הדסה, בית חולים לילדים
Hadassah Children's Hospital

מרכז רפואי אוניברסיטאי הדסה
The Hadassah Medical Center

Multiple breath washout: not only LCI

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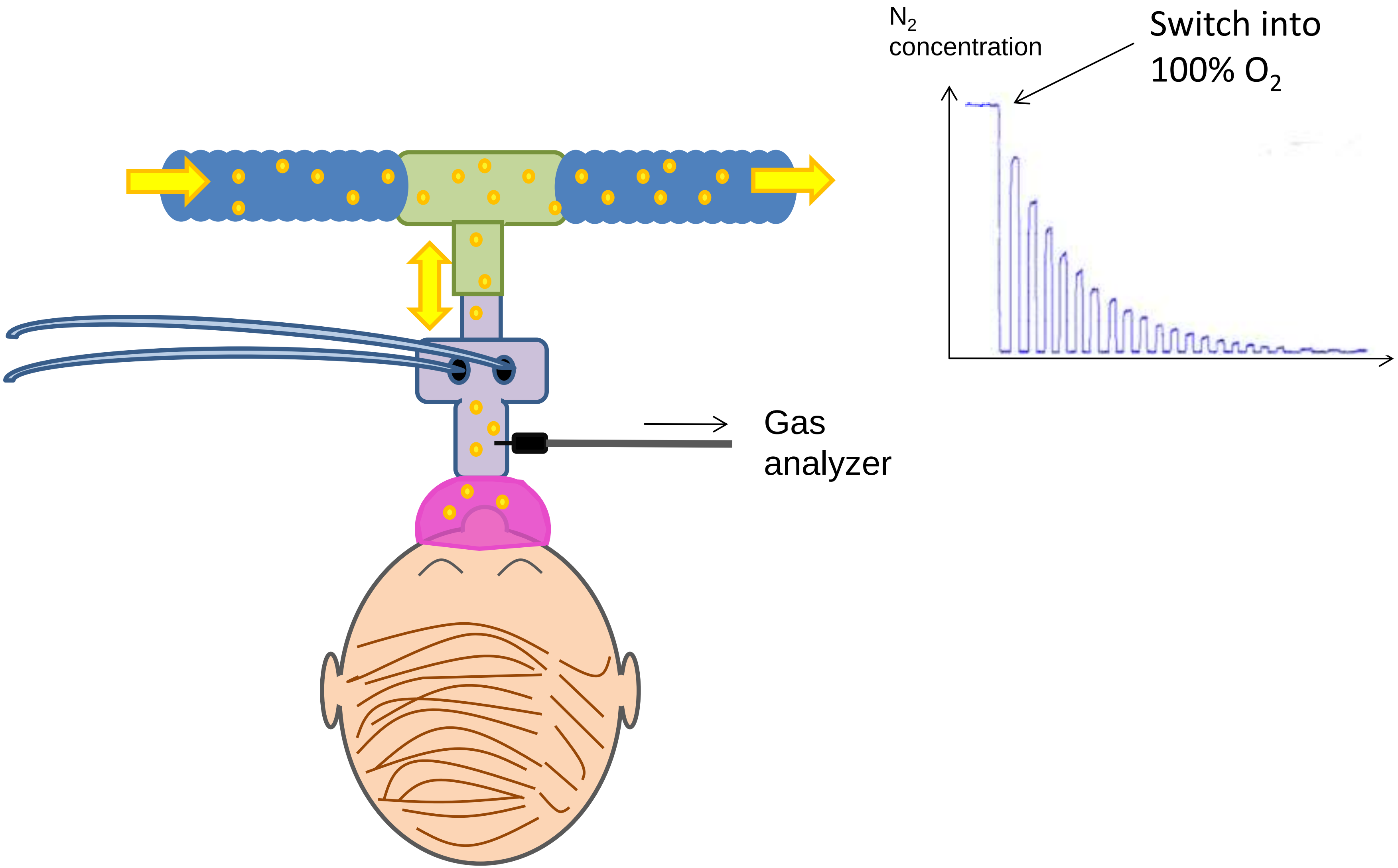
Pediatric Pulmonology and CF Center
Hadassah Hebrew University Medical Center

Multiple Breath N_2 Washout



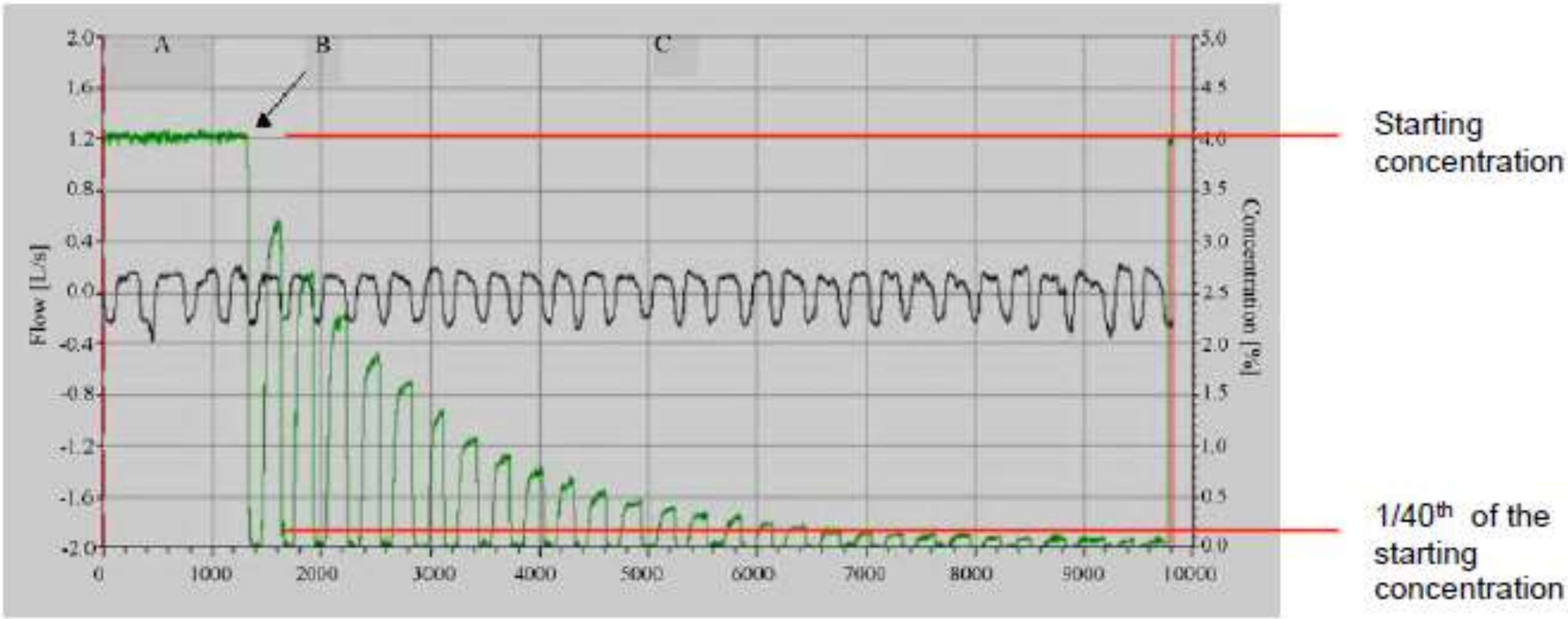
MBW - **indices** of ventilation

- LCI
- Phase III Slope analysis
- Lung compartment assessment

And many more…………

(Moments ratio, Nitrogen clearance index, Mixing ratio, Becklake Index, Mean dilution number, Pulmonary clearance Delay, PCD for moment ratio, Curvilinearity, Efficiency, Alveolar mean dilution Number, Alveolar lung clearance index, Inspired gas distribution index, Multiple-breath alveolar mixing inefficiency %)

Lung clearance index

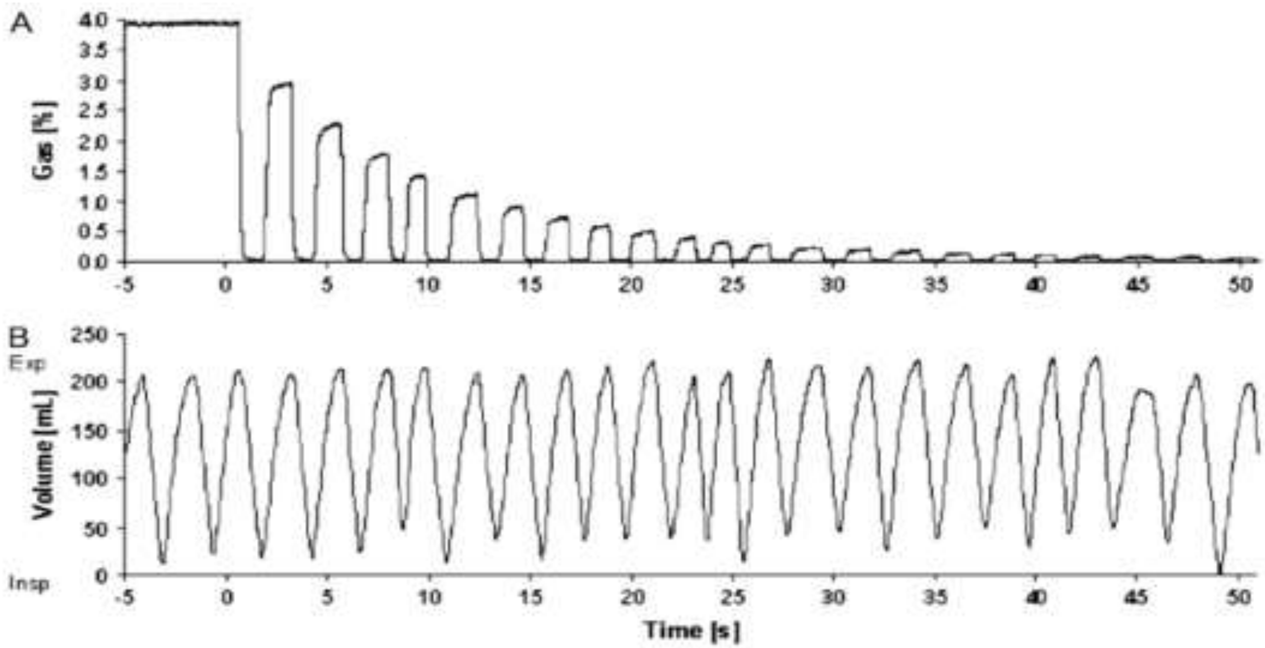


$$LCI = \frac{Cumulative\ Volume\ Expired\ air}{FRC}$$

$$FRC = \frac{\text{Net Volume of } \mathrm{SF_6} \text{ exhaled during washout}}{F_{SF6_{initial}} - F_{SF6_{final}}}$$

LCI

- LCI is the number of times the FRC must be turned over in order to wash out the tracer.



