Body Plethysmography

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Boyle-Marriot's Law

- The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system.

$$P \propto \frac{1}{V}$$

P = pressure
V = volume
(assumes temperature constant and closed system)

Shift volume

- Inspiration is initiated from end expiration by inspiratory muscles T.V increases.
- Airflow does not start immediately → pressure gradient is required for mass movement.
- Airflow lags behind the changes in lung volume due to airway resistance.

$$\underset{\{\text{Zero}\}}{\text{Resistance}} = \frac{\text{Change in pressure}}{\text{Flow} \quad \{\infty\}}$$

- If the airway is occluded during inspiration, there is decrease in alv. Pressure but no flow → Closed compartment→ *Boyle law*

- During inspiration the thoracic volume excursion is slightly ahead of the equilibrating mass flow .

- When thoracic & lung volume ceases to increase alveolar and box pressure will reach equilibrium.

- However as long as air is flowing, the increase in lung vol > vol of air that passed through the airways into lung.

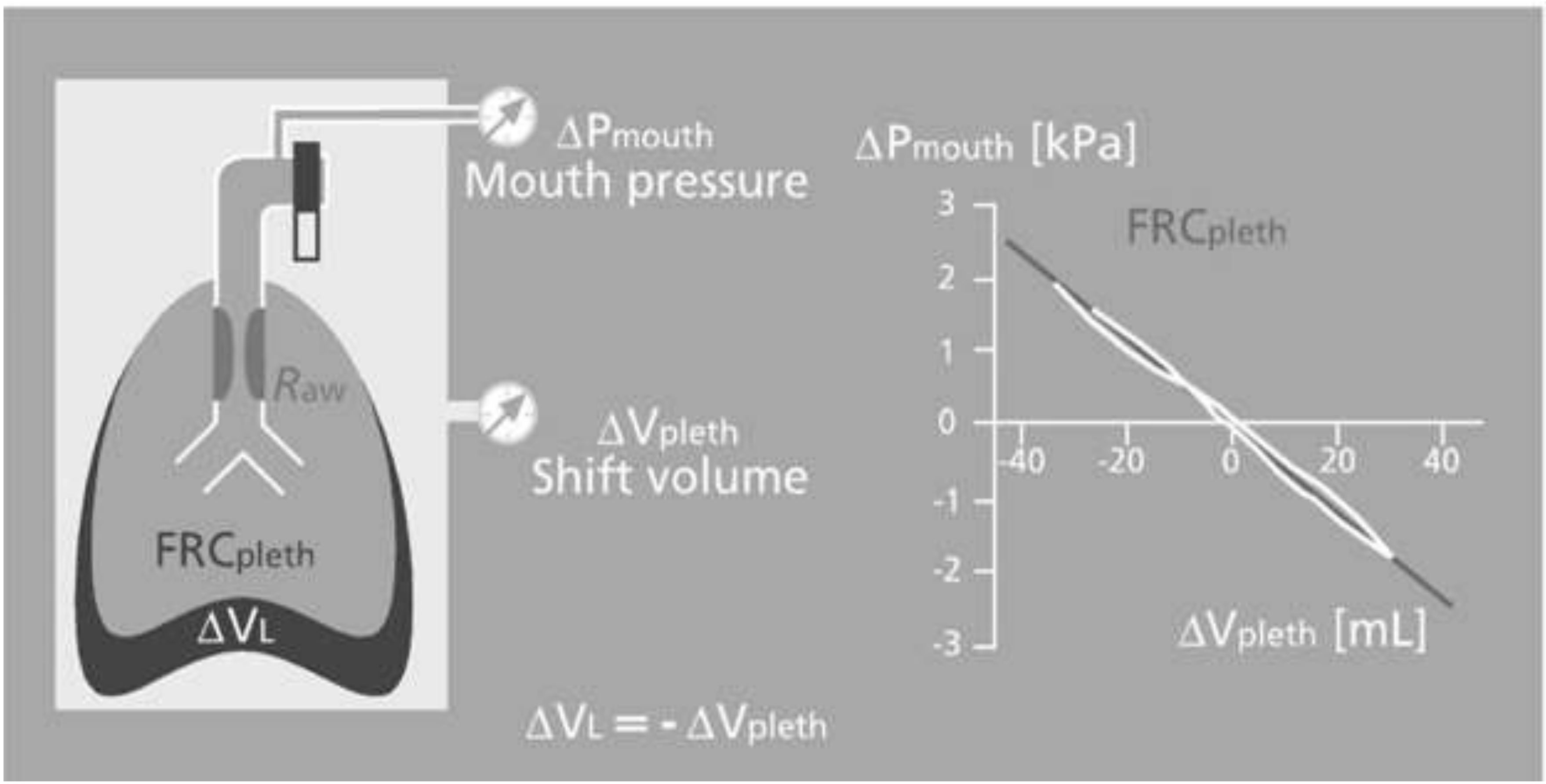
- This small discrepancy in mass flow is called “shift volume”

