The Royal Wolverhampton NHS
NHS Trust

Specialist Registrar (SpR) Training

Respiratory and Sleep Physiology

Portfolio of Evidence

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GMC Number_____

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Foreword

My early experiences of lung function reporting were as a junior registrar and being asked to report the overflowing pile of reports in the lung function lab. For this I had received no prior training or supervision and it was a daunting prospect. I bought a book on how to report lung function but sitting with the physiologists and reviewing the results together helped me much more. Overtime my lung function reporting skills have improved, particularly whilst working towards my MD thesis which explored discordant lung function in alpha-1 antitrypsin deficiency. During my thesis I worked closely with the physiologists at Queen Elizabeth Hospital, Birmingham who were very supportive and encouraged me to attend Association for Respiratory Technology and Physiology (ARTP) conferences and reporting courses.

Historically registrars in Respiratory medicine receive little or no structured training in Respiratory physiology or Lung function testing but clearly the tests are essential when diagnosing or monitoring respiratory patients. The development of this portfolio of evidence aims to tackle this problem and provide a recognised training portfolio in line with the syllabus set out by the Royal College of Physicians.

Respiratory Physiologists are a small but highly skilled group of staff who provide diagnostics and treatment for patients with respiratory and sleep disorders. In each placement you should take advantage of their extensive knowledge and skills and take the time to experience the full range of tests available to you in each of your rotations. The range of tests the lung function departments provide will vary between hospital trusts with some laboratories only having a single person department where others may have a team of ten physiologists.

With the support of the Respiratory Physiology teams throughout the region your practical, but more importantly, interpretation skills will develop. Don't be scared to ask them questions.

Finally, lung function interpretation is a skill that will be essential to each of you as you develop from being a registrar to a consultant. Take advantage of the time you spend with the Respiratory Physiologists and learn from them.

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Contents

Introduction

How to use the Specialist Registrar (SpR) training portfolio

A number of factors need to be considered when reviewing a lung function report. These factors include a technical understanding of the equipment and the testing methods but also quality assurance criteria (*see appendix 1*) and lung pathophysiology. These factors are not covered within this portfolio but in order to interpret lung function results knowledge of these are required.

Therefore the authors of the portfolio have assumed that each Specialist Respiratory Registrar will have an excellent understanding of lung physiology, can recognise and have a general understanding of lung function parameters (for example FEV_1, FVC, TLC and TL_{co} etc.). It is also assumed that there is an understanding relating to the use of reference ranges and their limitations.

With each of the lung function examples the reader can be confident that:

1. The equipment has been correctly maintained, calibrated and that regular quality control is undertaken;
2. That corrections for body temperature and pressure saturated with water vapour (BTPS) have been made;
3. That the reference ranges used are the most appropriate for the time the portfolio was developed;
4. Testing was performed to quality assured standards and guidelines;
5. Each test report is valid and of good quality.

The aim of this portfolio is to ensure an in-depth knowledge on how and when lung function tests are performed; as well as interpretation of results across the range of lung function diagnostics. It is to be used during 1-2-1 sessions with clinical mentors and/or senior respiratory physiology staff, in particular the reporting and interpretation of lung function tests found in section B.

The portfolio is split into three parts:

Part A

This section is the basic evidence log to document your time spent engaged with the physiologists in the Lung Function laboratory. It outlines the suggested number of observations to be made as well as the number of practical experiences to be attained. You will be required to observe testing and then experience the test for yourself as a patient.

Complete the evidence log A1, entering dates when each element is completed. On completion you must obtain sign off from either your clinical mentor or a Senior Respiratory Physiologist. You are advised to complete part A; before moving onto part B.

Part B

This section has a number of examples of lung function reports; some may have a brief clinical history for the patient; others may just show the lung function results. The Lung Function reports are split into spirometry either with or without a bronchodilator response (or reversibility study), a "partial" Lung Function test which comprises of spirometry and a gas transfer (TL_{co}) test or a "full"

Lung Function test which also includes a static lung volume measurement. There are also examples of respiratory sleep studies, an introduction to Cardio-Pulmonary Exercise Tests (CPET) plus sample CPET reports, basic respiratory muscle assessments or mouth pressures (MIP/MEP and SNIP), six minute walk tests and finally bronchial challenge tests.

In this section you will also find a brief guide on writing a clinical report as well as suggested stock statements you may wish to adopt when reporting lung function tests.

