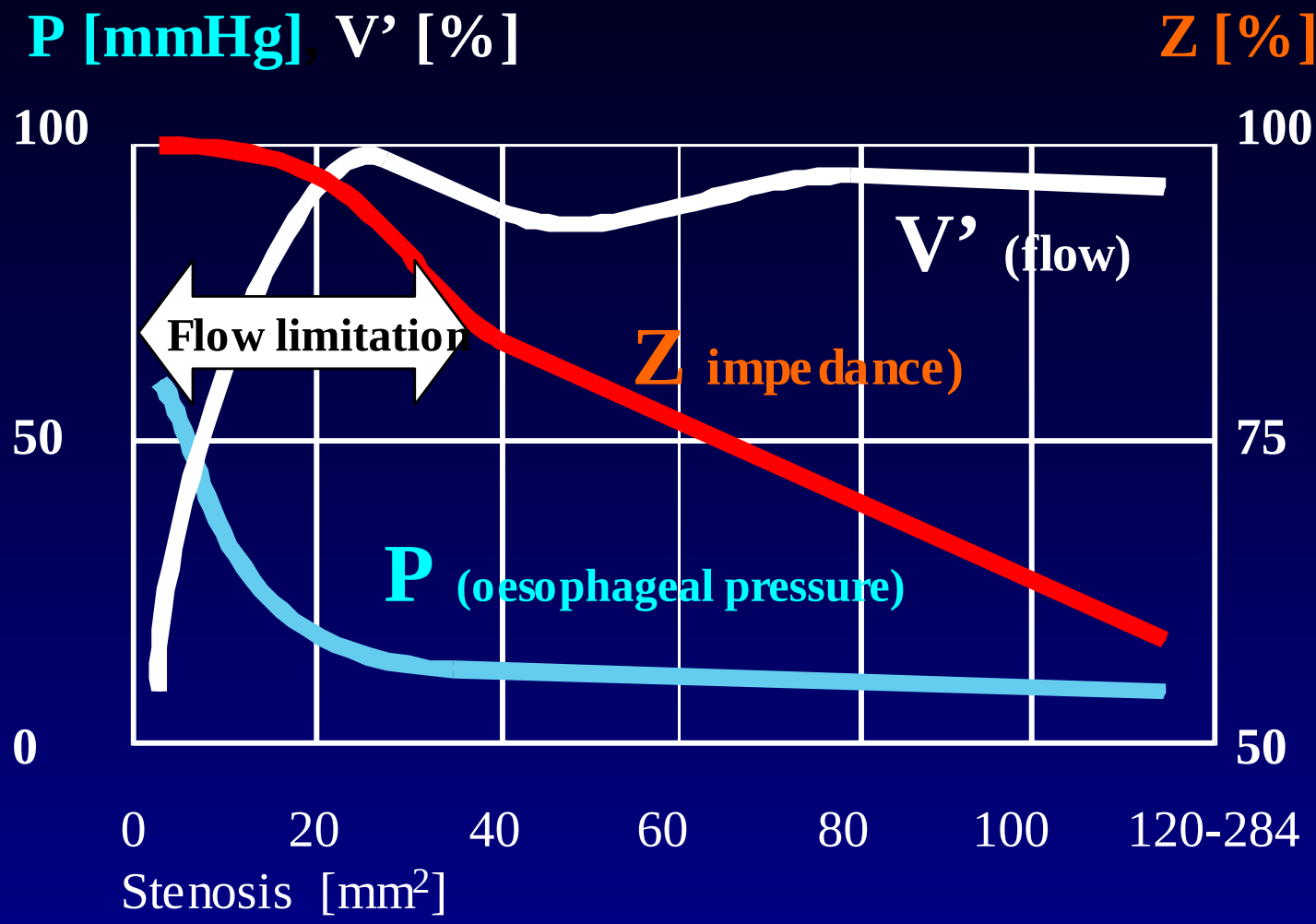
IOS in Pre-School Children

-first ambulant examination with mouth piece -



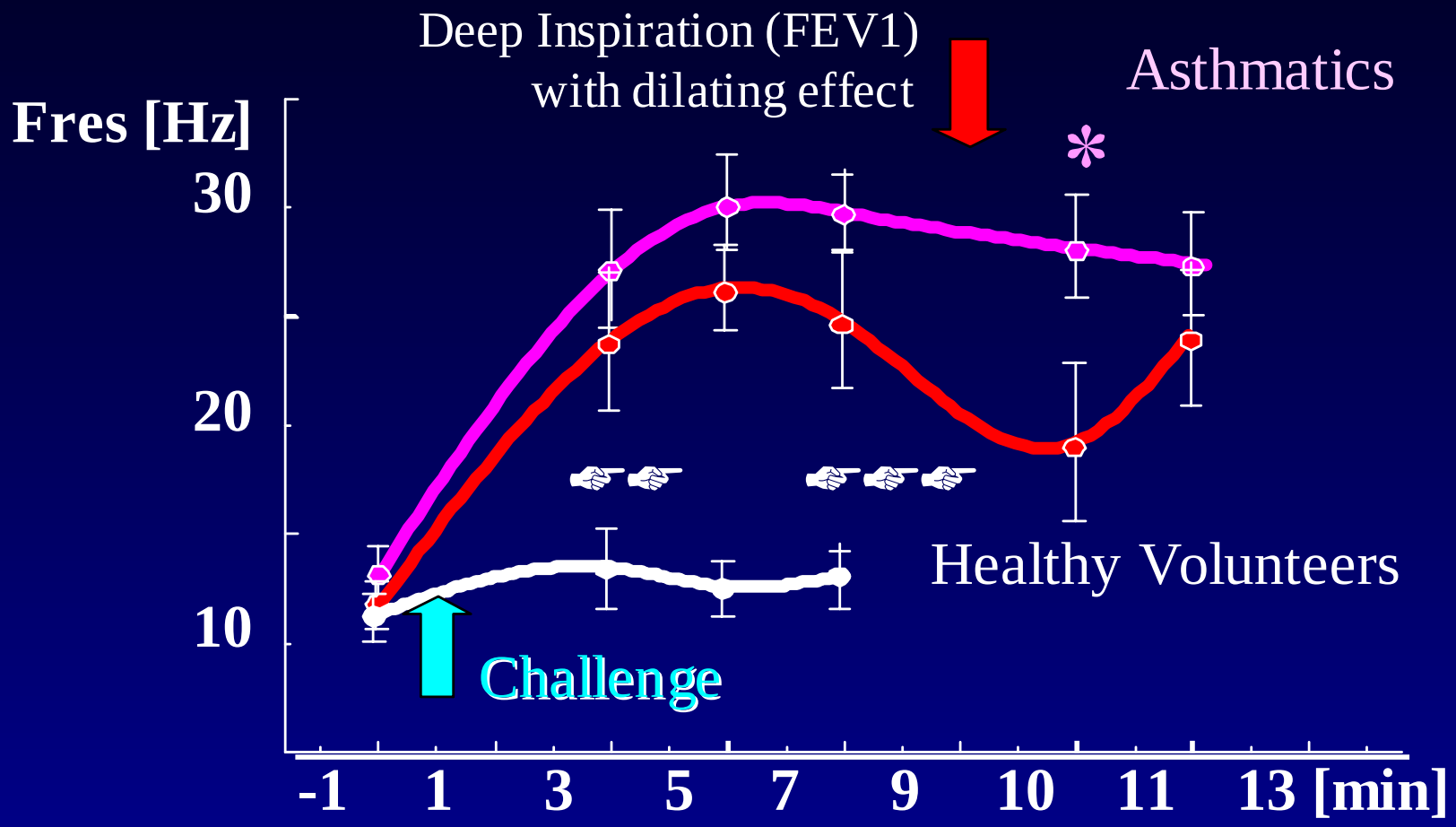
W. Kamin. I. Bieber, H. Trübel (1995)

