HELIUM DILUTION TECHNIQUE

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Kodati Rakesh
Senior Resident
Pulmonary medicine

- History
- Indications & contraindications
- Principle
- Apparatus
- Procedure & calculation
- Drawbacks
- Miscellaneous (single breath /mechanically ventilated)

Helium dilution

- It is a method recommended for routine measurement of lung volumes in patients other than those with communicable diseases
- Closed circuit gas dilution method
- 1941 by Meneely and Kaltreider

History

- H. Davy measured residual volume of his own lungs in 1800
- Davy conducted the experiment as follows: "after a complete exhaustion of my lungs in the usual posture, I respired from a large mercurial air holder 102 cubic inches [~1670 mL] of hydrogen apparently pure for rather less than a minute, making in this time 7 quick respirations”
- He measured the proportion of hydrogen remaining in the air holder "by inflammation with atmospheric air or oxygen of the detonating tube by the electric spark”

J-C. Yernault et al; Eur Respir J 2000; 16

History

- Risk of explosion of the hydrogen mixture, and also because the purity of hydrogen was not guaranteed (combined with some residual arsenic, it yields a very toxic mixture)
- Replacement of hydrogen with helium by Meneely and Kaltreider in 1941
- Helium has all the useful properties of hydrogen, but none of its disadvantages

J-C. Yernault et al; Eur Respir J 2000; 16

History

- The open circuit nitrogen washout method by R.E. Darling et al. in 1940
- Body plethysmograph by A.B. DuBois et al. in 1956
- Closed circuit gas dilution is the first method to determine residual lung volume

J-C. Yernault et al; Eur Respir J 2000; 16

Indications - diagnostic

- To diagnose restrictive disease patterns
- To differentiate between obstructive and restrictive disease patterns, particularly in the presence of a reduced VC
- To diagnose hyperinflation and gas trapping
- To diagnose, evaluate and monitor diseases which involve the lung parenchyma
- To aid in the interpretation of other lung function tests (eg, DL/VA, sGaw, RV/TLC)

MR Miller et al; Eur Respir J 2005; 26: 319–338

Indications – monitoring/assessment

- To make preoperative assessments in patients with compromised lung function (known or suspected) when the surgical procedure is known to affect lung function
- To assess response to therapeutic interventions (eg, drugs, transplantation, radiation, chemotherapy, lobectomy, lung-volume-reduction surgery)

MR Miller et al; Eur Respir J 2005; 26: 319–338

Indications – monitoring/assessment

- evaluate and monitor
  — pulmonary disability
  — impairment and disability a/w ILDs and COADs
  — pulmonary effects of radiation therapy, chemotherapy agents (eg Bleomycin)
  — pulmonary involvement in systemic diseases

MR Miller et al; Eur Respir J 2005; 26: 319–338

Indications – public health

- Epidemiological surveys
- Derivation of reference equations
- Clinical research

MR Miller et al; Eur Respir J 2005; 26: 319–338

Contraindications

- No apparent absolute contraindications exist
- Unstable cardiovascular status, unstable angina, recent myocardial infarction (within one month), or pulmonary embolism
- Haemoptysis of unknown origin / recent pneumothorax
- Thoracic, abdominal, or cerebral aneurysms
- Recent thoracic, abdominal or eye surgery
- Severe respiratory distress
- Physical limitations, cognitive impairment, dementia

AARC guideline: static lung volumes: 2001 revision & update

Principle

- *“Equilibribriation of gas in the lung with a known value of gas containing helium”*
- If a gas with known He concentration is breathed in, the He will be diluted by the He-free gas within the lungs
- If the expired He concentration is monitored the volume of gas within the lungs can then be calculated from the dilution effect
- Helium is commonly used because the appropriate analyser (katharometer) is accurate, robust and cheap

Principle

$$V_{app} \times F_{He1} = (V_{app} + FRC_{He}) \times (F_{He2})$$

$$FRC_{He} = V_{app}(F_{He1} - F_{He2}) / F_{He2}$$

V_{app} - *Volume of the spirometry apparatus*

F_{He1} - *Initial Helium fraction*

F_{He2} - *Helium fraction at the time of equilibriation*

FRC_{He} - *Lung volume (FRCHe) at the time the subject is*
connected to the spirometry apparatus

Principle

- Dead space of the valve and mouthpiece must be subtracted from the calculated lung volume
- Also should be corrected to BTPS conditions

Spirometer

- Spirometer capacity should be 7–10 L with 3% or better static volume accuracy
- Resolution should be 25 mL or better
- Water -seal or dry-seal models
- Pneumotachometers or other flow devices
- Vapp including the circuit tubing to the mouthpiece valve should not exceed 4.5 L
- Smaller the Vapp, the larger (and more accurate) will be measured changes in He concentration

R. Brown et al; Eur Respir J 1998

Equipment attached to spirometer

- Mixing fan
- CO_2 absorber
- Water vapour absorber
- Helium analyser or katharometer
- O_2 and helium supply
- Gas inlet and outlet

R. Brown et al; Eur Respir J 1998

Mixing fan

- Mix the gas throughout the circuit within 8 s after the end of exhalation into the circuit
- Maintain a steady flow through the katharometer
- Breathing circuit flows of 50 L /min are utilised to ensure adequate mixing of helium

R. Brown et al; Eur Respir J 1998

CO_2 and water absorbers

- CO_2 and water to be removed before the sample is introduced into helium analyser
- Soda lime canister is mounted vertically to ensure uniform distribution of the granules for absorbing CO_2
- The canister should be changed after every 20 determinations or when the CO2 concentration in the circuit rises above 0.5% to avoid patient discomfort and hyperventilation
- Activity should be ensured before each test

R. Brown et al; Eur Respir J 1998

Helium analyzer

- The helium analyser should have a range of 0–10% helium, a resolution of ≤ 0.01% helium over the entire range and a 95% response time of < 15 s to a 2% step change in helium concentration in the breathing circuit
- Calibrated over the range of O2 concentrations encountered during measurement of FRC
- Temperature of the gases entering the helium analyser should be same as that during calibration