Please note that the appearance of lung function reports can vary from trust to trust. The appearance and layout of Lung Function reports is dependent upon the equipment used, the test performed and protocol used. The department may have customised the report to suit their service. Therefore this portfolio contains reports that differ in appearance and general layout to help hone your interpretation skills. **An interpretation for each report is available after each example, as well as discussion points and any additional commentary to support teaching**. Although an example interpretation is available to you after each report it is very important to initially have a go formulating an interpretation yourself.

Part C

This section has a number of lung function case study questions with a multiple choice answer section to evaluate your reporting skills. The answers are available at the end of the section to help you evaluate your knowledge.

By the time the portfolio is completed the SpR should be confident with the following:

- Reasons for performing each test;
- Contraindications;
- Who should be referred and when;
- How to identify errors from reports and implications on results accuracy;
- Underpinning knowledge of how the test is performed and results derived;
- Interpretation of results and recommendations for further testing to aid diagnosis.

Essential Background Reading/References

Before collecting your evidence it is imperative you have completed some background reading. Below you will find a suggested reading list covering papers of interest and guideline documents.

General

1. Miller, M. Hankinson, J. Brusasco, V. Burgos, F. Casaburi, R. Coates, A. Crapo, R. Enright, P. van der Grinten, C. Gustafsson, P. Jensen, R. Johnson, D. MacIntyre, N. McKay, R. Navajas, D. Pedersen, O. Pellegrino, R. Viegi G & Wanger, J. (2005). **General Considerations for Lung Function testing**. European Respiratory Journal. 26. pp. 154–159
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Bronchodilator response

16. Miller, M. Hankinson, J. Brusasco, V. Burgos, F. Casaburi, R. Coates, A. Crapo, R. Enright, P. van der Grinten, C. Gustafsson, P. Jensen, R. Johnson, D. MacIntyre, N. McKay, R. Navajas, D. Pedersen, O.Pellegrino, R. Viegi G & Wanger, J. (2005). **Interpretative strategies for lung function tests** European Respiratory Journal. 26. pp. 943–963.

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PART A

Part A

The first section aims to ensure that you have observed a sufficient number of diagnostic tests, as well as undertaken the tests yourself experiencing them as a patient would. This is important as from this experience you will have a better understanding as to whether your patients are likely to be able to complete the test. You will also be able to explain to the patient what the test measures and how it is completed.

Part A below outlines the numbers of observations required, as suggested by the West Midlands Specialist Advisory Committee (SAC).

Test	Observe	Be a patient
PEF	2	2
FeN_O	2	1
Spirometry	5	1
Transfer Factor	5	1
Static Lung Volumes (plethysmography)*	5	1
Static Lung volumes (He /N2 washout)	5	1
Skin prick allergy test	2	0
Six minute walk test	2	0
Muscle assessment	2	1
O_2 assessment (LTOT)	3	0
Ambulatory 0_2 assessment	2	0
Fit to fly test	1	0
Challenge test	1	0
Limited Respiratory Sleep Study (LSS)	1	0
Cardio-Pulmonary Exercise Test (CPET)	2	1 (optional)

*Some centres may not undertake static lung volume measurements using body plethysmography, therefore it may be useful to attend a centre that does this.

N.B although Polysomnography does not appear within the list above the trainee must show awareness for the test including how and who to refer to if required. You may need to visit a different hospital trust to observe this test.

Complete the evidence log (A1) below to record your observation time spent in Respiratory Physiology.

A1 Evidence Log

Test	Observation date (enter date in boxes below)				
Peak Expiratory Flow (PEF)					
Fractional Exhaled Nitric Oxide Testing (FeN_O)					
Spirometry					
Gas Transfer Factor (TL_{co})					
Static Lung Volumes					
Skin Prick Allergy test					
Six Minute Walk test (6MWT)					
Simple Respiratory Muscle Assessment (MIP/MEP/SNIP/Supine vs Erect Spirometry)					
Oxygen Assessment (LTOT)					
Ambulatory 0_2 Assessment					
Fit to Fly assessment (Hypoxic Challenge test)					
Bronchial Challenge test (Mannitol/Histamine/Methacholine Challenge)					
Limited Respiratory Sleep Study (LSS)					
Cardio-Pulmonary Exercise Test (CPET)					

PART B

Part B

In the section below you will find examples of test reports for the following:

- Spirometry +/- bronchodilator response x10 (B1 – B10);
- Spirometry and Gas Transfer Factor testing x10 (B11 – B20);
- Spirometry, Gas Transfer Factor and Static Lung Volumes x10 (B21 – B30);
- Simple Respiratory Muscle Assessment (MIP/MEP and SNIP) x2 (B31 – B32);
- Introduction to limited respiratory sleep studies;
- Limited Respiratory Sleep Studies x8 (B33 – B40);
- Introduction to Cardio-Pulmonary Exercise Test (CPET) ;
- Cardiopulmonary Exercise test reports x 4 (B41- B44);
- 6 Minute Walk Test x4 (B45 –B48);
- Mannitol Bronchial Provocation test x4 (B49 – B52).

Some of the reports have a brief clinical history to aid reporting and interpretation. With your clinical mentor analyse and review the available data including any technical comments and produce a clinical report for each of them.

Each interpretation should ideally include the following:

- Technical comments if applicable (Technical report);
    - Comment on acceptability, reproducibility (if applicable) and test quality;
- Normality of measured parameters (Physiological report);
    - Comment on the shape of graphs i.e. the Flow Volume loop (FVL) for example the FVL shows a significant concavity on the expiratory limb which is suggestive of an obstructive pattern as well as commenting on the measured parameters, comparing them to a normal value or reference range;
    - Formulate a clinical interpretation, ensuring you reference which clinical guidelines have been used (if appropriate). If bronchodilator response is to be assessed ensure you reference which criteria has been used to interpret bronchodilator response.
- Diagnosis if applicable (Clinical context);
    - Are the results and brief history consistent with or suggestive of a particular disease pattern?
- Further testing?
    - What further Respiratory physiological tests or other diagnostics need to be considered to aid in the interpretation?

On page 16 there is a simple guide on how to write a clinical report as well as suggested stock statements (see table 1) that you may wish to adopt for reporting purposes.

However, before proceeding further it is important to consider the initial referral.

Making a referral for Lung Function Testing - A Quick introduction

When making a referral you should aim to give lots of clinical information and allow the physiology team to help you answer the clinical question. Consider discussing the patient with the physiologists and request the tests they feel would be most appropriate to help you answer the clinical question.

Firstly, consider what is the clinical question?

These might include the following:

- What is the cause for the patient's dyspnoea?
- Does the patient have COPD or Asthma?
- What is the surgical risk?
- How impaired is the patient's lung function?
- Is the current medication/treatment affecting lung function?
- Is there a gas exchange problem?
- ? Restrictive lung volumes;
- Cough?
- Is obesity affecting lung function, causing dyspnoea?
- Excessive daytime tiredness, OSA?

Who is the patient? Birth sex, age (is it an adult or child?), ethnic origin, BMI. What additional information can you provide i.e. resting $Sp0_2$? BMI? What is the patient's haemoglobin (H_b) level?

Depending upon how much space the referral form allows will of course determine the amount of information you can provide. The ideal referral would include a detailed history as this also greatly improves the reporting of the result. In some Lung Function departments the physiologist may take a brief history as part of the testing process. Either way it is important to ascertain the following information to assist you with the reporting process.

- What are the presenting symptoms? SOB, wheeze, chest tightness, cough etc.?
- Are these symptoms worse on exercise or at different times of the day?
- What is the patient's perceived level of breathlessness? Is there a Medical Research Council (MRC) breathlessness score?
- Are the symptoms chronic, acute or intermittent? Over what duration have they developed?
- If a cough is present is it productive or dry? If productive what colour, consistency and volume of sputum is produced?
- Smoker? Pack year history? When was the last time the patient smoked?
- Previous medical history? Including recent surgery or trauma, cardiac history, recurrent chest infection and allergies?
- Family history?
- What is the patient's occupation? Miner, Farmer, Baker, Foundry worker, Chemical plant operative etc.?
- Any significant environmental or occupational exposures? I.e. coal dust, asbestos, pollen, spray paints, does the patient keeps birds etc.?

- Current medication, any inhaled medication currently prescribed? Any medications with respiratory side effects?
- Any systemic symptoms? Fever, night sweats, weight loss?

A referral should also raise issues about contraindications [4].

Writing a clinical report (Lung Function Tests)

Proposed definition of a lung function report:

"A specific, formal document; to the referring doctor (or healthcare professional) regarding the results of the Lung Function Test. The main goal of the report is to provide a clear, concise, accurate, fully interpretative and authoritative answer to the clinical question posed on the referral document."