New analytical approaches

the Paiva Engel lung models

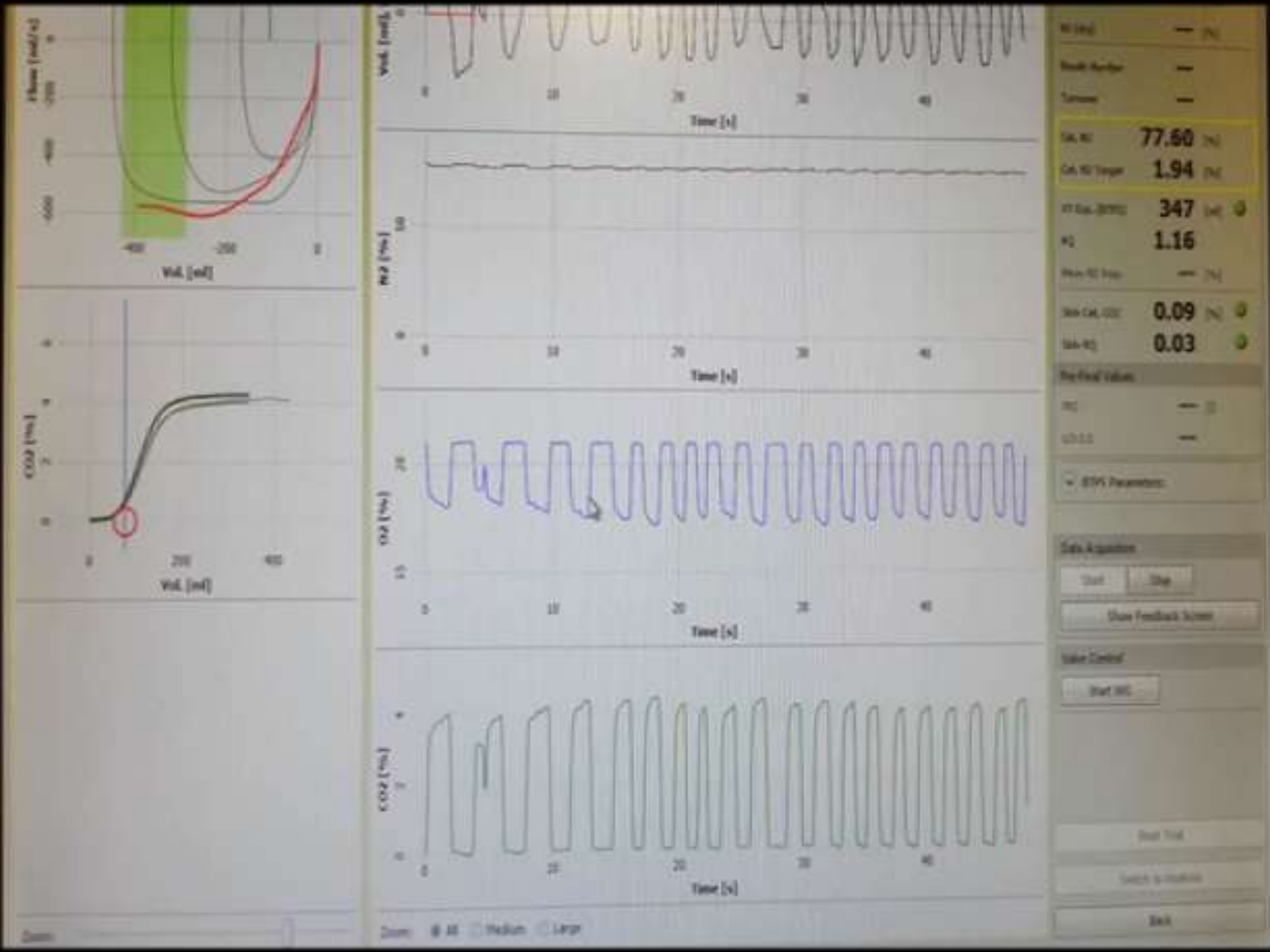
MBW

Sn_{III} analysis

S_{cond}, S_{acin}

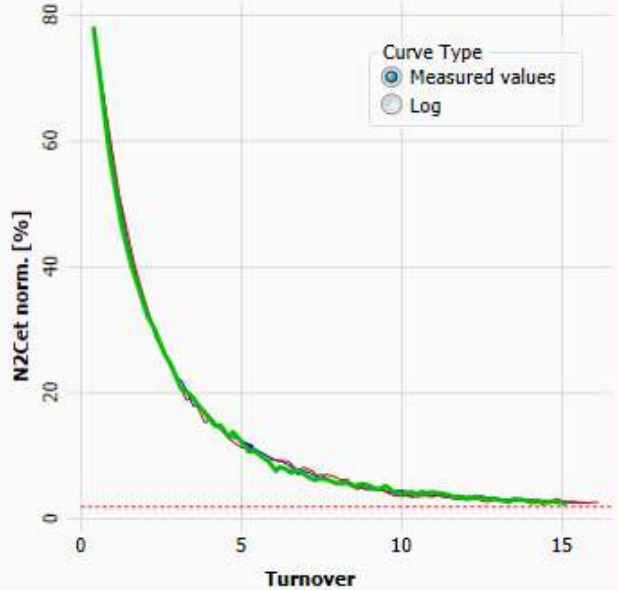
Paiva M, Engel LA. Gas mixing in the lung periphery. In: Chang HK, Paiva M, editors. Respiratory physiology: an analytical approach. New York: Marcel Dekker; 1989. pp. 245–276.

Crawford AB, Makowska M, Paiva M, Engel LA. Convection-and diffusion–dependent ventilation maldistribution in normal subject. J Appl Physiol 1985;59:838–846.

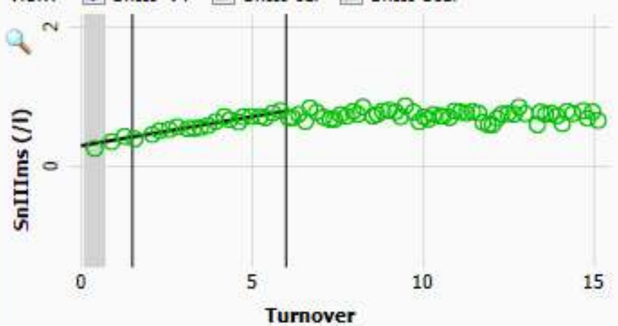


Vol. [ml]
Time [s]
N2 [%]
O2 [%]
CO2 [%]
77.60
1.94
347
1.16
0.09
0.03
Data Acquisition
Show Feedback Screen
Valve Control
Back
Zoom:
All
Medium
Large

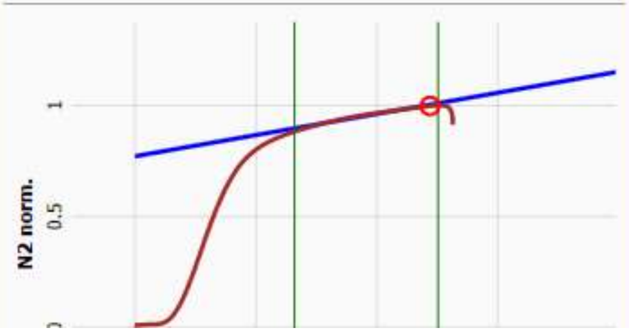
Y-axis type: FRC N2Cet norm.



View: SnIII*VT SnIII cdi SnIII dcdi



X-axis type: Breath No. Turnover



View: Trials Prephase breaths Washout breaths

Results

Summary	FRC [l]	LCI-2.5	LCI-5	Scond*VT [l]	Sacin*VT [l]	Pacin*VT [l]	M1/M0	M2/M0	N2Cet norm. @
Super-imposed	**2.224**	**15.73**	**9.34**	**0.070**	**0.275**	**0.401**	**3.32**	**24.47**	**8.78**
Predicted	—	*6.58*	*4.87*	*0.017*	*0.059*	*0.071*	*1.46*	*4.16*	*2.92*
% Predicted	—	*239*	*192*	*401*	*462*	*565*	*228*	*588*	*301*
Z-Score	—	*14.9*	*20.3*	*6.9*	*5.1*	*15.7*	*15.1*	*13.6*	*22.6*
SD	0.174	0.60	0.38	0.013	0.046	0.101	0.06	1.41	0.68
CV%	7.8	3.8	4.1	18.6	16.6	25.2	1.9	5.8	7.8

Trials

Time	Washout time [s]	Excluded for Superimposed/ SD calculation	Trial #	FRC [l]	LCI-2.5	LCI-5	Scond*VT [l]	Sacin*VT [l]
12:30:18	218.3		**Trial 1**	2.049	16.32	8.96	0.057	0.320
12:39:47	199.4		**Trial 2**	2.398	15.13	9.72	0.083	0.229
12:39:47	**218.3**		**Super-imposed**	**2.224**	**15.73**	**9.34**	**0.070**	**0.275**

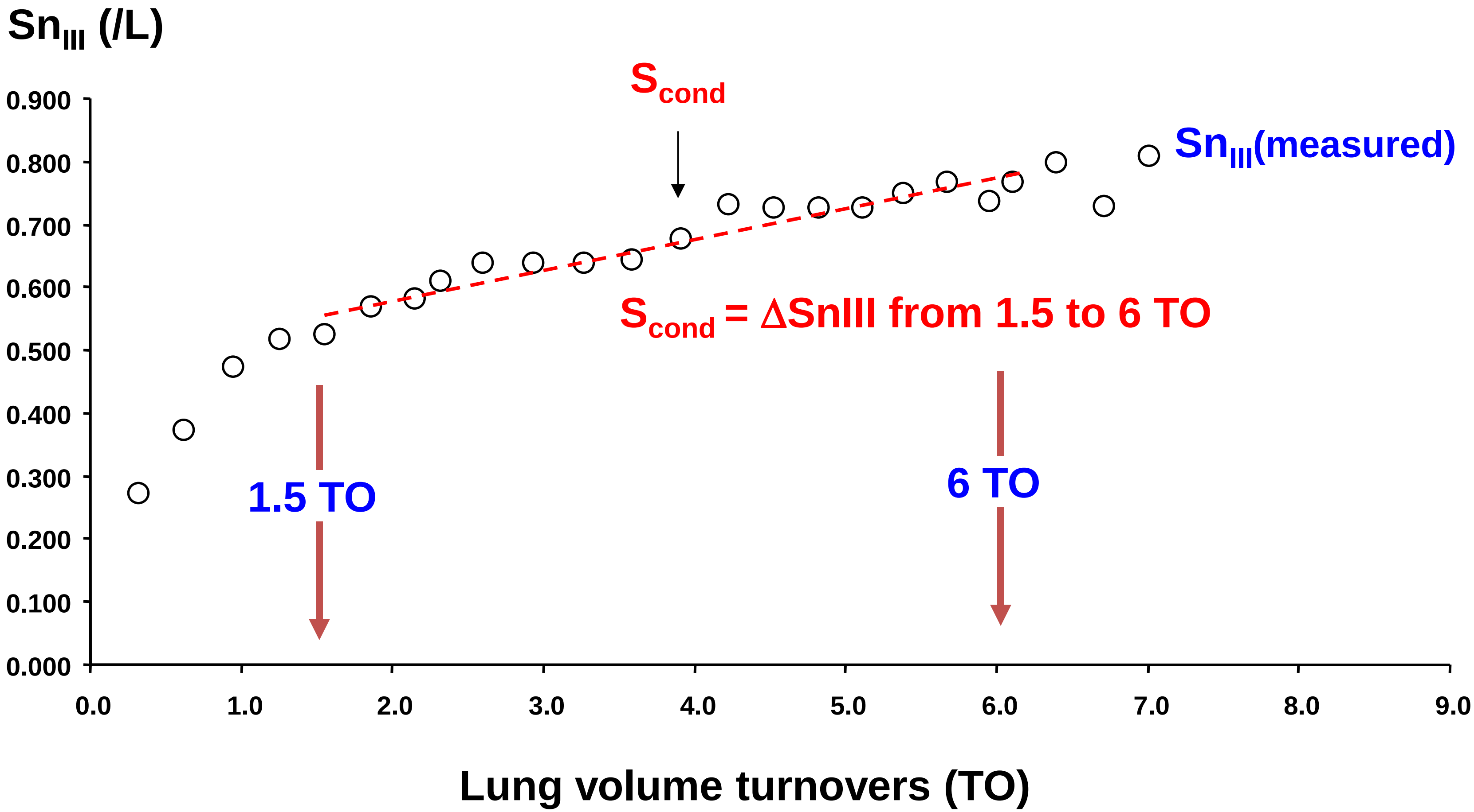
Prephase breaths

Washout breaths

Breath #	Excluded for Sacin/Scond calculation	FRC [l]	N2Cet norm. [%]	TO	CEV [l]	CEV-DS [l]	SnIIIms*VT	CumVolN2Netto [ml]
1		1.192	78.202	0.39	0.53	0.47	0.262	208
2		0.973	57.847	0.89	0.98	0.87	0.358	330
3		0.958	46.627	1.27	1.38	1.21	0.432	412
4		**1.034**	**40.355**	**1.56**	**1.84**	**1.62**	**0.398**	**495**
5	✓	**0.960**	**31.336**	**1.96**	**2.16**	**1.88**	**0.708**	**531**
6		**1.092**	**32.142**	**2.08**	**2.60**	**2.27**	**0.461**	**594**
7		**1.202**	**30.183**	**2.30**	**3.15**	**2.76**	**0.519**	**671**
8		**1.235**	**26.460**	**2.57**	**3.62**	**3.18**	**0.533**	**725**
9		**1.305**	**24.488**	**2.81**	**4.16**	**3.66**	**0.572**	**786**
10		**1.313**	**20.672**	**3.12**	**4.66**	**4.10**	**0.546**	**831**

