Paediatric Pulmonary Function Test

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Learning Objectives

• Review indications of Pulmonary Function Tests (PFTs) in children
• Review and Update different types of PFTs
• Review the basic interpretation of PFTs
• Nursing role in performing PFTs
Pulmonary Function Testing

• Collection of physiologic measurements
• Provide objective assessments of lung function
• Play an important role to confirm diagnosis and management of respiratory dysfunction
• Measure how well the lungs move air in and out
• Measure the lungs size
• Measure how well the lungs move gases, (O2) from atmosphere into the body’s circulation and (CO2) from the body to atmosphere
Pulmonary Function tests

- **Infant Lung Function test**

- **Impulse Oscillometry System (IOS) / Forced Oscillation Test (FOT)**

- **Spirometry**
  - **Total Lung Volume Test**
  - **Bronchial Challenge Tests**
  - **Cardio-pulmonary exercise test**
Indications for Pulmonary Function Test in children

- **Diagnosis:**
  - Recurrent wheezes/dyspnoea, chronic cough, abnormal breath sounds, exercise intolerance, chest pain

- **Peri-operation assessment:**
  - Fitness of OT, spinal OT
  - Impressment post-op

- **Monitoring:**
  - Asthma, BPD, CLD, NM disease, ILD, kyphoscoliosis, severe pneumonia, PTB

- **Prognosis**

- **Treatment response:**
  - Steroid, bronchodilator, immunosuppressant, enzyme replacement therapy

- **Insurance**

- **Clinical research**

- **Reference equation derivation**
  - Oversea vs Local reference
Types of PFTs

• **Routine:**
  - Spirometry (FVC, FEV1, flows) with/without Bronchodilator
  - Lung Volumes (TLC, FRC)
  - Diffusing Capacity (DLCO)

• **Special procedure:**
  - Respiratory Muscle Strength (MIP, MEP)
  - Bronchial Provocation/Challenge Tests (Methacholine, Mannitol, Exercise…)
  - Cardiopulmonary Exercise Test (CPET or VO2Max)
  - Exhaled Nitric Oxide (FeNO)
  - Nasal Nitric Oxide

*5 years old and up can do most of the tests*
Standardization

- SERIES “ATS/ERS TASK FORCE: STANDARDISATION OF LUNG FUNCTION TESTING”
  - Standardization of spirometry
  - Standardization of the measurement of lung volumes
  - Standardization of the single-breath determination of carbon monoxide uptake in the lung
  - Guideline for Methacholine and Exercise Challenge testing
  - General considerations for lung function testing

Eur Respir J 2005
**Spirometry**

- Basic Lung Function Test
- Like a stethoscope, but more sensitive
- Measures inhaled and exhaled volume of air as a function of time
- Affected by:
  - Mechanical properties: compliance & elastic recoil
  - Resistive elements: airway caliber
- Represent by Flow Volume Loop & Volume Time Loop
- Small capacities (VC) may suggest lung restriction
- Low FEV1 and Flow rates may suggest airway obstruction
**Classic Spirogram**

- **TLC** (Total lung capacity) = (FRC + IC)
- **ERV** (Expiratory reserve volume)
- **FRC** (Functional Residual Capacity)
- **IC** (Inspiratory capacity)
- **VC** (vital capacity)
- **IRV** (Inspiratory reserve volume)
- **RV** (residual volume) = (TLC - VC)
- **VT** (Tidal volume)
- **EEL** (Expiratory Equivalent Level)
Methodology for Spirometry (FVC maneuver)

- Check the spirometer calibration
- **Explain** the test in a clear and concise manner
- **Prepare** the subject
  - Ask about smoking, recent illness, medication use, etc.
  - Measure **weight and height** without shoes
  - **Sitting position** is preferred
    (sit up straight and legs are uncrossed)
  - Use of a nose clip
- **Wash hands**
- Instruct and demonstrate the test to the subject
Methodology for Spirometry (FVC manoeuvre)

- Perform maneuver
  - Place mouthpiece in mouth and close lips around the mouthpiece
  - **Inhale completely and rapidly** with a pause of 1 s at TLC
  - **Blast air out as fast and as far as possible** till completely empty, or until unable to blow any longer
  - Vigorous verbal encouragement/coaching is essential for the patient to continue to exhale to the end of the maneuver
  - Obtain at least 3 technically acceptable blows (usually not more than 8 blows are required)
  - Should meet ATS/ERS(2005) acceptability and repeatability criteria
ATS/ERS (2005)
acceptability and repeatability criteria

Repeatability:
3 acceptable trials -> the 2 largest tracing (FVC & FEV1 should be within 0.15L)

Acceptability:
1. Good start
2. Free from artifacts (cough, early termination, poor effort)
3. Satisfactory exhalation: duration of >=6s (3s for children)