Lung function tests do not provide a diagnosis and should only be used in conjunction with other diagnostic tests, a good clinical history and a physical examination. They support a possible site of the abnormality (airway, chest wall, alveoli) as well as identifying the presence or absence of an abnormality (i.e. obstructive, restrictive or a mixed pattern). If an abnormality is identified the test can be used to quantify the extent or severity of the disease (i.e. mild, moderate, severe or very severe).

To report lung function tests you must first have an excellent understanding of respiratory physiology (as cited in suggested reading list found at the beginning of this document) as well as the pathophysiology of the major respiratory and non-respiratory diseases. It is important to understand the effects on lung function of the major obstructive and restrictive lung diseases (for example COPD, Interstitial Lung Disease, Asthma) and also non-respiratory disorders such as rheumatoid arthritis and neuromuscular diseases. Lung function testing is also used in pre-operative evaluation, so having an understanding of the parameters that anaesthetic and surgical teams look at is also useful to enable effective reporting of pre-operative lung function tests.

The report that accompanies the lung function report needs to be concise, informative and address the clinical question. Take a look at the spirometry result below.

Spirometry	Normal range	Baseline	z-score	Post BD	% change
FEV_1	>2.26	2.74	-0.21	2.85	+4%
FVC	>2.80	3.55	+0.24	3.54	0%
FEV_1/FVC %	>72%	77	-0.79	81	

In theory the report could have been written in any of the following ways:

- NAD (no abnormality detected);
- Spirometry is normal;
- Spirometry is within normal limits;
- Test was performed to quality assured standards and is within normal limits;
- Test was performed to quality assured standards and is within normal limits, there is no significant response to bronchodilator;
- Test was performed to quality assured standards and is within normal limits, the flow volume loop appears normal. There is no significant response to bronchodilator. Asthma appears to be well controlled however spirometry cannot be used to confirm or refute asthma. Consider F_eN_O testing, serial home PEF monitoring. Please consider result in light of clinical correlation.

Although you could argue that each of the reports above are correct, each example provides more relevant information that enables the referring clinician to make more of an informed decision regarding clinical care or next steps/further testing.

Use the following simple steps when reporting Lung Function tests:

1. Review the referral;
2. Consider the patient and the medical history provided;
3. Review the lung function report; question acceptability and quality of the data if appropriate (*see appendix 1 for acceptability and reproducibility criteria*); review any graphical and tabulated data, consider and review any additional comments made during the test by the physiologist; look at any serial results – is there a significant change in lung function over time?
4. Formulate your conclusions/impression;
5. Write your report.

When assessing the acceptability and quality of the data consider the following:

1. Look at any technical or additional comments made by the physiologist; these may highlight issues relating to test data, patient effort, reproducibility and acceptability.
2. Review all graphs and flow volume loops, have the correct patient demographics and anthropometric data been entered? Have appropriate reference values been applied?
3. Did the patient adhere to the pre-test instructions, for example did they refrain from prior use of inhalers? Could there be any residual effect from bronchodilators that dampen the response during any reversibility testing? When did the patient last smoke a cigarette? Was it within an hour of testing?
4. During spirometry, does the Flow Volume Loop (FVL) show a sharp rise to Peak Expiratory Flow (PEF); is there any early termination of the blow? Was a volume plateau achieved? Did the patient forcefully expire for >6s?
5. Is there evidence of a slow start or poor effort with any forced spirometric blows; was there any coughing during the test?
6. Do the Forced Vital Capacity (FVC) and Slow Vital Capacity (SVC) agree? Is there any suggestion of dynamic compression of the airways or gas trapping (suggested by a “church steeple” shape/silhouette to the Flow Volume Loop)?
7. Was the transfer factor test performed to acceptable standards? Did the patient achieve 90% of their Inspiratory Volume (V_{in}); was a correction made for haemoglobin (H_b) if appropriate? In normal and restrictive patients the alveolar volume (V_A) should closely approximate to Total Lung Capacity (TLC). A V_A/TLC % <80% may indicate poor gas mixing. Is there any comment regarding smoking just prior to the measurement possibly reducing the gas transfer (TL_{co}) result? Any leak noted during breath holding?
8. Review the raw data from static lung volume measurement’s, is there evidence of any thermal drift or leak (gradual and steady shift upwards in the tidal volume tracing)? Does the tidal volume tracing remain level throughout? In body plethysmography do the Thoracic Gas Volume (TGV) efforts made against the closed shutter indicate any technical errors such as mouth leak and thermal drift (bending of loops), incorrect panting frequency or panting to rapidly or deeply (open loops or no loops, no clear line of best fit), failure to inspire or expire against closed shutter? In gas dilution methods was there any drift which might indicate a leak? Was an equilibrium point achieved? Was the patient “switched in” correctly at Functional Residual Capacity (FRC) or the end of a normal tidal breath?