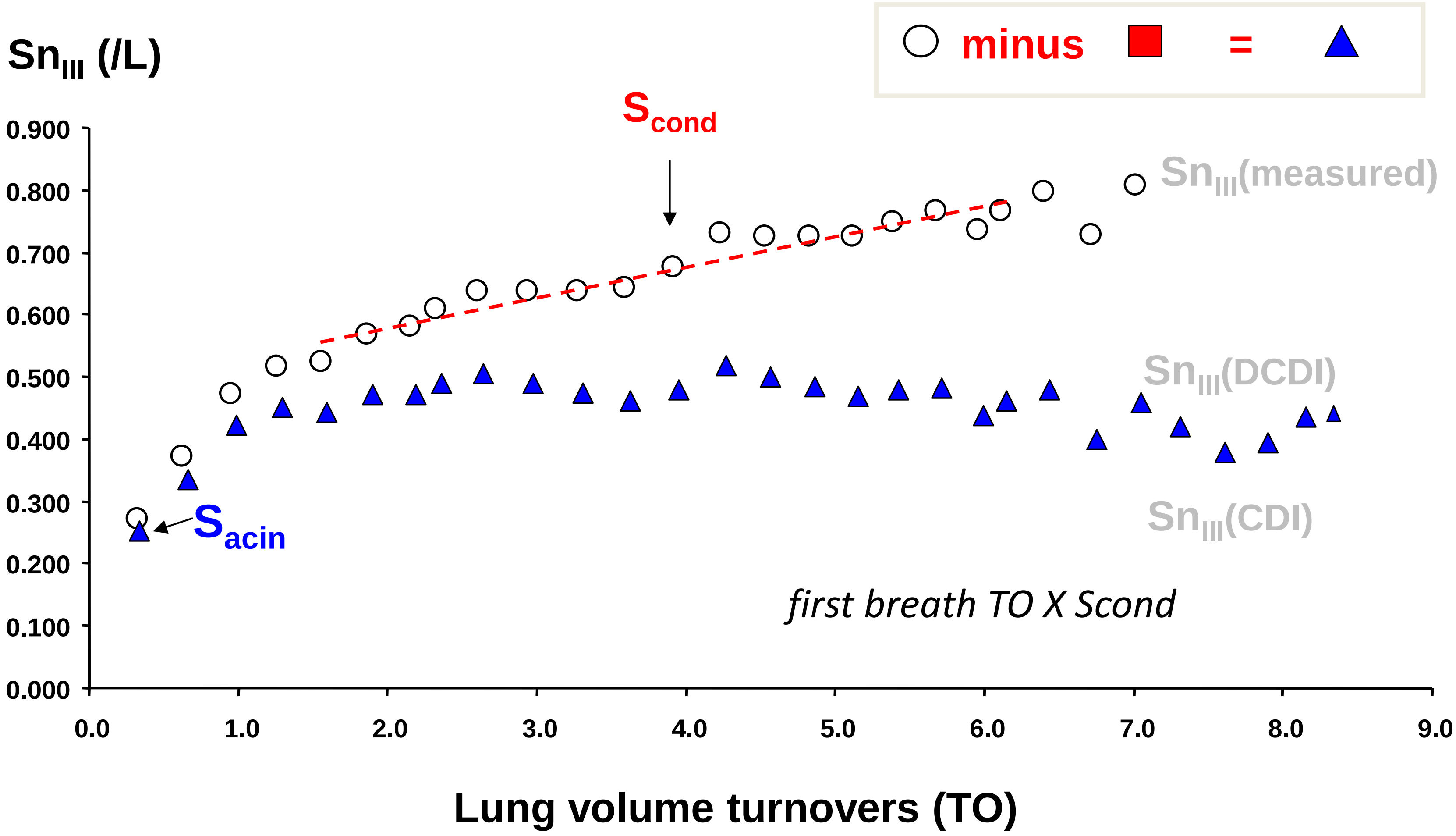
Sn_{III} analysis

progression of the concentration normalized phase III slopes



Sn_{III} analysis

progression of the concentration normalized phase III slopes



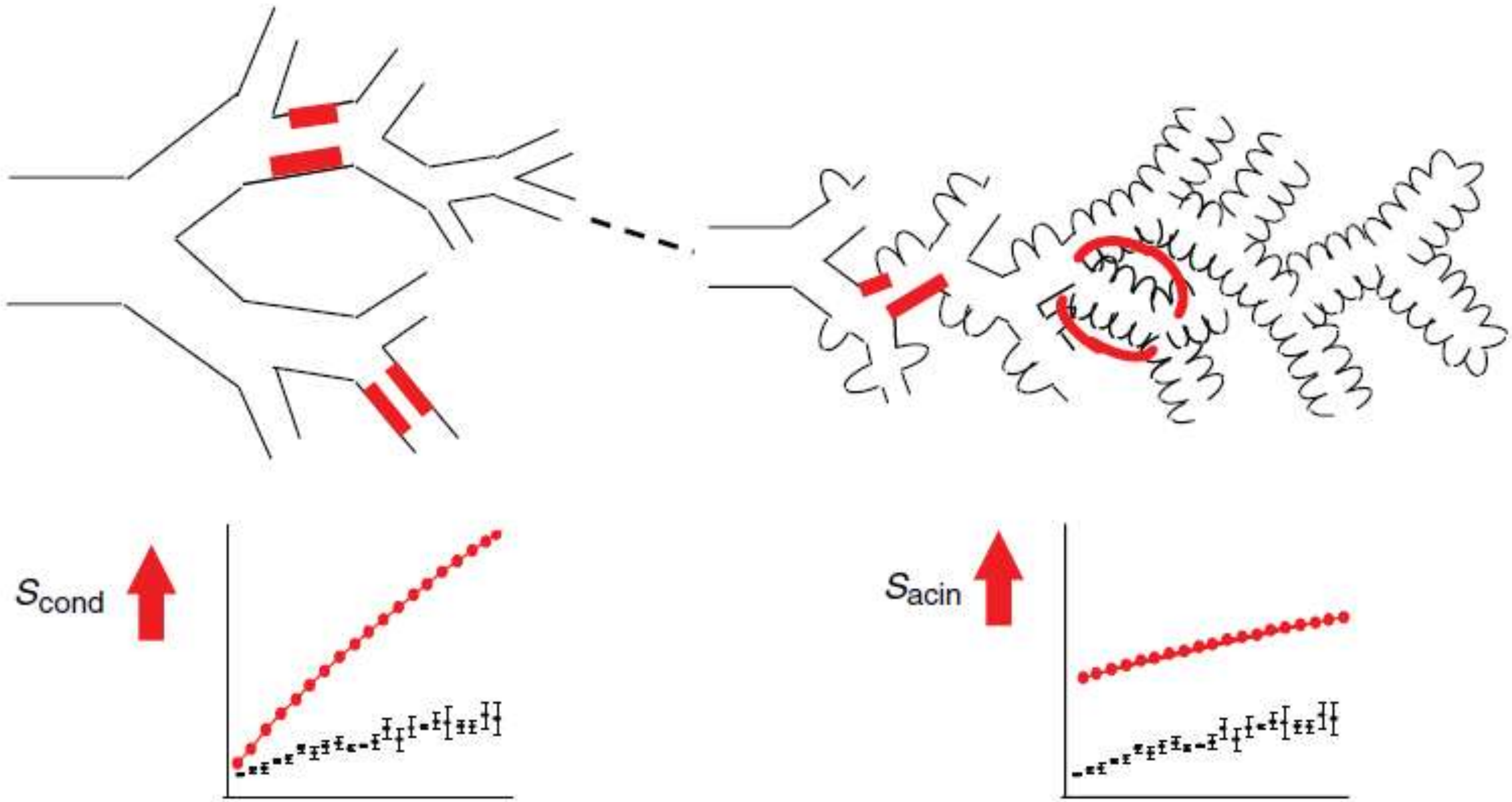
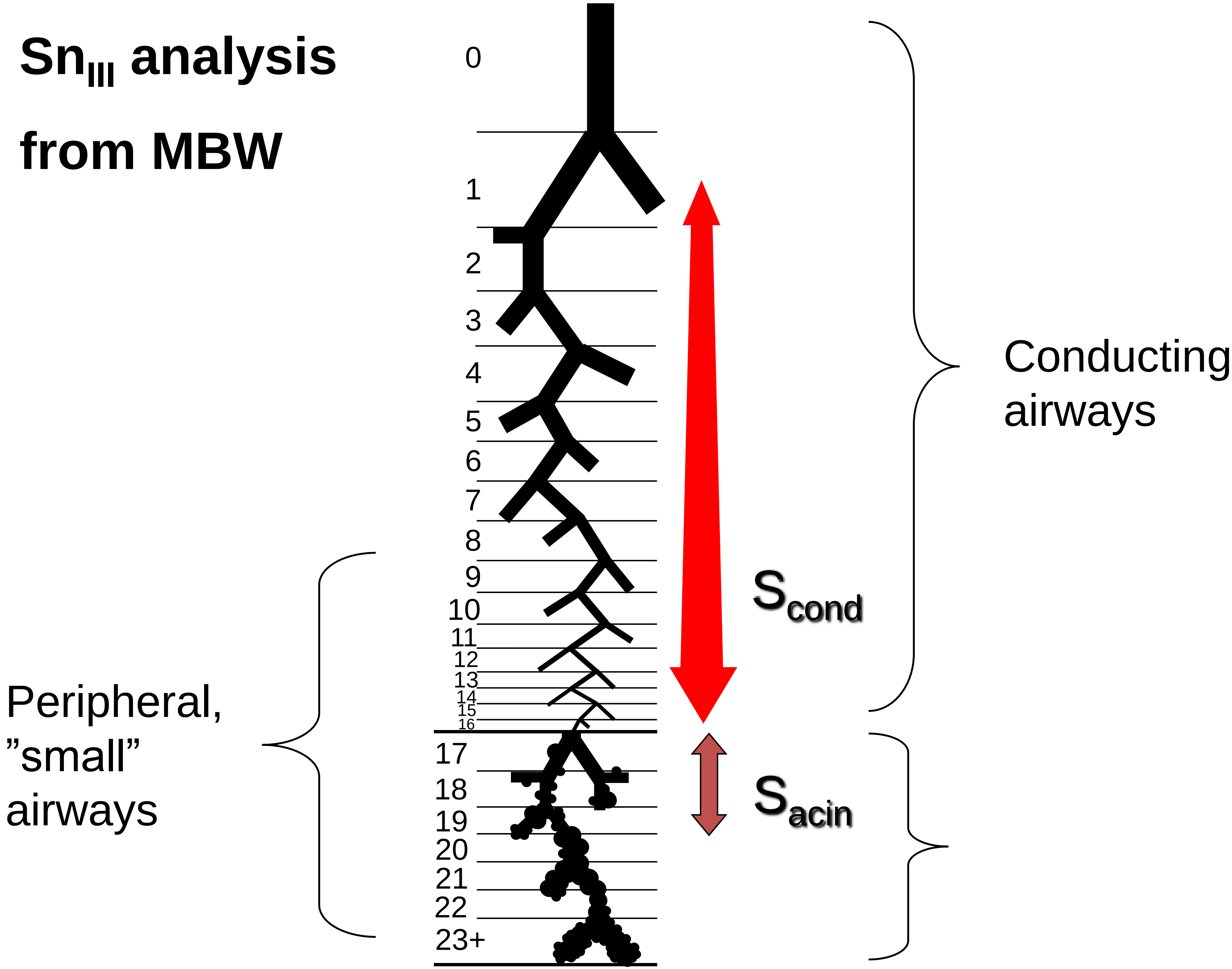


Figure 16 Schematic representation of predicted changes of normalized phase III slopes versus lung turnover or breath number and corresponding changes in MBW indices S_{acin} and S_{cond}, following structural alterations in the proximal or the peripheral lung.