Volume Time Curve
Flow Volume Loop
Flow Volume Loop

- FEFmax
- FEF50
- FEF75
- FEV1
- RV
- TLC
- FIF50
- FVC
- Normal
<table>
<thead>
<tr>
<th>Term</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEFR (L/sec)</td>
<td>Peak Expiratory Flow Rate</td>
<td>Maximal expiratory flow generated during the FVC maneuver during the initial fraction of the second</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>Forced Vital Capacity</td>
<td>Maximal Volume exhaled with maximal force from maximal inspiration to maximal exhalation</td>
</tr>
<tr>
<td>FEV1 (L)</td>
<td>Forced Expiratory Volume in 1 second</td>
<td>Maximal volume exhaled with maximal force in 1 second</td>
</tr>
<tr>
<td>FEF25-75 (L/s)</td>
<td>Forced Expiratory Flow between 25% and 75%</td>
<td>Average flow measured over the mid portion (50%) of the FVC maneuver</td>
</tr>
<tr>
<td>FEF50 (L/s)</td>
<td>Forced Expiratory Flow at exhaled 50% FVC</td>
<td>Flow measured at exhaled 50% FVC</td>
</tr>
</tbody>
</table>
### Common Spirometric terms and measurements (2 of 2)

<table>
<thead>
<tr>
<th>Term</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEF75 (L/s)</td>
<td>Forced Expiratory Flow at exhaled 75% FVC</td>
<td>Flow measured at exhaled 75% FVC</td>
</tr>
<tr>
<td>FIVC</td>
<td>Forced Inspiratory Vital Capacity</td>
<td>Maximal volume inhaled from maximal expiration to maximal inspiration</td>
</tr>
<tr>
<td>FIF50 (L/s)</td>
<td>Forced inspiratory flow at 50% of maximal inspiratory capacity</td>
<td>Flow measured at the 50% of FIVC maneuver</td>
</tr>
<tr>
<td>PIF (L/s)</td>
<td>Peak inspiratory Flow</td>
<td>Maximal inspiratory flow generated during FIVC maneuver</td>
</tr>
<tr>
<td>SVC (L)</td>
<td>Slow Vital Capacity</td>
<td>Maximal volume exhaled without maximal force from maximal inspiration to maximal expiration</td>
</tr>
</tbody>
</table>
Approach to interpretation

1. Demographics – age, weight, race, history

2. Flow-volume loop (Shape)

3. FVC, FEV1 and

4. FEV1/FVC ratio

5. Flows (FEF25-75%)

6. Response to bronchodiolator

7. Comparison to previous studies
Spirometry: Flow Volume Loop

Five Classic Types:

- Normal
- Variable Extra-thoracic Obstruction
- Variable Intra-thoracic Obstruction
- Fixed Obstruction
- Restrictive (non-obstructive) Pattern
Typical Patterns of Flow Volume Loops

Variable Intrathoracic Obstruction

Variable Extrathoracic Obstruction

Expiration

Inspiration

FEV1/FVC < LLN
FEF50/FIF50 << 1.0
e.g. asthma, bronchitis emphysema

FEV1/FVC ≥ LLN
FEF50/FIF50 > 1.0
 e.g. Tracheomalacia Vocal cord dysfunction
Typical Patterns of Flow Volume Loops

Restrictive
Non-Obstructive

Expiration

FEV1/FVC ratio ↑
↑ Flow rates at mid volume
FEF50/FVC > 1.5

Inspiration
e.g. pulmonary fibrosis

Fixed Obstruction
e.g. Subglottic stenosis
Bilateral vocal paralysis
FVC, FEV1, FEV1/FVC Ratio & Flows

• FEV1/FVC % ↓ = obstruction (N FVC, ↓ FEV1)
  ↑ = restriction (↓ FVC, ↓ FEV1)

  N = normal, early restriction, mixed obst/restr

• N FEV1 and ↓ FEF 25-75%, FEF 50%, FEF 75% = small Airway obstruction
Lower Limit of Normal - definition

5% of the population with healthy lungs have lower values
90% of the population with healthy lungs have values in this range
5% of the population with healthy lungs have higher values

Lower Limit of Normal - LLN

Predicted value
Airway bronchodilator response

- Spirometry with pre and post 15 mins of bronchodilator (Salbutamol 400 µg)
- Useful method of assessing airway reactivity.
- An increase of at least 12% in the FEV1 (baseline) helps to confirm asthma and predicts a good response to asthma therapy.
- The lack of acute improvement with bronchodilator inhalation does not rule out asthma.
Lung Volumes

- Static LV measures the various lung “capacities” and “volumes”
- “Hints” from Spirometry with ↓FVC with normal flow rates
- Differentiate between Obstructive and Restrictive
- Quantify the degree of gas trapping
- Quantify the degree of hyperinflation
Classic Spirogram:
Lung Volumes & Subdivisions

- **RV** (residual volume) = (TLC - VC)
- **FRC** (Functional Residual Capacity)
- **ERV** (Expiratory reserve volume)
- **TLC** (Total lung capacity) = (FRC + IC)
- **IRV** (Inspiratory reserve volume)
- **IC** (Inspiratory capacity)
- **VC** (vital capacity)
- **EEL**
- **VT** (Tidal volume)
- **ERV** (Expiratory reserve volume)
- **RV** (residual volume) = (TLC - VC)
Different Lung Volume measurement