Extra Thoracic Stenosis



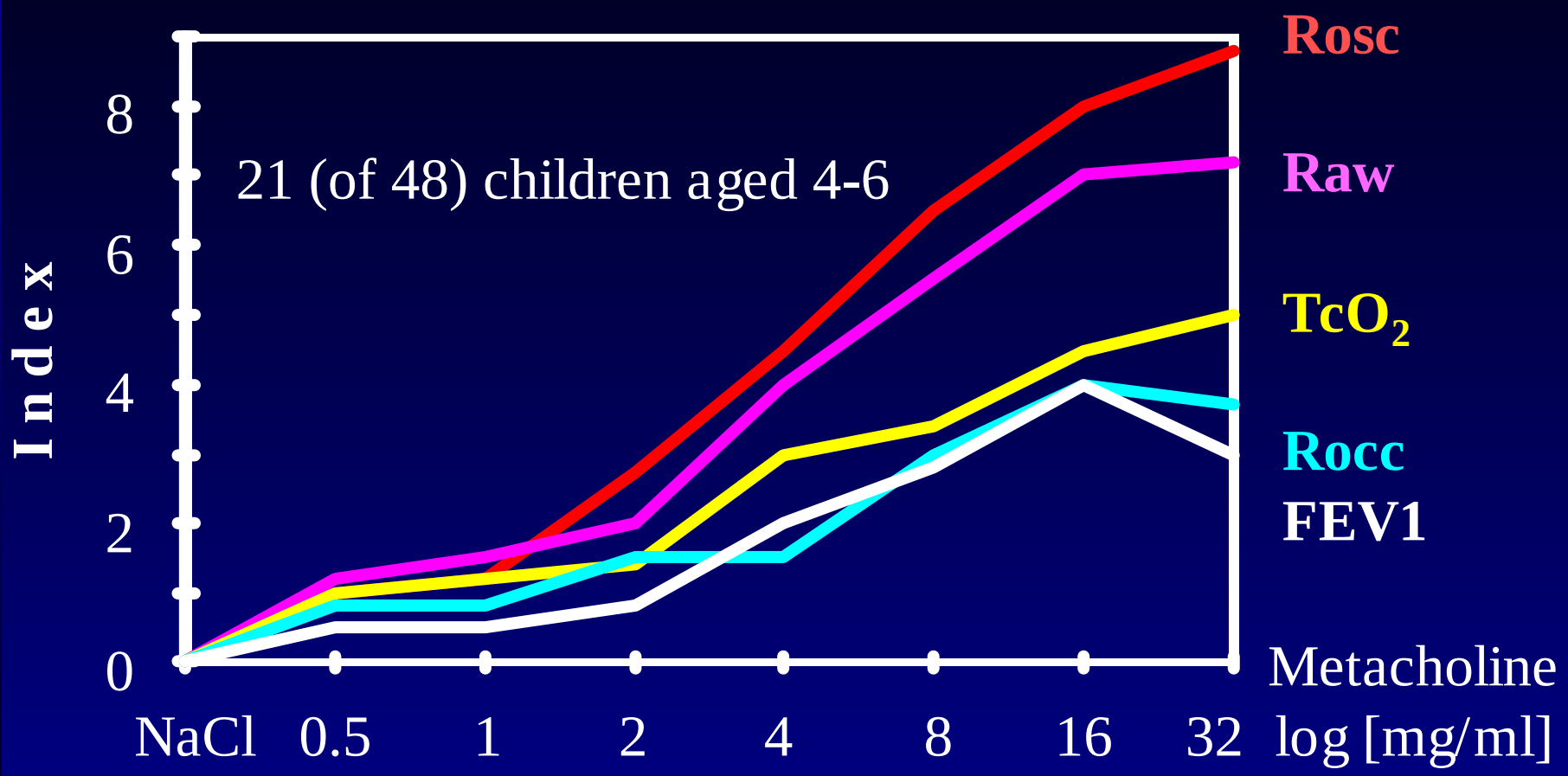
M. Hoster, E. Schlenker, K.-H. Rühle, Ambrock (1996)