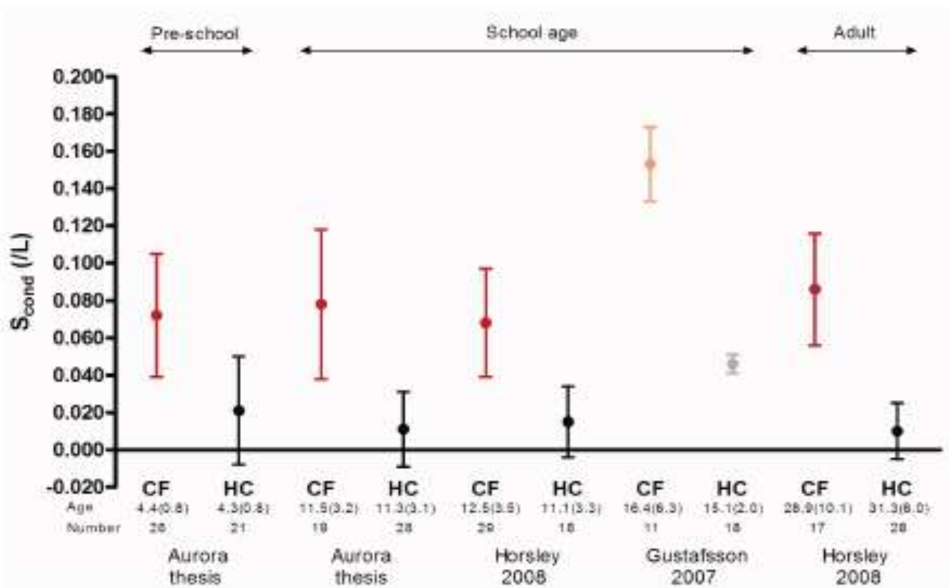
Verbanck S., Paiva M . Compr Physiol 1:809-834, 2011.

Sn_{III} analysis from MBW

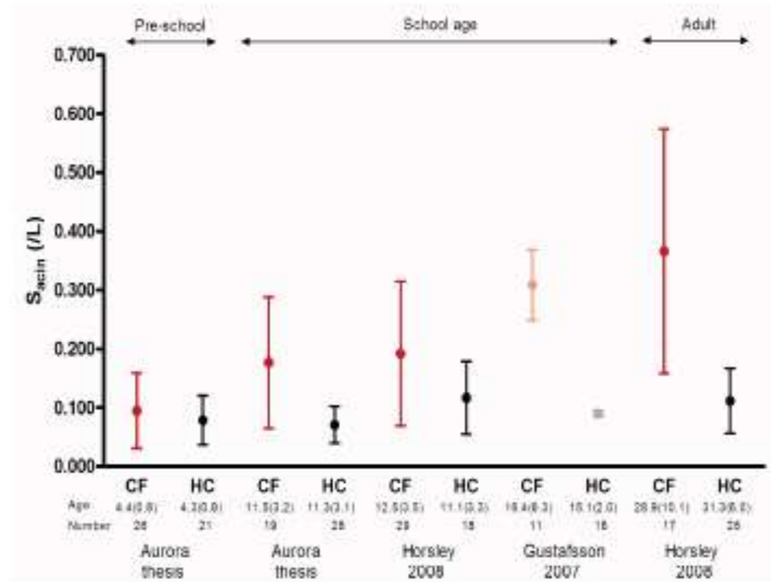


MBW Sn_{III} analysis in CF

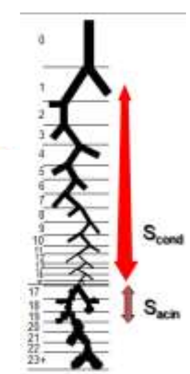
S_{cond} abnormality from early age



S_{acin} abnormality evolves over time

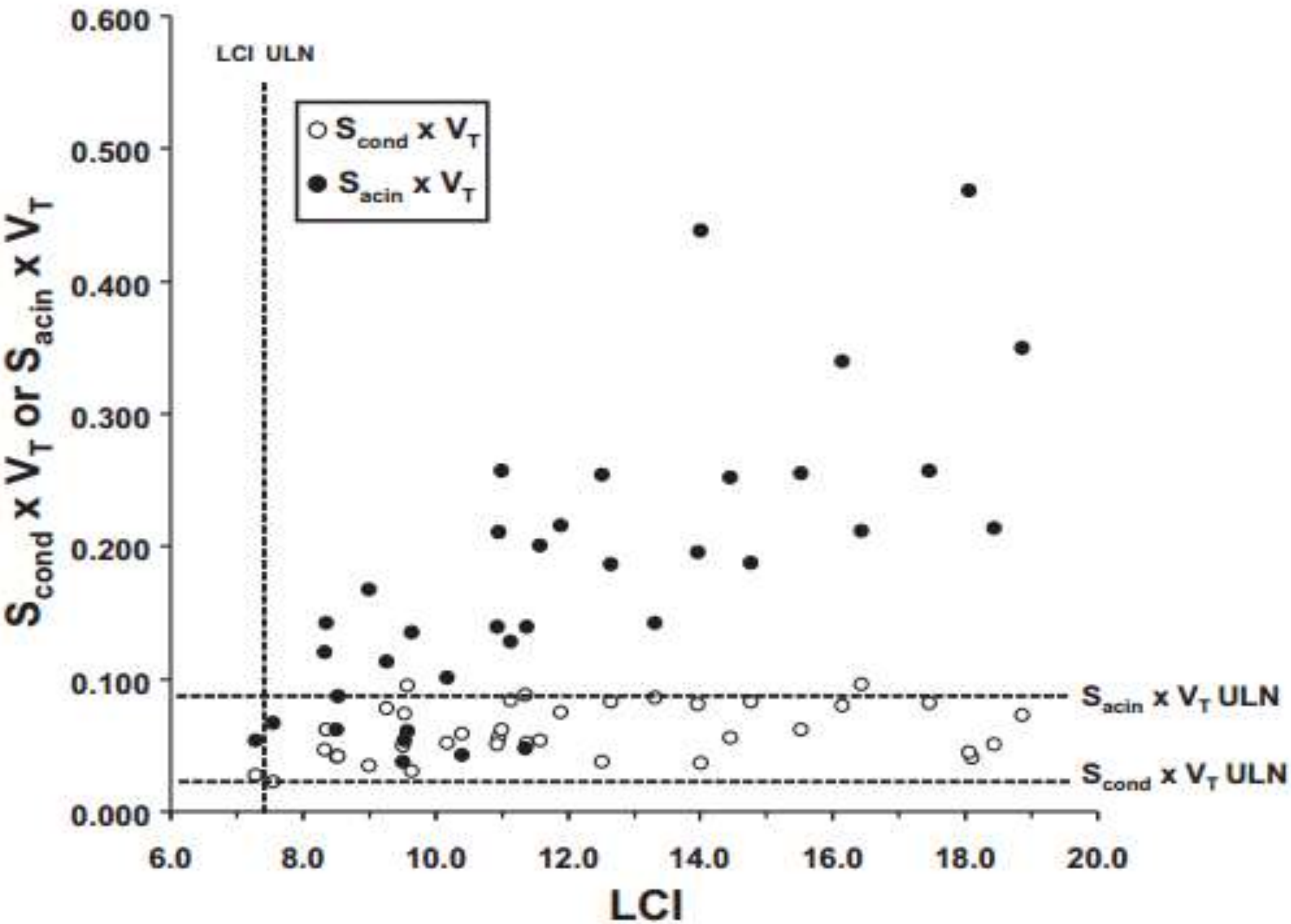


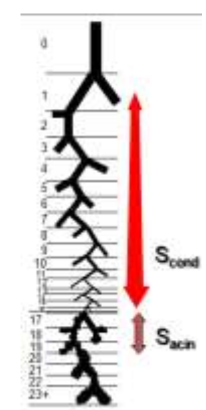
Data displayed as Mean with SD bars



Robinson P. D. Eur Respir Mon, 2010, 47, 87–104.

Relationships between LCI and SnIII indices



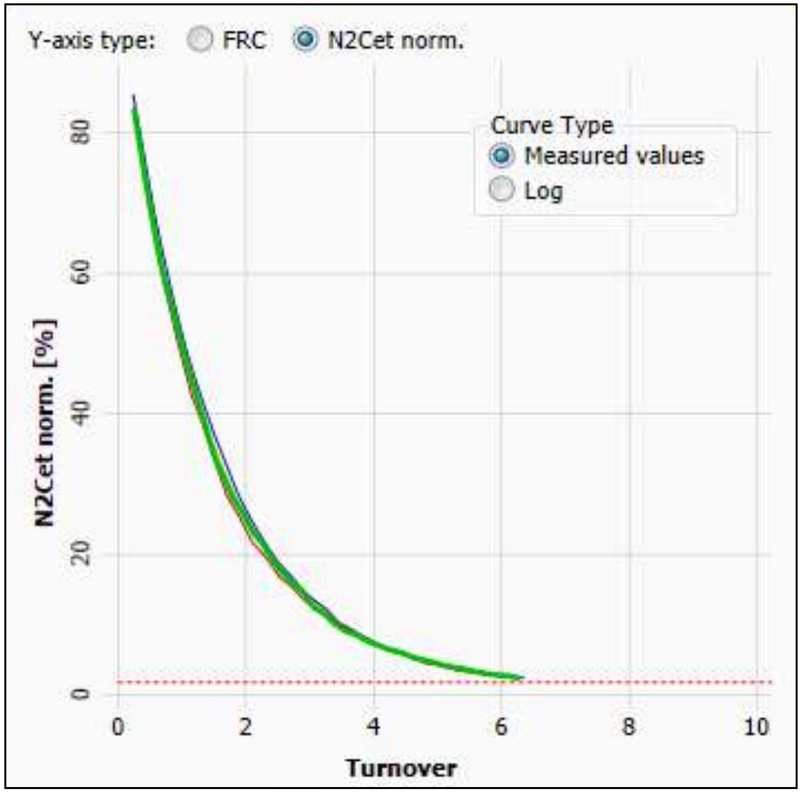


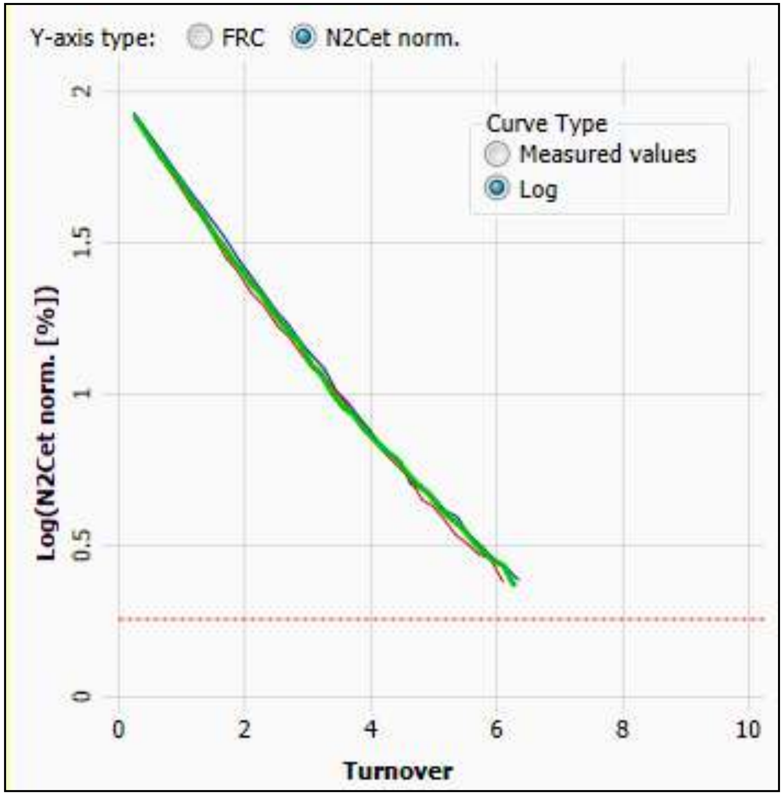
Gustafsson P. M. *Journal of Applied Physiology*, 2014.*117*(7), 720-9

