Interpretation of lung function test

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18 June 2013
• Dynamic lung function tests?
  • What is a valid test?
  • FVC maneuver?

• Static lung function tests
  • Lung volume Vs capacity?
  • SVC maneuver?
  • Measurement methods?

• Pattern of F-V loop?

• Diffusion Capacity

• Respiratory muscle

• How to interpret?
Dynamic lung function test

- FEV1- Vol. expired in first sec
- FVC
- FEF25-75%- flow over mid portion of FVC
- PEFR- Peak exp flow
- Flow-volume (FV) curve
- Volume-time (VT) curve
- Use of FVC maneuver
FVC maneuver

- FVC maneuver
  - expire as **forcefully and rapidly** as possible after maximal inspiration

- FVC test is important because there is a **unique limit to max. exp. flow at any lung volume**
- As volume decrease, dynamic compression of airway produces a critical narrowing that develop in trachea and produce limitation of flow

- FVC maneuver make the test **reproducible and interpretable**
A. Full Inspiration

Flow

d b
ea

c
Volume

B. Forced Expiration

Flow

f
e
Flow

CN

Volume
A Valid Test is

Within-maneuver criteria
Individual spiromgrams are "acceptable" if
- They are free from artefacts [3]
- Cough during the first second of exhalation
- Glottis closure that influences the measurement
- Early termination or cut-off
- Effort that is not maximal throughout
- Leak
- Obstructed mouthpiece

They have good starts
- Extrapolated volume <5% of FVC or 0.15 L, whichever is greater
- They show satisfactory exhalation

Duration of ≥6 s (3 s for children) or a plateau in the volume–time curve or
- If the subject cannot or should not continue to exhale

Between-maneuver criteria
After three acceptable spiromgrams have been obtained, apply the following tests
- The two largest values of FVC must be within 0.150 L of each other
- The two largest values of FEV1 must be within 0.150 L of each other
- If both of these criteria are met, the test session may be concluded
- If both of these criteria are not met, continue testing until
- Both of the criteria are met with analysis of additional acceptable spiromgrams
- A total of eight tests have been performed (optional) or
- The patient/subject cannot or should not continue

Save, as a minimum, the three satisfactory manoeuvres

ATS guideline 2005
Hesitation in blowing out before initial blast

Most easily seen in F-V curve (peak flow displaced to right)

Extrapolated vol >0.15L or 5% of VC

Affect FEV1, not FVC

Early Termination

Lack of plateau on the VT curve

The falsely reduced FVC may be misinterpreted as indicating a “restrictive impairment.”

The falsely increased FEV1/FVC ratio may miss a true “obstructive impairment”
ARTIFACTS

COUGH:
Jagged interruption in the FV curve

Coughing in the first second may affect the FEV1, while coughing after the first second will not affect the FVC measurement unless the subject stops blowing prematurely.

VARIABLE, NON SUSTAINED EFFORT

Often seen as a dip in FV curve

May reduce FEV1 and thus FEV1/FVC ratio

Ask the subject to blast one breath out HARD and FAST, and KEEP BLOWING out
BETWEEN MANEUVER ACCEPTIBILITY

Gap between the FVC plateaus on multiple VT curves

Similar shape but curves will vary in size.

FV curves with sharp peaks → Good initial blasts, but the difference in maximal airflow (PEF) may be caused by lower elastic recoil associated with less “stretching” of the lung with smaller volumes

**Falsely reduced FVC** can be misinterpreted as “restrictive impairment.”
Which values should we use?

- The largest FVC and the largest FEV1 should be measured.

- PEF is the largest value from an acceptable effort.

