Pulmonary Function Test
Interpretation and Applications in
Asthma Diagnosis and Management
Pediatric Postgraduate Conference 2019

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Lecture Goals

- Practitioners understand objectives and limitations of pulmonary function testing
- Practitioners understand spirometry methodology
- Practitioners recognize spirometry abnormalities
- Practitioners apply spirometry in asthma diagnosis and management
Purpose of Spirometry

- Define lung disease (obstructive vs. restrictive)
- Define severity of lung disease
- Monitor disease progression and response to therapy
- Preoperative evaluation
- Aid in research study (epidemiology; therapy)
Pulmonary Function Testing: Limitations

- Age: At least 5 years of age ideal due to effort but can be done as young as 3 years of age
- Subject ability and effort affects spirometry volumes
- Knowledge of operator

- Limited chest wall and abdominal expansion
  - Obese patients
  - Tight clothes
  - Heavy meal 2 hours prior to testing

- Noting ambient temperature and barometric pressure prior to machine calibration which can affect gas volumes

- Reference normal values
  - Should reflect patient population
  - Limited in those less than 3 years of age or 90 cm
Spirometry

This inverted bell position changed with inspiration and expiration causing a tracing of respiratory pattern

Bell and counter weight
Water lock

Consists of inverted canister or “bell” floating in a water filled space
The space inside the inner drum (closed to atmospheric pressure) is connected to a tubing extending to the mouthpiece.
During inspiration, the bell floats lower and raises on expiration.
The bell is attached to a pulley and pen which traces the breathing pattern

Spirometry cannot measure residual volume, functional residual volume or total lung capacity


Paulev P et al. Textbook in Medical Physiology And Pathophysiology Essentials and clinical problems
Spirometry Maneuvers

Expiratory Volume Time Loop

Flow Volume Loop

Morgan Scientific - www.morgansci.com/.../clip_image006_0000a.jpg

Morgan Scientific - www.morgansci.com/.../clip_image006_0000a.jpg

expiratory

inspiratory
**Good Spirometry Effort**
1. Instantaneous start of exhalation
2. Rapid rise in flow to peak flow
3. Shap peak occurring early in exhalation
4. Smooth continuous fall in flow without interruption
5. Gradual fall in low flow to RV
6. Smooth continuous inhalation to TLC
7. Reproducible shape

**Poor or Bad Spirometry Effort**
1. Slow start
2. Slow rise in flow
3. Broad, late peak
4. Erratic Flow (cough)
5. Abrupt return to 0 flow
6. Incomplete inhalation
7. Non-reproducible
Spirometry Values

- Predicted normal values based on age, height, gender and race of healthy subjects
- Acceptable ATS-ERS criteria
  - Adult: 3 efforts & variability of 5%; exhalation: 6 seconds
  - Children: 2 efforts & variability within 10%; exhalation can be as short as 3 to 5 seconds due to smaller lung volume
- FVC  Forced Vital Capacity (liters)
- SVC  Slow Vital Capacity (liters)
- $FEV_1$  Forced Expiratory Volume 1 sec (liters)
- $FEF_{25\%-75\%}$  Forced exp flow at 25% to 75% VC (liters/sec)
- FVC, SVC, $FEV_1$ - Effort dependant
- $FEF_{25\%-75\%}$ - Effort independent due to airway closure at lower lung volumes during forced exhalation
Normal Values For Pediatrics

- Forced vital capacity (FVC) \( \geq 80\% \) predicted
- Forced expiratory volume in 1 second (FEV1) \( \geq 80\% \) predicted
- FEV1/FVC 80% to 85% (range is age dependent and lower in those 35 years and older)
- Peak expiratory flow rate (PEFR) > 78 to 80% predicted
- Forced expiratory flows at 25 to 25% of VC (FEF\(_{25\%-75\%}\)) > 60 to 65% predicted
- Total Lung Capacity (TLC) 80 to 100% predicted
  - cannot be measured with spirometry; can confirm restrictive disease
- Residual Volume (RV) 60 to 160% predicted
  - cannot be measured with spirometry
- RV/TLC ratio 30 to 35%
  - cannot be measured with spirometry; index of gas or air trapping
Obstructive Lung Disease