• “FRC” from Gas dilution (Closed-circuit Helium dilution)
• “FRC” from Multiple breath Nitrogen washout
• “TLC” as VA from Single-breath (DLCO)
• “FRC or VTG” from Body Plethysmograph
Lung Volumes measurements

• Direct measurement:
  - Function Residual Capacity (FRC)
  - Inspiratory Capacity (IC)
  - Vital Capacity (VC)
  - Expiratory Reserved Volume (ERV)

• Calculated parameters:
  - Total Lung Capacity (TLC) = FRC + IC
  - Residual Volume (RV) = TLC – VC
    = FRC – ERV
  - RV/TLC%
Body Plethysmograph

- Transparent airtight chamber with pressure transducer on the wall
- Patient breaths through a mouthpiece connected to pneumotachometer
- Data calculated by microprocessor unit for thoracic gas volume & airway resistance
FRC by multi-breath N$_2$ washout

- Using a demand valve connected to 100% O$_2$ tank, switch in at E.E.L.(FRC level)
- Breathe quietly until the expired N$_2$ < 1.5 for at least 3 successive breaths or at least 7 mins elapsed
Lung volume Distribution of Various Diseases
Interpretations

• Functional residual capacity:
  ➢ >120% air-trapping
  ➢ <80% restrictive lung disease

• Residual volume/total lung capacity (RV/TLC) 20-35% normal

• TLC:
  ➢ < 80% = restrictive lung disease
  ➢ >= 80%, air trapping if RV/TLC > 35%
  ➢ Normal if RV/TLC <35%
Diffusing Capacity (DLCO)(Transfer Factor)

To assess the gas exchange ability of the lungs into the pulmonary capillaries
Indications for Diffusing Capacity

- Assess disease severity in patient with parenchymal or pulmonary vascular disease
- Early indication of certain pulm infections (e.g. Pneumocystis pneumonia)
- Monitor progression of parenchymal lung disease or assess its response to therapy
- Monitor patient with pulmonary hemorrhage syndromes
- In pediatrics, this measurement most often is used to follow patients with or at risk for pulmonary fibrosis, such as oncology patients receiving chemotherapy.
Methodology of Diffusing capacity

• The lung’s ability to take up oxygen can be estimated by having a seated individual inhale a single breath of a mixture of gases that includes a low concentration of carbon monoxide.

• By comparing the difference in amount of carbon monoxide between inhaled and exhaled gases the amount of carbon monoxide absorbed can be calculated.

• This measurement, first described by Krogh, is called the single breath carbon monoxide diffusing capacity ($D_{LCO}$) in Northern America or transfer factor ($T_{L,CO}$) in Europe.
Procedural Sequence of DLCO

- Start with tidal breath
- Exhale to RV
- Inhale fast to TLC
- Breath-hold
- Exhale for sampling
Interpretation

Two main components:

- area & thickness of blood gas barrier
- capillaries blood volume

Normal Range:
100 ± 25% Pred
or ≥ LLN
## Conditions that affect DLco

<table>
<thead>
<tr>
<th>DLco decrease in</th>
<th>DLco increase in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Diseases of pulmonary circulation (pulmonary thromboembolic disease, primary pulmonary HT, AV malformation, vasculitis-scleroma, lupus)</td>
<td>Conditions that increase the amount of haemoglobin available to bind CO</td>
</tr>
<tr>
<td>2. Condition affecting alveoli (pneumonic consolidation or collapse, emphysema, ARDS, fibrotic lung disease, granulomatous diseases, lung resection)</td>
<td>1. Pulmonary blood flow increase (L→R shunt, exercise, supine position)</td>
</tr>
<tr>
<td>3. Cardiac diseases (pulmonary oedema, R→L shunt)</td>
<td>2. Polycythemia</td>
</tr>
<tr>
<td>4. Miscellaneous conditions (anaemia, pregnancy, recent smoking)</td>
<td>3. Pulmonary haemorrhage syndromes</td>
</tr>
</tbody>
</table>

Uncertain mechanism:
1. Asthma
2. Massive obesity
Respiratory Muscle Strength

- Measure the maximal inspiratory pressure (MIP) and the maximal expiratory pressure (MEP)
- Or measure supine and erect VC
- Indication:
  - Neuromuscular disease (SMA, DMD…….)
  - Restrictive lung disease
  - Obstructive lung disease with hyperinflation
  - Unexplained dyspnea
  - Weaning off ventilator
- Fall in VC when the patient changed from seated to supine position may suggest of diaphragmatic paralysis
Bronchial Challenge Tests

• Purpose
  ➢ To identify airway hyper-responsiveness
  ➢ Diagnosis of asthma
  ➢ Assess severity of asthma and response to treatment

• Types
  ➢ Direct challenges
    o Use of stimuli that act directly on receptors causing airway smooth muscle contraction
  ➢ Indirect challenges
    o Stimuli that act indirectly by causing release of endogenous mediators that cause airway narrowing
Bronchial Challenge Tests

- The most used tests are the Methacholine, Exercise and Mannitol Challenge Test.