Isocapnic Hyperventilation of Cold Air



B. Schmekel, H.J. Smith (1997)

Metacholine Provocation

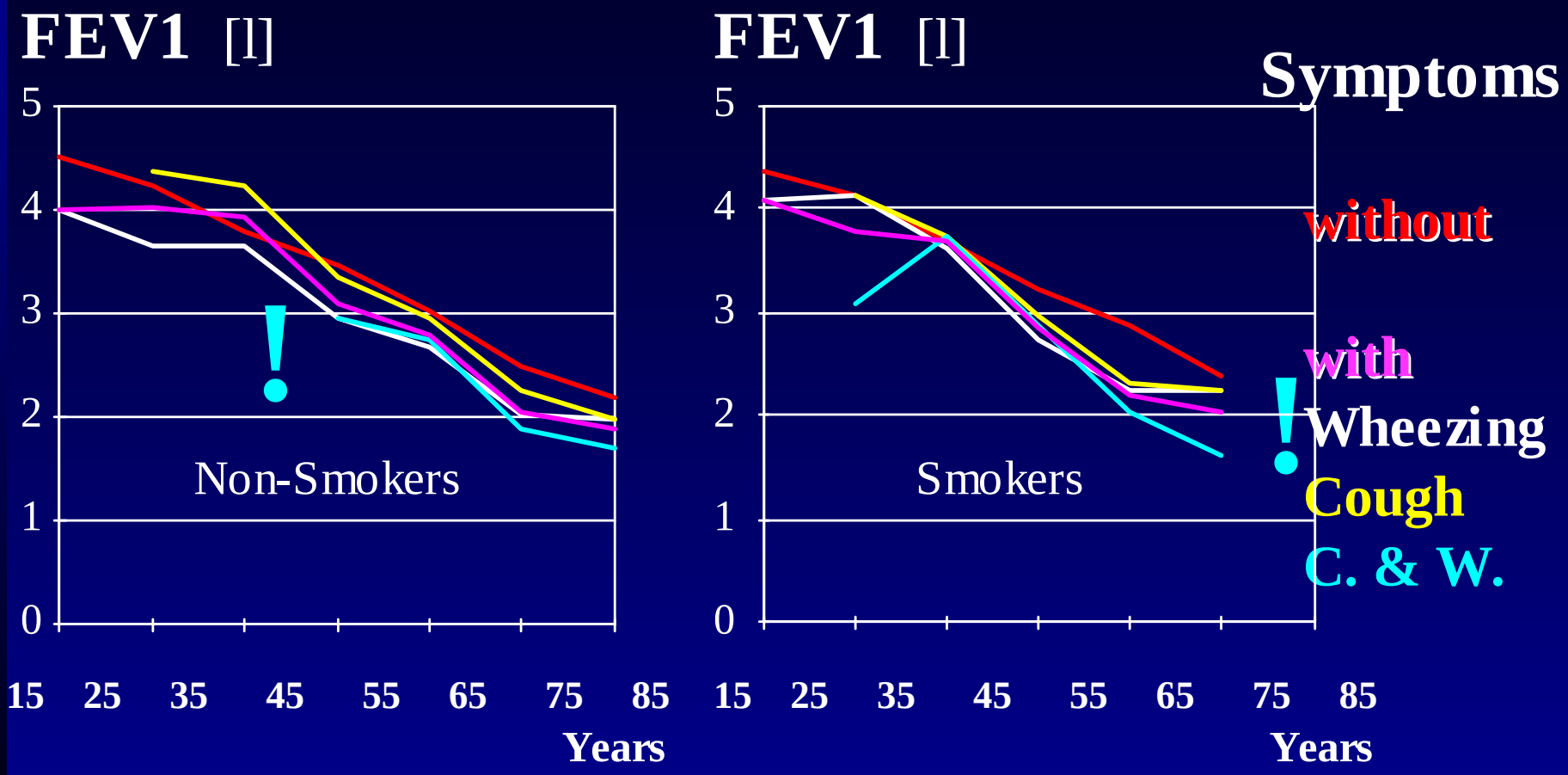


B. Klug, H. Bisgaard, Copenhagen (1996)

Comparison of FEV1

Male Non-Smokers - Smokers

(3.500 each, Pneumobile, Portugal)

