Spirometry Workshop

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Learning Outcomes

- Understand the indications & contraindications for spirometry testing
- Perform spirometry within clinical guidelines
- Understand quality assurance principles for spirometry
- Understand spirometry interpretation

Introduction to Spirometry

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Spirometry Overview

- A measurement of airflow and lung vital capacity during a forced expiratory manoeuvre from full inspiration
- Different ways of describing…
  - Dynamic lung volumes
  - Maximal flow rates at different lung volumes
  - The mechanical properties of the lungs
- Measured using a spirometer

Why spirometry?

- To detect and quantify extent of airways obstruction and its alternative – lung restriction
- Spirometry is recommended by:
  - National Asthma Council Australia
  - Lung Foundation Australia
  - Thoracic Society of Australia and New Zealand

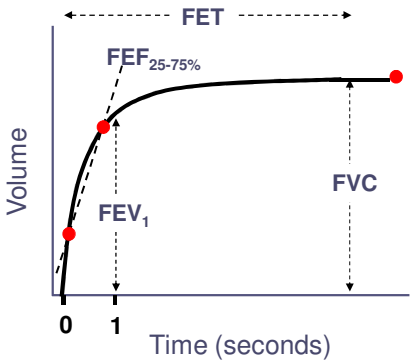
Peak Expiratory Flow (PEF)

- PEF measured by a peak flow meter is no substitute for full spirometry
- PEF doesn't provide sufficient information to assess lung function
- PEF is often done in general practice and is sometimes confused with spirometry

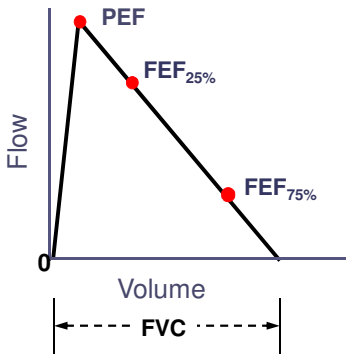
Definitions

- FEV_1:
  - Volume expired in the first second of a forced maximal expiration initiated after maximal inspiration
- FVC
  - maximum volume of air which can be expired with
  - maximal force (after a maximal inspiration) during a
  - forced manoeuvre
- FEV1/FVC (FEV1/FVC ratio or Forced Expiratory Ratio)
  - FEV1 expressed as a percentage of the FVC
- PEF
  - maximal expiratory flow achieved during the forced
  - expiratory manoeuvre (L/s)
- FEF25–75% (forced expiratory flow between 25% and 75% of FVC):
  - Average expiratory flow during the middle half of the FVC manoeuvre
- FET (forced expiratory time):
  - Time required to perform the FVC manoeuvre

Volume-Time (Spirogram)



Flow-Volume Curve



All volumes and flows reported at
Body **T**emperature and **P**ressure **S**aturated (BTPS)

BTPS

- All volumes and flows reported at Body Temperature and Pressure Saturated (BTPS)
- When "warm" air is expelled into a "cold" spirometer, the volume recorded by the spirometer is less than that blown out of the lungs
  - Gas shrinkage (Charles' Law)
  - Condensation of water vapour (vapour pressure falls when gas cools)

Considerations when selecting a spirometer

- Meets the ATS/ERS spirometer performance criteria
- Ease of use and easy to follow instructions
- Provides a real-time graphic display of the manoeuvre (large enough to see)
- Accurate (can be calibrated or accuracy validated)
- Relevant predicted values
- Hardcopy of the results possible

Johns DP., Burtson D., Swanney MP. "Spirometer Users' and Buyers' Guide" National Asthma Council Australia, 2015 Available at: http://www.nationalasthma.org.au/health-professionals/spirometry-resources/spirometer-users-buyers-guide

Considerations when selecting a spirometer

- Reliable with low maintenance requirements
- Flow sensor is disposable or easily cleaned/disinfected
- Provision of technical support and supplies
- Easy access to regular servicing (e.g.doesn't need to go overseas)
- Links with clinical software
- Price (including consumables)

Johns DP., Burtson D., Swanney MP. "Spirometer Users' and Buyers' Guide" National Asthma Council Australia, 2015 Available at: http://www.nationalasthma.org.au/health-professionals/spirometry-resources/spirometer-users-buyers-guide