- All other flows (e.g., FEF 25-75%) are taken from the acceptable effort with the largest sum of FVC and FEV1.
**Static Lung function test**

- Lung volume
  - FRC
  - RV, TLC

- **Slow vital capacity (SVC) maneuver**
  - maximal amount of air exhaled *slowly and steadily* from full inspiration to maximal expiration. Not time-dependent
  - Expiratory VC (EVC) vs Inspiratory VC (IVC)
  - < FVC esp. in patients with airway obstruction
Lung volumes are directly measured
Lung capacities are inferred from lung volumes
Methods to measure FRC

- Nitrogen washout method
- Helium dilution method
- Plethysmography (body box/TGV)
Given 100% oxygen for several minutes, with nitrogen in the lung washout; exhaled to separate bag

The concentration of collected nitrogen is measured and the volume collected is measured

FRC was then calculated
Helium dilution method

The spirometer system contain a known volume of gas (He with known conc)

The subject rebreath until the He conc reach plateau (equal conc He in lung and system)

FRC was then calculated
Plethysmography

- By applying Boyles law \( PV = \text{constant} \)
- FRC = changes of volume / changes of pressure x (pleth pressure)
- Volume measured is also call thoracic gas volume (TGV)

- Measurement not affected by degree of airway obstruction
- \( \Rightarrow \) values are usually larger then that measured by nitrogen washout or helium dilution method
How about non communicating bulla??

• The gas trapped in the bulla cannot be measured by dilution method

• TGV could measure all air in the chest including trapped air in the bulla
Interpretation of lung function test

ATS 2005
71/M, Chronic smoker
c/o: progressive SOB and
wheezing on exertion

FVC: 1.94L (45% predicted)
FEV1: 1.03L (31% predicted)
FEV1/FVC: 53%
FEF 25-75: 0.4 (15% predicted)
MVV: 51 (41% predicted)
TLC: 9.37 (142% predicted)
RV/TLC: 75 (214% predicted)
DLCO: 10 (40% predicted)
Interpretation

- Low FEV1/FVC, increased TLC, low DLCO
- Obstructive pattern with hyperinflation, low DLCO consistent with emphysema
Obstruction Pattern

Dynamic lung function parameters:
- FVC, FEV1, **FEV1/FVC ratio**, PEF, PFE 25-75%: decreased
- MVV decreased
- Slope of FV curve: decrease

Static Lung function test
- TLC, RV, RV/TLC ratio: increase

Diffusion:
- **DLco**: decrease (esp. in emphysema)
- **Kco**: decrease (esp. in emphysema), except in asthma

Respiratory muscle
- **PEmax/PImax**: not affected
- **Raw**: elevated
Fixed ratio (0.7) Vs LLN ???

- FEV1/FVC decreases with increasing age and height in normal subjects
  - Fixed cut-off will over-diagnosis of airflow obstruction in elderly and tall subjects

- ATS/ERS task force recommend the use of lower limit of normal (LLN) if prediction equations are available

- The LLN is typically the 5th percentile value
Updated Spirometric Reference Values for Adult Chinese in Hong Kong and Implications on Clinical Utilization

Mary Sau-man Ip, MD, FCCP; Fanny Wai-san Ko, MBChB, FCCP; Arthur Chun-wing Lau, MBBS, FCCP; Wai-cho Yu, MBBS, FCCP; Kam-shing Tang, MBBS; Kahlín Choo, BMBS, FCCP; Moira Mowah Chan-Yeung, MBBS, FCCP; on Behalf of the Hong Kong Thoracic Society and American College of Chest Physicians (Hong Kong and Macau Chapter)

Author and Funding Information

Chest. 2006; 129(2). 384-392. doi:10.1378/chest.129.2.384
FEV6 could replace FVC?

- FEV6 is suggested as a surrogate of FVC

- 99% of the FVC can be obtained in the first 6.64s for patients with FEV1/FVC ratio as low as 50%

- The FEV1/FEV6 ratio below LLN has a positive and negative predictive value of 97% for diagnosis of airway obstruction

- When using fixed cut-offs, one may refer to the conclusion by two large population studies that FEV1/FEV6 < 0.73 is an valid alternative to the FEV1/FVC < 0.70 to diagnose airflow obstruction
HOW TO MEASURE SMALL AIRWAY ???