R. Brown et al; Eur Respir J 1998

Temperature sensors

- The temperature of gas inside the system differs from both BTPS and ATPS conditions
  - exhaled warm gas
  - room temperature
  - heat generated by absorption of CO2 in the soda lime canister
- Temperature of the gas in the breathing circuit should be measured so that these lung volumes can be corrected to BTPS conditions

R. Brown et al; Eur Respir J 1998

Dead space

- The breathing valve and mouthpiece should have a combined dead space of < 100 mL
- The size of this dead space should be available from the manufacturer or measured by water displacement

R. Brown et al; Eur Respir J 1998

Procedure

- Turned on and allowed an adequate warm-up time (< 10 min)
- Calibration to be done according to manufacturer's instructions
- Check list before procedure
  - Activity of the CO_2 and water absorbers in the helium meter line
  - Water level in case of water-sealed spirometers
  - Circuit leaks

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Procedure

- Patient preparation
  - Checked for a perforated eardrum (if so, an earplug should be used)
  - Seated comfortably, with no need to remove dentures
  - Procedure is explained, emphasising the need to avoid leaks around the mouthpiece during the test and
    to use a nose clip

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Procedure

- Circuit is flushed with air
- Oxygen is subsequently added to raise the final oxygen concentration to about 25-30%
- Helium meter reading adjusted to zero, helium is added to raise the helium concentration to nearly full scale deflection (10%) on the analyser

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Procedure

- The patient breathes for 30-60 s on the mouthpiece to become accustomed to the apparatus, and to ensure a stable end-tidal expiratory level
- The patient is turned “in” (i.e. connected to the test gas) at the end of a normal tidal expiration and instructed to breathe regular tidal breaths

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Procedure

- A constant flow of 100% oxygen is added to the circuit at a rate determined by an estimate of the patient's oxygen consumption. This estimate is usually 3–4 mL/kg/min for adults. The equipment should allow and assure oxygen flows up to 500 mL/min
- Boluses of oxygen can be added as needed (*e.g*. every 15–30 s) to keep spirometer volume constant at end expiration
- Starts with elevated concentrations of oxygen in the circuit; further oxygen is not added

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Measurement

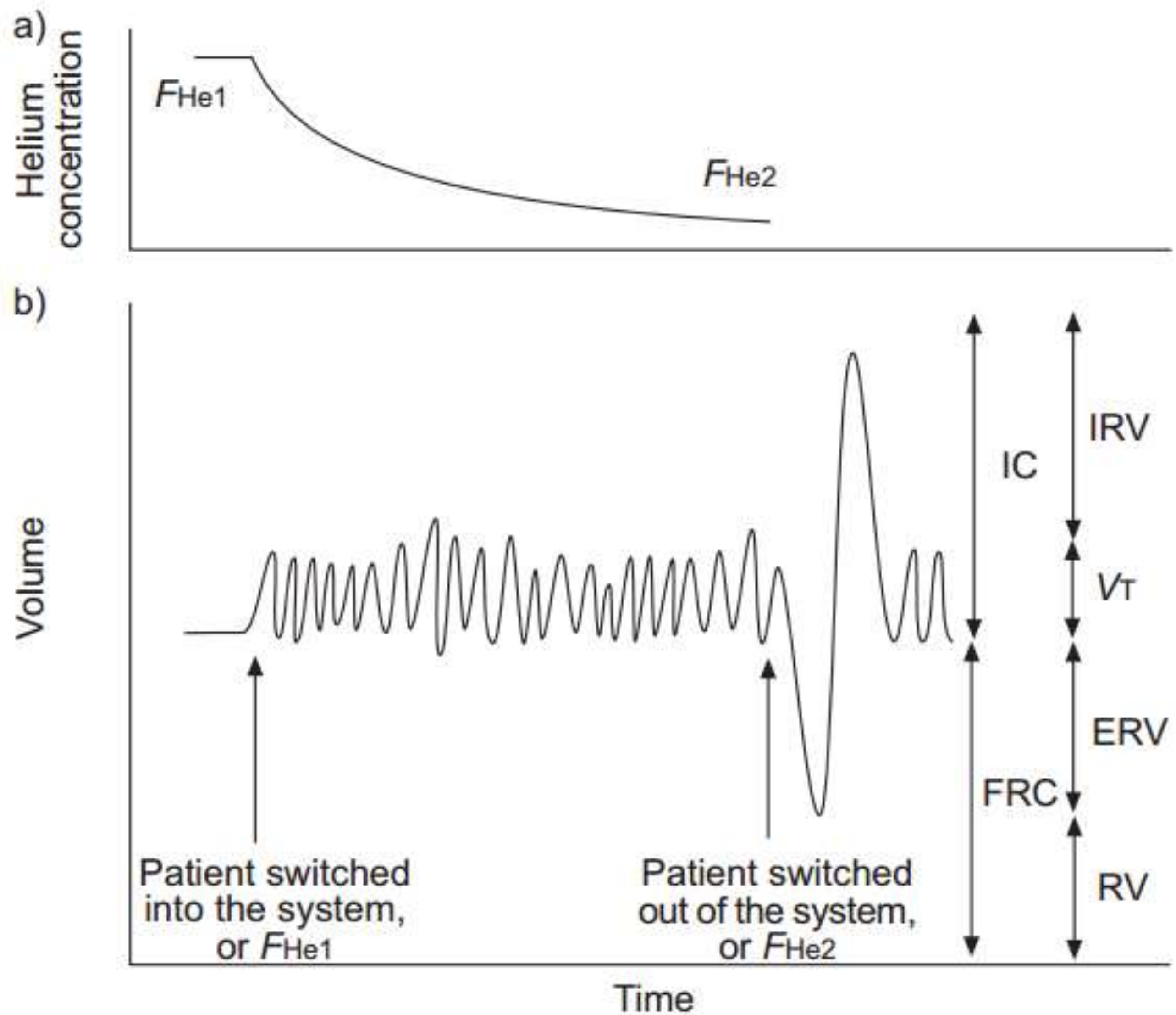
- The helium concentration is noted every 15 s and equilibration is considered to be complete
  - Change in helium concentration is < 0.02% for 30 s
  - Change in FRC is less than 40 mL per 30 s in systems that report FRC directly
- Once the helium equilibration is complete, the patient is turned “out” (i.e. disconnected from the test gas) of the system
- The test rarely exceeds 10 min, even in patients with severe gas-exchange abnormalities