Indications & Contraindications

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Indications for Spirometry

- **Diagnostic:**
  - To evaluate symptoms, signs or abnormal laboratory tests;
  - To measure the effect of disease on respiratory function;
  - To screen individuals at risk of having respiratory disease;
  - To assess pre-operative risk;
  - To assess prognosis;

Indications for Spirometry

- **Monitoring:**
  - To assess therapeutic intervention;
  - To describe the course of diseases that affect respiratory function;
  - To monitor people exposed to injurious agents;
  - To monitor for adverse reactions to drugs with known respiratory toxicity;

Indications for Spirometry

- **Disability/impairment evaluations:**
  - To assess subjects as part of a rehabilitation programme;
  - To assess risks as part of an insurance evaluation;
  - To assess individuals for legal reasons;

Indications for Spirometry

- **Public Health**
  - Epidemiological surveys;
  - Derivation of reference equations;
  - Clinical research.

Contraindications

- Absolute Contraindication:
  - Could cause trauma, injury or death to patient if undertaken. Tests are not to be performed.
- Relative Contraindication:
  - Require requesting physician/healthcare expert to judge when it is safe and appropriate to perform breathing test.

Importance?

- Risk management:
  - The likelihood of an event occurring;
  - The severity of the consequences of an event occurring.
- Benefits to patient of obtaining test results need to outweigh risks.

Potential Harm

- Requires maximal effort which may result in:
  - Transient breathlessness
  - Cough
  - Light headedness/ Syncope
  - Chest pain
  - Oxygen desaturation
  - Incontinence
  - Headache
- In patients with poorly controlled asthma:
  - Forced manoeuvre can also induce bronchospasm
  - Progressive decrease in FEV_1 with successive blows

Potential Harm

- Maximal pressures generated in thorax impact on thoracic/abdominal tissues/organs;
- Large swings in BP causing stresses on other tissues in body (eg limbs, head);
- Expansion of chest wall and lungs;
- Active communicable diseases.

Current recommendations

- 1996, American Association for Respiratory Care:
  - Haemoptysis of unknown cause;
  - Pneumothorax;
  - Unstable cardiovascular status;
  - Thoracic, abdominal or cerebral aneurysm;
  - 'Recent' eye surgery;
  - Presence of acute illness/symptom;
  - Recent abdominal or thoracic surgery.
- 2005, ATS/ERS, General Considerations for Lung Function:
  - Myocardial Infarction within 1 month
  - Chest/abdominal pain of any cause
  - Oral or facial pain exacerbated by mouthpiece;
  - Stress incontinence;
  - Dementia/confused state

Absolute Contraindications

Do not proceed with test if any of these criteria are met.

- Myocardial Infarction (wait 1 month);
- AAA- ascending aortic aneurysms (>6cms);
- Respiratory embolism;
- Angina (unstable);
- Severe hypertension (systolic >200mmHg, diastolic > 120mmHg) (Measure before tests if suspected).

Relative Contraindications

Use clinical judgement before proceeding with test. Seek medical advice if any of these criteria are met

- Thoracic/abdominal surgery (see table below for examples);
- Brain, eye, ear, ENT surgery (see table below for examples);

Surgery Type	Recommendations
Abdominal (conventional or laparotomy)	1 week
Caesarean section (uncomplicated)	6-8 weeks
Laser eye surgery	1 week
Brain surgery	3-6 weeks
Vascular surgery (especially lower limb)	4-6 weeks

- Pneumothorax (wait 2 weeks);
- Haemoptysis;
- Subjects with an inability to understand instructions, confused/demented subjects or subjects unable to provide consent;
- Subject discomfort – vomiting, diarrhoea, cold sores, common cold; (wait until main symptoms abate);
- Infection control issue – norovirus, TB, flu (wait until main symptoms abate);
- *Chest or abdominal pain of any cause;
- *Oral or facial pain exacerbated by a mouthpiece;
- *Stress incontinence.

