Spirometry

A quick guide

Sue Filsell
Clinical Respiratory Physiologist
South Link Health Conference
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What is it? What are we measuring?
- Equipment performance & validation
- Performing spirometry to ATS/ERS standards
- Choosing test results for reporting
- Reference values/interpretation

Why measure spirometry?
- Diagnosis? eg identification of airflow obstruction. Asthma/COPD
- Differentiate with other patterns of abnormality
- Assess severity/progression respiratory disease. TSANZ: Spirometry is the gold standard for diagnosing, assessing and monitoring COPD
- Assess objective therapeutic benefit
- Measure effect of smoking or occupational risk
- Assess long term risk. FEV1 is a clinically useful marker to identify patients at greatest risk of all cause mortality due to smoking (Eur Resp J 2007; 30: 616-22)

Well performed spirometry can indicate the cause of impaired ventilatory function

Obstructive: Air flow limitation in relation to max expired vol
- Asthma:
  - Increased airways resistance
- COPD:
  - Reduced elastic recoil & increased airways resistance

Restrictive: Reduced volume (Less common)
- Lungs have lost elasticity
- Respiratory muscles have lost strength
- Chest wall/pleura limits ability of lung to expand
  Requires other lung function tests for confirmation (TLC)

Spirometry variables

FVC (L BTPS)
- Forced Vital Capacity – the maximum volume of air that can be exhaled forcefully, following a maximum inspiration.

FEV1 (L BTPS)
- Forced Expiratory Volume (1 second) – the maximum volume of air that can be expired during the first second of an FVC manoeuvre
The FEV₁ expressed as a percentage (%) of the FVC:

\[ \text{FEV₁/FVC} = \frac{\text{FEV₁}}{\text{FVC}} \times 100 \]

* Measurement of airflow obstruction

**SVC (L BTPS)**
- The maximum volume of air (litres) that can be exhaled slowly, following a maximum inspiration.
- Normal ventilatory function FVC = SVC

**FEV₆ & associated indices**
- The FEV₆ may be substituted for VC if the appropriate LLN for the FEV₆ & FEV₁/FEV₆ is used (from the NHANES III equations)

**PEF (PEFR, PFR) L/sec**
- Peak expiratory flow – the maximal flow generated during an FVC manoeuvre.
- Index of large airway obstruction
  
  (Gives information about the effort produced during the spirometry maneuver)

**FEF 25-75% L/sec**
- Forced mid-expiratory flow rate – the average flow of air measured over the middle 50% of an FVC manoeuvre.
- Index of flow limitation in smaller airways (<2 mm diam)
Flow Volume Loop

- The inspiratory loop pattern can be helpful in some conditions
- It is effort dependent

Clinically Useful Spirometry

- Critically dependent on
  - Spirometer accuracy & maintenance
  - Knowledge of correct technique
  - Good communication skills to help patient achieve consistent & maximal effort
  - Testing experience (troubleshooting)

ATS/ERS Task Force 2005

- Published Recommendations for Standardisation of Spirometry
  - Definitions
  - Equipment
  - Procedure

Spirometers: what sort?

- Volume Displacement
- Flow Spirometers

Eur Respir J 2005;26:319-338
Infection control

• Mouthpieces – recommend bacterial/viral filters
  – 99.9% filtration efficiency
  – Single use only
  – Low resistance to flow
  – Protects sensors
  – Minimize moisture
    • affects performance and accuracy

Equipment performance

Prepare Equipment

• Daily calibration with 3L syringe
  – Record ambient conditions
    • Temperature
    • Barometric pressure

  • Ensure equipment and cal syringe at the same room temperature 17 – 40 deg C
  • 3 L Cal syringe must have accuracy of +/- 15 ml (0.5%)
  • Leak free connection to spirometer

Correction Factor

- Correction factors are calculated from calibration and applied to all measurements
  - Correction factor = Measured / Expected value
  - Should be
    - 3.00 (syringe volume)
    - 3.00 (expected volume)
    - = 1.0
  - Acceptable range 0.97 – 1.03

All spirometers require regular validation

Weekly

- Volume check with 3L syringe in test mode
- Flow linearity; deliver 3L syringe at 3 flow rates

** Volumes must reach accuracy requirement of +/- 3.5%

Biological Controls

- Assessment of all aspects of the spirometer
- Use healthy non smoking individuals
- Derive mean, standard deviation and CV%
- Test weekly or more often if required
Example of biological control