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Measurement

- At least one technically satisfactory measurement should be obtained
- Two or more measurements of FRCHe need to be made only when necessitated by clinical or research need due to the extra costs and time in making multiple measurements
- For younger children, at least two technically satisfactory measurements be performed
- In case of multiple measurements, value reported for FRCHe should be the mean of technically acceptable results that agree within 10%

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005


a)
Helium concentration
F_{He1}
F_{He2}
b)
Volume
IC
IRV
V_T
FRC
ERV
RV
Patient switched into the system, or F_{He1}
Patient switched out of the system, or F_{He2}
Time

Linked ERV f/b IVC

- Mean value of three satisfactory linked in ERV manoeuvres to be reported
- Factors that lead to unsatisfactory manoeuvres include cough, glottal closure, gas leak from the nose or mouth and too brief effort
- Largest of the three satisfactory IVC manoeuvres should be reported

RV = FRC – ERV
TLC = RV + IVC

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Linked IC manoeuvre

- In those with severe obstructive dysfunction or severe dyspnea who are unable to follow the FRC measurements with a linked ERV manoeuvre
- Separate IVC or EVC manoeuvre can be performed after the FRC determination

TLC = FRC + IC
RV = TLC - IVC

R. Brown et al; Eur Respir J 1998
J Wanger et al; Eur Respir J 2005

Calculation

Calculation of $V_{apparatus}$

- The initial helium concentration ($F_{sp,He,1}$) is noted
- An additional 2- 3 L of room air is then added (measured with a calibrated syringe) and the second meter reading ($F_{sp,He,2}$) noted when it is stable. If Vsp is the volume of the spirometer prior to this last addition of air, and Vair the precise volume of air added during the last step, then:

$$V_{sp} = V_{air} \cdot F_{sp,He,2} / (F_{sp,He,1} - F_{sp,He,2})$$

Calculation

- Fsp,He,3 is the helium concentration at the end of the determination and Vds is the valve and mouthpiece dead space

$$V_L = V_{air} \cdot F_{sp,He,1}/F_{sp,He,3}$$
$$(F_{sp,He,2} - F_{sp,He,3})/(F_{sp,He,1} - F_{sp,He,2}) - V_{ds}$$

Reproducibility

- Little information is available in the literature to base reproducibility standards
- Issues in regard to reproducibility
  - magnitude of change that is of clinical relevance
  - time constraints in busy laboratories
  - differences amongst equipment of different manufacturers
  - effect of patient stature, age and disease state
  - time required for helium washout to occur between measurements not known

R. Brown et al; Eur Respir J 1998

Reproducibility

- Number of FRC measurements to be tailored to fit the reason why the measurements were made
- When accurate readings are needed, mean of two FRC measurements should be reported
- If values vary by 200 ml, third measurement should be made and the mean of two closest values reported
- Errors of less than 200 mL in FRC are considered to be negligible attributed to expected individual variation

R. Brown et al; Eur Respir J 1998

Loss of Helium / leaks

- Lead to over estimation of FRC
- Continued helium loss leads to failure to achieve equilibration
  - Helium dissolution in the water of the spirometer
  - Equipment leaks
  - Leaks around the nose clip and mouthpiece
  - Transfer through ruptured tympanic membranes
  - Swallowing and absorption into the fluids and tissues of the body

R. Brown et al; Eur Respir J 1998

Loss of Helium / leaks

- The effect of He absorption is a small overestimation of FRC
- Uncertainty as to the exact magnitude of the correction and the variability from patient to patient
- No correction be made until better data are available

R. Brown et al; Eur Respir J 1998

Effect of N_2 excretion

- Upon rebreathing, a redistribution of gas takes place with helium moving from spirometer to lung and nitrogen from lung to spirometer
- This decrease in helium in the spirometer results in a relative increase of the concentration of nitrogen in the gas mixture in the spirometer
- Nitrogen excretion must be considerably less because the alveolar to spirometer gradient for nitrogen is much smaller
- Correction for nitrogen excretion is not necessary