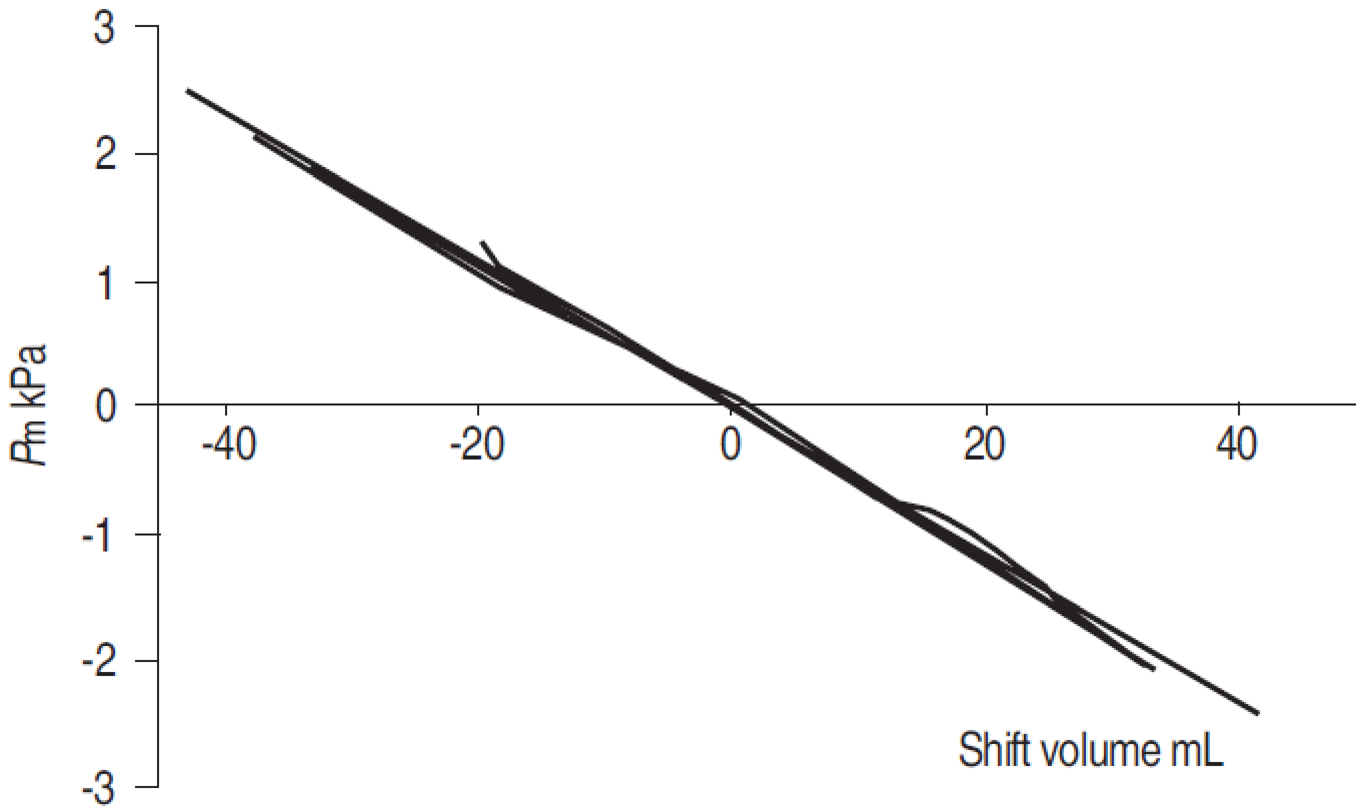
- *Shift volume* is the tiny pressure generating fraction of the tidal volume, tiny→ ~ 1/100
- Volume defect in the lung is equal in magnitude but opposite in sign to the volume defect in the box.
- Volume of box = Tot box vol-Body vol(est. from weight)
- Why shift volume ?
  - Provides the link to box pressure
  - Allows determination of TGV & sRaw