- FVC normal or decreased (high RV)
- FEV\(_1\) decreased
- FEV\(_1\)/FVC ratio decreased
- Decreased FEF\(_{25\%-75\%}\) relative to FEV\(_1\) resulting in concave curve shape

- Internal airway obstruction (asthma, cystic fibrosis, bronchiolitis, chronic aspiration, intrathoracic tracheal and bronchomalacia, intrathoracic airway foreign body, bronchiectasis, bronchiolitis obliterans)

- External airway obstruction (mediastinal adenopathy, vascular anomaly – vascular ring or compression of airway, cardiac chamber enlargement)

Concave shaped expiratory flow loop
Restrictive Lung Disease

- FVC decreased
- FEV$_1$ <80% predicted
- FEV$_1$/FVC (> 85 – 90%)
- Pulmonary – lobar pneumonia, atelectasis, interstitial lung disease (infectious, cystic fibrosis, aspiration, connective tissue disease, vasculitis, pneumonitis, drug induced, malignancy, congenital), pulmonary edema, Pleural disease
  Chest Wall (kyphoscoliosis, rib cage anomalies)
- Neuromuscular disorders
- May need to confirm by measurement of total lung capacity using plethysmography or helium dilution technique

Convex shaped expiratory flow loop
Variable Extrathoracic Obstruction

- On inspiration, airway pressure lower than surrounding atmospheric pressure
- Results in compression at area of obstruction
- Results in chopped inspiratory loop
- Laryngeal edema, malacia, hemangioma, masses, foreign body, vocal cord paralysis, vocal cord dysfunction, extrathoracic tracheomalacia
Variable Intrathoracic Obstruction

- On expiration, airway pressure lower than surrounding intrathoracic pressure
- Results in compression at area of obstruction
- Results in chopped expiratory loop
- Intrathoracic tracheomalacia, foreign body, asthma, vascular or mediastinal airway compression
Fixed Intra or Extrathoracic Airway Obstruction

- Results in a chopped inspiratory and expiratory loop
- Subglottic stenosis, proximal tracheal stenosis
Evaluation of Asthma

- Episodic airflow obstruction manifested wheeze, cough, chest pain/tightness or dyspnea and “recurrent bronchitis” or recurrent pneumonia

- Symptoms occur with known asthma triggers and often worse at night

- Patients may have clinical response and spirometry hyperResponsiveness with short-acting beta agonist/bronchodilator

- Practitioners can use pre & post short-acting bronchodilator spirometry, start a 2 to 8 week clinical trial with short-acting bronchodilator, assess clinical response to 2 to 4 week trial of asthma controller therapy (preferably ICS)

- Consideration as necessary to exclude other diagnoses
Why have an Office Spirometry or do it?

- History and physical exam not predictive of lung impairment
  Often chronic asthma patients have poor perception of symptoms
  Wheeze not correlative with degree of spirometry impairment

- Preferable to peak flow meters for diagnosis of asthma
  GINA (Global initiative for asthma) uses peak flow for diagnosis
  NIH EPR 2007 does not use peak flow for diagnosis

- Useful in excluding other lung disease processes
  Especially if abnormal and not reversible after short-acting beta agonist
  or worse with short-acting beta agonist (worry about malacia or bronchiectasis)
Office Spirometry: Bronchial Challenge

- Bronchodilator Response Testing for Asthma
  - Need to use short acting bronchodilator
  - 2 – 4 puffs of 90mcg/actuation inhaler or nebulizer vial
  - Perform test before and 15 minutes after bronchodilator
  - Positive response is (increase change) $\Delta FVC$ or $\Delta FEV_1 > 12\%$ or $> 200$ ml volume or $\Delta FEF_{25\%-75\%} > 24\%$
  - Changes such as decreased gas trapping or increased partial expiratory flows may be seen in absence of FVC or FEV1 improvement
Therefore, lack of spirometry hyper-response does not preclude clinical response
Example of Hyper-responsiveness on Spirometry