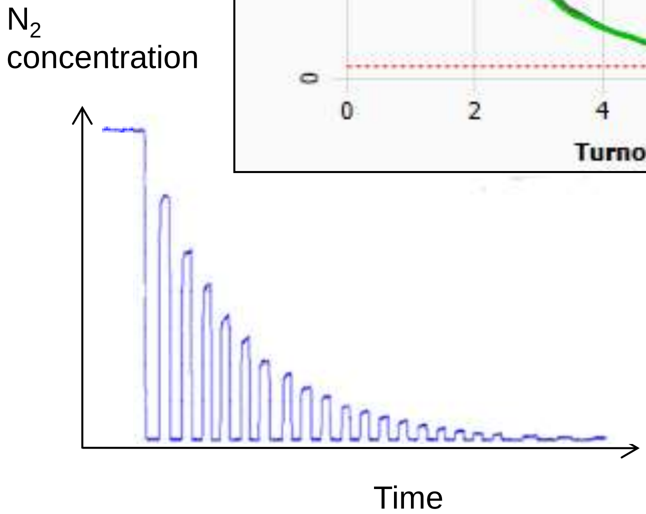
MBW - **indices** of ventilation

- LCI
- Phase III Slope analysis
- Lung compartment assessment

Lung compartment assessment

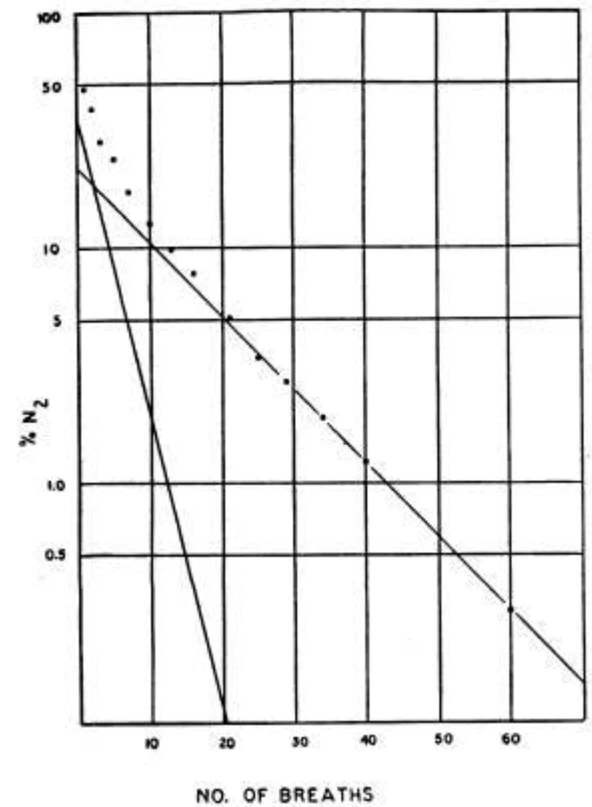






Volumes of inhomogeneity

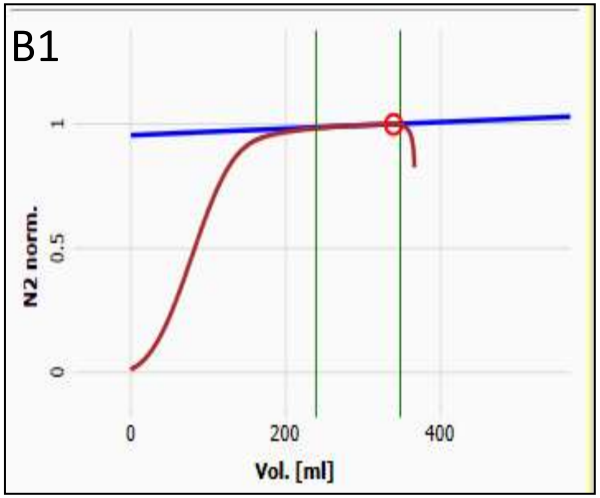
"The lungs of healthy subjects, to a small degree, and of persons with cardiorespiratory disease to a greater degree, are ventilated unevenly... The respective volumes and ventilation rates of these several, regions can be determined"

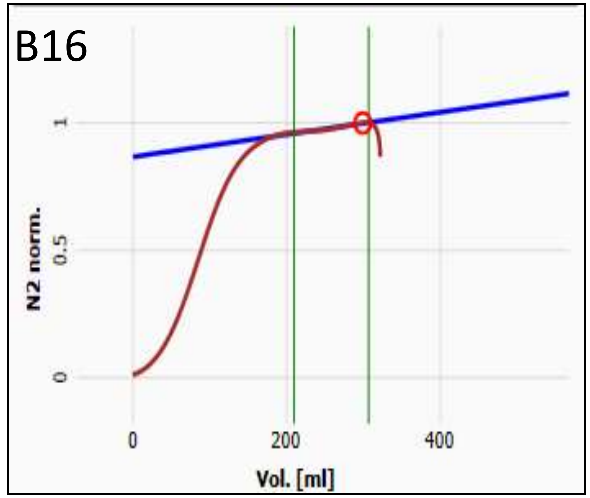


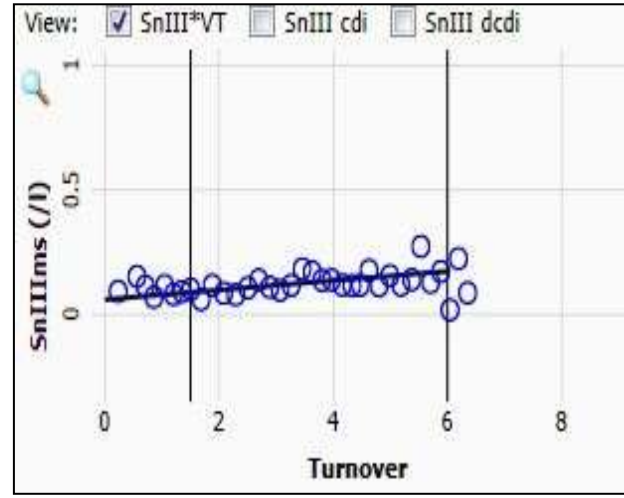
Fowler W. S. et al. J Clin Invest. **1952** Jan; 31(1): 40–50.

Examples

Healthy 9yr boy



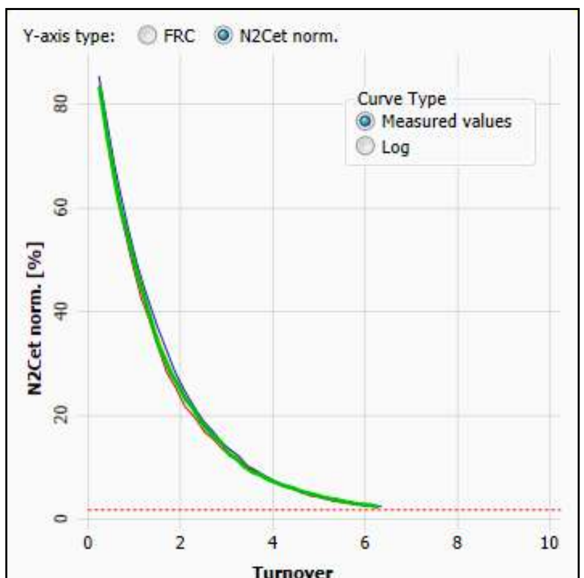


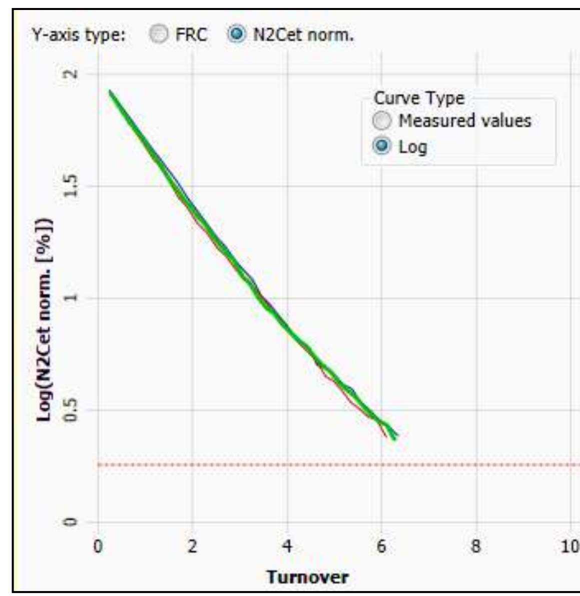


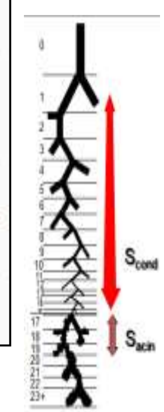
LCI= 6.24

Sacin= 0.0 (Z-score)

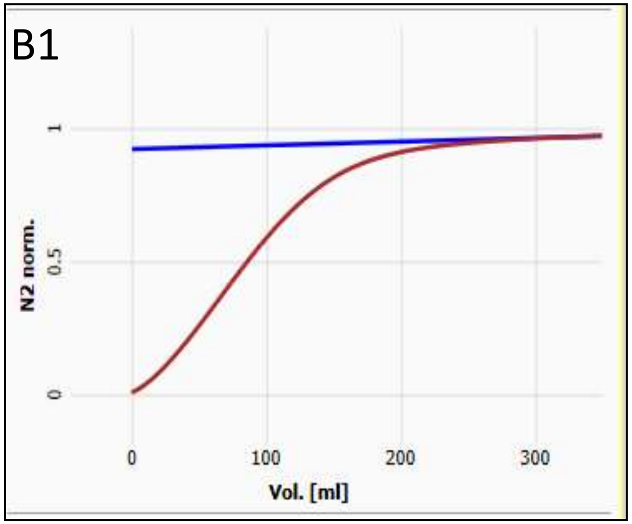
Scond = 1.1 (Z-score)