9. Ask to see any raw data and each individual attempt made should you be in any doubt about the quality of the results provided (some lung function reports do not provide all this information and you may need to sit with the physiologist using the actual testing equipment to do this).

When reporting, you must be able to justify your decisions and relate them to the physiology/pathophysiology. Get to know the guidelines used but also their limitations, be prepared to compromise to adhere to locally used guidance/viewpoints. For example, respiratory physiologists are trained to interpret lung function tests using z-scores/standardised residuals (SR) and lower limits of normal (LLN) as this is generally considered to be statistically superior to using %predicted and a fixed FEV_1/FVC ratio of <0.7 (70%) to identify airflow obstruction[18]. Unfortunately, current guidelines such as NICE COPD $_{2010}$ use % predicted FEV_1 to grade severity of airflow obstruction, we know from published data that this leads to an over-estimation of COPD in the elderly population[18]. It is good practice to state which guidelines you have used to interpret the results. *Appendix 2 shows the severity classification using z-scores.*

Reviewing serial lung function data in patients with conditions such as ILD and COPD is important. Monitoring the decline in FEV_1 over time can be used as a prognostic tool in COPD and Cystic Fibrosis. Published studies[15,16] suggest that a change in transfer factor (TL_{co}) >±1.60mmol/min/kPa over the short term and a >10% in the longer term (over a year) probably reflect clinically significant changes. Locally, we state that in patients with interstitial lung disease (ILD) - that a 15% decline in transfer factor (TL_{co}) and/or a 10% decline in %predicted vital capacity (VC) over a 6 month period should trigger alerting the consultant responsible for the patients care.

It is important that the referral question is not only addressed but any incidental findings are highlighted. Using the clinical information provided gives some context to the interpretation or recommends further investigations to assist with answering the clinical question. This last step can be difficult when the reporter is not the referrer due to the limited clinical information. Typically the referrer is the best individual to form the clinical context based on the technical interpretation of the available data. Any additional findings should be reported back to the referrer. Ideally the report should be in a standardised format which is used by all team members. A consistent format helps avoid omitting information and may speed up the reporting process. It is important to write the report clearly and confidently.

Suggested headings might include:

- Reason for the test – what is the clinical question?
- Technical comments – Technical comments made by the individual who performed the test which might provide insight into the test performance;
- Results of the assessment/test – include text here that states the actual data when compared to the upper and lower limits of normal or a reference range;
- Impression – An interpretation of the results in relation to the patient history and test data, here you might also suggest further testing when appropriate; use your knowledge and expertise of both physiology and the available test procedures to recommend further testing; a summary of the results may be offered which may highlight the consistencies with a known pathophysiology.

- Closing statement - End your report with a closing statement that asks that the results are considered in light of the available clinical history and diagnostic test results. You may wish to use "*Please interpret findings in light of clinical correlation*" as a signing off statement to highlight that the report should be considered alongside the patients symptoms and other clinical information.
- Reporter details – include name, position, pin number/registration numbers, the date and a signature (if appropriate - ? e-reporting/e-signatures).

Remember there are no universally accepted standards for interpretation and report writing for lung function tests. Develop your own style but remember to keep it simple, use stock phrases (*see table 1 below for examples*). Try to refrain from over interpreting the data and confusing the recipient of the finalised report.

Interpretation of lung function has an element of subjectivity associated with it. This may impact on the management and care of the patient, the difficulty is therefore to keep subjectivity to a minimum. Subjectivity arises due to personal opinions, diversity in the literature regarding interpretation strategies, lack of data in interpreting certain tests or parameters and finally the knowledge of the clinical background of the patient.

To reduce subjective reporting, stick to published interpretation strategies, agree locally what strategy is to be employed. All personnel locally should use a standardised reporting strategy which is peer-reviewed/audited regularly.