- Airway response is expressed as the percent fall in FEV1.

\[
\text{% Fall in FEV1} = \left( \frac{\text{FEV1}_{\text{pre}} - \text{FEV1}_{\text{post}}}{\text{FEV1}_{\text{pre}}} \right) \times 100\%
\]
## Factors that may decrease BHR

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>Withholding period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhaled agents</td>
<td></td>
</tr>
<tr>
<td>Short-acting bronchodilators</td>
<td>8 hrs</td>
</tr>
<tr>
<td>Inhaled anticholinergics</td>
<td>1 week</td>
</tr>
<tr>
<td>Medium-acting bronchodilators</td>
<td>1 week</td>
</tr>
<tr>
<td>Long-acting bronchodilators</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Inhaled corticosteroid/LABA</td>
<td>4 weeks</td>
</tr>
<tr>
<td>Oral bronchodilators</td>
<td></td>
</tr>
<tr>
<td>Theophylline</td>
<td>24 hrs</td>
</tr>
<tr>
<td>Intermediate theophylline</td>
<td>48 hrs</td>
</tr>
<tr>
<td>Long-acting theophylline</td>
<td>48 hrs</td>
</tr>
<tr>
<td>Standard β-agonist tablets</td>
<td>24 hrs</td>
</tr>
<tr>
<td>Long-acting β-agonist tablets</td>
<td>48 hrs</td>
</tr>
<tr>
<td>Corticosteroids</td>
<td>No washout for topical steroids on the skin unless high potency steroids</td>
</tr>
<tr>
<td>Other medications</td>
<td></td>
</tr>
<tr>
<td>Hydroxyzine, cetirizine (and other antihistamines)</td>
<td>72 hrs</td>
</tr>
<tr>
<td>Tiotropium bromide</td>
<td>72 hrs</td>
</tr>
<tr>
<td>Nasal steroids</td>
<td>1 week</td>
</tr>
<tr>
<td>β- blockers</td>
<td>1 week</td>
</tr>
<tr>
<td>Cromolyn sodium</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Nedocromil</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Leukotriene modifiers</td>
<td>6 weeks</td>
</tr>
<tr>
<td>Foods</td>
<td></td>
</tr>
<tr>
<td>Coffee, tea, cola drinks, chocolate (caffeinated foods)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>Strenuous exercise or exposure to cold air that would be expected to interfere with challenges</td>
<td>12 hrs</td>
</tr>
<tr>
<td>Tobacco</td>
<td>6 hrs</td>
</tr>
</tbody>
</table>
Methacholine Challenge Test

- This is Direct Challenge Test and the most common test
- Use to rule out asthma
- After a baseline spirometry, methacholine is inhaled in increasing concentration, FEV\textsubscript{1} is measured about 30 and 90 seconds after inhalation of drug and the highest FEV\textsubscript{1} of acceptable maneuvers is noted.
- The methacholine is stepped up until a 20\% drop in FEV\textsubscript{1} is documented. The concentration of methacholine is noted as PC\textsubscript{20}.
- Then the subject is given bronchodilator and spirometry is repeated afterwards.
Methacholine Challenge Test (con’t)
Exercise-Induced Bronchoconstriction Test Treadmill Protocol

- To look for exercise induced asthma
- Indirect challenge Test
- Use of FEV1 to measure changes before and after exercise
- Acquire 80-90% max HR (220 – Age) within 2 mins
- Run for 6 mins (keep HR within 80-90% of max HR)
- Measure FEV1 @ 5, 10, 15, 20, 30 mins interval
- Given bronchodilator when FEV1 drop >10% from baseline or finished the measurement, spirometry is repeated afterwards
Exercise Challenge Test Report

--- SPIROMETRY ---

<table>
<thead>
<tr>
<th>Stage</th>
<th>Pre</th>
<th>1 min</th>
<th>10 min</th>
<th>15 min</th>
<th>30 min</th>
<th>Post 15 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (L)</td>
<td>2.80</td>
<td>2.60</td>
<td>3.00</td>
<td><em>+3.35</em></td>
<td>+3.31</td>
<td>+3.5</td>
</tr>
<tr>
<td>% Change</td>
<td>+0.4</td>
<td>-2</td>
<td>+0</td>
<td>+1</td>
<td>+5</td>
<td></td>
</tr>
<tr>
<td>FEV1 (L)</td>
<td>2.58</td>
<td>2.40</td>
<td>2.76</td>
<td><em>+3.03</em></td>
<td>+3.17</td>
<td>+2.89</td>
</tr>
<tr>
<td>% Change</td>
<td>+0.4</td>
<td>-2</td>
<td>+0</td>
<td>+1</td>
<td>+5</td>
<td></td>
</tr>
</tbody>
</table>