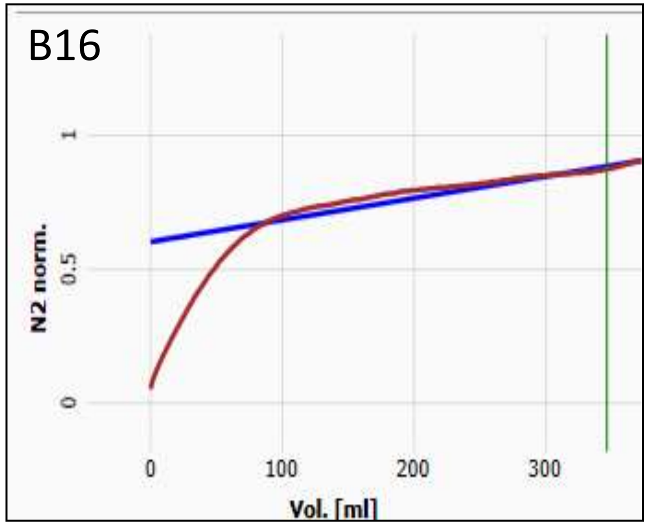


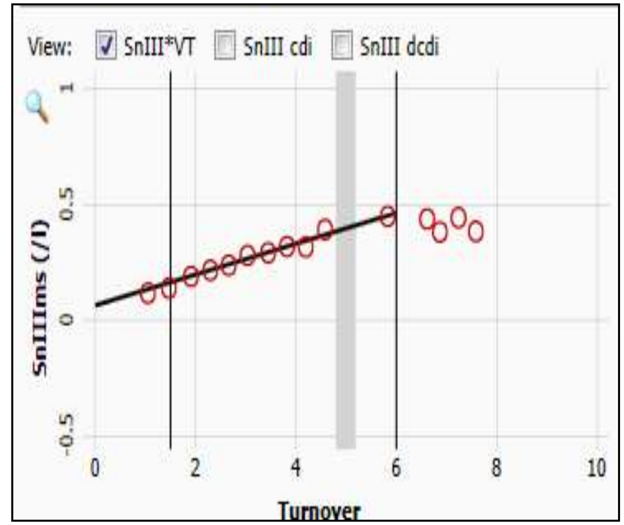




6yr CF patient chronic PA, FEV1=103%Pred



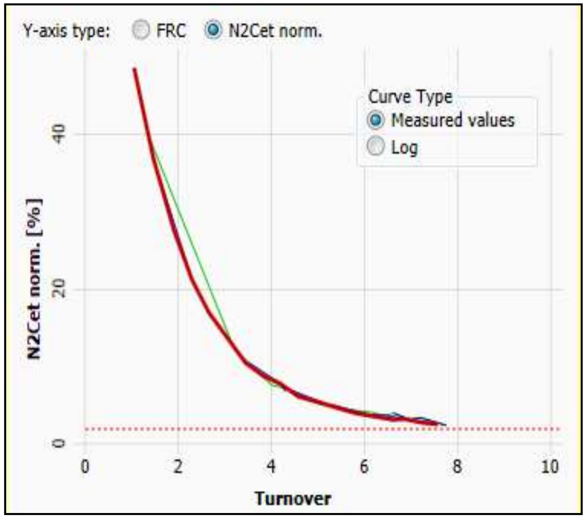


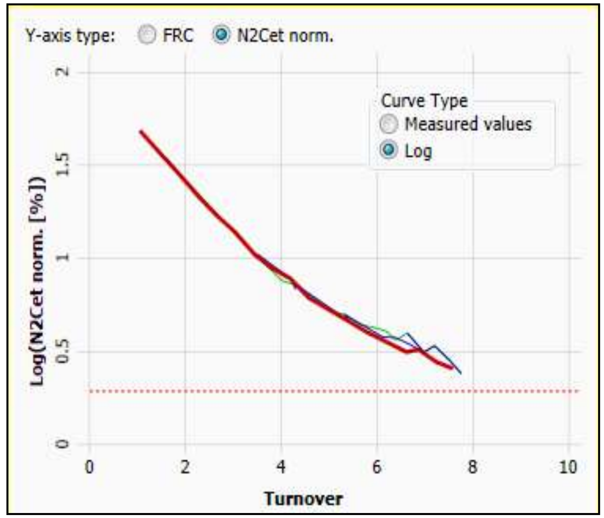


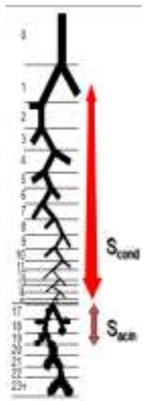
LCI=7.86

Sacin= 1.2 (Z-score)

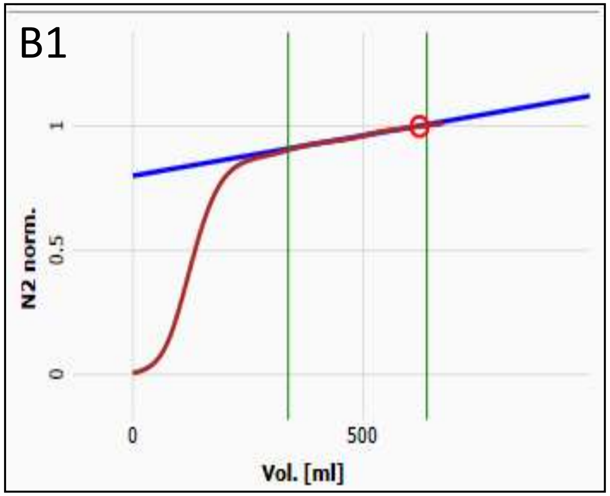
Scond = 9.3 (Z-score)

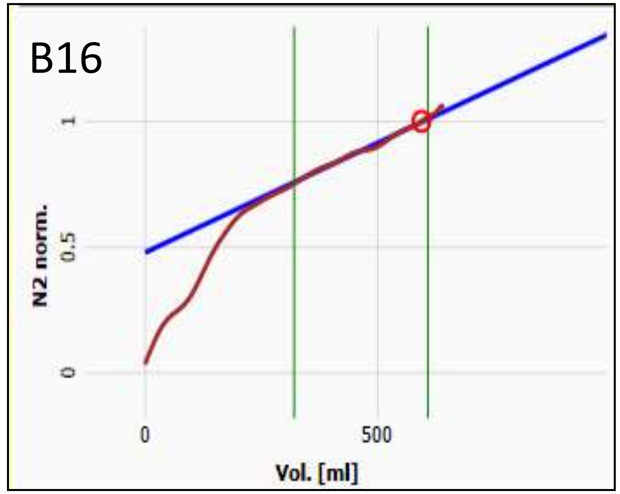


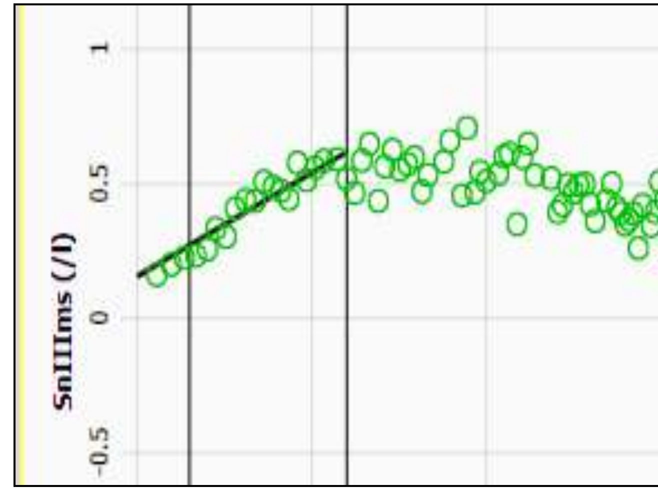




22yr CF patient, FEV1=86%, no PA!



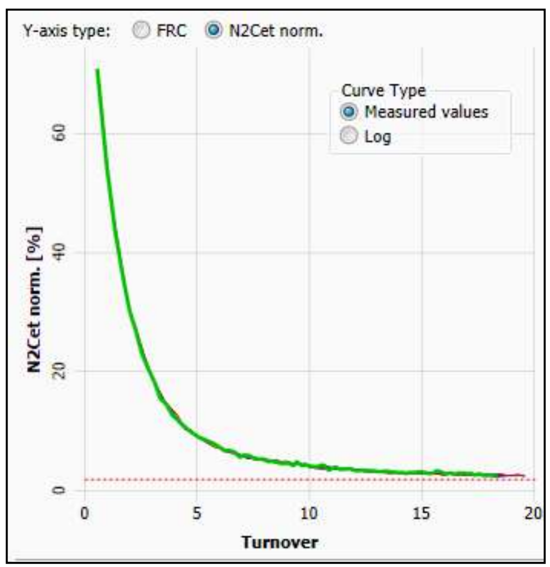


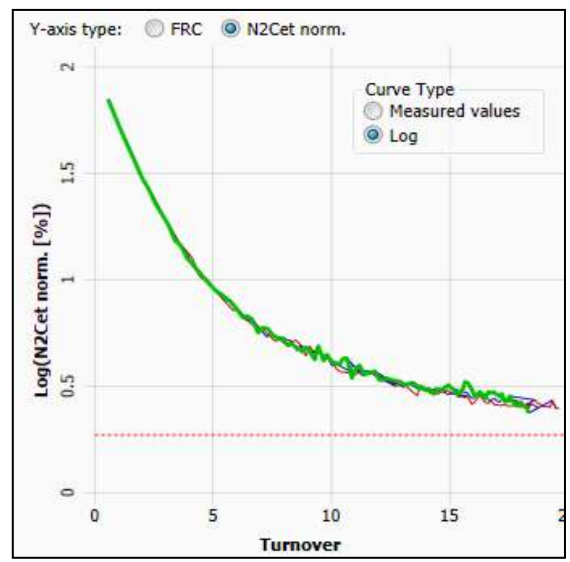


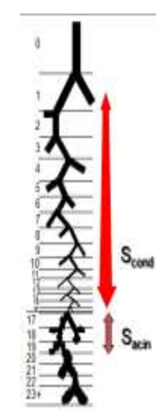
LCI= 18.97

Sacin= 3.5 (Z-score)

Scond = 6.7 (Z-score)








[R]
[L]
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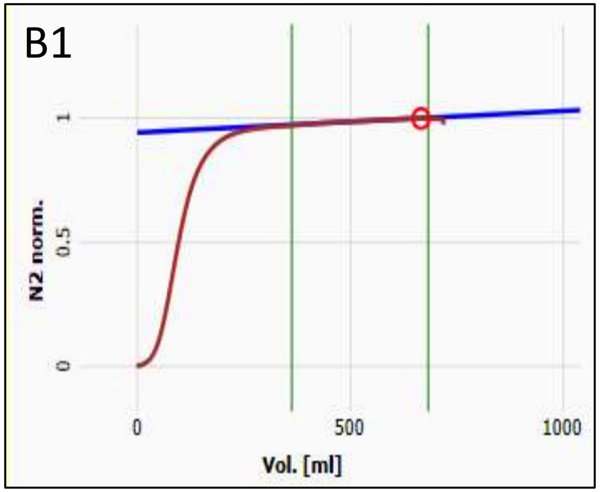
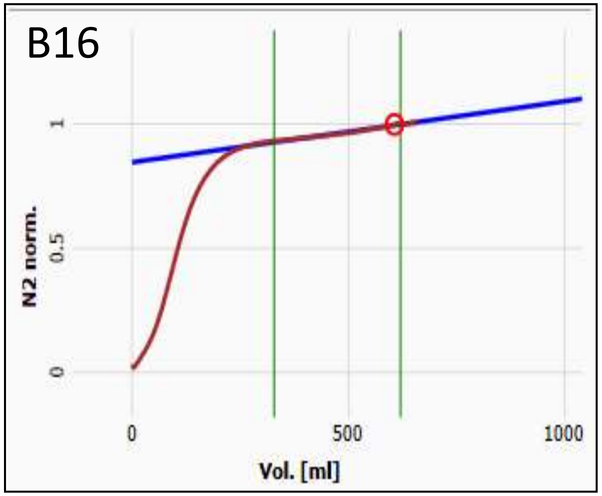
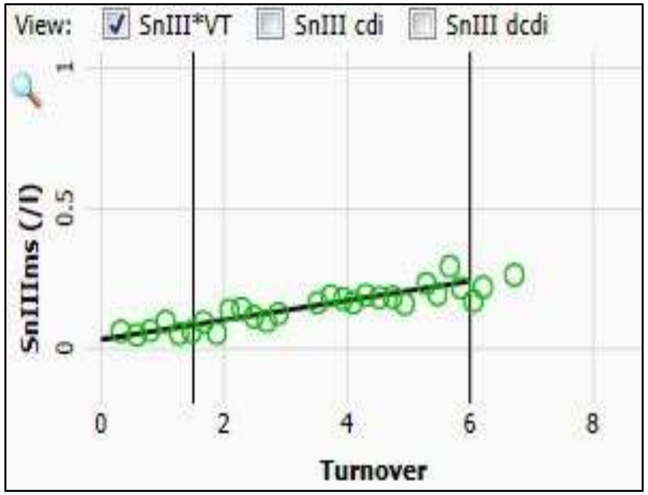
16yr CF patient, FEV1=93%, no PA!