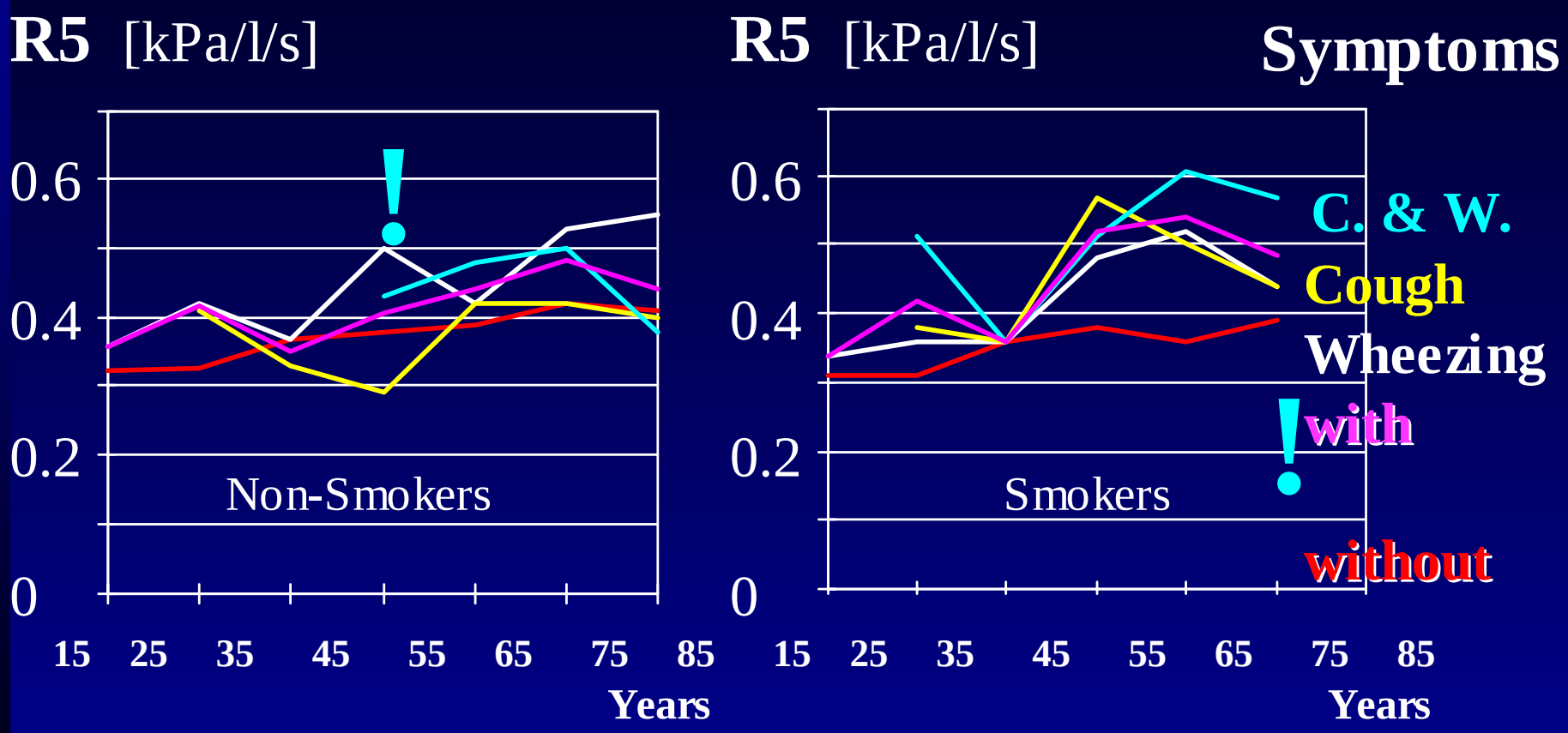


A. Paes Cardoso, R. Ferreira, Portugal, (1997)

Comparison of R5

Male Non-Smokers - Smokers

(3.500 each, Pneumobile, Portugal)

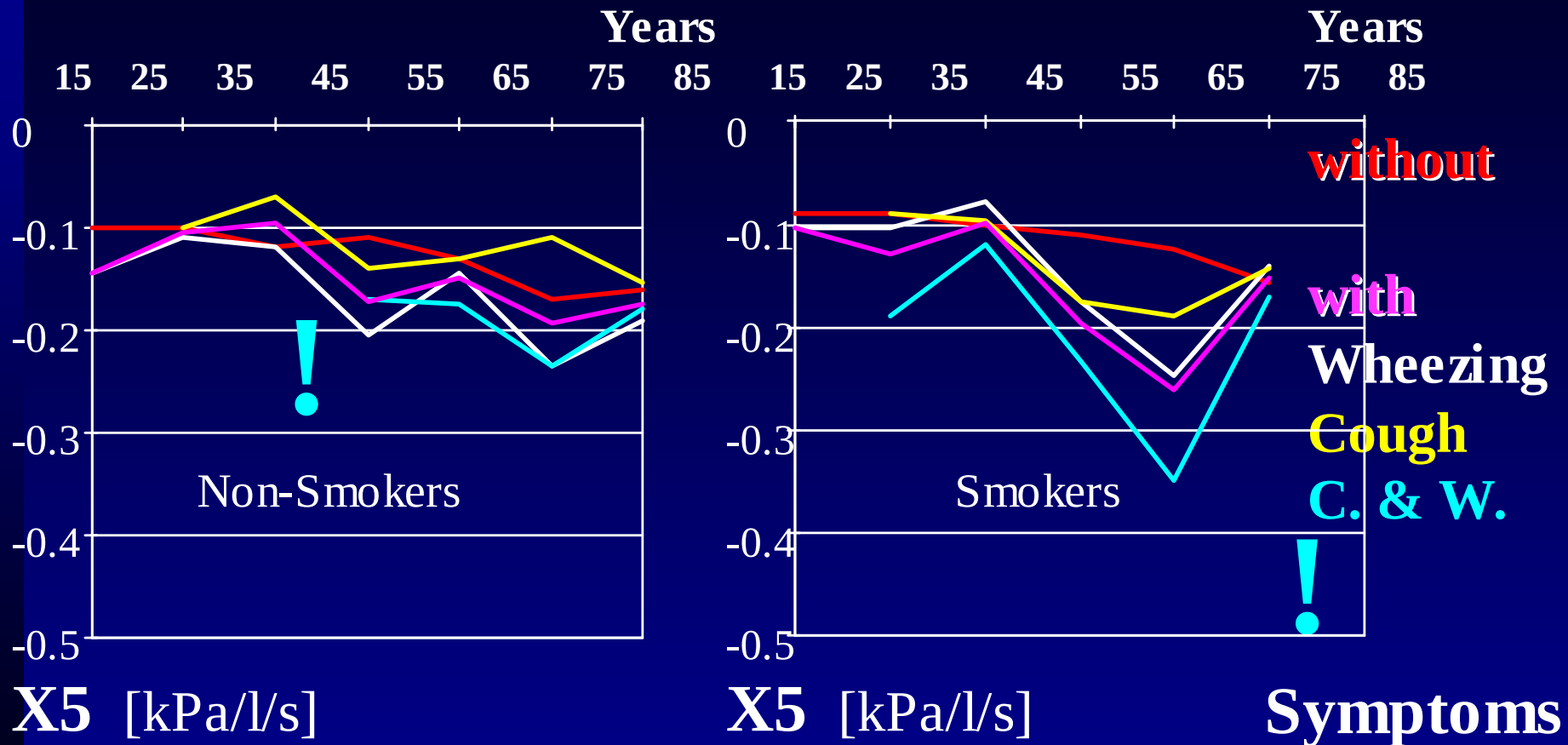


A. Paes Cardoso, R. Ferreira, Portugal, (1997)

Comparison of X5

Male Non-Smokers - Smokers

(3.500 each, Pneumobile, Portugal)