Exercise-induced Bronchoconstriction Worksheet

Name: Kwong Wah Hospital Department of Paediatrics Paediatric Respiratory Research Centre

Exercise-induced Bronchoconstriction Worksheet

ta of Assessment: Exercise Induced Cough

dilation(s) prior to test:

Exercise Maximum Heart Rate: 210 - 0.63 x Age

Heart Rate: 169 - 9 ± 9 x Max

Method: Treadmill, Ergrometer, Running

Skeletal: 2.2 km/h, mph

Max: Target heart rate duration: 6 min
tal duration: 7.28 min

Stable Heart Rate: 77 ± 8 bpm

Maximum Exercise Heart Rate: 87 ± 8 bpm

23.9% of predicted max

Minimum Heart Rate Reserve

min: 171

max: 107

Exercise symptoms: Cough, Fatigue, Dyspnoea

<table>
<thead>
<tr>
<th>Severity</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10%</td>
<td>Normal</td>
</tr>
<tr>
<td>≥ 10% but &lt; 25%</td>
<td>Mild</td>
</tr>
<tr>
<td>≥ 25% but &lt; 50%</td>
<td>Moderate</td>
</tr>
<tr>
<td>≥ 50%</td>
<td>Severe</td>
</tr>
</tbody>
</table>

Tested by: [Signature]

Clinician: [Signature]
Mannitol Challenge Test

- Indirect challenge Test
- To rule in asthma
- An Aridol dry powder inhaler was used for the delivery
- Osmotic diuretic that is metabolically inert in humans and occurs naturally, as a sugar or sugar alcohol, in fruits and vegetables.
- A deep forced inhalation through the aridol and then hold their breath for 5 sec.
- Children then performed the challenge with doses consisting of 0 mg (placebo), 5, 10, 20, 40, 80, 160, 160 and 160 mg (total 635 mg)
Measuring Mannitol Response

• The FEV1 value measured after the 0 mg capsule was taken as the prechallenge FEV1
• After a baseline spirometry, Mannitol is inhaled in increasing concentration, FEV₁ is measured 60 seconds after inhalation of drug and the highest FEV₁ of acceptable maneuvers is noted.
• The mannitol is stepped up until a 15% drop in FEV₁ is documented. The dosage of mannitol is noted as PD₁₅.
• The challenge was complete when a 15% fall in FEV₁ was documented or a cumulative dose of 635 mg of mannitol had been administered
• Then give bronchodilator and spirometry is repeated afterwards
• Categorization of Bronchial Responsiveness:

<table>
<thead>
<tr>
<th>PD₁₅</th>
<th>BHR Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 35mg</td>
<td>Severe BHR</td>
</tr>
<tr>
<td>35 &lt; PD₁₅ ≤ 155mg</td>
<td>Moderate BHR</td>
</tr>
<tr>
<td>155 &lt; PD₁₅ ≤ 635mg</td>
<td>Mild BHR</td>
</tr>
</tbody>
</table>
Assessment of exercise limitation: Respiratory vs Cardiac

Indications: dyspnea on exertion, chest pain, fatigue, EIB and arterial desaturation

Using incremental-work or constant-work protocols by cycle ergometer or treadmill

Common protocol is Progressive multi-stage (Stage I) by increasing the workload at three-minute interval until exhaustion
SOB?

SPIROMETRY

↓ FEV₁/FVC < LLN

Obstruction

Bronchodilator

↑ FEV₁ >12% and 200 ml

Asthma

COPD?

↓ FEV₁ ≥ 20%

Hyper-reactive airways (Asthma)

Normal

Asthma?

MCT

No △

Normal

Restricted

↓ VC

D₃CO

Nonprenchymal

MIPS/MEPS

Low

Neuromuscular

Chest wall, pleura

“Emphysema”

“Chr bronchitis”/Asthma

Parenchymal

Normal

Low
Fractional Exhaled Nitric Oxide (FeNO)

• Measure Nitric Oxide in exhaled air as a marker of airway inflammation
• Airway inflammation is the main pathogenic factor in asthma
• NO is endogenously produced when airways are inflamed and FeNo levels are elevated in asthma patients
• Use for diagnosing, treating and monitoring asthma patients
Exhaled Nitric Oxide (eNO) Test
Guide to Interpretation of FE\textsubscript{NO} Values:

<table>
<thead>
<tr>
<th>FENO (ppb)</th>
<th>Low</th>
<th>Normal</th>
<th>Intermediate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>&lt; 5</td>
<td>5-25</td>
<td>25-50</td>
<td>&gt;50 (or a rise of &gt; 60%)</td>
</tr>
<tr>
<td>Children &lt; 12 years</td>
<td>&lt; 5</td>
<td>5-20</td>
<td>20-35</td>
<td>&gt;35 (or a rise of &gt; 60%)</td>
</tr>
</tbody>
</table>