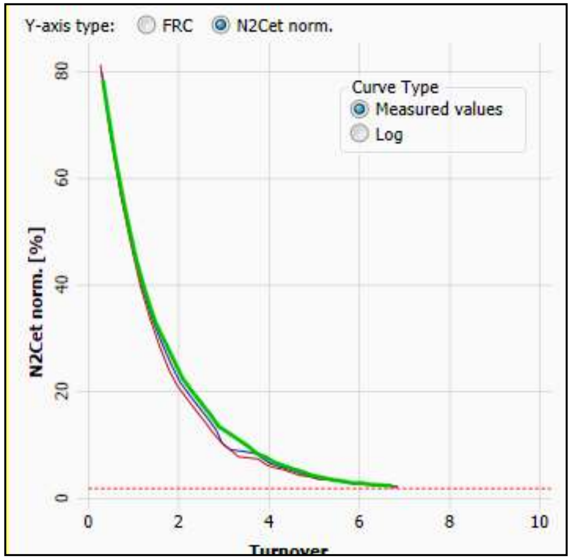


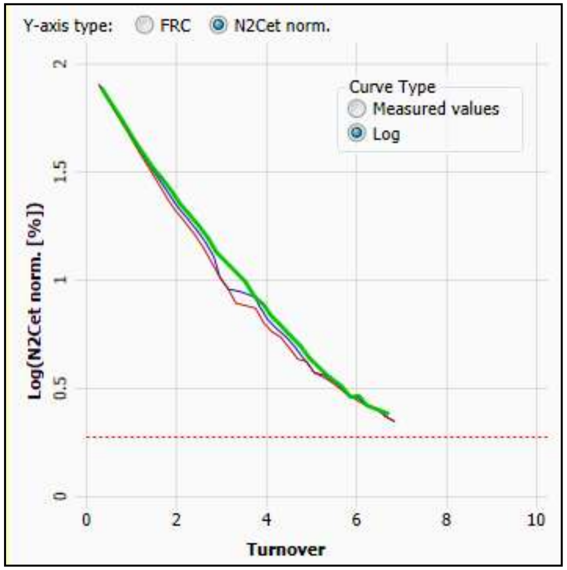


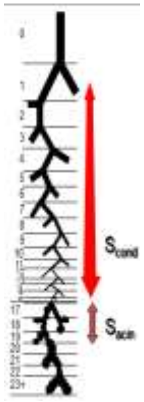
LCI= 6.78

Sacin= 1.4 (Z-score)

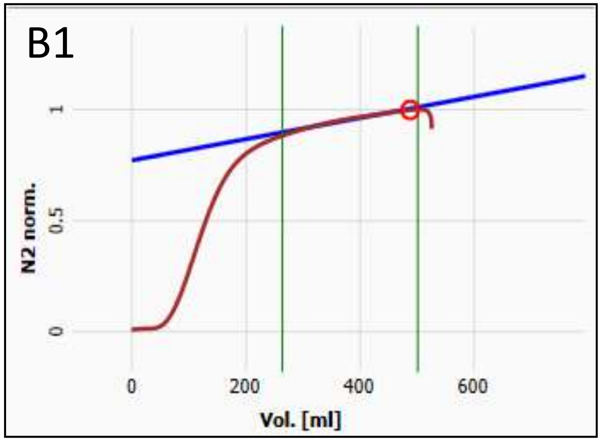
Scond = 3.0 (Z-score)

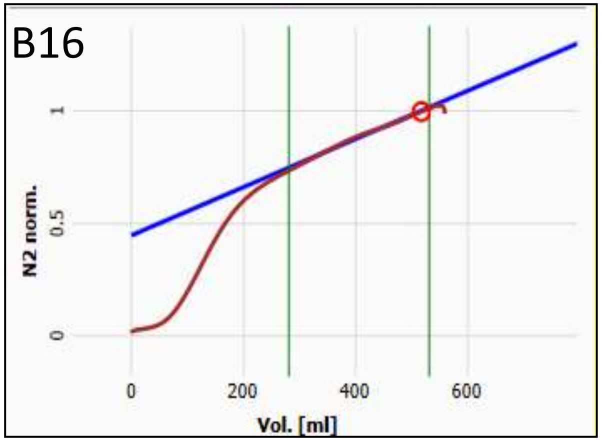


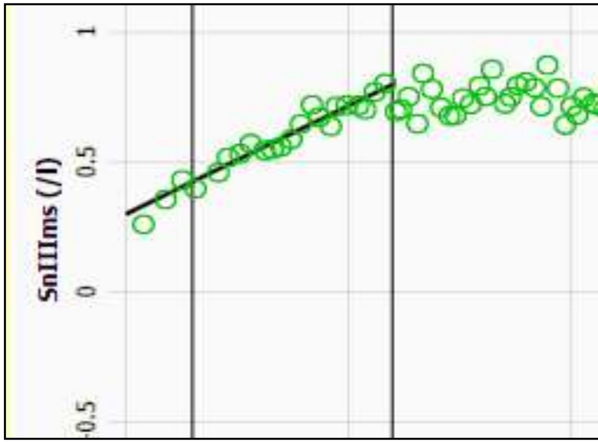




14yr CF patient, FEV1=90% to 71%, NTM



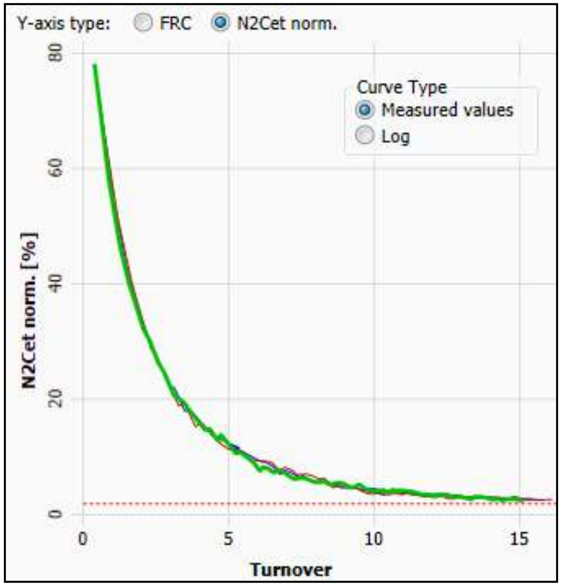


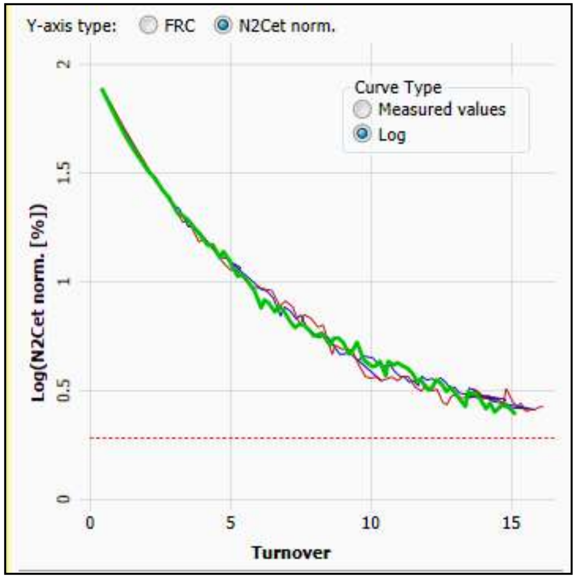


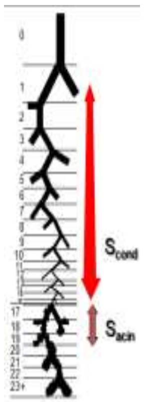
LCI= 15.73

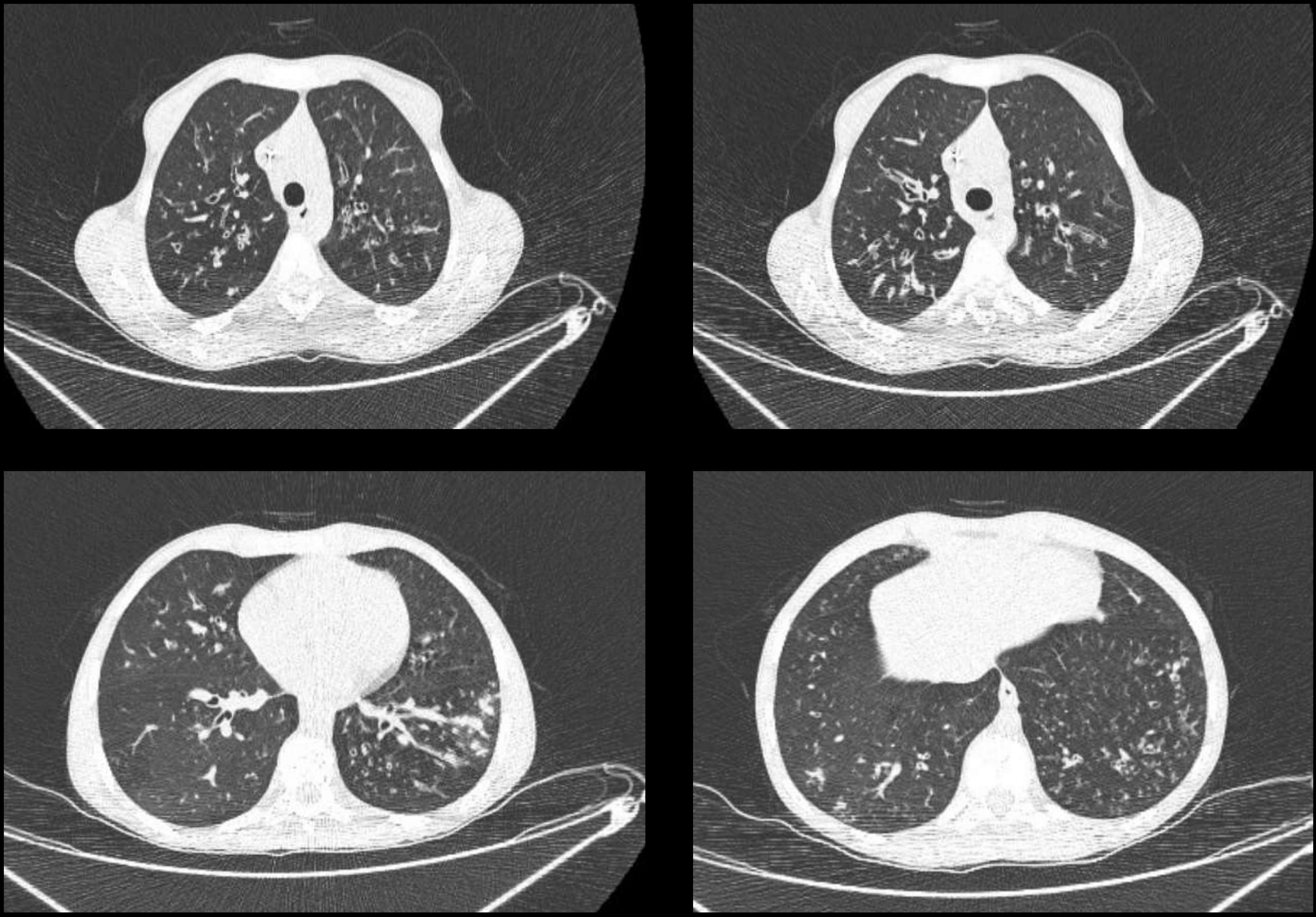
Sacin= 5.1 (Z-score)

Scond = 6.9 (Z-score)