ΔP mo

$$\frac{\text{Alveolar } \Delta P}{\text{Alveolar } P} = \frac{\text{Alveolar } \Delta V}{\text{Lung vol}}$$

Alveolar ΔP ∞ Shift volume





- Pm plotted on y axis, shift vol on x axis.
- Inspiratory efforts causes neg Pm & positive S.V
- Little deviation in both inspiratory & expiratory efforts.
- Expiratory efforts causes visa- versa
- The slope Pm vs shift volume ∞ to FRCpleth.

DuBois AB et all,J Clin Invest 1956; 35: 322–326.

Lung volume and shift volume

- When moving a plunger a equivalent distance in a short vs. long syringe, the pressure change will be greater in the short cylinder .
- Larger the lung volume for a given shift vol, the smaller the pressure change.
- Greater the pressure change, the smaller lung vol. relative to shift volume.
- In a large lung occlusion pressure curve will be more flat, in a small lung more steep.

- FRC- TGV at occlusion
- ERV- maximal expiration
- IVC- maximal inspiration
- RV- FRC-ERV
- TLC- IVC + RV

- Specific airway resistance(sRaw)
- Airway resistance (Raw)
- Conductance (Gaw)

Specific airway resistance

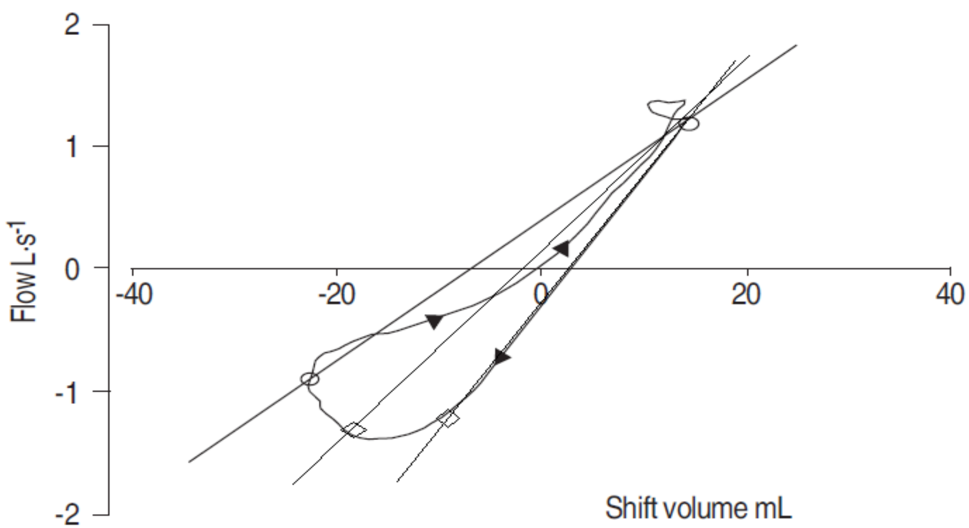
sRAW

- Resistance is def.= $\frac{\text{driving pressure}}{\text{Flow}} = \frac{\text{Palv-Pmo}}{\text{Flow rate}} \rightarrow \frac{\text{Shift vol}}{\text{Flow}}$
- The more the driving pressure for a given flow, the greater the resistance.
- Pmo- constant during unimpeded breathing
- Palv- not available during free breathing.
- Shift volume represents the thoracic excursions which is needed to establish the driving pressure to the lung.
- Though not identical, closely related to driving pressure.
- Ratio of shift vol to flow rate is called specific airway resistance or sRaw

Duboius et all; J Clin Invest 1956; 35: 327–335.