**Eosinophilic inflammation**

- **Unlikely**
- **Unlikely**
- **Present, but mild**
- **Significant**

**Consider:**
- Smoker

**In children also consider:**
- Primary ciliary dyskinesia
- Cystic fibrosis
- Chronic lung disease of prematurity

**If not well controlled, review diagnosis:**
- Neutrophilic asthma
- Anxiety/hyperventilation
- Vocal cord dysfunction
- Gastro-esophageal reflux
- Rhinosinusitis
- Cardiac disease

**In children also consider:**
- Wheezy bronchitis
- ENT disorders
- Immunodeficiencies

**If well controlled and on anti-inflammatory treatment:**
- Implies patient is compliant with treatment
- Reduce dose or, in case of low ICS dose, even withdraw ICS

**Interpretation based on clinical presentation**

**If not well controlled and on anti-inflammatory treatment, consider:**
- Infection as reason for worsening
- High levels of allergen exposure
- Adding in other therapy apart from ICS (e.g. Long acting β-agonist)
- Consider ICS dose increase

**In children also consider:**
- Continuous high level allergen exposure
- Imminent exacerbation or relapse depending on history of individual patient (more likely if ICS dose is zero)
- Steroid resistance (rare)

**If well controlled and on anti-inflammatory treatment:**
- No change in ICS dose, if patient is stable

**If well controlled and on anti-inflammatory treatment:**
- No change in ICS dose, if patient is stable
Nasal Nitric Oxide (Nasal NO)

• Nasal NO measuring methods:
  ➢ Breath Hold, oral exhalation against resistance and Tidal breathing

• Values affected by:
  ➢ Measuring method, age, ambient air, circadian change, drugs and underlying diseases

• Lower in primary ciliary dyskinesia, nasal decongestant and cystic fibrosis

• Higher in rhinosinusitis

• Controversial in adenoidal hypertrophy
PFTs for Pre-school Children (2-6 yrs. Old)

- Impulse Oscillometry System (IOS) / Forced Oscillation Test (FOT)
  - Measurement of overall Resistance of the entire respiratory system
  - Can be used to evaluate bronchodilator effect or airway hyperresponsiveness
  - a wide range of patient age - children as young as 2 years old
  - only tidal breathing maneuver
  - Pressure oscillations are transmitted to the airway opening Respiratory System Resistance (Rrs) and Reactance (Xrs) are reported
Impulse Oscillometry System (IOS)

- Pressure oscillations are applied at the mouth that propagate via movement of the air column in the conducting airways.
- The pressure oscillations are applied at a fixed (square wave) frequency, from which all other frequencies of interest are derived (multiple frequencies).
  - Low-frequency signals (5 Hz): lung periphery
  - High-frequency signals (20 Hz): only reach the proximal airways
Impulse Oscillometry (IOS) Testing

• Simple, noninvasive, minimal patient cooperation
• Usually can be performed for ≥ 3 years old
• Effort-independent
• Tidal breathing maneuver, 30 sec/ trial
• Posture
  ➢ Sitting
  ➢ Head neutral position
  ➢ A nose clip in place
  ➢ Cheeks firmly supported
Impulse Oscillometry

- Pressure signals separately quantify the degree of obstruction in the central and peripheral airways

- Resistance:
  - R5 (mean resistance at 5Hz)
  - R20 (mean resistance at 20Hz)
  - R5-20 (Frequency dependent change in resistance)
Impulse Oscillometry

- Distal Obstructive Diseases
  - Frequency-dependent increase in resistance (high R5–R20)
  - A decrease in reactance

- Positive bronchodilator response
  - R5 (mean resistance at 5Hz) decreased by > 29%, or
  - R5-20 (Frequency dependent change in resistance) decreased by ≥ 44.2%
**Impulse Oscillometry**

\[ \uparrow R5 \rightarrow \text{distal obstruction} \]
\[ \uparrow R5-20 \rightarrow \text{distal obstruction} \]

### Impulse Oscillometry Report

<table>
<thead>
<tr>
<th>Metric</th>
<th>Pred</th>
<th>PredLL</th>
<th>PredUL</th>
<th>Pre Avg</th>
<th>%Pred</th>
<th>Post Avg</th>
<th>%Pred</th>
<th>%Chlg</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT [L]</td>
<td>0.28</td>
<td>0.16</td>
<td>0.40</td>
<td>0.35</td>
<td>125.50</td>
<td>0.30</td>
<td>145.12</td>
<td>15.64</td>
</tr>
<tr>
<td>Z at 5 Hz [kPa/(L/s)]</td>
<td>0.88</td>
<td>0.56</td>
<td>1.19</td>
<td>1.52</td>
<td>173.07</td>
<td>0.60</td>
<td>90.66</td>
<td>-47.62</td>
</tr>
<tr>
<td>R at 5 Hz [kPa/(L/s)]</td>
<td>0.98</td>
<td>0.73</td>
<td>1.22</td>
<td>1.37</td>
<td>140.52</td>
<td>0.57</td>
<td>77.06</td>
<td>-45.16</td>
</tr>
<tr>
<td>R at 20 Hz [kPa/(L/s)]</td>
<td>0.71</td>
<td>0.50</td>
<td>0.92</td>
<td>0.78</td>
<td>110.16</td>
<td>0.51</td>
<td>96.31</td>
<td>-12.57</td>
</tr>
<tr>
<td>Diff R5-R20 [kPa/(L/s)]</td>
<td>0.295</td>
<td>0.029</td>
<td>0.561</td>
<td>0.594</td>
<td>201.17</td>
<td>0.053</td>
<td>24.081</td>
<td>-88.03</td>
</tr>
</tbody>
</table>