A. Paes Cardoso, R. Ferreira, Portugal, (1997)

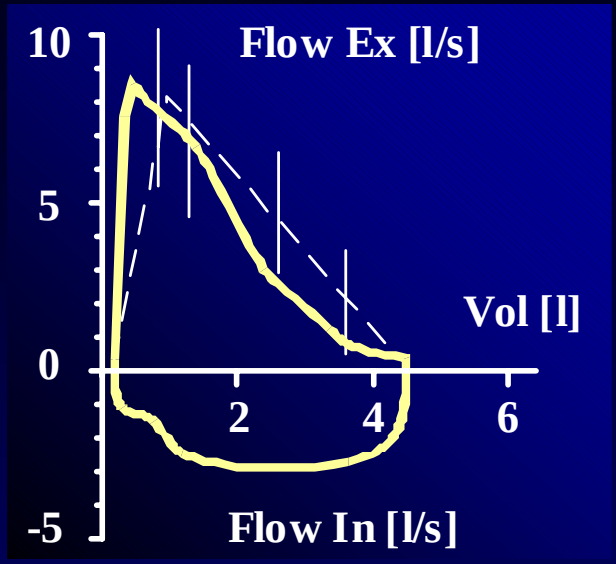
Comparison of Methods

Patient 1: Tumour in Epiglottis

Patient 2: Vocal Cord Dysfunction

- ⇨ Forced Spirometry
- ⇨ Impulse Oscillometry
- ⇨ Body Plethysmography

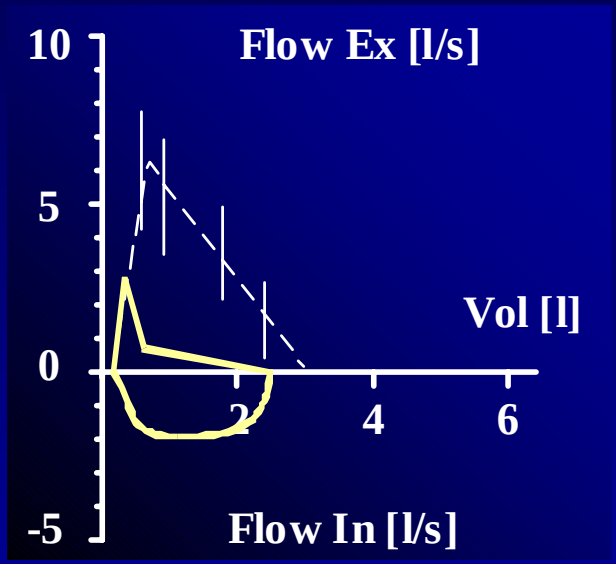
Forced Spirometry



male, 57years, 171cm, 81kg

	pred	act	%pred
FVC...[l]	4.44	4.27	96.1
FEV1..[l]	3.54	3.37	95.0
PEF..[l/s]	8.61	9.28	108
MEF25[l/s]	2.10	2.01	95.8

Diagnosis: normal lung function

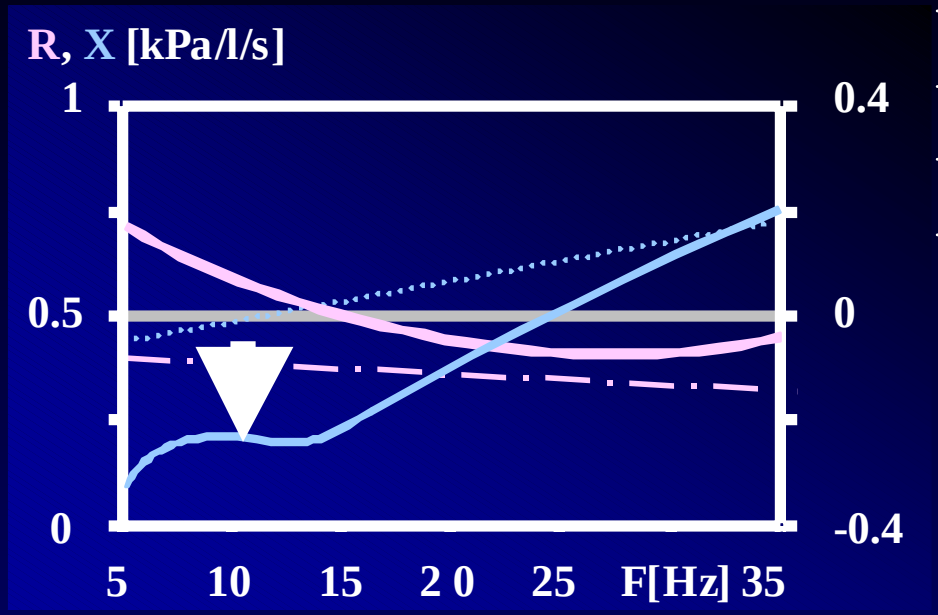


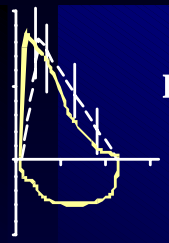
male, 70years, 154cm, 41kg

	pred	act	%pred
FVC...[l]	2.71	2.11	77.8
FEV1..[l]	2.10	0.83	39.3
PEF..[l/s]	6.60	2.42	36.7
MEF25[l/s]	0.86	0.11	12.8

Diagnosis: Asthma (Emphysema)