Table 1. Examples of stock statements that can be used for reporting purposes

Spirometry	
Normal FEV_1/FVC% >LLN FEV_1 > LLN (F)VC >LLN	Spirometry is within normal limits.
Non-specific ventilatory pattern	Spirometry shows a reduced (F)VC and or FEV_1 but with a normal FEV_1/FVC% (>LLN) and a normal TLC (>LLN)
Obstructive spirometry FEV_1/FVC% <LLN	Pre/Post bronchodilator spirometry is consistent with a mild/moderate/severe/very severe airflow obstruction.
Restrictive spirometry (F)VC < LLN FEV_1/FVC% > LLN but can also be >ULN	Spirometry suggests a restrictive pattern (small lung volumes) indicated by a reduced vital capacity (typically in conjunction with a normal or elevated FEV_1/FVC %).
Restrictive pattern confirmation?-further tests (F)VC < LLN and TLC < LLN	A reduced vital capacity suggests a restrictive process; the presence of a restrictive pattern (reduced volumes) should be confirmed by the measurement of static lung volumes. *Check BMI?*
Mixed obstructive and Restrictive spirometry FEV1/FVC% <LLN (F)VC < LLN	The spirometry is consistent with an obstructive airflow pattern with a reduced vital capacity. The reduced vital capacity may be due to a true lung restriction or airflow limitation (gas trapping) and can be better defined by the measurement of static lung volumes.
Upper Airways Obstruction (UAO)	The flow-volume loop is suggestive of a fixed/variable/ intra/extra thoracic airway obstruction. Extra thoracic – the flow volume loop shows some decapitation/flattening of the maximal expiratory FVL but a more extreme collapse of the FVL during inspiration. This may be due to the possible collapse of the trachea (this pattern can be seen in vocal cord paralysis/Goitre/tracheal lesion (above sternal notch) Intra thoracic – there is a reduction in airway patency during expiration, particularly early during expiration around PEF, with little or any reduction in the inspiratory loop. This pattern is typically seen in a retro-sternal goitre or a lesion below the sternal notch. Fixed UAO-due to airway narrowing there is a fixed limitation in flow during both expiratory and inspiratory FVL The Empey index, which assists in identifying upper/large airway obstruction is >10 and adds diagnostic weight to the possible presence of UAO. N.B. Empey index =FEV_1 **(ml)** / PEF **(l/min)** An Empey index >10 diagnostic for UAO
Bronchodilator Response	
No response	Following administration of a bronchodilator for the assessment of reversibility there is no significant improvement. *+ or – the following* -However it should be noted that the patient may have a residual effect of prior inhaler use which may have dampened the possible response seen. -The reversibility test was performed using 400mcgs of salbutamol via a spacer; this does not rule out that the patient may respond to another bronchodilator drug or method of administration more effectively.