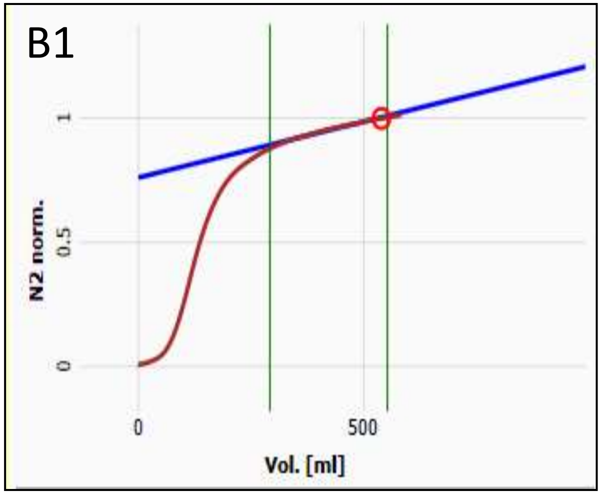


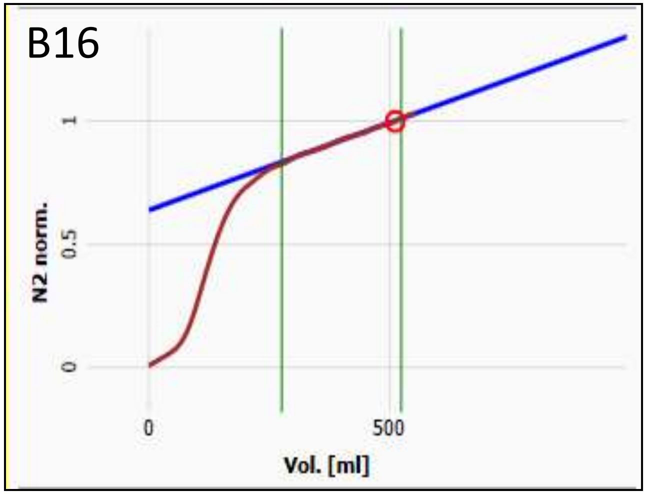


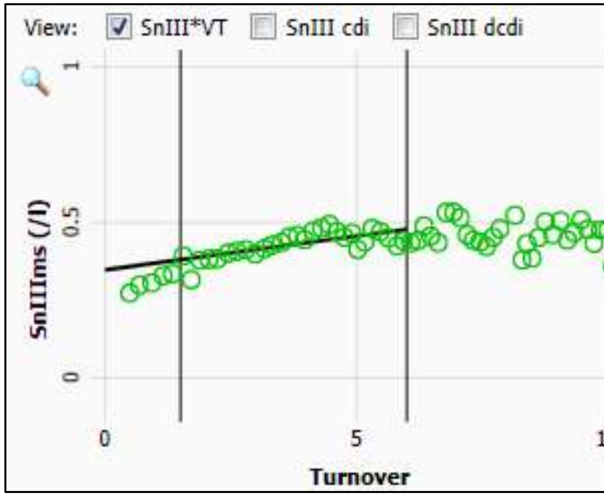




16yr, Interstitial lung Dis , FEV1= 78%



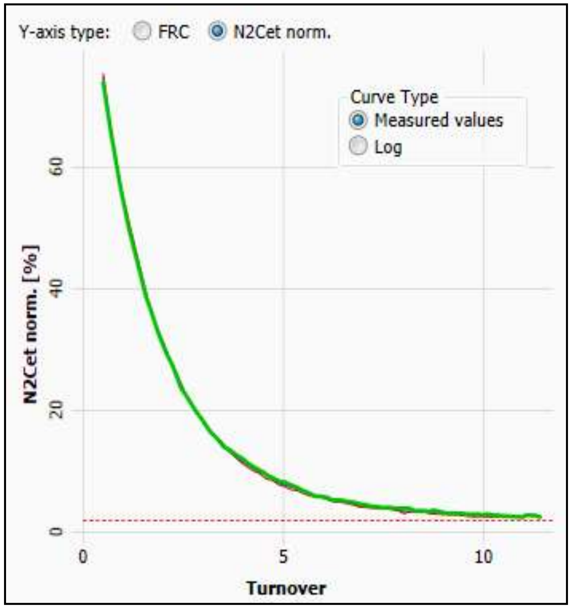


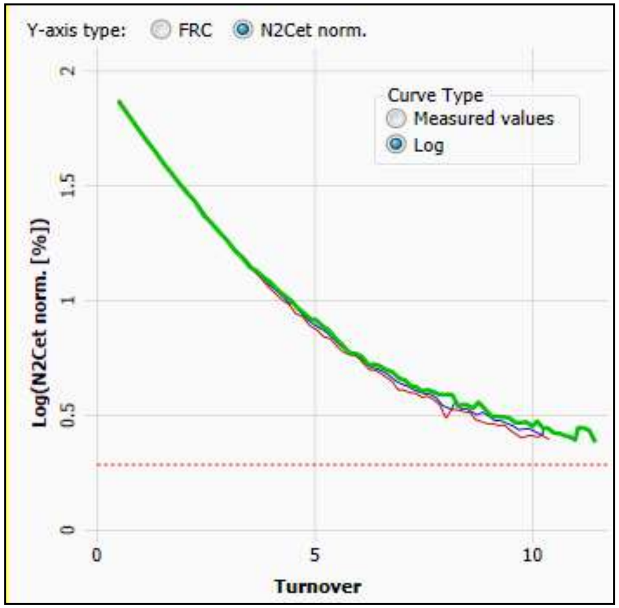


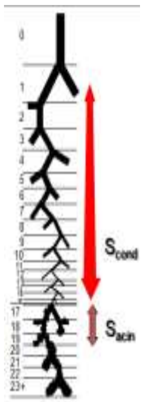
LCI=10.9

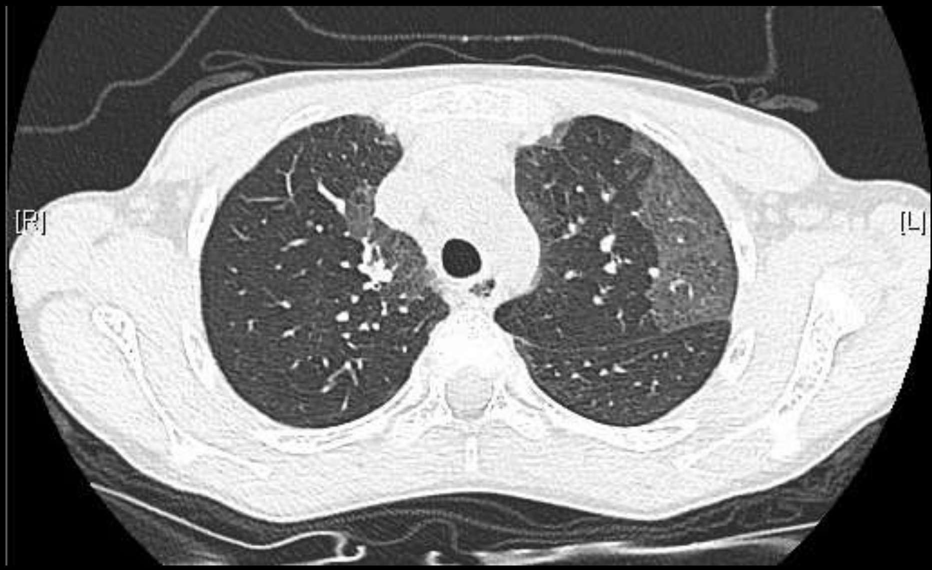
Sacin= 5.1 (Z-score)

Scond = 1.0 (Z-score)





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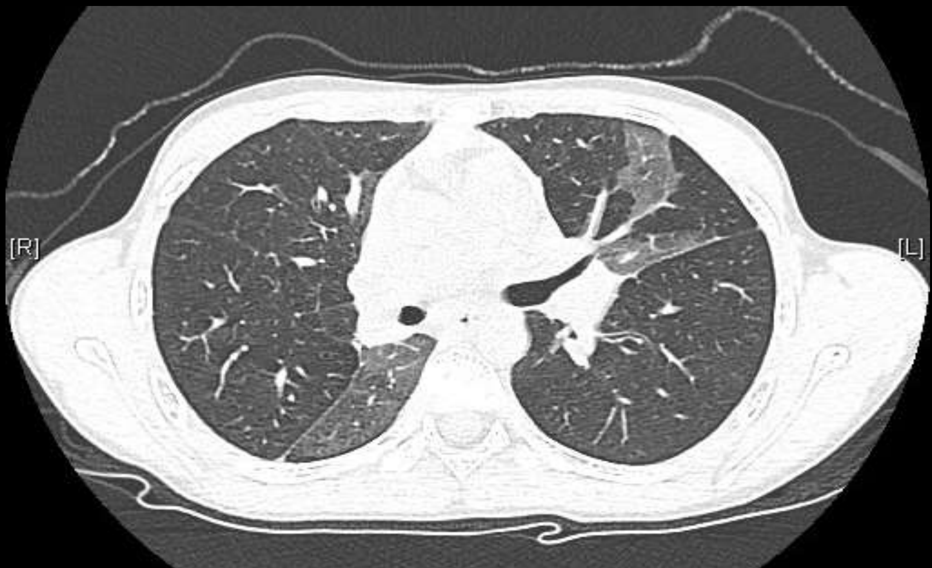
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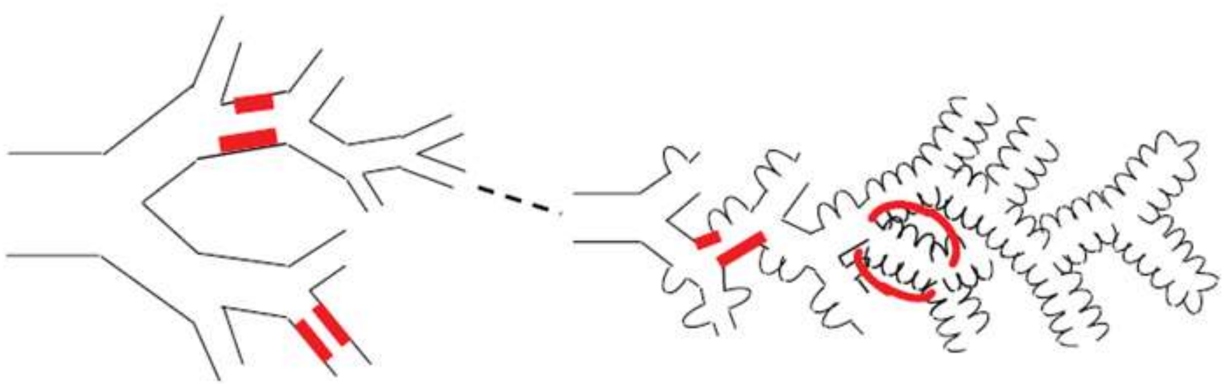
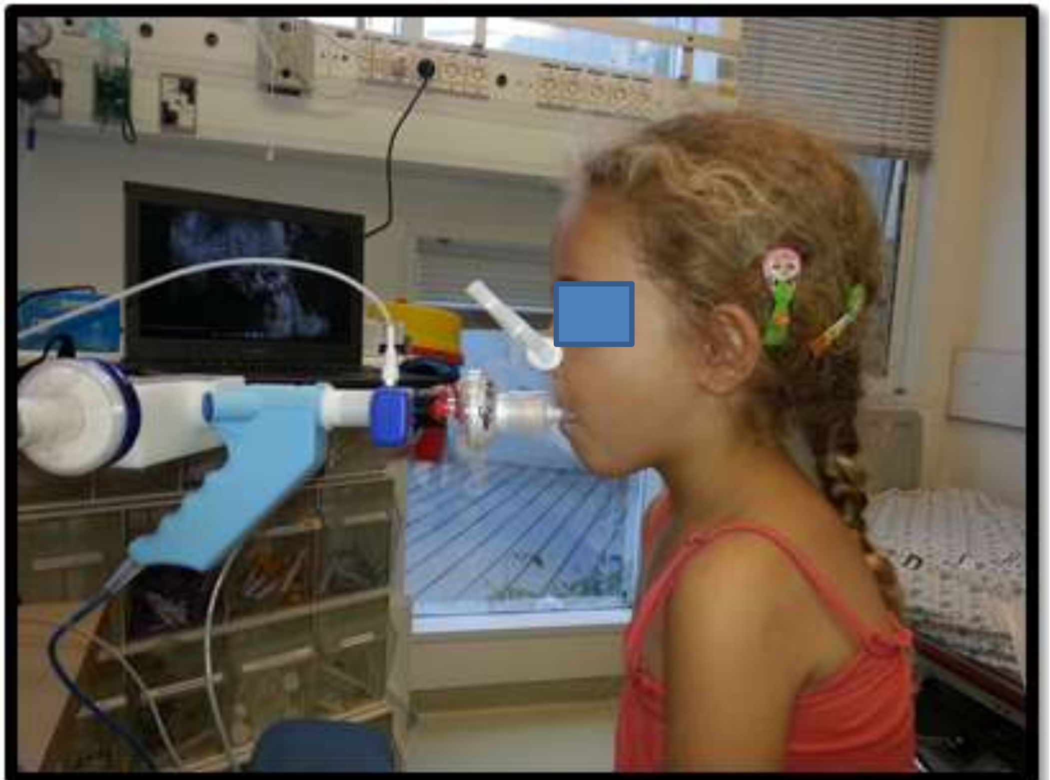
Summary

- SnIII indices have poorer reproducibility than LCI due to variations in breathing pattern
- Analysis of SnIII can offer insight into the location of pathological processes along the airway tree associated with changes on chest HRCT
- Lung compartments assessment allows estimation of the volume of uderventilated lung





Thank you!