Impulse Oscillometry



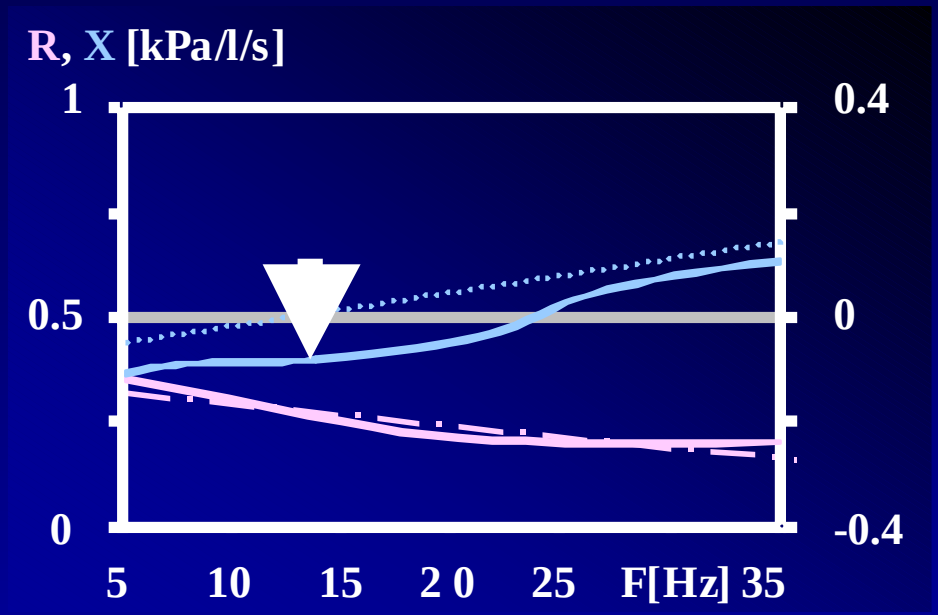


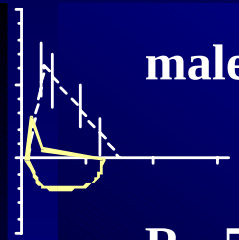
male, 57years, 171cm, 81kg

	pred	act	%pred
R 5Hz	0.39	0.68	174
R 20Hz	0.33	0.41	124
X 5Hz	-0.07	-0.18	-

Interpretation: Obstruction

Stenosis





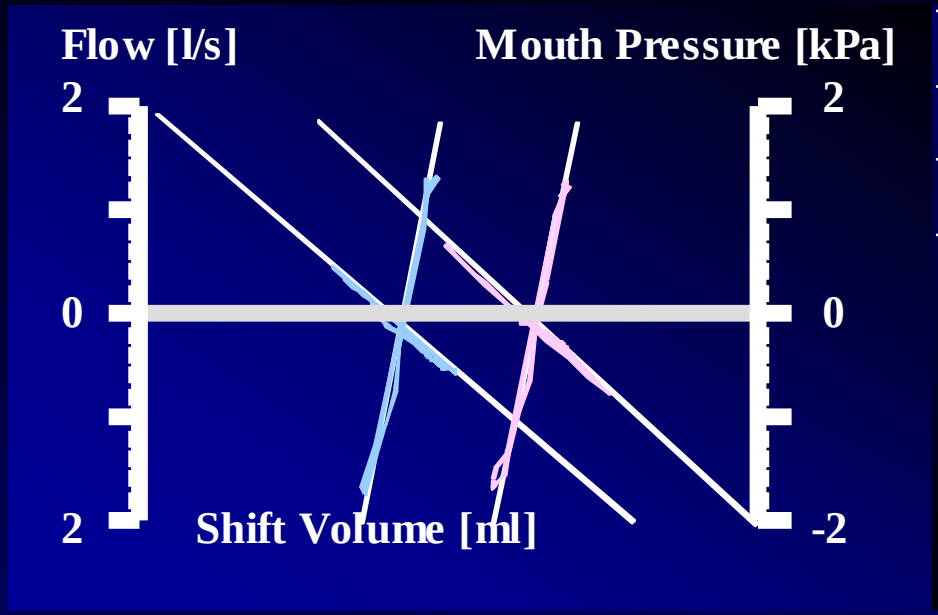
male, 70years, 154cm, 41kg

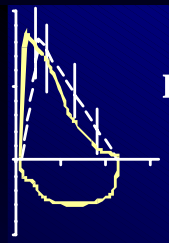
	pred	act	%pred
R 5Hz	0.31	0.39	127
R 20Hz	0.27	0.22	81
X 5Hz	-0.03	-0.10	-

Interpretation: normal Lu Fu

Stenosis

Body Plethysmography

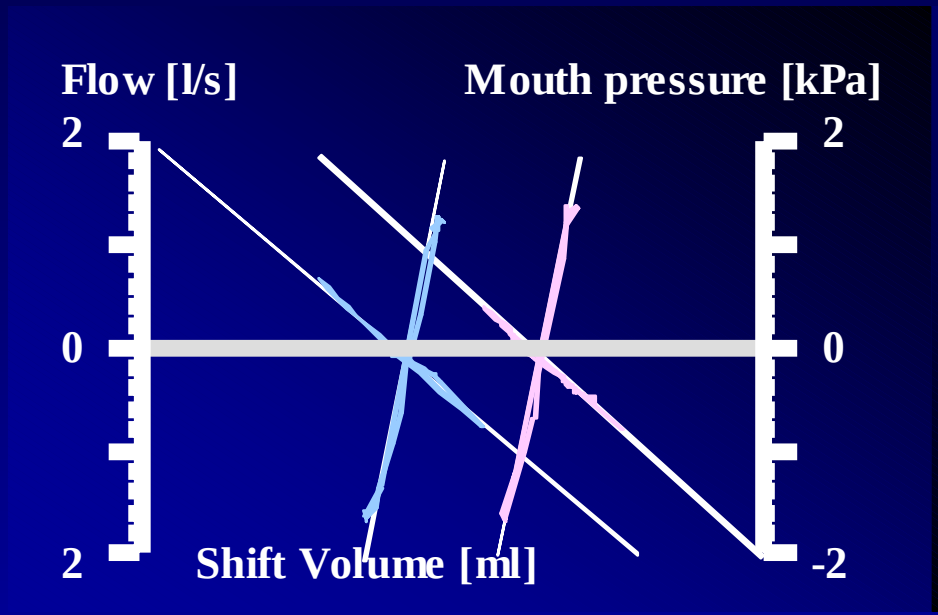


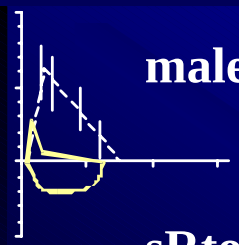


male, 57years, 171cm, 81kg

	pred	act	%pred
Rtot	1.18	1.04	87.9
ITGV	3.43	3.93	115
RV	2.25	3.05	136

Interpretation: normal Lu Fu





male, 70years, 154cm, 41kg

	pred	act	%pred
sRtot	1.18	1.29	109
ITGV	3.14	3.08	98.1
RV	2.33	2.67	112

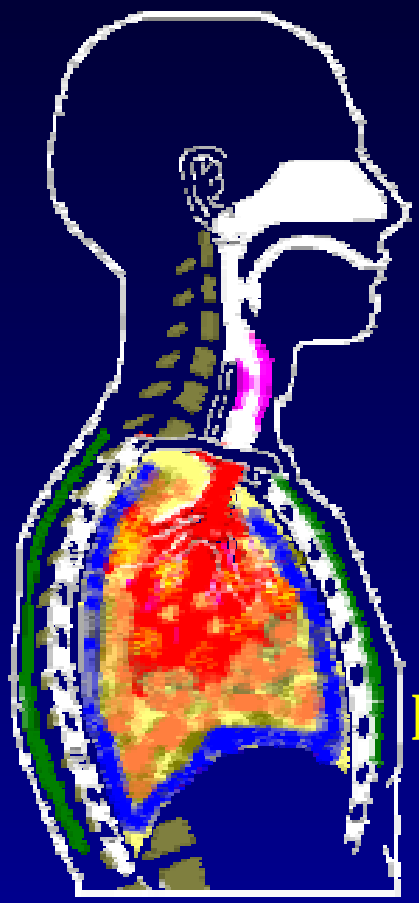
Interpretation: normal Lu Fu

Summary

The complementary use of different lung function tests increases specificity and objectivity of the examination.