Significant response-Asthma?	Following administration of a bronchodilator there was a significant response seen in the FEV_1 which is ≥400ml. This is suggestive of significant reversible airflow obstruction and is generally seen in Asthma.
Significant response *(This is dependent upon which bronchodilator response criteria is used locally – note only 2 examples included here).*	Post bronchodilator spirometry shows a significant improvement in accordance with the ATS/ERS criteria of ≥200ml and a 12% increase in FEV_1 and/or FVC. Or>8% increase in FEV_1 % predicted, favours a diagnosis of Asthma and active treatment. A change in z-score of 0.7 has been proposed as a clinically meaningful change, FVC post BD z-score > 0.64 was more pronounced in severe obstruction, suggesting a clinically important relief of hyperinflation. BD response should be expressed as a change in z-score for both FEV_1 and FVC with the %predicted change being an acceptable alternative
FVL is normal post BD	Following administration of a bronchodilator for assessment of airway reversibility there was a significant response as indicated by the spirometry parameters returning to within normal ranges post bd. Typically this response is seen in Asthma. Reversible airflow obstruction.
Significant response - fixed airflow obstruction with a reversible element	Post bronchodilator spirometry shows a significant improvement in accordance with the ATS/ERS criteria of ≥200ml and a 12% increase in FEV1 and/or FVC. However the post bronchodilator spirometry still shows an airflow obstruction.
Static Lung Volumes	
Lung volumes within normal limits	The total lung capacity (TLC) is within normal limits for this patient.
Hyperinflation (FRC, TGV) Hyperinflation (TLC)	Static lung volume measurement shows a significantly elevated FRC or TGV and RV/TLC% which would be suggestive of lung hyperinflation. (TLC < ULN) Static lung volume measurement shows a significantly elevated (>ULN) TLC, FRC or TGV and RV/TLC%.
Gas trapping due to airflow obstruction TLC, FRC or TGV <ULN RV/TLC% > ULN	Static lung volumes show a significantly raised RV/TLC ratio >Upper Limit of Normal (ULN) this would suggest an element of gas trapping/poorly ventilated air spaces. This is typically seen in obstructive airway disease. *+ or – the following* -The TLC is normal or raised.
Restrictive TLC < LLN	The total lung capacity measured using static lung volumes is significantly reduced (<LLN). This is consistent with a restrictive lung pattern. *+ or – the following* -The RV/TLC% is elevated with a normal FRC or TGV (consider possible neuromuscular weakness)
Obesity?	Typically in obesity (BMI >35.0kg.m^{-2}) the Expiratory Reserve Volume (ERV) and Total Lung Capacity (TLC) can be reduced.
Technical –underestimation?	Lung volumes were measured using a gas dilution method (Helium dilution/Nitrogen washout). Typically, this method can under-estimate lung volumes in obstructive patients because of poorly ventilated air spaces or non-communicating regions being excluded from the measurement of the lung volume, impacting upon the dilution of gases within the lung. Plethysmography may over-estimate results when the measured mouth pressure changes are not equivalent to alveolar pressure changes, this typically occurs in the

	presence of significant airflow obstruction.
Gas Transfer	
Reduced transfer factor – introductory statement	A low gas transfer (TL_{co}) is due to either a low alveolar volume (V_A-the number of contributing lung units) or the diffusion constant (K_{co}) which informs us of the efficiency per lung unit or both
Normal (TL_{co} >LLN, V_A > LLN, K_{co}>LLN)	The transfer factor for this patient is within normal limits. There is no significant evidence to suggest a gas exchange abnormality.
TL_{co} > LLN, V_A < LLN	The transfer factor is within normal limits in the presence of a reduced alveolar volume.
TL_{co} < LLN, V_A>LLN TL_{co}<LLN, V_A<LLN, K_{co}<LLN	Transfer factor is reduced but in the presence of a normal Alveolar Volume. This pattern is seen in parenchymal or pulmonary vascular disease. Both transfer factor and alveolar volume are reduced with a decreased K_{co}, suggestive of parenchymal or pulmonary vascular disease.
Transfer factor low (<LLN) with a reduced V_A and K_{co} – in the presence of a significant obstructive defect on spirometry, lung hyperinflation, ↑TLC, ↑RV/TLC %	The ↓V_A likely reflects the poor uptake of the transfer gas in relation to the poorly ventilated air spaces (*check V_A against TLC from lung volume measurement, i.e. is the V_A/TLC% <80%)*. This leads to a possible underestimation in the number of contributing or "accessible" lung units. The resulting transfer factor reflects the gas exchange from ventilated tissue only. The low TL_{co} and K_{co} is a result of the decreased surface area available for gas exchange and alveolar destruction. Typically seen in emphysema.
TL_{co}<LLN, V_A<LLN, K_{CO} within normal limits	Both TL_{co} and V_A are reduced. As the K_{co} is within normal limits, pathology may be present when K_{co} is normal in the presence of a reduced TL_{co} and V_A. The result may be due to the loss of lung units (discrete or diffuse), poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these.
TL_{co}<LLN, V_A<LLN, K_{CO}>ULN	Both transfer factor and alveolar volume are reduced. The elevated K_{co} suggests that the reduction in TL_{co} is due to incomplete expansion of alveoli rather than parenchymal or pulmonary vascular disease. Extra-thoracic lung restriction – obesity? Muscle weakness? Correlate clinically. Check test quality – Incomplete inhalation to TLC?
Transfer factor (TL_{co}) within normal limits (but usually ↑ >ULN), V_A is within normal limits or reduced, ↑↑K_{co} > ULN	Transfer factor shows a raised TL_{co}. This may suggest polycythaemia, left to right shunt, pulmonary haemorrhage. Also seen in altitude, a mueller manoeuvre (decreased intra-thoracic pressure, resistance breathing as in Asthma), exercise, supine position (↓surface area-not full inflation), Obesity (↓surface area-incomplete unfolding of lung membrane).