<table>
<thead>
<tr>
<th>Date</th>
<th>FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/10/06</td>
<td>3.97</td>
</tr>
<tr>
<td>14/10/06</td>
<td>4.07</td>
</tr>
<tr>
<td>21/10/06</td>
<td>4.11</td>
</tr>
<tr>
<td>28/10/06</td>
<td>4.07</td>
</tr>
<tr>
<td>04/11/06</td>
<td>3.92</td>
</tr>
<tr>
<td>09/12/06</td>
<td>4.25</td>
</tr>
</tbody>
</table>

Mean (x) 4.03
Standard deviation (SD) 0.12
Co-efficient of variation (CV) 2.86

Values must be within +/- 2 std deviations

Biological control data: FVC

Performing Spirometry

Prepare Patient
- Withhold
  - Bronchodilators
    - Short acting eg ventolin, combivent 4 hours
    - Long acting eg serevent 12 hours
  - Large meal, vigorous ex

Obtain Patient Details

<table>
<thead>
<tr>
<th>Name</th>
<th>ID</th>
<th>Date &amp; time of Test</th>
<th>DOB</th>
<th>Height</th>
<th>Gender</th>
<th>Weight</th>
<th>Ethnicity</th>
</tr>
</thead>
</table>

Further Useful Information

- Reason for Performing Test
  - Any symptoms, occupational screening, pre op assessment

- Inhaled medications
  - Type and time of last use

- Smoking History
  - Current/Ex/Never
  - Calculate pack years

- Other Exposures / Medications
Spirometry is an **Effort Dependent Test**

- Explain and demonstrate the objectives of the test
- Clear instructions, encouragement and reinforcement are necessary to achieve acceptable results

**FEV₁ and FVC**

- Instruct patient to:
  
  "take a maximal breath in, then with your lips sealed around the mouthpiece, immediately blast the air out as fast & as far as you can. You must force it out for at least 6 secs but it may take longer than this to completely empty the lungs...."

  **Continue to encourage** patient "keep going, keep going"

  For inspiratory loop instruct
  "at the end of your maximal expiration inhale forcefully and maximally"

**SVC**

- Instruct patient to:

  "take in a maximal breath in, then with the mouthpiece sealed in your mouth exhale maximally without force as far as you possibly can"

**Acceptability Criteria (ATS/ERS)**

- Perform at least 3 tests (may need up to 8 tests)
- Must have an abrupt start
- Must be a continuous & forced expiration of at least 6 seconds and until
  - there is no change in volume for 1 second
  - or > 15 seconds
  - Or clinical indication to stop

  Ideal to have real time FVL & software feedback

**Reproducibility Criteria (ATS/ERS)**

- FEV₁ must be within 150mls (0.15)
- FVC must be within 150mls (0.15)
- PEF must be within 10%

**Performance Related problems**

Bronchodilator Reversibility

- Spirometry is measured before and after administration of bronchodilator.
- Used to determine whether airflow obstruction is reversible, i.e., if FEV₁/FVC < 70%.
- COPD:
  - Long-term control/deterioration based on post BD FEV₁.
  - Provides evidence of their best FEV₁ & permanent change in lung function (fixed obstruction).

Bronchodilators

- Short acting β agonist e.g. Ventolin
  - 400mcg MDI via spacer
  - Lower dose can be used
  - Repeat tests after 15 minutes
- Short acting anticholinergic e.g. Combivent
  - 400mcg Ventolin & 80mcg Atrovent
  - If aged >40 with smoking history
  - Repeat tests after 30 minutes
- Drug and Dose given must be included on final report

Selecting results

- The Highest FEV₁ and FVC
  - From acceptable & reproducible tests
  - Not necessarily from the same test

<table>
<thead>
<tr>
<th></th>
<th>FEV₁</th>
<th>FVC</th>
<th>FEV₁/FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>2.75</td>
<td>3.50</td>
<td>79</td>
</tr>
<tr>
<td>Test 2</td>
<td>2.80</td>
<td>3.35</td>
<td>84</td>
</tr>
<tr>
<td>Test 3</td>
<td>2.90</td>
<td>3.40</td>
<td>85</td>
</tr>
</tbody>
</table>