- **FEF 25%-75%** (also called maximum mid expiratory flow rate MMFR):
  - average flow during the middle half of the FVC maneuver
  - In the presence of borderline value of FEV1/VC a reduced FEF25-75 may suggests airflow limitation
  - wide variability of FEF25-75
  - => should not be used alone
FEV3/FVC

- More sensitive and reliable index to identify early expiratory flow limitation when compared to FEF25-75

- While a decrease in FEV1/FVC reflects reduction in short-time-constant lung units, a decrease in FEV3/FVC or increase in the fraction that had not been expired during the first 3 seconds (1-FEV3/FVC) represents an increase in long-time-constant lung units.

- Therefore these indices should be sensitive in detecting early airflow limitation.

- The variability of FEV3/FVC is much lower than FEF25-75 and also lower than that of FEV1/FVC in a large population.

- Prediction equations for FEV3 and FEV3/FVC have been published.

- FEV3 and FEV3/FVC however are not yet included as a standard parameter by the ATS/ERS1.
Nitrogen washout test-Closing volume

Phase I-
Pure O2 Gas from the anatomic deadspace

Phase II-
Rapid rise of N2, coming from both bronchial and alveolar areas (50% deadspace & 50% alveolar)

Phase III-
The plateau phase with gas coming from alveoli. slope is measure of inequality of ventilation

Phase IV-
Closure of the airway in lower lung and emptying of the apices (high in amount of nitrogen)
• **Closing volume (CV):** *lung volume from the beginning of airway closure to the end of maximal expiration.*

• In normal, young individuals, the CV is about 10% of vital capacity or 0.4-0.5 L.

• **Closing capacity (CC):** *lung volume at which small airways in the dependent part of the lung close*

• **Small airway disease:**
  - Steeper slope of Phase III (ventilation inhomogenicity)
  - Increase in CV

閉合容量 (CC): 閉合容量(CV)與殘氣(RV)之和  \[ CC = CV + RV \]
30/F, non smoker
Progressive dyspnoea and decrease exercise tolerance
P/E: joint pain and tightening of skin

FVC: 1.12 (19% predicted)
FEV1: 1.04 (21% predicted)
FEV1/FVC: 93%
FEF 25-75: 2.2 (48% predicted)
MVV: 81 (43% predicted)
TLC: 2.09 (28% predicted)
RV/RLC: 44 (232% predicted)
DLCO: 9 (26% predicted)
INTERPRETATION

- Restrictive pattern
  - Steep slope of FV curve
  - Normal FEV1/FVC ratio,
  - TLC: decreased
  - Decrease DLco: lung parenchyma disease

- Scleroderma with interstitial fibrosis
Restrictive lung diseases

**Intrapulmonary Cause**

- Fibrosis/ inflammation:
  - Pulmonary fibrosis and interstitial pneumonitis
  - BOOP
  - HistiocytosisX
- Infection:
  - Pneumonia
- Neoplasms,
  - e.g. carcinomatosis
- Sarcoidosis
- Asbestosis
- Ateletasis

**Extrapulmonary Cause**

- Pleural cavity:
  - Pleural effusion, pneumothorax, fibrothorax, cardiac enlargement
- Neuromuscular:
  - Diaphragmatic paralysis
  - Neuromuscular diseases e.g. MND, MG, polio etc
- Chest wall:
  - Kyphoscoliosis
  - Ankylosing spondylitis
  - Thoracoplasty
  - Ascites
  - pregnancy
Lung function pattern in restrictive diseases:

**INTRAPULMONARY**

**Dynamic:**
- FVC, FEV1 decrease
- FEV1/FVC ratio normal or elevated
- MVV normal (decreased volume compensated by increase in RR)
- Slope of FV curve: increase

**Static:**
- TLC, RV, FRC: decrease

**Diffusion:**
- DLco decrease
- Kco: normal or decrease

**Resp muscle**
- PEmax, Plmax not affected

**EXTRAPULMONARY**

**Dynamic:**
- FVC, FEV1: decrease
- FEV1/FVC: normal
- MVV decreased
- Slope of FV curve: normal or decreased

**Static:**
- TLC, RV, FRC: decreased

**Diffusion:**
- DLco: normal
- Kco: normal

**Resp muscle**
- PImax, PEmax: normal (decreased when in neuromuscular disease)
30/F, non smoker
Progressive dyspnoea and decrease exercise tolerance
P/E: joint pain and tightening of skin