Infective Contraindications

1. Harm to patients performing the test;
2. Pain or discomfort to patients (vomiting etc);
3. Harm to staff or other patients;
4. Redundant results because of submaximal effort;
5. Results do not contribute to clinical plan.

Performing Spirometry

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Patient Instructions

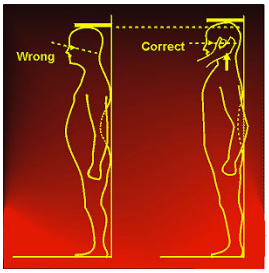
- Activities that should preferably be avoided prior to lung function testing:
  - Performing vigorous exercise within 30 min
  - Smoking within 1hr
  - Consuming alcohol within 4hr
- Do not wear clothing that substantially restricts full chest and abdominal expansion

Patient Instructions

- Ideally:
  - No short acting β-agonist (SABA) within 4hrs of test
  - No long acting β-agonist (LABA) used within 12hrs (e.g. efometerol); or 24hrs (e.g. indacaterol) of test
  - No long acting anti muscarinic/anticholinergics within 24hrs of test
- If any bronchodilator medications have been taken, note time last used

Pre Test Preparation

- Wash hands
- Prepare the spirometer
- Enter patient demographics:
  - Height and weight without shoes, age, gender and ethnic origin
- Ask about smoking, recent illness and medication use
- Ensure subject is sitting up tall with their legs uncrossed. Feet should be flat on the floor.
- Explain procedure to patient. Demonstrate if necessary.



Open Circuit VS Closed Circuit

- Open Circuit:
  - Patient performs only expiratory portion of manoeuvre on spirometer
- Closed Circuit:
  - Patient performs entire manoeuvre (inspiratory and expiratory portions) on spirometer

Method – Open Circuit

- Patient should:
  - Inhale completely and rapidly away from the mouthpiece;
  - Seal lips around mouthpiece and blast out as hard and fast as possible;
  - Continue blowing until lungs are empty (>6seconds and plateau achieved for adults).

Method – Closed Circuit

- Patient should:
  - Seal lips around mouthpiece and inhale completely and rapidly;
  - Blast out as hard and fast as possible;
  - Continue blowing until lungs are empty (>6seconds and plateau achieved for adults).

Test Performance

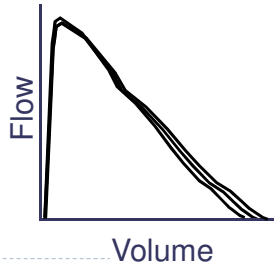
- Manoeuvre should be repeated until 3 acceptable and repeatable efforts are obtained
  - Usually no more than 8 attempts
- Manoeuvre must be "Acceptable" and "Repeatable"

Acceptable

- Subject must have taken a full breath in before blowing out;
- Subject must blow all the way out (achieve a plateau);
- The forced expiratory manoeuvre must be:
  - Immediate (no hesitation);
  - Maximal Effort;
  - Be smooth and continuous (ie free from cough or glottic closure)

Repeatable

- Obtain at least **3** acceptable blows
- The two largest values for FEV_1 should be within 150 mL of each other
- The two largest values for FVC should be within 150 mL of each other
  - If FVC is ≤1L should be within 100mL of each other



Practical Session…

Quality Assurance

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Quality Control

- Calibration
  - Testing with known volume at different flow rates;
  - 3L calibration syringe, read 3L ±0.5% (2.895 – 3.105 L* (ATPS))
- Biological Control
  - Known healthy test subject with >10 data points
  - Plot over time
- Personnel Training
  - Regular & ongoing