Spirometry component of the lung function test shows
Forced expiratory lung volume versus time (A) and Forced expiratory flows versus lung volume (B)
(A) 3.07L (post) – 2.71L (pre) divided by 2.71L (pre) = 0.133 or 13% change
This depicts significant response to beta agonist

National Heart, Lung, and Blood Institute, National Asthma Education and Prevention Program:
Lung Function Laboratory: 
Bronchoprovocation Study

- Exercise Challenge
  
  Treadmill or bicycle exercise for at least 6 to 8 minutes to cause heart rate to be at 80-85% predicted maximum for age
  
  Lung function changes 5 to 15 minutes after exercise stops
  
  Positive response is (decrease change) $\Delta FVC$, $\Delta FEV_1$ or $\Delta PEF$ by >12 to 15%

- Treadmill is preferable to bicycle for bronchoconstriction response
Lung Function Laboratory: Bronchoprovocation Study

- Methacholine or histamine response
  - 98% of those with symptomatic asthma respond to this
  - Spirometry performed before and after titrating doses of challenge
    This is typically followed by short acting bronchodilator
  - Positive response is (decreased change) $\Delta\text{FEV}_1$ or greater than >20% with small amount of challenge
Can use cold air, inhaled allergens or particulate matter
Office Spirometry: Asthma Severity Assessment

- Low FEV1 indicates current obstruction and risk for future exacerbation.

- In children FEV1/FVC is a sensitive measure of severity in the impairment domain.

- Children with low lung function are at risk for fixed airflow obstruction over time.

- Peak flow is not reliable for classifying severity.

Peak flow meters
### Components of Severity

<table>
<thead>
<tr>
<th>Impairment</th>
<th>Classification of Asthma Severity (Children 5-11 years of Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intermittent</td>
</tr>
<tr>
<td></td>
<td>Mild</td>
</tr>
<tr>
<td><strong>Symptoms</strong></td>
<td>≤2 days per week</td>
</tr>
<tr>
<td><strong>Nighttime Awakenings</strong></td>
<td>≤2x/month</td>
</tr>
<tr>
<td><strong>Short acting beta agonist use for symptom control (not prevention of EIB)</strong></td>
<td>≤2 days per week</td>
</tr>
<tr>
<td><strong>Interference with normal activity</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Lung Function</strong></td>
<td>Normal FEV1 between exacerbations FEV1 ≥80% pred FEV1/FVC &gt;80%</td>
</tr>
</tbody>
</table>

### Risk

Risk of exacerbation or progressive loss of lung function

<table>
<thead>
<tr>
<th>Exacerbations requiring oral systemic steroids</th>
<th>0-1 per year</th>
<th>≥2 in one year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider severity and interval since last exacerbation. Frequency and severity may fluctuate overtime for any patient in any severity category. Relative annual risk of exacerbation may be related to FEV1.</td>
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**Components of Severity**

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<tr>
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### Impairment

**Normal FEV1/FVC:**
- 8-19yo: 85%
- 20-39yo: 80%
- 40-59yo: 75%
- 60-80yo: 70%

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Intermittent</th>
<th>Persistent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤2 days per week</td>
<td>&gt;2 days/wk but not daily</td>
</tr>
<tr>
<td>Nighttime</td>
<td>≤2x/month</td>
<td>3-4x/month</td>
</tr>
<tr>
<td>Awakenings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short acting beta agonist use for symptom control (not prevention of EIB)</td>
<td>≤2 days per week</td>
<td>&gt;2 days/wk but not &gt;1x/day</td>
</tr>
</tbody>
</table>

### Interference with normal activity

- None
- Minor limitation
- Some limitation
- Extremely limited

### Lung Function

- Normal FEV1 between exacerbations
- FEV1 >80% pred
- FEV1/FVC normal

- FEV1 ≥80% pred
- FEV1/FVC normal

- FEV1 = >60 but <80% pred
- FEV1/FVC reduced 5%

- FEV1 < 60% pred
- FEV1/FVC reduced 5%

### Risk

- Exacerbations requiring oral systemic steroids
- 0-1 per year
- ≥2 in one year

Consider severity and interval since last exacerbation. Frequency and severity may fluctuate overtime for any patient in any severity category. Relative annual risk of exacerbation may be related to FEV1.
Office Spirometry: Long Term management