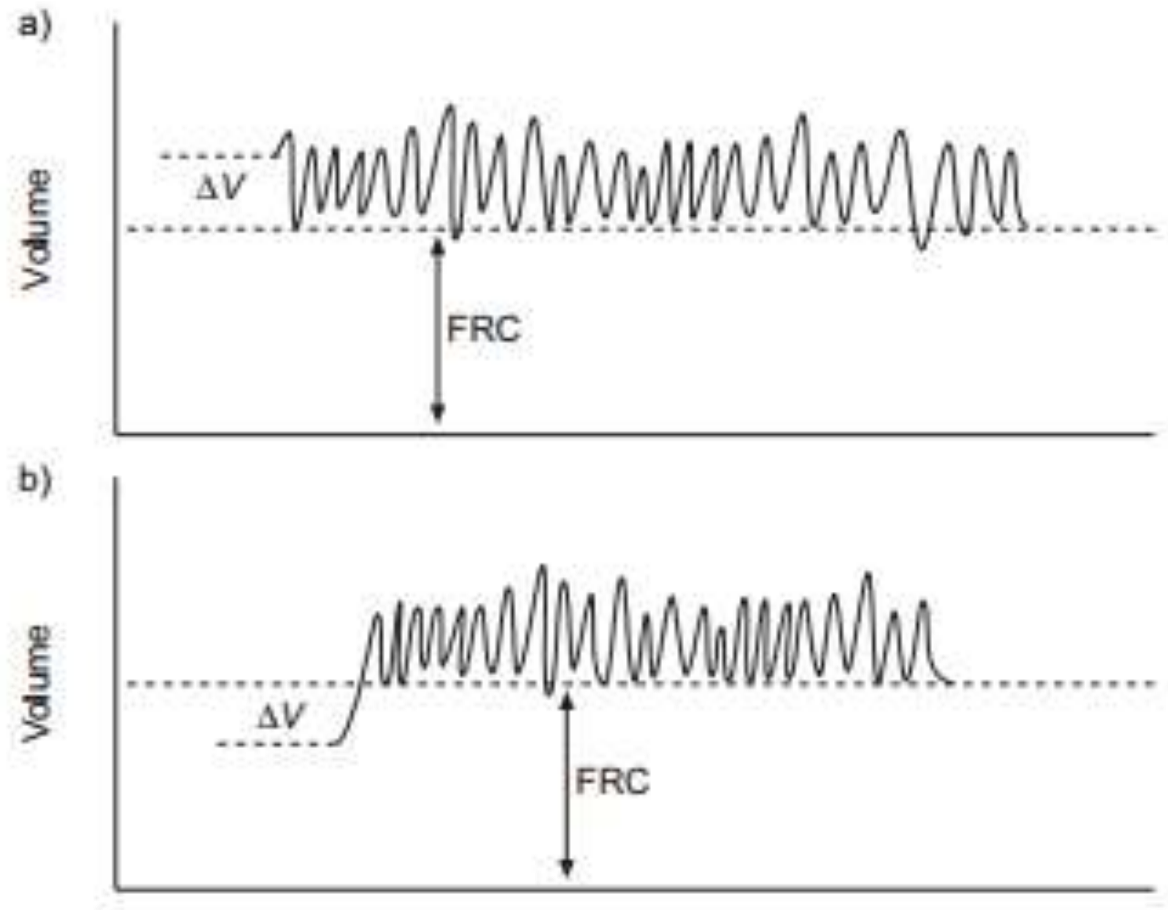
R. Brown et al; Eur Respir J 1998

Effect of ‘R’

- Ratio of carbon dioxide production (*V*'CO_2) to oxygen consumption (*V*'O_2)
- Error due to R less than or greater than 1 lead to over estimation or under estimation of FRC respectively
- Because R is not measured and the effect of it is negligible, it is recommended that no correction be made