Annual Scientific Meetings 2003

Airway Resistance compared to Spirometry

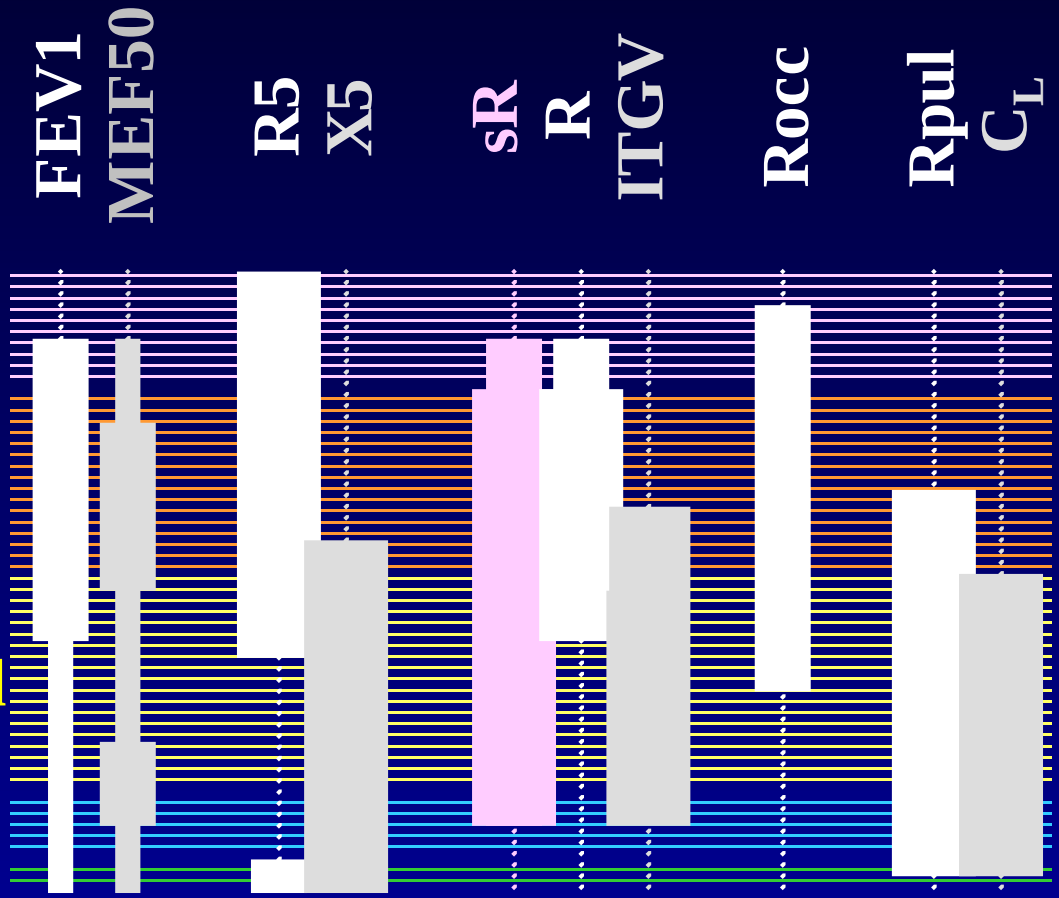


extra thoracic

central

peripheral

pulmonary thoracic



Summary of Important Features of Oscillometry

Specific Parameters based on registration of Mouth Flow V' and Mouth Pressure Pm

⇨ early detection of pulmonary diseases (sensitivity)

⇨ differentiated & objective
- extra thoracic stenoses
- proximal obstruction
- distal volumoreactive changes (R, C, Thorax)
- trapped air

⇨ simple determination of bronchial hyperreactivity

⇨ minimal co-operation (patient, assistant)

Spirometry & Oscillometry

Screening (Spiro-Oscillometry)

Paediatric- , Occupat.-, Geriatr.- Medicine, Pneumology

age range: 3 - 5 - ∞ **time: 6 min + 30 s**

Spirometry	Oscillometry
FEV1, PEF	R5, R20
FEF 75	X5
VC	Z5=f (VC)

Additional Features:

- functional situation of upper airways
- degree of proximal and distal obstruction
- trapped air (collapse)
- determination of bronchial hyperreactivity

OverRead Service in USA

The OverRead Department is a laboratory, staffed by highly qualified exercise physiologists and respiratory therapists, under the direction of skilled medical staff, who analyze and scores ***IOS/Forced Spirometry*** tests.

Tests are sent to a secure and confidential OverRead website where they are analyzed and scored. A report is then generated and transmitted back to the clinician.

OverReads are also useful for physicians who own an instrument and need a fast method of reviewing test data, or if they want a second opinion from an expert.

Diffusion & Oscillometry

Pneumology (optimal combination)

age range: 3 - 5 - ∞ **time 15 min + 1 min**

Spirometry	Diffusion	Oscillometry
FEV1, PEF	FRC	R5, R20
MEF 25	RV, TLC	X5
VC	T_{LCO}	Z5=f (VC)

Additional Features:

- functional situation of upper airways
- degree of proximal obstruction
- degree of distal, volumoreactive obstruction
- trapped air (collapse)
- determination of bronchial hyperreactivity

Features of Impulse Oscillometry 1

- Determination of differentiated and specific **input impedance parameters** (R5, R20, X5, Fres, Z5)
- Because of the artificial test signal (impulse) **almost independent of co-operation** and therefore especially suited for use in **paediatrics** (down to 2 years of age), **geriatrics, occupational medicine** as well as additional special applications
- Assessment and differentiation of lung function in **resting condition**
- Sensitive determination of obstruction

Features of Impulse Oscillometry 2

- Differentiation between **proximal** (central airways) and **distal** (peripheral airways) **components** of pulmonary obstruction.
- Sensitive detection and differentiation of **extra thoracic changes**.
- Save method for differentiation between **respiratory collapse** and obstruction.
- Airway impedance via complete **VC-manoeuvre** to answer further clinical questions.

Features of Impulse Oscillometry 3

- Recorded parameters provide valuable information for **early diagnosis** of pulmonary diseases and **distribution analysis**.
- Automatic **graphic interpretation** of measurement on the basis of a lung-thorax model for improved patient information.
- **Breath by breath analysis** for determination of differentiated flow- and volume dependent, in- and expiratory parameters.