- Helpful in assessing control

- Identifies airflow obstruction in “poor perceivers” unable to feel symptoms until severe airflow obstruction

- Tracks disease progression

- Assesses risk of exacerbation, decline in lung function/reduced growth

- Measures response to therapy

- Reinforces therapy decisions to the patient
### Components of Control

#### Impairment

<table>
<thead>
<tr>
<th>Classification of Asthma Control (Children 5-11 years of Age)</th>
<th>Well Controlled</th>
<th>Not Well controlled</th>
<th>Very Poorly Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptoms</strong></td>
<td>≤2 days/wk but not more than once on each day</td>
<td>&gt;2 days/wk or multiple times on ≤2 days/wk</td>
<td>Throughout the day</td>
</tr>
<tr>
<td>Nighttime Awakenings</td>
<td>≤1x/month</td>
<td>≥2x/month</td>
<td>≥2x/week</td>
</tr>
<tr>
<td>Short acting beta agonist use for symptom control (not prevention of EIB)</td>
<td>≤2 days per week</td>
<td>&gt;2 days per week</td>
<td>Several times per day</td>
</tr>
<tr>
<td>Interference with normal activity</td>
<td>None</td>
<td>Some limitation</td>
<td>Extremely limited</td>
</tr>
<tr>
<td>Lung Function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV1 or peak flow</td>
<td>&gt;80% pred/personal best</td>
<td>60 – 80% pred/personal best</td>
<td>&lt;60% pred/personal best</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>&gt;80%</td>
<td>75-80%</td>
<td>&lt;75%</td>
</tr>
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</table>

#### Risk

- Exacerbations requiring oral systemic steroids
- Reduction in lung growth
- Treatment related adverse effects

Evaluation of reduction in lung growth requires long term follow up. Medication side effects can vary in intensity from none to very troublesome and worrisome. The level of intensity does not correlate to specific levels of control but should be considered in the overall assessment of risk.
### Components of Control

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<td>Lung Function</td>
<td></td>
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<tr>
<td>FEV1 or peak flow</td>
<td>&gt;80% pred/personal best</td>
</tr>
<tr>
<td>Validated Questionnaires</td>
<td></td>
</tr>
<tr>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Risk of exacerbation or progressive loss of lung function</td>
<td></td>
</tr>
<tr>
<td>Exacerbations requiring oral systemic steroids</td>
<td>0-1/year</td>
</tr>
<tr>
<td>Progressive loss of lung function</td>
<td></td>
</tr>
<tr>
<td>Treatment related adverse effects</td>
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</table>

Evaluation of progressive loss of lung function requires long term follow up. Medication side effects can vary in intensity from none to very troublesome and worrisome. The level of intensity does not correlate to specific levels of control but should be considered in the overall assessment of risk.
Recommended Frequency of Office Spirometry

- At the time of initial assessment
- After treatment is initiated and symptoms and peak flows have stabilized, to document attainment of (near) “normal” airway function
- During a period of progressive or prolonged loss of asthma control
- At least every 1–2 years to assess the maintenance of airway function

May be indicated more often than every 1–2 years, depending on the clinical severity and response to management

Should be followed to detect potential for decline and rate of decline of pulmonary function over time

Office & Home Spirometers

KoKo© PC Spirometer

KoKo© Portable Spirometer

$1500

These are not by any means only product available
Office & Home Spirometers

Spirobank G spirometer
Medical International Research
$1300

Piko -1 Somerset Medical LLC

These are not by any means only product available
This is an 11 year old female with recurrent bronchitis and dyspnea.

She had sepsis with multiorgan failure and acute respiratory failure at 5 years old.

What pattern is seen on spirometry?

Does she have asthma?

If so, why and what should be considered?

If not why and what other evaluation would one consider?
This is an 11 year old female diagnosed with asthma. Mother says child has no symptoms.

What pattern is seen on spirometry?

Does she have asthma?

If so, why and what should be considered?

If not why and what other evaluation would one consider?
This is an 17 year old male with chronic productive cough and dyspnea.