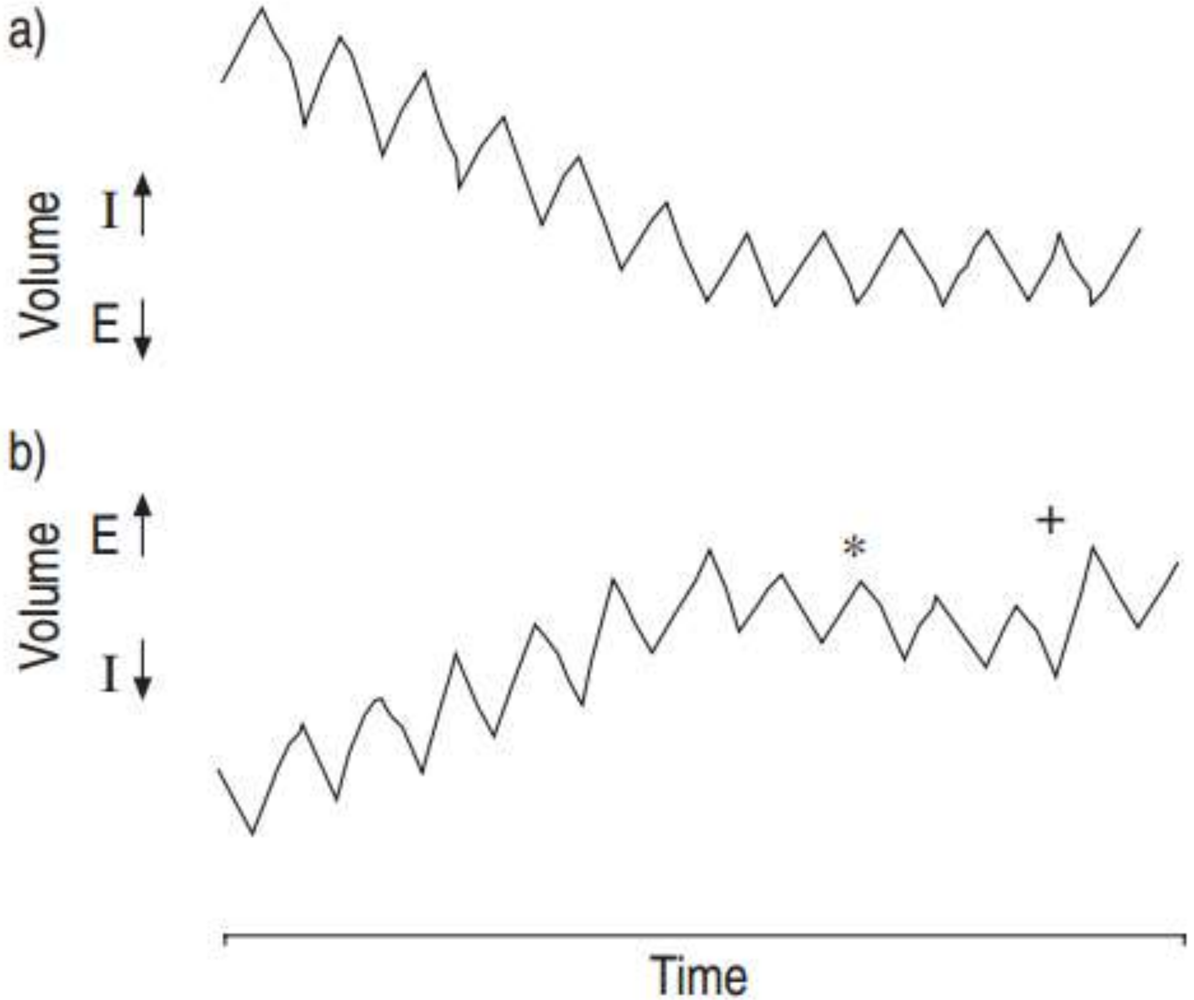
R. Brown et al; Eur Respir J 1998

Switch in errors



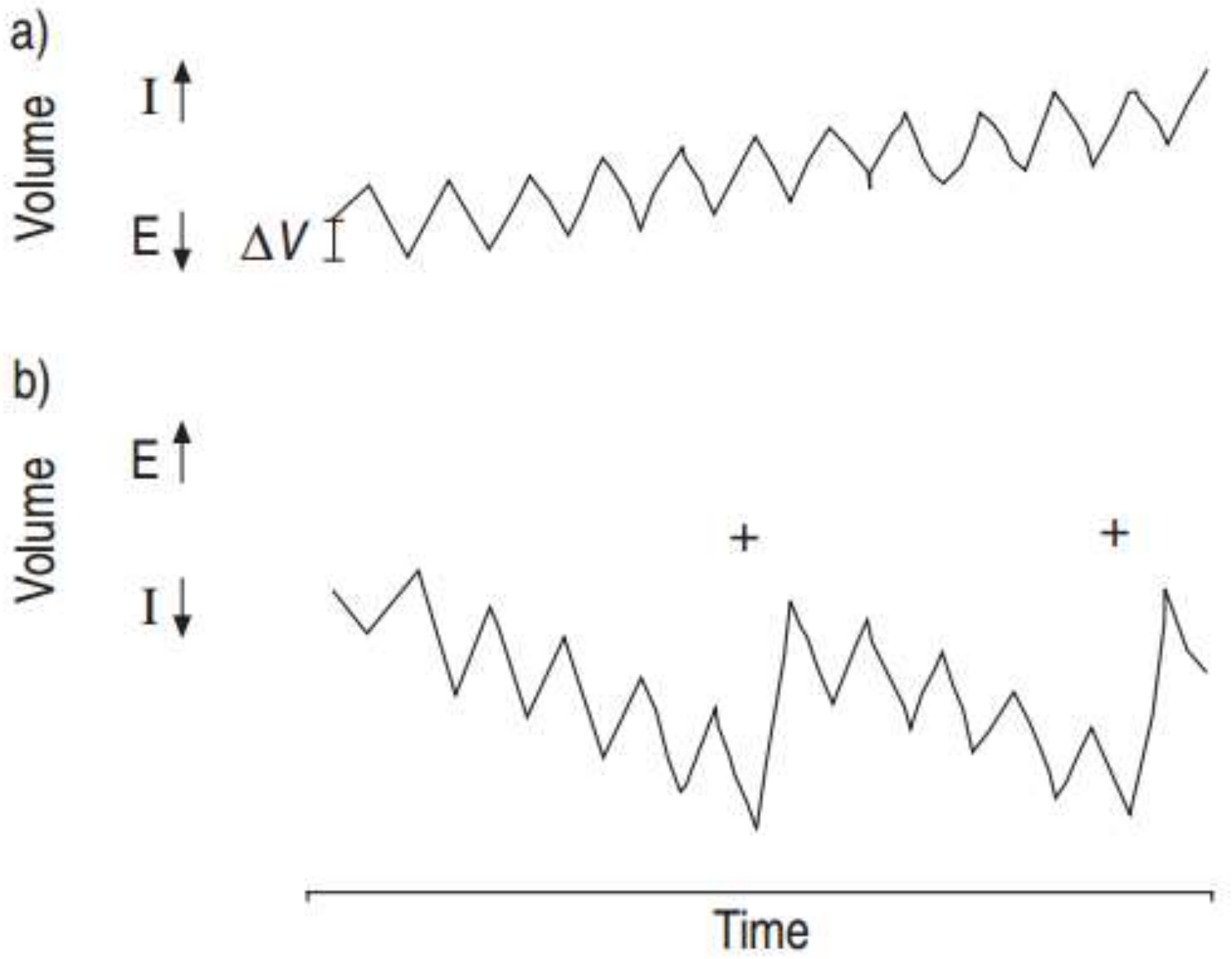
R. Brown et al; Eur Respir J 1998

Variations in FRC



R. Brown et al; Eur Respir J 1998

Variations in FRC



R. Brown et al; Eur Respir J 1998

Hazards

- Infection may be contracted from improperly cleaned tubing, mouthpieces, manifolds, valves, and pneumotachometers
- Hypercapnia and/or hypoxemia may occur as consequence of failure to adequately remove CO_2 or add O_2 to the rebreathed gas

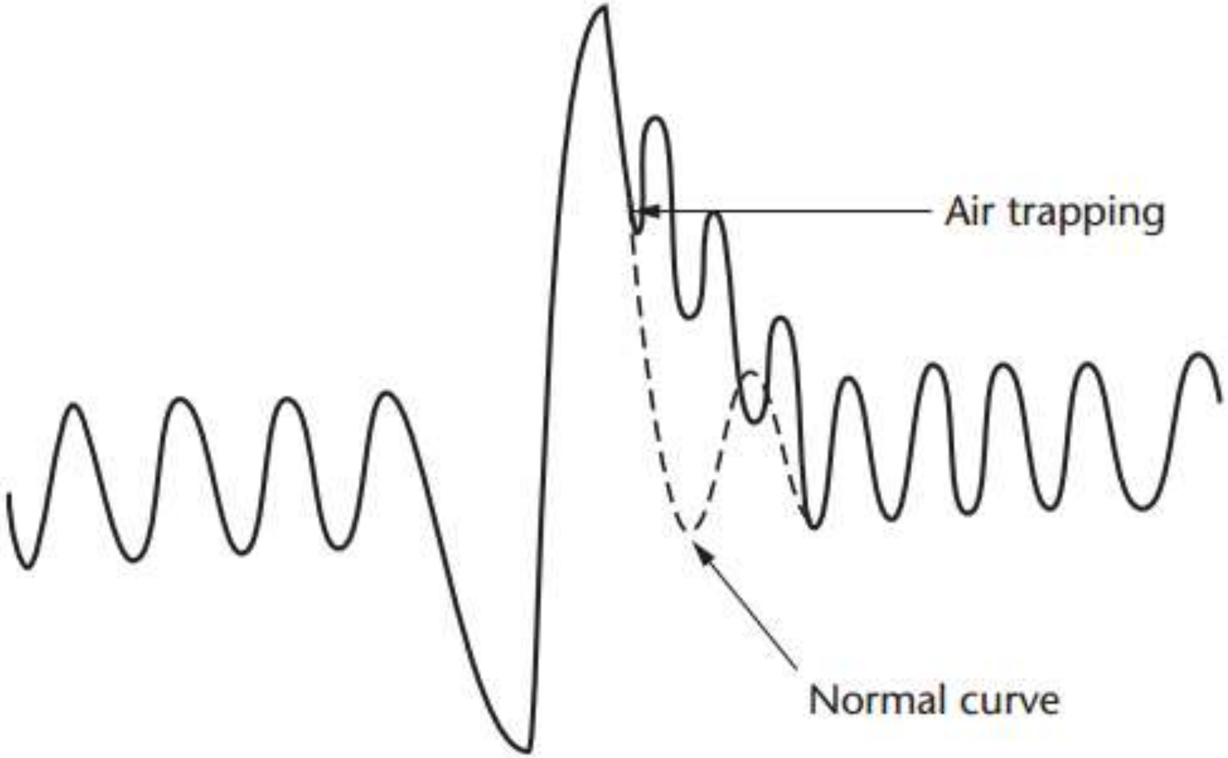
AARC guideline: static lung volumes: 2001 revision & update