FVC:  (80% predicted)
FEV1:  (80% predicted)
FEV1/FVC:  93%
FEF 25-75:  2.2 (48% predicted)

TLC  (90% predicted)

DLCO  9 (26% predicted)
Disproportionate decrease in DLCO

- ? Pulmonary vascular disease
- ? Early interstitial lung disease
**Diffusion capacity**

- **The diffusion capacity (DLco)**
  - Measures ability of lungs to transport inhaled gas from alveoli to pulmonary capillaries

- A sensitive index of the integrity of blood gas interface

- Amount of oxygen transferred is determined by
  - Area and thickness of alveolar-capillary membrane
  - Driving pressure (the difference in oxygen tension between alveolar gas and the venous blood)
  - Hemoglobin concentration
  - Cardiac output

- Diffusion capacity of oxygen is difficult to measure, so diffusion capacity of CO₂ is used
• Technique: single breath method

• Subject exhales to residual volume and then inhaled a gas mixture containing very low concentration of CO and inert gas

• After maximal inhalation to TLC, hold breath for 10 sec, and gas is collected and analyzed

• Conc of exhaled CO and He was measured and the TLC and DLCO was calculated
## Diffusing Capacity

<table>
<thead>
<tr>
<th>Decreased DLCO (&lt;80% predicted)</th>
<th>Increased DLCO (&gt;120-140% predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstructive lung disease</td>
<td>Asthma (or normal)</td>
</tr>
<tr>
<td>Parenchymal disease</td>
<td>Pulmonary hemorrhage</td>
</tr>
<tr>
<td>Pulmonary vascular disease</td>
<td>Polycythemia</td>
</tr>
<tr>
<td>Anemia</td>
<td>Left to right shunt</td>
</tr>
<tr>
<td></td>
<td>Supine position, (higher perfusion and blood volume of upper lobe in this position)</td>
</tr>
<tr>
<td></td>
<td>Exercise( increase in blood volume )</td>
</tr>
</tbody>
</table>
Causes of a decreased diffusion capacity

Decrease area of diffusion
- Emphysema
- Lung/lobe resection
- Bronchial obstruction
- Multiple pulmonary emboli
- Anaemia

Increase thickness of alveolar capillary membrane
- Idiopathic pulmonary fibrosis
- CHF
- Asbestosis
- Sarcoidosis
- Collagen vascular disease: scleroderma, SLE
- Drug induced alveolitis or fibrosis
- Hypersensitivity pneumonitis
- Histiocytosis X
- Alveolar proteinosis
Interpretation of DLCO

**Increased DLCO**
- Polycythemia
- Severe obesity
- Asthma
- Pulmonary hemorrhage
- Left-to-right intracardiac shunting
- Mild left heart failure — increased pulmonary capillary blood volume
- Exercise just prior to the test — increased cardiac output

**Low DLCO with normal spirometry**
- Anemia — mild decrease
- Pulmonary vascular disease — mild to severe decrease
- Early interstitial lung disease — mild to moderate decrease

**Low DLCO with obstruction**
- Emphysema
- Cystic fibrosis
- Bronchiolitis
- Lymphangioleiomyomatosis

**Low DLCO with restriction**
- Interstitial lung disease
- Pneumonitis

**Other**
- Anemia — reduces DLCO
- Carboxyhemoglobin — reduces DLCO
- Altitude — increases DLCO
**Kco**

- Kco = DLco/VA (alveolar volume)
- Is volume standardized measure of DLco
- Intrinsic property of alveolar-capillary membrane
- Kco is reduced in emphysema and intrathoracic causes of restrictive lung disease, it is normal in extrathoracic causes of restrictive lung disease and pneumonectomy
- Kco is elevated when there is **discrete loss** of alveolar volume, high cardiac output or pulmonary hemorrhage
50/M, non smoker
Hx of bulbar poliomyelitis 19 yrs ago
c/o: SOB on climbing stairs