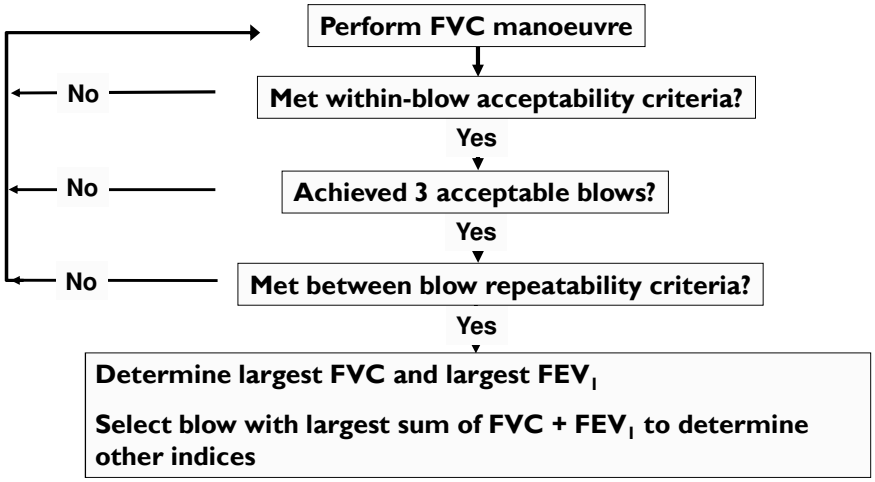
Quality Control

- Equipment Maintenance (must keep log/records)
  - Calibration check (or validation of accuracy)
  - Cleaning and disinfection procedures
  - Electrical operation and safety checks
  - Mechanical operation and safety checks
  - Software/database maintenance and back-up

Quality Control

- Infection Control
  - Need to provide safe equipment and environment
  - Wipe down spirometer between each patient
  - Barrier filters reduce risk of cross-infection – single patient use where possible
  - Operator to stand clear to avoid potential airborne/droplet transmission

Measurement Procedures



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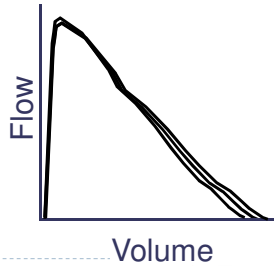
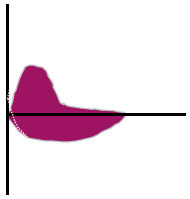


Consistent Effort

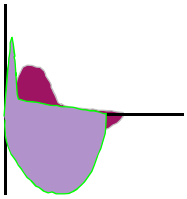
Not maximal effort



PEF 100 L/min

FEV1 1.50 L

Maximal effort



PEF 150 L/min

FEV1 0.90 L

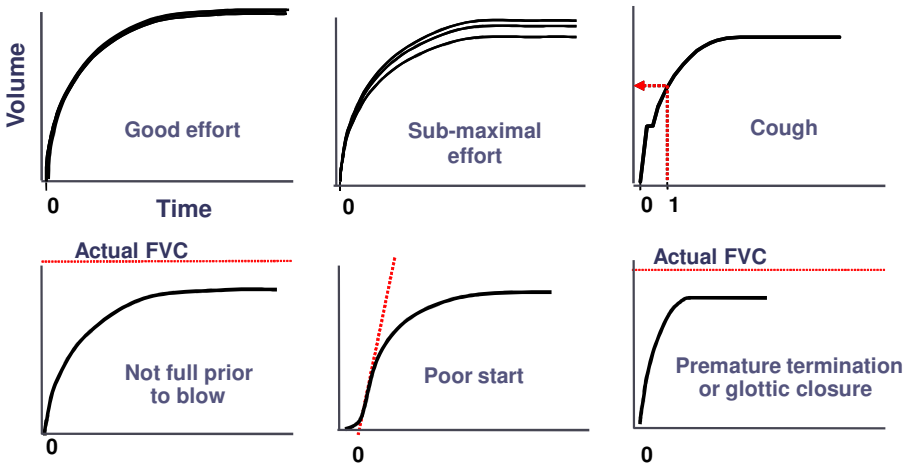
Causes of Poor Quality Spirometry

- Lack of tester knowledge/experience
- Inaccurately measured or entered patient details (i.e. age, gender, height and ethnicity)
- Poorly maintained or calibrated spirometer
- Results not repeatable