Visual evidence of air trapping

- Encouraging deep inhalation - gas mixing in regions of relatively poor ventilation and to decrease equilibration time
- Following a deep inhalation, however, a patient with severe airways obstruction may take many breaths before returning to the original FRC
- Errors in the amount of oxygen added during the procedure so the practice is not recommended, at least in patients with considerable airways obstruction

Cotes textbook of lung function 6th ed

Visual evidence of air trapping

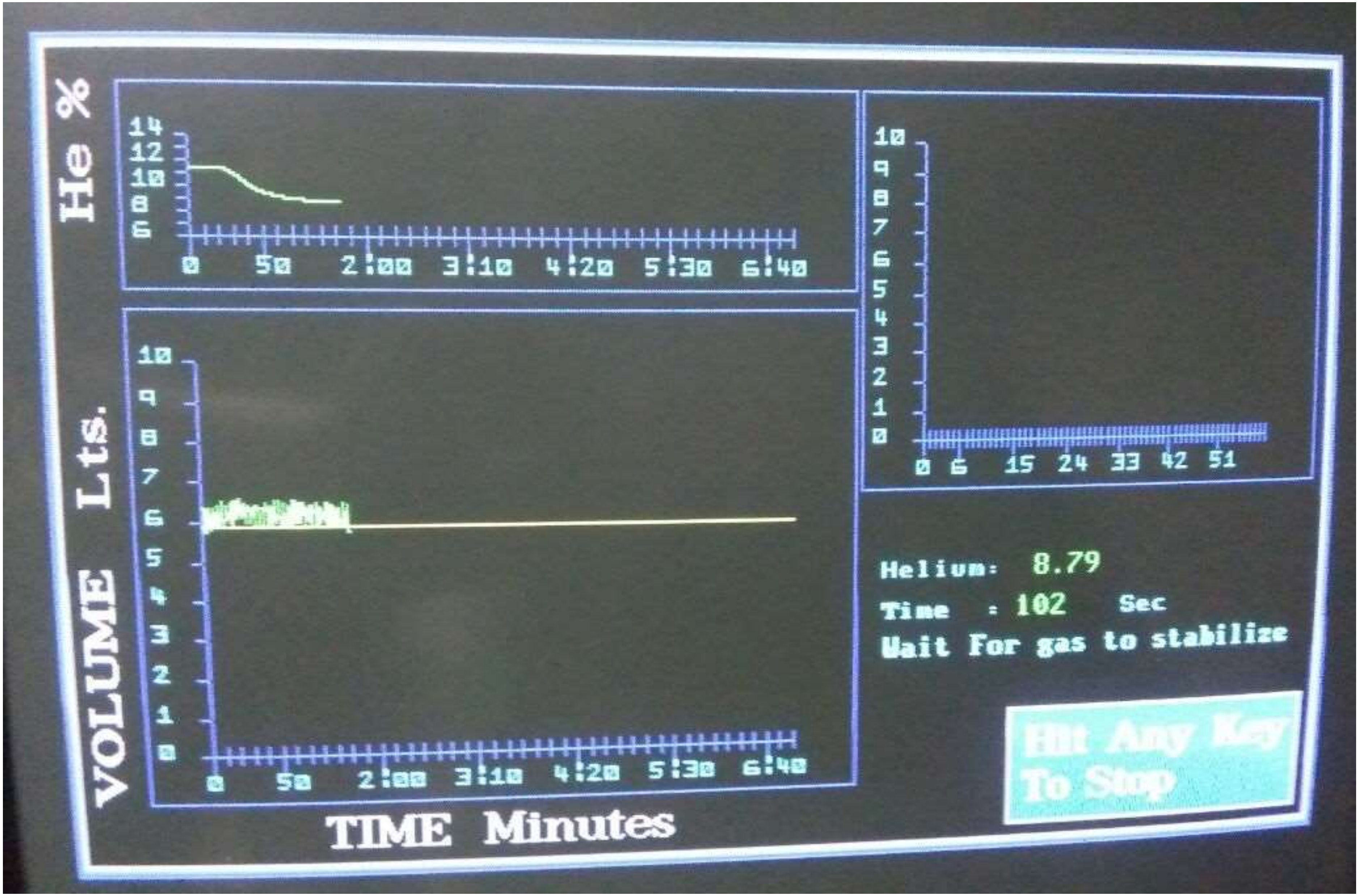


Cotes textbook of lung function 6th ed

Helium dilution

Advantages	Disadvantages
Simple to perform	FRC underestimated in sever air flow obstruction or emphysema
Inexpensive	Cant be used in case of communicable diseases

He %
VOLUME Lts.
TIME Minutes
0
50
2:00
3:10
4:20
5:30
6:40
0 6 15 24 33 42 51
Helium: 9.00
Time : 72 Sec
Wait For gas to stabilize
Hit Any Key
To Stop


He %
14
12
10
8
6
0
50
2:00
3:10
4:20
5:30
6:40
VOLUME Lts.
10
9
8
7
6
5
4
3
2
1
0
TIME Minutes
0
6
15
24
33
42
51
Helium: 8.79
Time : 102 Sec
Wait For gas to stabilize
Hit Any Key To Stop


He %
14
12
10
8
6
0
50
2:00
3:10
4:20
5:30
6:40
10
9
8
7
6
5
4
3
2
1
0
0
6
15
24
33
42
51
VOLUME Lts.
TIME Minutes
Helium: 8.79
Time : 112 Sec
Good Test.
Hit Any Key To Stop