FEV₁/FVC %

- Calculated from the best FEV₁ and the best FVC

\[
 FEV₁/FVC \% = \left( \frac{\text{best } FEV₁}{\text{best FVC}} \right) \times 100 \\
= \left( \frac{2.90}{3.50} \right) \times 100 \\
= 0.83 \times 100 \\
= 83\% 
\]
Selecting Results

- **FEF** \(_{25-75}\) L/sec
  - From the test with the highest sum of \(\text{FEV}_1\) + FVC
  - Test 3

<table>
<thead>
<tr>
<th></th>
<th>FEV(_1)</th>
<th>FVC</th>
<th>FEV(_1) + FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>2.75</td>
<td>3.50</td>
<td>6.25</td>
</tr>
<tr>
<td>Test 2</td>
<td>2.80</td>
<td>3.35</td>
<td>6.15</td>
</tr>
<tr>
<td>Test 3</td>
<td>2.90</td>
<td>3.40</td>
<td>6.30</td>
</tr>
</tbody>
</table>

PEF (L/min)

- The highest PEF measured from an acceptable test
- Reproducible within 10%

Final Spirometry Results

<table>
<thead>
<tr>
<th></th>
<th>Pred</th>
<th>Best</th>
<th>% Pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV(_1) (L)</td>
<td>2.90</td>
<td>2.90</td>
<td>100</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>3.55</td>
<td>3.40</td>
<td>96</td>
</tr>
<tr>
<td>FEV(_1)/FVC (%)</td>
<td>82</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>

BTPS vs ATPS

- Gas volumes vary with temperature and pressure
- All spirometric volumes are reported BTPS
  - BTPS (patients)
    - Body temperature, ambient pressure, saturated with water vapour
  - ATPS (spirometers)
    - Ambient temperature & pressure, saturated with water vapour

Comments

- Make as many comments as necessary regarding test performance and results.
- If acceptable & reproducible result
  - The tests met ATS/ERS criteria for acceptability and reproducibility
- If not acceptable or reproducible
  - Why not?
    - Start of test or end of test criteria not met
    - Cough during expiration

Reference Values

- Dunedin NZMJ 91: 1-5 1980
  - \(n = 328\) aged 15-75
  - \(\text{FEV}_1\)
  - \(\text{FVC}\)
  - \(\text{FEF}_{25-75}\) (L/sec)
- Crapo
  - \(\text{FEF}_{25-75}\) (L/sec)
Determination of Normal Range

- % predicted

Abnormal if
- FEV₁ and FVC < 80% predicted
- FEF₂₅₋₇₅% < 60% predicted
- FEV₁/FVC < 70%

Final report

The results of this test meet all acceptability & reproducibility criteria.

Patterns in Spirometry

Classification of Ventilatory Abnormalities by Spirometry

<table>
<thead>
<tr>
<th>Obstructive</th>
<th>Restrictive</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>↓</td>
<td>↓ or N</td>
<td>↓</td>
</tr>
<tr>
<td>↓</td>
<td>↑ or N</td>
<td>↓</td>
</tr>
</tbody>
</table>

Obstruction

Restriction eg pulmonary fibrosis
Fixed extrathoracic obstruction

Variable extrathoracic airway obstruction

Interpretation of Spirometry

Measured Parameters

- FEV₁/FVC (%)
- FEV₁ (L)
- FVC (L)
- FEF₂₅₋₇₅% (L/sec)

Interpreting results: limit to 3-4 variables + inspection of FVL

Interpretation

Was it done well?
-Spirometer calibrated/validated
-ATS/ERS criteria met for accuracy & reproducibility?
- Any technical comments on test performance?

Are you using appropriate normal values?
-Local ones may differ from those on your spirometer
-No recognised normal values for Maori

Has your patient used any drugs/inhalers?
-Your measurements may not be typical

Interpretation algorithm
Spirometric classification for COPD

<table>
<thead>
<tr>
<th>Severity</th>
<th>% Pred FEV₁</th>
<th>Post BD FEV₁/FVC</th>
<th>ATS/ERS &amp; GOLD</th>
<th>TSANZ</th>
<th>NICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&lt;70</td>
<td>&gt;80</td>
<td>&gt;60=80</td>
<td>50-80</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>&lt;70</td>
<td>50-80</td>
<td>40-59</td>
<td>30-49</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;70</td>
<td>30-50</td>
<td>&lt;39</td>
<td>&lt;30</td>
<td></td>
</tr>
<tr>
<td>Very severe</td>
<td>&lt;70</td>
<td>&lt;30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bronchodilator Response

? reversibility of airflow obstruction-complete or partial. Usually based on FEV₁

Significant reversibility
- ATS: if FEV₁ increases by 12% and 200mls
- TSANZ: 15% & 200ml increase

nb indicates reversibility, not necessarily asthma

Bronchodilator Reversibility

FVL showing reversible airflow obstruction

Spirometry: a measure of physiological change

FEV₁ is a measure of abnormal airway calibre. This is non-specific and can occur in asthma, COPD or bronchiectasis. It is a measure of physiological change but an indirect measurement of airway pathology.