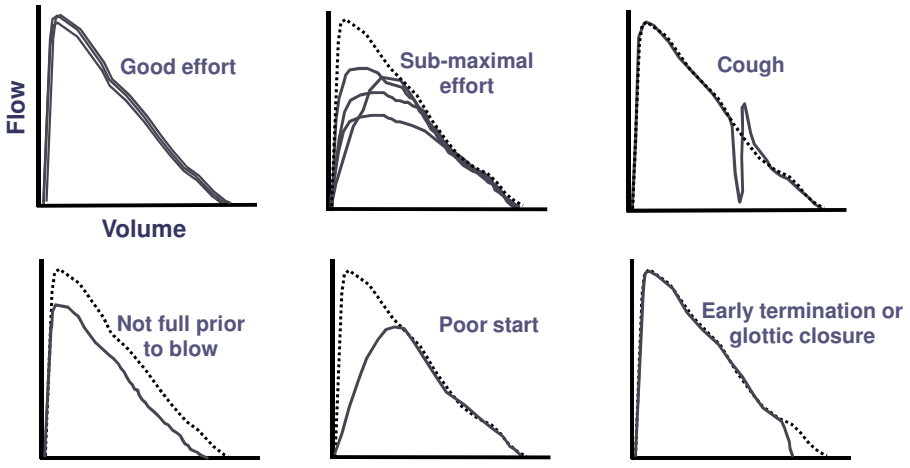
Patient-Related Problems

- Lack of patient understanding/compliance
- Patient not completely 'full' at the start
- Delay in initial effort
- Premature termination of blow
- Tongue occlusion
- Glottic closure
- Cough – especially during the first second
- Vocalisation during the blow
- Poor posture
- Leak (e.g. around mouthpiece)

Troubleshooting: poor spirograms



Troubleshooting: poor flow–volume



Interpretation of Spirometry

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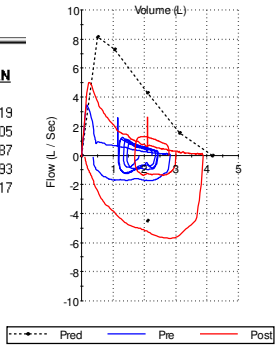
W's Spirometry

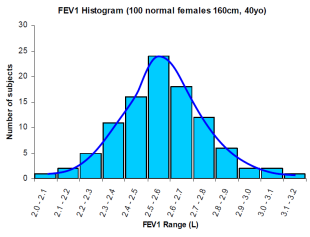
	Pred	Pre Actual	Pre %Pred	Post Actual	Post %Pred	%Chng	LLN	ULN
---- SPIROMETRY ----								
FVC (L)	4.18	2.82	67	3.87	92	+36	3.17	5.19
FEV1 (L)	3.21	1.17	36	2.11	65	+81	2.37	4.05
FEV1/FVC (%)	75	41	55	55	72	+32	63	87
FEF 25-75% (L/sec)	3.21	0.43	13	1.24	38	+184	1.49	4.93
FEF Max (L/sec)	8.17	3.40	41	5.18	63	+52	6.17	10.17
Expiratory Time (sec)		10.90		11.34		+4		
Back Extrap Vol (L)		0.06		0.07		+28		

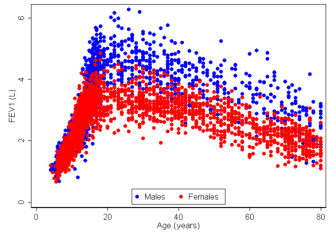


What does this tell you??

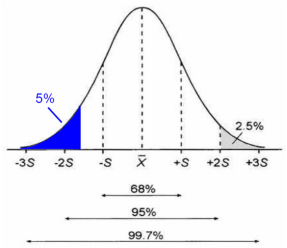
Predicted Values

POPULATION SAMPLE





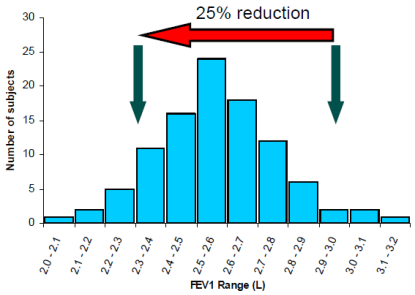
NORMAL DISTRIBUTION



- In disease a ↓ in FEV_1 usually occurs therefore we want to determine LLN of normal
- Margin of error is usually 5% and the LLN is calculated by: mean ± 1.64S
(5% of healthy subjects will have values below the LLN)

