HELIUM DILUTION TECHNIQUE


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
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)

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)
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
Indications – public health

- Epidemiological surveys
- Derivation of reference equations
- Clinical research
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

• “Equilibration 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

\[ V_{\text{app}} \times F_{\text{He1}} = (V_{\text{app}} + FRCH_{\text{He}}) \times (F_{\text{He2}}) \]

\[ FRCH_{\text{He}} = V_{\text{app}}(F_{\text{He1}} - F_{\text{He2}})/F_{\text{He2}} \]

\[ V_{\text{app}} - \text{Volume of the spirometry apparatus} \]

\[ F_{\text{He1}} - \text{Initial Helium fraction} \]

\[ F_{\text{He2}} - \text{Helium fraction at the time of equilibration} \]

\[ FRCH_{\text{He}} - \text{Lung volume (FRCH_{\text{He}}) at the time the subject is connected to the spirometry apparatus} \]
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
• CO2 absorber
• Water vapour absorber
• Helium analyser or katharometer
• O2 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
CO₂ and water absorbers

- CO₂ 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 CO₂
- 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 $\leq 0.01\%$ 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 CO₂ 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
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
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

\[
\text{RV} = \text{FRC} - \text{ERV} \\
\text{TLC} = \text{RV} + \text{IVC}
\]

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

\[
\text{TLC} = \text{FRC} + \text{IC} \\
\text{RV} = \text{TLC} - \text{IVC}
\]

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

Calculation of $V_{\text{apparatus}}$

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

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

• $F_{sp,He,3}$ is the helium concentration at the end of the determination and $V_{ds}$ is the valve and mouthpiece dead space

$$VL = V_{air} \cdot \frac{F_{sp,He,1}}{F_{sp,He,3}} \left( \frac{F_{sp,He,2} - F_{sp,He,3}}{F_{sp,He,1} - F_{sp,He,2}} \right) - V_{ds}$$
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
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 ($V_{CO2}$) to oxygen consumption ($V_{O2}$)
- Error due to $R$ less than or greater than 1 lead to overestimation or underestimation 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 CO₂ or add O₂ to the rebreathed gas
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
Visual evidence of air trapping

Cotes textbook of lung function 6th ed
# Helium dilution

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple to perform</td>
<td>FRC underestimated in severe airflow obstruction or emphysema</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>Cant be used in case of communicable diseases</td>
</tr>
</tbody>
</table>
Helium: 9.00
Time: 72 Sec
Wait for gas to stabilize

Hit any key to stop
Helium: 8.79
Time: 102 Sec
Wait for gas to stabilize
Hit any key to stop
Helium: 8.79
Time: 112 Sec
Good Test.

Hit Any Key To Stop
<table>
<thead>
<tr>
<th>Test</th>
<th>Pred</th>
<th>%Pred</th>
<th>Best</th>
<th>Worst</th>
<th>%Best</th>
<th>Mean</th>
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<td>3.14</td>
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<td>FRC</td>
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<td>3.30</td>
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<td>ME</td>
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<td>ERV</td>
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<td>RV</td>
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<td>TLC</td>
<td>5.97</td>
<td>6.91</td>
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<td>RV/TLC</td>
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<td>22</td>
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<td>DLCO unc</td>
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<td>DLCO Corr</td>
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<td>DLCO SB O2</td>
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<td>Study</td>
<td>Participants</td>
<td>Objective</td>
<td>Outcome</td>
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<tr>
<td>Schaanning CG et al 1973</td>
<td>10 normal subjects 10 hyperinflation Concurrent testing by HDT &amp; plethysmography</td>
<td>Comparison between two methods</td>
<td>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)</td>
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<tr>
<td>Andersson et al 1988</td>
<td>82 subjects I (20): normal PFT II (23): FEV1 40-65% III (20): FEV1 &lt; 40% IV (19): emphysema</td>
<td>Comparison between two methods</td>
<td>No significant difference of TLC was seen except in group of severe obstruction</td>
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<tr>
<td>Claudio Tantucci et al 2016</td>
<td>20 - obstructive 7 - restrictive 10 - normal</td>
<td>Comparison between HDT, body plethysmography and radiographic</td>
<td>Both radiograph &amp; plethysmography provide similar values of TLC. He dilution method measures lower TLC in patients with airflow obstruction</td>
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# In airflow obstruction

<table>
<thead>
<tr>
<th>Carl R. O’Donnell et al, CHEST 2009</th>
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</table>
| **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 ≤ 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
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
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