FVC: 4.02 (87% predicted)
FEV1: 3.23 (88% predicted)
FEV1/FVC: 80%
FEF 25-75%: 3.0 (88% predicted)
MVV: 46 (31% predicted)
- Normal contour of FV curve
- Unexplained isolated decreased in MVV
  - Poor effort, major airway lesion, neuromuscular problems
- FV loop show variable extrathoracic central airway obstruction
Maximal voluntary ventilation (MVV)

- Volume of air exhaled in 12 seconds during rapid, forced breathing ( <15sec because may produce syncope)

- A measure of overall function of the resp system, affected by airway resistance, resp muscles, compliance of lung, ventilatory control system

Acceptability criteria:
- Tracing shows continuous, rhythmic effort for at least 12 seconds
- End expiratory lung volume is relatively constant
- 2 acceptable maneuvers obtained, with values within 10%
Maximal voluntary ventilation (MVV)

- Approximately equal to FEV1 x40;
- If lower than the predicted value:
  - poor effort or fatigue
  - Major airway obstruction
  - Resp muscle weakness
  - (less specific when in advanced level of obstructive disease)
Flow-Volume loop

Expiration

Inspiration

Flow (liters per second)

PEF, MEF

FEF_{25\%}

FEF_{50\%}

FEF_{75\%}

FVC

Volume (L)

FIF_{25\%}

FIF_{50\%}

FIF_{75\%}
Different characteristic flow volume loop pattern
Effect of dynamic extrathoracic airway obstruction  Effects of forced expiration and inspiration in dynamic extrathoracic airway obstruction. Left, during forced expiration, intratracheal pressure (Ptr) exceeds the pressure around the airway (Patm), lessening the obstruction. Right, during forced inspiration, when intratracheal pressure falls below the atmospheric pressure, the obstruction worsens resulting in flow limitation. (Redrawn from Kryger, M, Bode, F, Antic, R, et al, Am J Med 1976; 61:85.)
Effects of dynamic intrathoracic airway obstruction  Left panel, during forced expiration, the intrathoracic intratracheal pressure ($P_{tr}$) is less than the pressure in the pleural pressure ($P_{pl}$), worsening the obstruction. Right, during forced inspiration, intratracheal pressure exceeds the pleural pressure, lessening the degree of obstruction. (Redrawn from Kryger, M, Bode, F, Antic, R, et al, Am J Med 1976; 61:85.)
<table>
<thead>
<tr>
<th></th>
<th>Extrathoracic</th>
<th>Intrathoracic obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed</td>
<td>Variable</td>
</tr>
<tr>
<td>PEF</td>
<td>Decreased</td>
<td>Normal or decreased</td>
</tr>
<tr>
<td>MIF50</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td>MIF50/MEF50</td>
<td>~1</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

PEF: peak expiratory flow; MIF50: maximum inspiratory flow at 50% of forced vital capacity (FVC); MEF50: maximum expiratory flow at 50% of FVC.

Variable intrathoracic lesions
- Tumor of lower trachea
- Tracheomalacia
- Strictures
- Wegener’s granulomatosis or relapsing polychondritis

Variable extrathoracic lesions:
- Vocal cord paralysis (due to thyroid operation, tumor invading recurrent laryngeal nerve, amyotrophic lateral sclerosis, post polio)
- Subglottic stenosis
- Neoplasm (primary hypopharyngeal or tracheal, metastatic from primary lesion in lung or breast)
- Goiter

Fixed lesions
- Fixed neoplasm in central airway (at any level)
- Vocal cord paralysis with fixed stenosis
- Fibrotic stricture
Figure 4 Example of unilateral main bronchus obstruction due to a valve-like mechanism occluding the main left stem bronchus during inspiration as a result of a surgical scar. There is a delay in gas filling towards the end of the forced inspiration as evidence of the variable unilateral main bronchus obstruction (forced expiratory volume in one second (FEV1): 76%; FEV1/vital capacity: 70%; peak expiratory flow: 93%; total lung capacity: 80%). *: predicted expiratory flow-volume loop; ●: recorded maximum inspiratory and expiratory flow-volume loops. Pellegrino, R, Viegi, G, Brusasco, V, et al. Interpretative strategies for lung function tests. ATS/ERS task force: standardisation of lung function testing. Eur Respir J 2005; 26:948.
68/M, chronic smoker
c/o: SOB especially when lying down, 
not much dyspnoea when walking