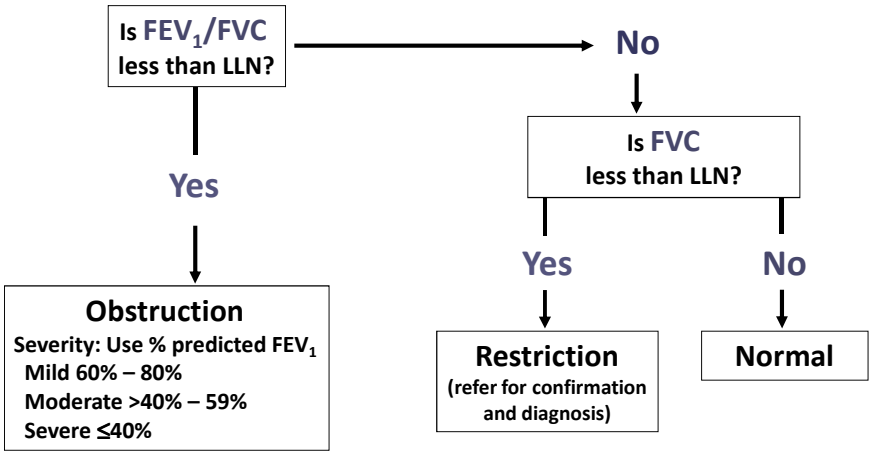
Predicted Values

- Cannot say that a result is 'normal', only can say that it is 'within normal limits' since we do not know an individual's starting point
- It is more valuable to compare results with previous results than with predicted values



- Note large inter-individual variability of normal sample suggestion of ± 20%
- Intra-individual variability of ± 5% with well trained patient

Interpretation algorithm

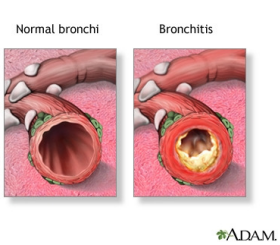


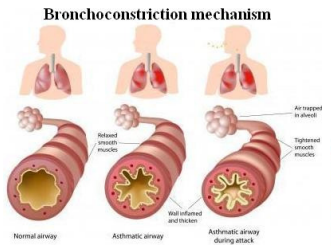
Spirometry Interpretation

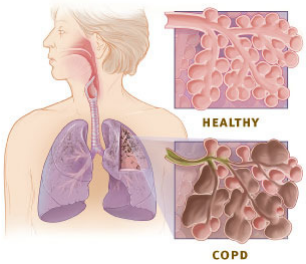
- Use the **FEV_1/FVC** ratio to **detect obstruction**
- Use **FEV_1 as % predicted** to grade severity of obstruction
- Use **FVC** to **assess restriction**
  - Low FVC (VC) in presence of significant obstruction does not necessarily indicate restriction
  - Need to confirm and quantify restriction with measurement of Total Lung Capacity
- A low $FEF_{25–75\%}$ in the presence of normal FEV_1 can be used to detect 'early airflow obstruction' but only if FVC is within normal limits.
  - Lower limit of normal $FEF_{25–75\%}$ is about 60% predicted
- **Bronchodilator Reversibility**
  Significant reversibility is a **12% (or greater)** improvement in FEV_1 and in addition an increase of **at least 200 ml**

Obstructive disorders (airflow limiting)

- In obstructive respiratory disorders, airflow is reduced as a result of airway narrowing (unable to blow out quickly)
- Reduced maximum expired flows are due to:
  - airway lumen narrowing by mucus **(bronchitis)**
  - Reactive airways caused by airway wall thickening/inflammation **(asthma)**
  - Loss of lung elastic recoil **(emphysema/COPD)**

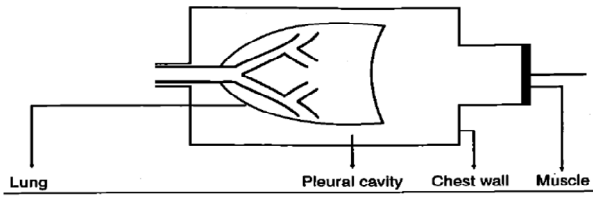






Restrictive disorders (volume limiting)