IC

Test _3.14

	Test	Pred	%Pred	Best	Worst	%Best	Mean
IC	3.14	3.61	87	....	....	....	....
FRC	2.83	3.30	86	....	....	....	....
ME	....	....	....	....	....	....	....
ET	....	....	....	....	....	....	....
ERV	1.54	1.78	87	....	....	....	....
IRV	....	....	....	....	....	....	....
RV	1.15	1.52	76	....	....	....	....
TLC	5.97	6.91	86	....	....	....	....
RV/TLC	19	22	86	....	....	....	....
VT	....	....	....	....	....	....	....
MV	....	....	....	....	....	....	....
FB	....	....	....	....	....	....	....
DLCO unc	30.31	34.91	87	....	....	....	....
DLCO Corr	29.98	34.91	86	....	....	....	....
DLCO SB 02	....	....	....	....	....	....	....

Comparison with body plethysmography

Study	Participants	Objective	Outcome
Schaanning CG et al 1973	10 normal subjects 10 hyperinflation Concurrent testing by HDT & plethysmography	Comparison between two methods	Plethysmography yielded a higher FRC than HDT, with a mean difference of 0.3 L in healthy subjects and 0.5 L in obstructed patients ($p=0.001$)
Andersson et al 1988	82 subjects I (20): normal PFT II (23): FEV_1 40-65% III (20): $FEV1 < 40\%$ IV (19): emphysema	Comparison between two methods	No significant difference of TLC was seen except in group of severe obstruction
Claudio Tantucci et al 2016	20 - obstructive 7 - restrictive 10 - normal	Comparison between HDT, body plethysmography and	Both radiograph & plethysmography provide similar values of TLC. He dilution method measures lower TLC in

In airflow obstruction

Carl R. O’Donnell et al, CHEST 2009	
Population	132 subjects 79 had obstruction (60%)
Method	Spiral CT scanning of the entire lung field at full inspiration in the supine position, Helium dilution & Body plethysmography
Results (Mean TLC)	Pleth - 6.18 L (± 1.69 L) HDT - 5.55 L (± 1.39 L) CT scan - 5.31 L (± 1.47 L) **Pleth-derived TLC was significantly greater than either He-derived TLC or CT scan-derived TLC ($P \leq 0.01$)** **Plethysmographic overestimation of TLC was greatest among subjects with FEV1 < 30% of predicted**
Outcome	In airflow obstruction, Pleth systematically overestimates lung volume relative to He or thoracic imaging despite adherence to current recommendations

Comparison with body plethysmography

- The difference is attributed to
  - air spaces in the lung which do not communicate with the central airways during quiet breathing
  - due to trapped gas which increases with exacerbations of a reversible bronchial obstruction
  - mouth pressure does not reflect the intrapulmonary pressure variations during rapid compression and decompression manoeuvres in plethysmography in cases of airway obstruction

Single breath tests

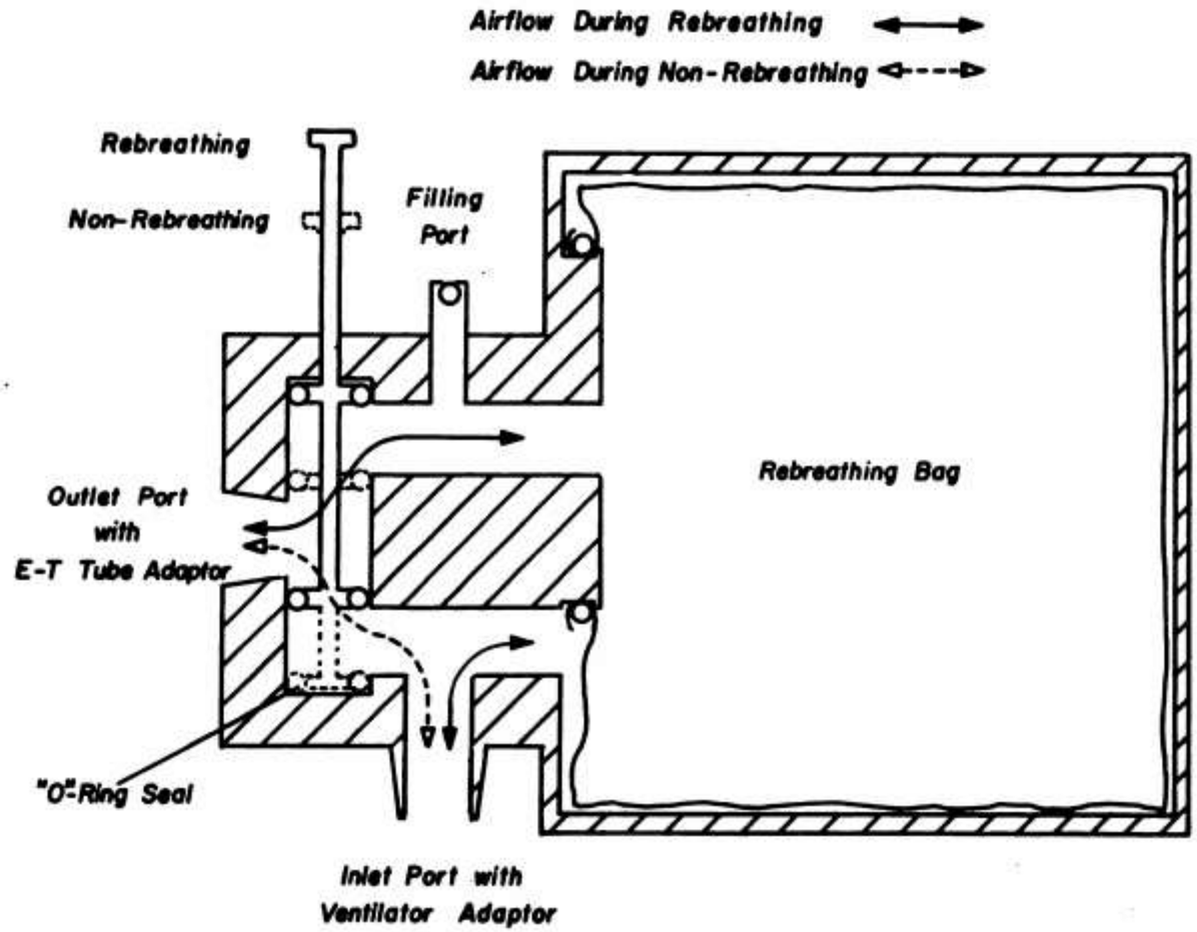
- Performed almost exclusively in conjunction with the determination of the transfer factor of the lung for CO
- Underestimates the true lung volume in subjects with airflow limitation
- Not recommended for routine use, unless in connection with the determination of the effective *TL.CO* when screening large numbers of subjects