- If airflow is plotted on the vertical axis and shift vol on the horizontal axis, closed loops are obtained.
- The reciprocal slope of the breathing loop represents the sRAW.
- Normally the curves are straight lines
- A more flat curve indicates an elevated shift volume relative to airflow and therby an increase of sRaw.
- Various respiratory diseases provide different patterns.

- The contents of the sRaw loop is often complex not always uniform, or straight lines esp in in obstructive diseases.
- sRaw loop involves varying flows through out the cycle.
- Where to calculate the plot of sRaw ?



- sRaw total
- sRaw effective
- sRaw at .5Ls^{-1}

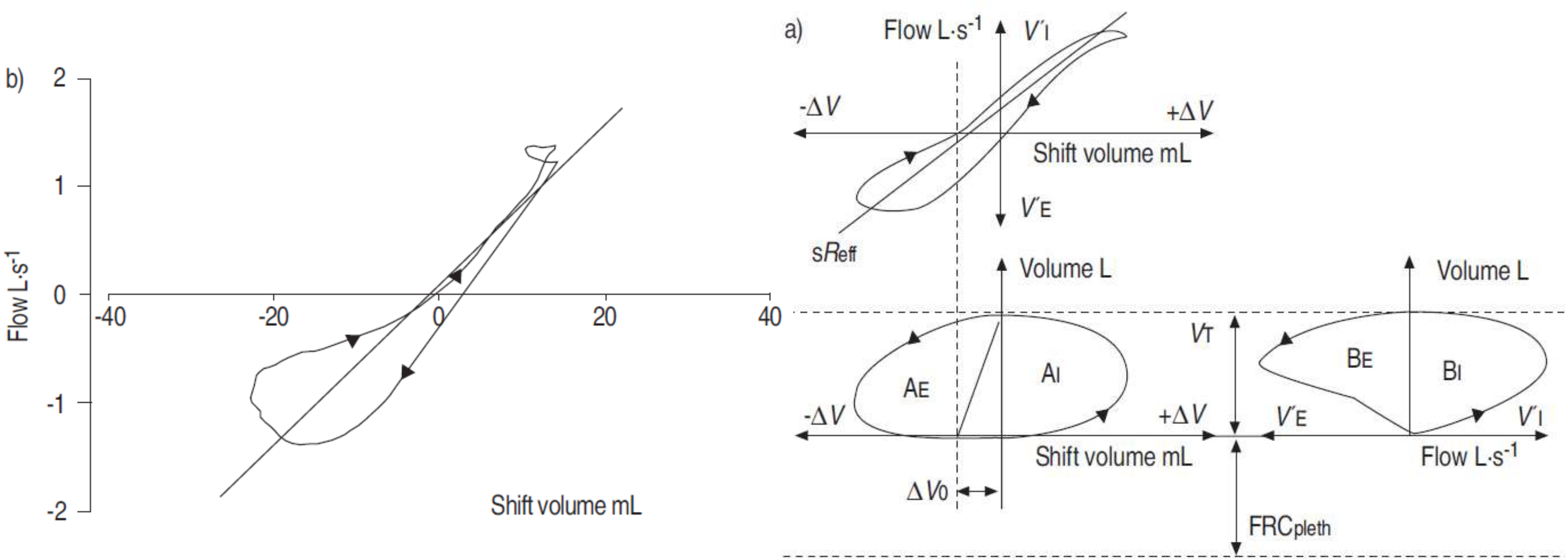
Total specific resistance.