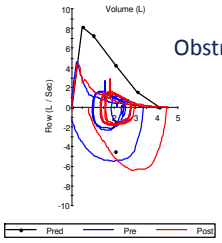
- In restrictive disorders there is a reduction in the FVC
- This can be either **intrapulmonary** or **extrapulmonary**



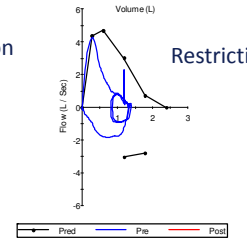
Lung	Pleural cavity	Chest wall	Muscle
Resection (lobectomy, pneumonectomy)	Effusion	Scleroderma	Neuromuscular disease
Atelectasis	Enlarged heart	Ascites	Old polio
Stiff lung – eg, fibrosis	Tumor	Pregnancy	Paralyzed diaphragm
CHF – engorged vessels, edema		Obesity	
Thickened pleura		Kyphoscoliosis	
Tumor		Splinting due to pain	
Airway obstruction – asthma, chronic bronchitis			
Emphysema			

Hyatt, Scanlon & Nakamura 2003

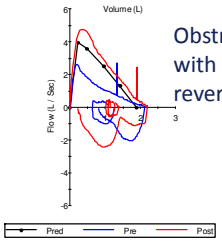
Abnormal Flow Volume Loops



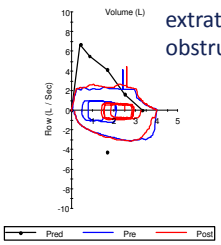
Obstruction



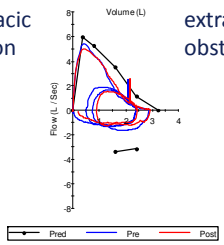
Restriction



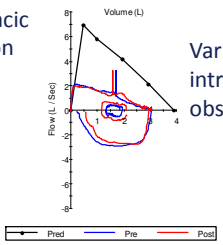
Obstruction with reversibility



Fixed extrathoracic obstruction



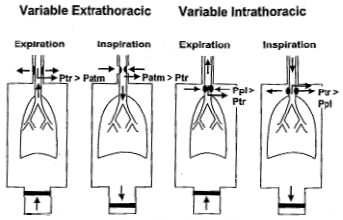
Variable extrathoracic obstruction



Variable intrathoracic obstruction

Upper Airway Physiology

- Variable extrathoracic lesions
  - Vocal cord paralysis
  - Subglottic stenosis
  - Neoplasm (primary hypopharyngeal or tracheal, metastic from promary lesion in lung)
  - Goitre
- Variable intrathoracic lesions
  - Tumour of lower trachea (below sternal notch)
  - Tracheomalacia
- Fixed lesions
  - Fixed neoplasm in central airway
  - Vocal paralysis with fixed stenosis
  - Fibrotic strictures



Bronchodilator Reversibility

- To assess bronchodilator (BD) reversibility:
  - Perform pre-BD spirometry
  - Administer BD, e.g. 4 separate puffs salbutamol via MDI and spacer
  - Wait 10min
  - Repeat spirometry
- If any bronchodilator medications have been taken, note time last used

Bronchodilator Reversibility

- **FEV_1** is the most commonly used index to quantify reversibility
- Positive BD response is an increase in :
  - FEV_1 (or FVC) of ≥12% *(% improvement)*
  - **and** FEV_1 of ≥200 mL *(absolute change)*

$$\textbf{\% Improvement in } FEV_1 = 100 \times \frac{FEV_1 \text{ (post-BD)} - FEV_1 \text{ (baseline)}}{FEV_1 \text{ (baseline)}}$$

$$\textbf{Absolute change in } FEV_1 = \text{post-BD } FEV_1 - \text{baseline } FEV_1$$

References

- Johns DP., Burtson D., Swanney MP. "Spirometer Users' and Buyers' Guide" National Asthma Council Australia, 2015 Available at: http://www.nationalasthma.org.au/health-professionals/spirometry-resources/spirometer-users-buyers-guide
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- Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R et al; "ATS/ERS Task Force: Standardisation of lung function testing. Number 1 in this series: General considerations for lung function testing," European Respiratory Journal, 26:153-161, 2005.
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