What pattern is seen on spirometry?

Does he have asthma?

If so, why and what should be considered?

If not why and what other evaluation would one consider?
This is a 5 year old female with recurrent pneumonia.

What pattern is seen on spirometry?

Does she have asthma?

If so, why and what should be considered?

If not why and what other evaluation would one consider?
Vocal Cord Dysfunction (VCD)

- Paradoxical adduction of the vocal cords on inspiration
- Characterized by tightness, wheezing, stridor and dyspnea
- Often treated for refractory asthma with inhaled and systemic corticosteroids
- History of ED or urgent care visits and hospital admissions
- May undergo intubation or tracheostomy
- Predominantly female
- One retrospective study found 10% of patients with intractable asthma had VCD and 30% had VCD coexisting with asthma
Vocal Cord Dysfunction Pathophysiology

- Pathogenesis not fully understood

- Intrinsic and extrinsic stimulation causing hyperresponsiveness of laryngeal sensory and motor innervation

- Alteration of vagal mediated laryngeal tone

- Possible stimulants identified
  Irritants (chemical cleaners, organic solvents, smoke) may alter vagal laryngeal tone lowering threshold for inspiratory adduction
  GERD may accentuate glottic closure due to acid injury of laryngeal mucosa
  Emotional stress, anxiety

- Although rarely a cause, neurologic conditions such as Chiari malformation, cerebrovascular accident, or brainstem injury should be considered
<table>
<thead>
<tr>
<th>Clinical Presentation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VCD</strong></td>
<td><strong>Asthma</strong></td>
</tr>
<tr>
<td>Tightness at the neck (extratoracic)</td>
<td>Tightness at the chest (intrathoracic)</td>
</tr>
<tr>
<td>Stridor/wheeze, voice change, difficult inspiration globus sensation</td>
<td>Wheeze, dyspnea</td>
</tr>
<tr>
<td>Abrupt beginning and end</td>
<td>Symptoms prolonged</td>
</tr>
<tr>
<td>Occurs primarily during day while awake</td>
<td>Diurnal pattern (increased nocturnally)</td>
</tr>
<tr>
<td>Resolve with relaxation Albuterol no relief</td>
<td>Relieved with beta agonist</td>
</tr>
<tr>
<td>Occurs soon after exercise</td>
<td>Starts within 5 to 15 minutes of exercise and increases steadily</td>
</tr>
<tr>
<td>Findings</td>
<td>VCD</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Displays “La Belle Indifference” or distress</td>
</tr>
<tr>
<td>Wheeze loudest</td>
<td>Over neck</td>
</tr>
<tr>
<td>Can hold breath during</td>
<td>event</td>
</tr>
<tr>
<td>No cyanosis or hypoxia</td>
<td></td>
</tr>
<tr>
<td>Normal blood gas; no</td>
<td>alveolar arterial gradient</td>
</tr>
<tr>
<td>Chest xray normal</td>
<td></td>
</tr>
</tbody>
</table>
Picture A True vocal cords are abducted during inspiration in normal larynx.

Picture B Noted adduction of the true vocal cords anterior during inspiration with posterior diamond shaped opening.

Place R et al Journal of Adolescent Health 2000
The blunted inspiratory loop is seen both on tidal breathing (blue) and forced inspiration (red). Patient J.D. 1/2003
Vocal Cord Dysfunction Management

- Recognition and diagnosis of disease and possible stimulant mechanism
- Anti-anxiolytic therapy, mood disorder therapy, psychotherapy
- Recognition and treatment for GERD
- Although rare, awareness of possible neurologic disease
- Speech therapist who is experienced with VCD
  Relaxed throat breathing techniques
Conclusion

- Office spirometry is preferred to peak flow in diagnosing and establishing asthma severity.
- Office spirometry is useful for maintaining asthma control and detecting decline in lung function.
- Lung function FEV1 can predict asthma severity, risk of exacerbation and loss of lung function/growth.
References


References


  Major reference which can be accessed via the NIH-NHLBI website at http://www.nhlbi.nih.gov/guidelines/asthma/index.htm in pdf format