Attributes of Impulse Oscillometry

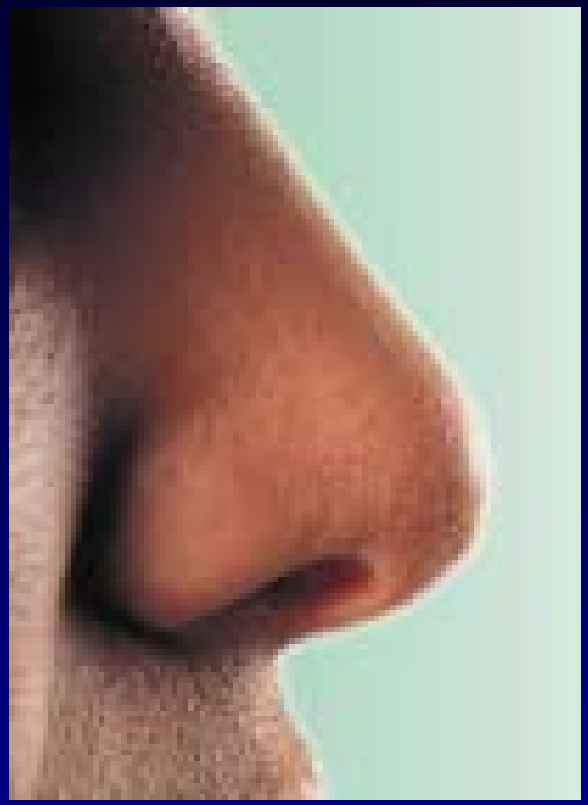
- Impulse test signal provides **extreme broad spectrum of frequencies** (>0 Hz - 100 Hz) for improved differential diagnostics.
- **Quick** (30 s recording time), **non invasive**, **objective** and **differentiated** determination of respiratory input impedance.
- **High resolution** with maximal 10 measurements per second.
- Low technical expenditure and **no costs for disposables**.
- **Portable** when used with a notebook computer.

Limits of Oscillometry

- Detection and differentiation of **Restrictive Diseases** only in higher degree of disease or with VC-manoeuvre.
- A further **differentiation between distal obstruction and distal restriction** becomes possible with additional determination of VC (Spirometry) or TLC (Body Plethysmography).

Rhinomanometry

Rhinomanometry -Indications



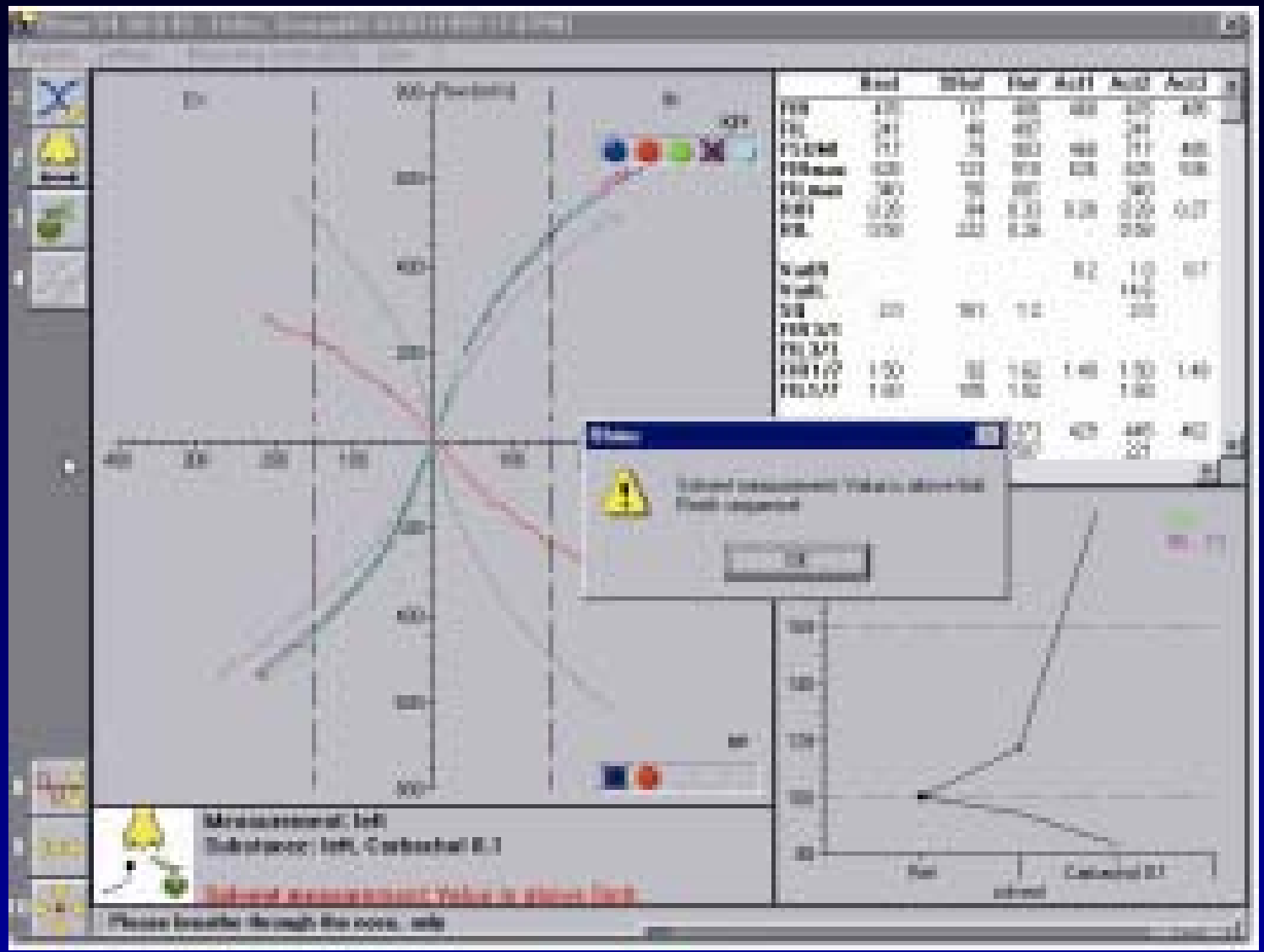
- confirmation of clinical topicality of an allergen (check of rhinitis)

- pre-post-measurements on surgery

- bronchial provocation is contraindicated

- objectivization of nasal flow

Rhinomanometry - Application



Assessment of Reaction

- Determination of obstruction, secretion, irritation

- Control measurement of threshold values: R +30%, V‘ –20%

- Allergen response: ΔR > 60%, -ΔV‘ > 40%

- Take care: possible late response after 4 - 8 h

In case of doubt about normal reactions:
non-specific provocation recommended