- The sRtot is determined by a straight line between maximal inspiratory and maximal expiratory shift volume points
- The outstanding characteristic of sRtot is its sensitivity to partial obstruction of peripheral airways.
- The potential disadvantage of sRtot would appear to be a greater variability from test to test, as a consequence of using only two points at the extremes of inspiratory and expiratory shift volume.

Islam M, Ulmer W. Respiration 1974; 31: 449–458.

Effective specific resistance

- Introduced to integrate the effects of variable flows and non-linearity of mouth flow shift volume loops during tidal breathing.
- Calculated from the quotient of integrated shift vol-volume loop and integrated flow-volume loop.

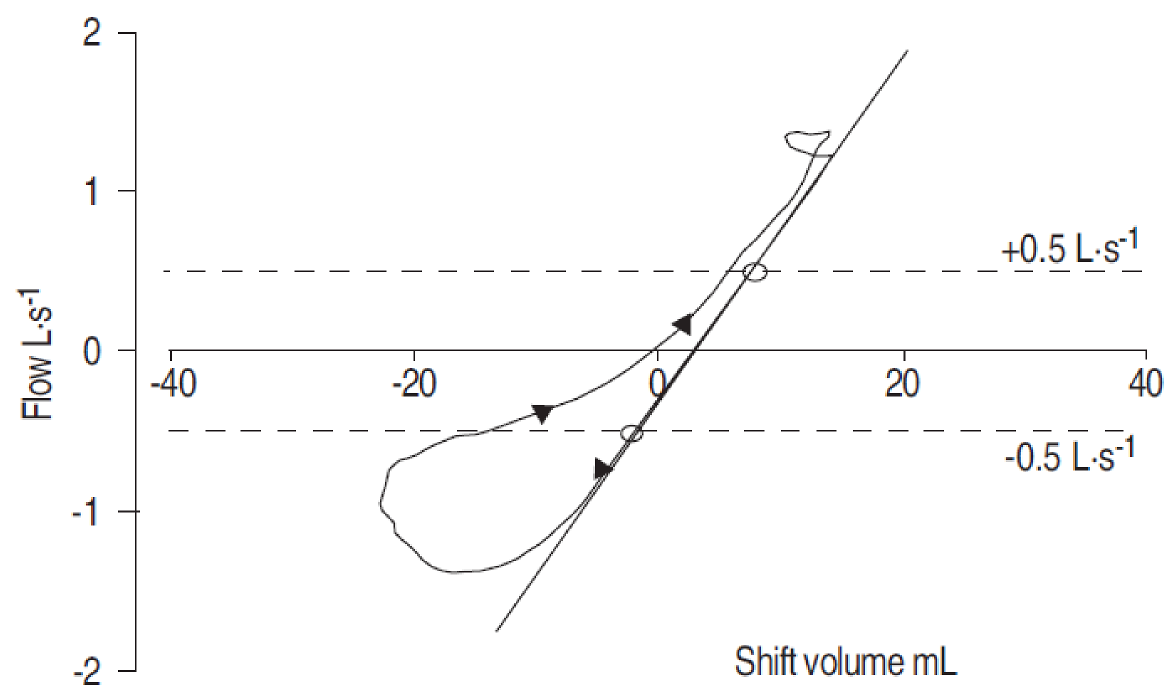


Advantages over sRtot

- Better assessment of the airway behaviour
- Reflects larger central airways than sRtot
- Improved SNR.

sRaw at .5 Ls $^{-1}$

- Dubois initially measured the slope of sRaw at a fixed flow of 1Ls-1
- Subsequently for standardization purposes for calculation of resistance ,the flow range at which sRaw is measured has been limited to .5Ls-1
- Denoted larger more proximal airways.



Conductance

- The reciprocal of resistance is denoted as specific conductance
- $sGaw = \frac{1}{sRaw}$

Resistance

- To obtain airway resistance Raw, Palv is indispensible.
- It is seen that, sRaw can be changed to Raw by dividing sRaw/ FRC_{pleth}.
- $$Raw = \frac{sRaw}{FRC_{pleth}}$$
- However, breathing loops are obtained at an hihger lung volumes than FRC_{pleth}, so to correct for this Vt/2 is added.
- $$Raw = \frac{sRaw}{(FRCpleth+Vt/2)}$$

Gaw = 1/ Raw

Interpretation

- Numerical values of sRaw, sGaw,Raw,Gaw and TGV can be compared with the normative data to define obstructive, restrictive or mixed defects.
- Graphical or based on the appearance of the loop.