Concerning resistance:
- Mean resistance at 5Hz (R5)=1.37kPa/L/s (H)
- Mean resistance at 20Hz (R20)=0.78kPa/L/s
- Frequency dependent change in resistance (R5-R20)=0.594 (H)

Concerning post-bronchodilator:
- R5 decreased 45%
- R5-R20 decreased 88%

Impression:
- High resistance measured by IOS at baseline.
- Positive bronchodilator response.
PFTs for Pre-school Children (2-6 yrs. Old) con’t

- Multiple-Breath inert gas Washout (MBW)
  - Tidal breathing through a mouthpiece/facemask
  - Assesses the efficiency of gas distribution and mixing within the lungs
  - Using inert gas or nitrogen washout, FRC and LCI (lung clearance index = Washout Volume/FVC) are reported
Infant Lung Function Test

- **Indication**
  - To study the mechanics of the lungs and airway in infant
  - To assess lung disease, such as broncho-pulmonary dysplasia,
  - To assess the response of treatment
Preparation of Infant Lung Function Test

• Environment: quiet, warm
• Instrument: calibration before test
• Patient
  ➢ 3kg < BW <13kg
  ➢ Not on continuous oxygen therapy / NIV therapy
  ➢ Oral Sedation (Chloral Hydrate) is necessary
  ➢ NPO for 3 hours
  ➢ Sleep deprivation if possible
  ➢ Informed consent is necessary
Pamphlet for Infant LFT

Kwong Wah Hospital
Department of Paediatrics

Infant Lung Function Test

What is lung function test?
Complete respiratory assessment includes history, physical examination, chest X-ray, arterial blood gas and pulmonary function tests. Main purpose of pulmonary function test is to determine the severity of lung injury and to collect baseline data for follow-up comparison.

How should I prepare my child for the test?
Your child should not take anything by mouth since 3 hours before the procedure. This is to avoid vomiting and aspiration pneumonia during and after the procedure.

How is the procedure done?
Older child has to cooperate and breathe according to instruction when performing pulmonary function tests. As infant is not able to follow our instruction, we have to make use of some instrument to simulate the different pattern while the child is still asleep.

The child would be placed in the Babybox after fallen asleep, a mask will be used to cover his mouth and nose. He will breathe through the mask and a flow sensor, which allows us to collect information concerning the child's specific airway resistance (rRaw) and plethysmographic functional residual capacity (FRCP).

After that, we will wrap up the child with an inflatable jacket; pulmonary function test will be performed by raised volume rapid thoracoabdominal compression (RVTC) technique. Data like FVC, FEV0.5, FEV1 will be extracted.

Despite taking sedation, about 10% of children will remain awake or wake during the test. The test will be aborted if the child has woken up and we will scheduled patient for another session if necessary.

Is there any complication?
Infant lung function test is very safe. Complications are usually caused due to sedatives & they include:
1. Transient respiratory depression and desaturation which due to the use of sedative effect completely
2. Apnoea resulting in vomiting and possible aspiration pneumonia
3. Hyperventilation leading to convulsions
4. Unsteady gait before effect of sedation has been wore off
Infant Lung Function Test

1. Tidal breathing analysis

   • Measured values
     a. Tidal breath indices: tidal volume (VT), respiratory rate (RR), the ratio of time to peak expiratory flow to total expiratory time (tPTEF:tE )
     b. Shape of flow/volume loops
Tidal breathing analysis

VT, RR, tPTEF:tE
2. Passive mechanics (single/double occlusion methods)

- The total respiratory system compliance (Crs)
- Resistance of the respiratory system (Rrs)
- Respiratory time constant = Rrs x Crs
Passive mechanics (single/double occlusion methods)

- The occlusion technique for measuring passive respiratory mechanics is based on the ability to invoke the Hering-Breuer reflex.
- During occlusion: **mouth pressure = alveolar pressure** (as shown by the presence of plateau at the airway opening).
- After opening: **corresponding flow & appropriate volume**.
3. **Baby Body Plethsmography**

- Measures the total volume of gas in the lungs, FRC_{pleth} (i.e. all compressible gas in the thorax including any trapped gas)
Based on the principle of Boyle’s law, $P_1 \times V_1 = P_2 \times V_2$ (at a fixed temperature)

A shutter is closed at the end of an inspiration when stable EEL established, thereby enclose a fixed mass of gas within the lungs, while the infant continues breathing against the occlusion