Reduced FEV₁/FVC in asthma

Sensitivity = 35%
Specificity = 100%

Smith et al. AJRCCM, 2004

Patient examples
30 yr old female, non smoker. Intermittent wheeze.

<table>
<thead>
<tr>
<th></th>
<th>Pred</th>
<th>Meas</th>
<th>% pred</th>
<th></th>
<th>Meas</th>
<th>% Pred</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1</td>
<td>3.17</td>
<td>2.08</td>
<td>66</td>
<td>After salbutamol:</td>
<td>3.40</td>
<td>107</td>
<td>63%</td>
</tr>
<tr>
<td>FVC</td>
<td>3.99</td>
<td>3.85</td>
<td>96</td>
<td></td>
<td>3.85</td>
<td>108</td>
<td>12%</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>79%</td>
<td>54%</td>
<td>43</td>
<td></td>
<td>79%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEF25-75</td>
<td>3.58</td>
<td>1.14</td>
<td>32</td>
<td></td>
<td>3.14</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

Is spirometry technically satisfactory
low FEV1/FVC ratio & low FEV1; mild airflow obstruction
Spirometry corrects to normal after bronchodilator
Example of asthma, complete reversibility

29 yr old male; 185 cm
Clinical: wheeze on exertion & at night time

Check the spirometry is technically accurate & reproducible
Evidence of airflow obstruction
Significant reversal but incomplete
No improvement in PEF not significant

41 yr old male Caucasian, chronic severe asthma
Severely reduced FEV1 & ratio with significant reversibility but not normalised
Nb FVC can also rise significantly so that FEV1/FVC can fall despite good BD
Other PFTs to exclude mixed defect (TLC)

31 yr old Samoan male
Ht 174 cm Wt 83 kg

Wheeze with allergen exposure
Regular medications: daily Ventolin use
Normal FEV1 but FEV1/FVC ratio lower than predicted (?LLN)
Significant reversibility in FEV1
Are the reference values appropriate for this patient?

41 yr old male Caucasian, chronic severe asthma
Severely reduced FEV1 & ratio with significant reversibility but not normalised
Nb FVC can also rise significantly so that FEV1/FVC can fall despite good BD
Other PFTs to exclude mixed defect (TLC)

COPD: obstructive irreversible
Post BD results give you fixed obstructive component.
Nb collapse pattern of FVL & exp time

COPD: obstructive irreversible
Post BD results give you fixed obstructive component.
Nb collapse pattern of FVL.
60 yr old male
Slow onset SOB over a few years
Ex smoker, 25 pack years
keeps pigeons

<table>
<thead>
<tr>
<th></th>
<th>Pred</th>
<th>Meas</th>
<th>% pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1</td>
<td>3.32</td>
<td>1.75</td>
<td>53</td>
</tr>
<tr>
<td>FVC</td>
<td>4.67</td>
<td>2.54</td>
<td>54</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>71%</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>FEF25-75</td>
<td>3.19</td>
<td>0.97</td>
<td>30</td>
</tr>
</tbody>
</table>

FEV1/FVC ratio is normal in relation to predicted values
The FEV1 & FVC are reduced
FEF25-75 is low suggestive of obstruction
The flow volume loop is tall & narrow - this suggests a restrictive disorder
Restriction needs to be confirmed with further lung function tests (TLC)

**Trend Monitoring**

- **Useful**
  - Disease progression
  - Response to medications
  - Occupational setting

**Significant change over time?**
- normal decline in FEV1: 30 mL/yr
- >150 ml (natural variability of the test)
- & >15% (Pellegrino et al Eur Resp J 2006)

**Further reading**

- Standardisation of Spirometry; ATS/ERS Task Force. Eur Resp J 2005;26: 319-338

**Useful Websites**