Restrictive lung diseases

- Can be suspected when FVC is reduced and FEV1/FVC is normal or elevated.
- However can be ***confirmed*** only by demonstration of a reduced TLC by plethysmography.
- TLC below 5^{th} percentile of normal value is considered as restrictive lung disease.

Obstructive diseases

- Characterized by a normal or elevated FRC, TLC, and RV, and elevated Raw and sRaw.
- Additionally determination of RV and RV%TLC allows to determine the degree of hyperinflation.

	Mild	Moderate	Severe
RV/TLC	>95th percentile - < 140%	140 -170 %	>170 %

- In the presence of severe defect, plethysmographic volumes tends to overestimated, as pressure changes are not properly transmitted to the mouth.

- Body plethysmography can also demonstrate the effects of Rx on hyperinflation
  - Decrease in FRC following bronchodilator Rx
  - Decrease following successful Rx of AE-COPD
- These determination's are not influenced by the patient effort, which may be substantially decreased in the presence of hyperinflation.
- Body plethysmography directly measures the FRC.

Table 2 Alterations in body plethysmographic measures as observed in major disorders (see also Fig. 4).

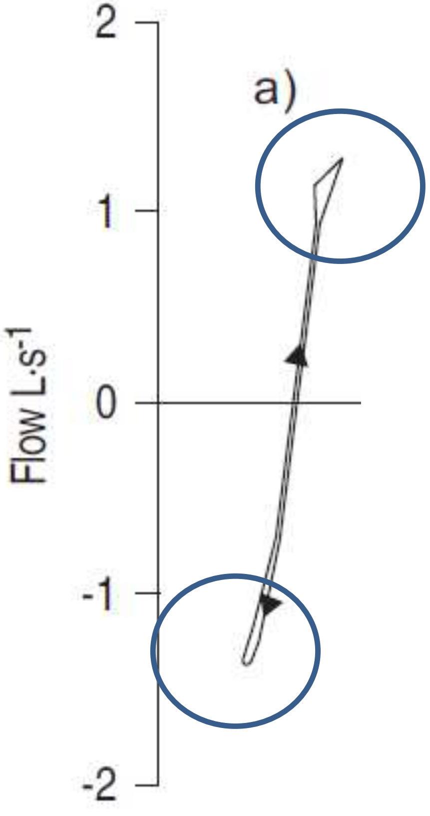
	FRC	RV	TLC	*Raw*	*sRaw*
Obstructive airway diseases	Normal or elevated	Normal or elevated	Normal	Elevated	Elevated
Hyperinflation	Elevated	Elevated	Normal or elevated	Normal	Elevated
Restrictive disorders	Reduced	Reduced or normal	Reduced	Normal	Normal

Interpretation

- Numerical values of sRaw, sGaw,Raw,Gaw and TGV can be compared with the normative data to define obstructive, restrictive or mixed defects.
- Graphical or based on the appearance of the loop.