→ Causes cyclic expansion and compression of the fixed gas

$FRC_{pleth} = (\Delta V_B/\Delta P_{ao}) \times \text{barometric pressure} \ (\sim= \text{initial pressure in the lungs at time of occlusion})$
Baby Body Plethsmography
4. **Raised volume Rapid thoracic-abdominal compression (RVRTC)**

- Determine the severity of bronchial obstruction
- Produces expiratory flow-volume curve similar to the spirometry, measure **FVC, FEV0.5, PEF, MEF75/25**
Raised volume Rapid thoracic-abdominal compression (RV RTC)

“Raised Volume (RV)”

- Lungs inflated to TLC with Neopuff (simulated inspiration)
- Standardized intermittent positive pressure 30cmH20 is applied

“Rapid thoracic-abdominal compression (RTC)”

- Thorax squeezed (jacket and inflatable bladder) by the manoeuvre ending when the infant reaches residual volume (RV)
Raised volume Rapid thoracic-abdominal compression (RVRTC)
Raised volume Rapid thoracic-abdominal compression (RVRTC)
Raised volume Rapid thoracic-abdominal compression (RVRTC)

Report:
- Restrictive if FVC less than LLN
- Obstructive if FEF25-75 and/or FEV0.5 or Rrs < LLN

Bronchodilator Responsiveness
- Bronchodilator: Ventolin 4 puffs
- Positive BDR =
  - FEV0.5 of > 13%,
  - or FEF25-75 > 24%
**Kwong Wah Hospital**  
Department of Paediatrics  
Paediatric Respiratory Research Centre  
Cardio-Pulmonary Function Test Request Form

### Clinical Diagnosis:

### Indications for Test:

#### Current Asthma Medications:

- **ICS**  
  - NO  
  - YES, if yes: □ continue □ withhold _______ for day/hr

- **ICS+LABA**  
  - NO  
  - YES, if yes: □ continue □ withhold _______ for day/hr

- **Short acting Beta 2**  
  - NO  
  - YES, if yes please withhold 1 day

**Note:**
1. No Booking for Active TB and infectious cases
2. In order to obtain reliable results, patient must be able to follow verbal instructions
3. Please discuss with respiratory team if you have queries about the tests or you want to book test (except IOS) for young children, ie, <=6yrs old

<table>
<thead>
<tr>
<th>Test Requested</th>
<th>You are looking for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Spirometry / □ Spirometry with bronchodilator*</td>
<td>Baseline Spirometry and bronchodilator response</td>
</tr>
<tr>
<td>□ Total lung volume (include Spirometry, SVC, DLCO and FRC(N2)/ TGV)</td>
<td>TLC, lung volume, diffusing capacity and FRC/TGV</td>
</tr>
<tr>
<td>□ FeNO (please discuss with Resp Team before booking)</td>
<td>Eosinophilic airway inflammation, PCD</td>
</tr>
<tr>
<td>□ airway □ Nasal</td>
<td></td>
</tr>
<tr>
<td>□ IOS with bronchodilator</td>
<td>Asthma, can be performed by ≥ 3 yrs old</td>
</tr>
<tr>
<td>□ Exercise Challenge Test ** Consent</td>
<td>Exercise induced bronchoconstriction</td>
</tr>
<tr>
<td>□ Methacholine Challenge test **Consent</td>
<td>Airway hyperresponsiveness</td>
</tr>
<tr>
<td>□ MIP/MEP</td>
<td>Respiratory muscle weakness</td>
</tr>
<tr>
<td>□ Erect and Supine VC (include FVC and SVC)</td>
<td>Respiratory muscle weakness</td>
</tr>
<tr>
<td>□ VO2 Max ** Consent (include post bronchodilator spirometry)</td>
<td>The fitness of child, the limiting factor of exercise</td>
</tr>
<tr>
<td>□ Treadmill ** Consent</td>
<td>Cardiac ischaemia during exercise</td>
</tr>
<tr>
<td>□ Energy Expenditure Assessment (Urea = _______)</td>
<td>To assess daily energy requirement</td>
</tr>
<tr>
<td>□ Hypoxic Challenge Test ** Consent</td>
<td>Fitness to flight test</td>
</tr>
<tr>
<td>□ Oxygen Titratin (O2 prescribed _______) (please discuss with Resp Team before booking)</td>
<td>O2 supplement for ADL or Max. MET/speed_______</td>
</tr>
<tr>
<td>□ Infant Lung Function Test** Consent</td>
<td>Tidal Volume, specific airway resistance (sRaw) plhysmogphlogic functional residual capacity (FRCp)</td>
</tr>
</tbody>
</table>

**Please send request form with consent to N8 for booking**  
*Basic spirometry can be conducted in asthma clinic.*

For any enquire, please contact Paediatrics Respiratory Research Centre via Ext 7820
Nursing role in Paediatric Pulmonary Function Test

- Act as a senior technologist
- Obtain the accurate report
- Management of Broncho-contraction /asthma attack
- Administer medicine for the test (e.g. Ventoline puff)
- Check patient medication’s compliance and technique
- Asthma education
- Close supervision when the baby’s sedated
Q & A
Thank you