FVC                 2.43 ( 56% predicted)
FEV1               1.59 ( 52% predicted)
FEV1/FVC                66%
FEF 25-75       0.7 ( 26% predicted)
MVV                87 ( 75% predicted)

TLC                 4.95 ( 63% predicted)
RV/TLC           51% (116% predicted)
DLCO:             28 ( 90% predicted)
INTERPRETATION

- Mild obstructive component as shown by mild decrease in FEV1/FCV ratio
- TLC decreased → mixed restrictive disease
- Normal DLco: extrapulmonary causes
- PIMax and PEMax done: decreased
- Fluoroscopy done: confirmed diaphragmatic paralysis
Respiratory muscle power

- Neuromuscular causes of resp failure:
  - CNS system
  - Neuropathy
  - MN junction
  - Muscle disease
• Vital capacity is a useful screening test

• Sensitivity of test may be increased by measurement supine (weight of abdominal viscera give additional load to diaphragm), a disparity of greater than 25% of VC is indicative of NM disease

• A normal supine VC exclude clinically important muscle weakness

• Also best mean of monitoring of progress of resp muscle impairment

• If VC is <30ml/kg → impaired ability to cough

• In chronic resp muscle disease, VC of less than 1/3 of normal predict impending resp failure
- Arterial pCO2 raised
- TLC, FVC decreased, RV increased
- Kco increased

- MIP
- MEP

- Transdiaphragmatic measurement
  - Sniff Pdi
  - Twitch Pdi

- Radiological assessment of muscle strength (insensitive)
**PEmax/Plmax**

- The strength of expiratory muscles is measured near the TLC and that of inspiratory muscles is measured near the residual volume.
- PEmax around twice of Plmax.
Normal values for Plmax/PEmax

<table>
<thead>
<tr>
<th>Pressure</th>
<th>20–54</th>
<th>55–59</th>
<th>60–64</th>
<th>65–69</th>
<th>70–74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plmax, cm H₂O*</td>
<td>-124 ± 44</td>
<td>-103 ± 32</td>
<td>-103 ± 32</td>
<td>-103 ± 32</td>
<td>-103 ± 32</td>
</tr>
<tr>
<td>Male</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>-87 ± 32</td>
<td>-77 ± 26</td>
<td>-73 ± 26</td>
<td>-70 ± 26</td>
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<tbody>
<tr>
<td>PEmax, cm H₂O*</td>
<td>233 ± 84</td>
<td>218 ± 74</td>
<td>209 ± 74</td>
<td>197 ± 74</td>
<td>185 ± 74</td>
</tr>
<tr>
<td>Male</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>152 ± 54</td>
<td>145 ± 40</td>
<td>140 ± 40</td>
<td>135 ± 40</td>
<td>128 ± 40</td>
</tr>
</tbody>
</table>

PEmax, maximal expiratory pressure; Plmax, maximal inspiratory pressure. *Numbers represent mean ± 2 standard deviations.
• **PEmax:**
  • Subject inhale maximally, hold the rubber tubing firmly against the mouth and exhales as hard as possible, the highest positive pressure maintained for 0.9sec is recorded

• **PImax:**
  • Subject exhale to RV, hold the rubber tubing against the lip and suck as hard as possible, the highest negative pressure sustained for 2 seconds is recorded
• Indications for measuring resp muscle strength
  • In patient with neuromuscular disease
  • In patient with isolated unexplained decrease in vital capacity or MVV; (may be early signs of respiratory muscle weakness)
  • To assess weaning potential, PI_max < -20 cmH2O and PE_max > +50 cmH2O are favourable
Thank You