He dilution in mechanically ventilated

- An increase in FRC is the goal of therapy with positive end-expiratory pressure (PEEP) in ARDS
- Useful in determining the efficacy of a particular level of PEEP
- Allows reliable, simple, and reproducible measurements of lung volume in mechanically ventilated ALI/ARDS patients

Gregory P. Heldt et al, CHEST 1978

He dilution in mechanically ventilated



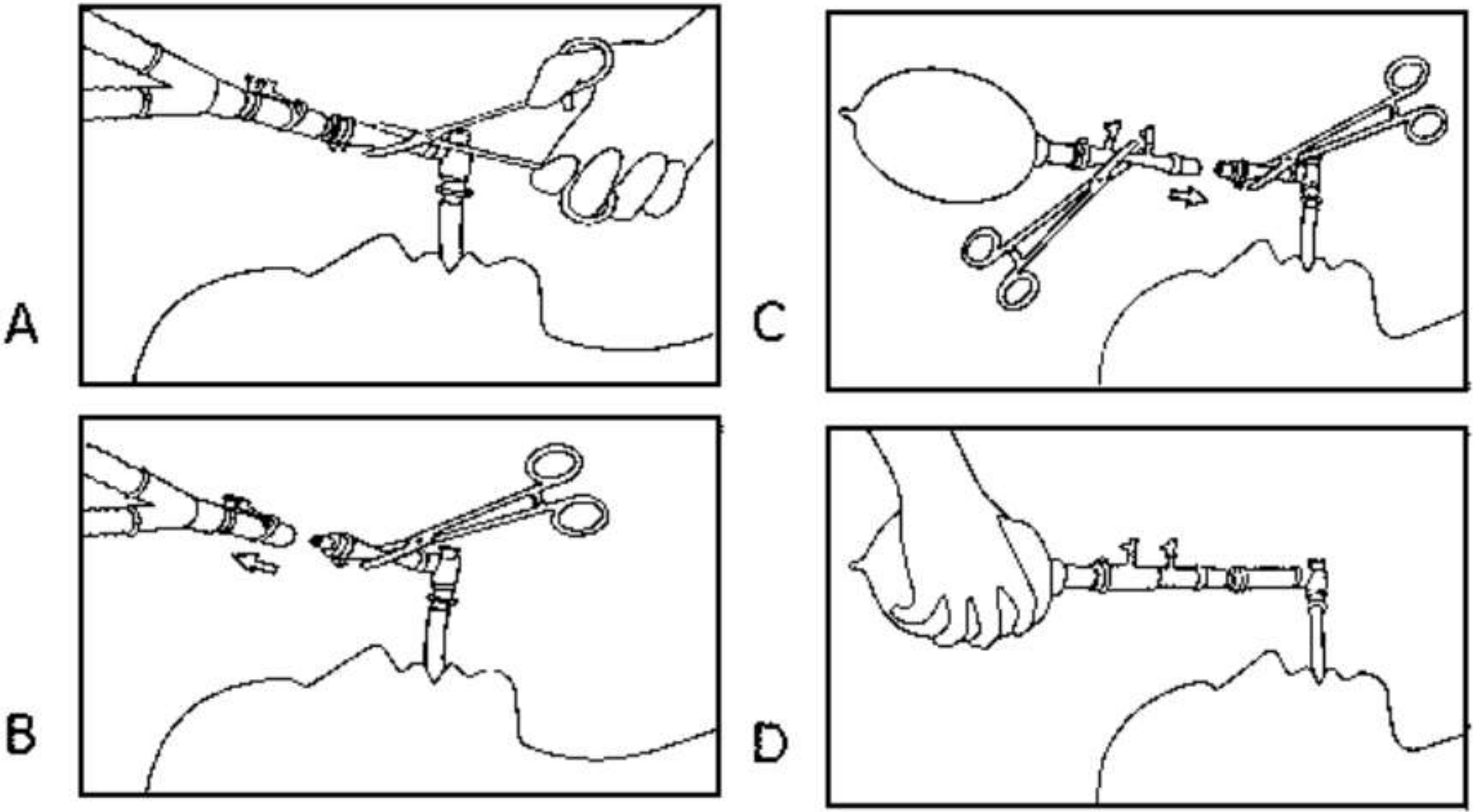
Gregory P. Heldt et al, CHEST 1978

He dilution in mechanically ventilated

- In the non rebreathing position, the patient's airway is attached to the outlet side of the spool valve. The ventilator is attached to the inlet side of the valve
- During rebreathing position, the airway is connected to the bag, and the inspiratory volume of the ventilator is pushed into the plastic box, emptying the bag into the patient's lungs
- The pressurized gas in the box escapes through the ventilator during the expiratory cycle, and the patient simultaneously exhales into the rebreathing bag
- Thus, by a simple switching of the valve, the ventilator can be changed from directly ventilating the patient to compressing the rebreathing bag

Gregory P. Heldt et al, CHEST 1978

He dilution in mechanically ventilated



Nicolo Patroniti et al, Intensive Care Med 2004

He dilution in mechanically ventilated

- Good correlation was found EELV measured by CT scan in 21 mechanically ventilated ARDS patients
- Practical alternative to $EELV_{CT}$

Nicolo Patroniti et al, Intensive Care Med 2004

Take home message

- Simple method to measure FRC
- Underestimates FRC in cases of airway obstruction
- Difference of FRC b/n HDT and body plethysmograph quantify non ventilated lung and trapped air
- HDT can also used for EELV measurement in critically ill

Thank you