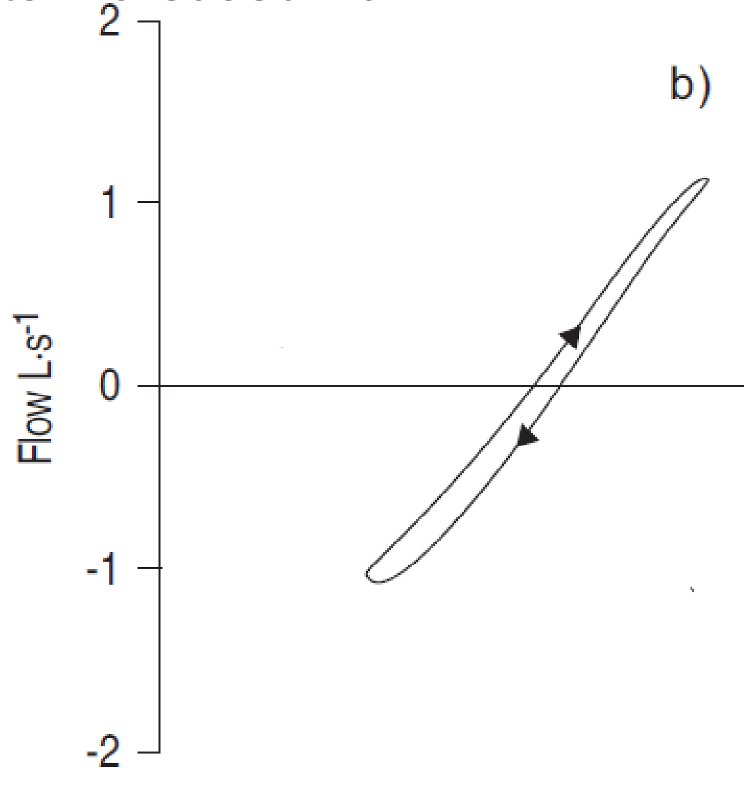
Normal

- Normal subjects manifest a steep linear loop during tidal breathing without hysteresis, ie no "openness"
- Flattening= increased ʼΩ,
  Openness = localised resistance !
- During panting the upper and lower extremities of the loop become curvilinear- 's' shape



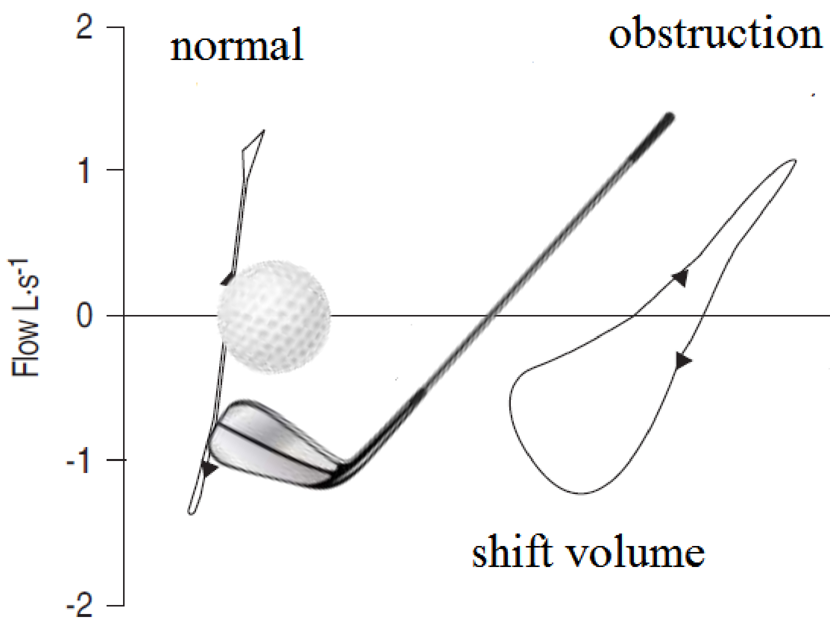
Large airway obstruction

- There is uniformly increased airway resistance and not localised, there is little hysteresis or “openness”
- Linear sRaw loop that is tilted clockwise, manifesting a slope less steep than normal reflects increased Raw



Small airway obstruction

- In patients with non-homogenous airway obstruction, there is
  - "opening" / hysteresis in the loop
  - Alinerierity
- This represents the expiratory flow limitation or the dynamic compression which occurs in expiration.
- Denotes the large changes in shift volume that occurs at mid-expiration without comparable increases in flow.



Fixed localised central airway obstruction

- Seen in fixed or functional stenosis of the airways like laryngeal abnormality or VC palsy
- Flow limitation during inspiration, in that at sufficiently high flows further increases in driving pressure does not increase in airflow.