Technical versus clinical interpretation

Lung function reporting consists of two aspects, technical interpretation and the clinical context.

Technical reporting can generally be performed without any clinical history or knowledge of the patient. It includes notes on test quality, the reference values used and any additional comments. It also identifies the pattern of abnormality (obstructive, restrictive etc.) and the severity.

Clinical context includes the above plus provides an answer to the clinical question posed, therefore is reliant upon additional clinical information being available. It is best provided by the referring clinician (assuming they are competent in lung function reporting). The clinical context will also provide advice on additional testing to aid diagnosis further.

Reference values and limits of normality in lung function.

Results from lung function tests are reported by comparing them against a predicted reference range. This reference range must reflect the patient being tested and therefore should have been developed using an appropriate population study. It is important that the report includes which reference set has been used. Sometimes a patient may not "*fit*" a reference range for example the Global Lung Initiative (GLI) spirometry[20] reference values were developed using an age range from 3 – 95years, other reference sets have a tighter age range for example The European Community for Coal and Steel (ECCS) reference values are valid for 18-70yrs. If reference values are to be extrapolated beyond the limits of the reference equation then a cautionary comment to the report should be added. This might state:

"*The reference or predicted value for this patient have been extrapolated for age therefore please interpret with caution*"

Lung function results are also affected by race. There are known clear differences between Caucasians, Asians, Chinese and those of African-American descent. The patient's ethnicity should therefore be taken into account when selecting an appropriate reference range. The GLI spirometry reference values were developed using a multi-ethnic population group and therefore addresses this issue better than any other previous reference set produced. Pre GLI the less than ideal solution was the application of a correction factor, for example 0.88 (88%) for FEV_1 and FVC being applied to a Caucasian reference value when testing a non-Caucasian patient. Again as this is not an ideal solution a cautionary comment should be added to the report:

"*Reference values have been adjusted for ethnicity, please interpret with caution*"

During the first review of this portfolio there are now GLI reference values for spirometry and transfer factor measurements with static lung volumes soon to follow. The normal range is defined as the range in which 95% of the normal population would fall. The 95% confidence limits are determined using a predicted mean value which is calculated by the reference equation and the Residual Standard Deviation (RSD) which describes the scatter or variation around the predicted value. Both the Upper Limits of Normal (ULN) and Lower Limits or Normal (LLN) is calculated using the predicted mean value and the RSD. In parameters where it is possible to have an abnormally low result such as the FEV_1, then the lower 95% confidence limits are used (i.e. 5% lie <u>below</u> the normal range).

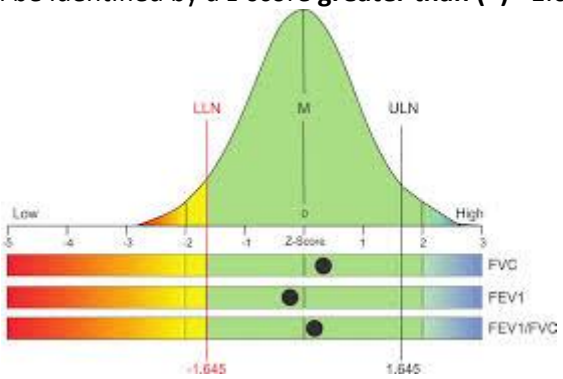
LLN = mean predicted value – 1.645 x RSD.

For parameters where it is possible to have an abnormally <u>high</u> result e.g. RV and TLC (which are measured during static lung volume measurements) then the upper 95% confidence limit is given by:

ULN = mean predicted value + 1.645 x RSD.

A z-score is the number of standard deviations a measured value is from the predicted mean value. Z-scores below the predicted mean value are shown as a negative (-) value and values above the predicted mean value are shown as a positive (+) number.

When using the 95% confidence limits to set an ULN and a LLN: Lung function parameters with an abnormally low result can be identified by a z-score that is **less than (<)** –1.645. Parameters with abnormally high results can be identified by a z-score **greater than (>)** +1.645, see pictogram below.



Below is an example of severity classification using z-scores for airflow obstruction.

Threshold for Z-score	Severity Grading	Approximate chance of finding this result in a healthy population
< - 1.645	MILD	1 in 20
< - 2.00	MODERATE	1 in 40
< - 2.50	MODERATELY SEVERE	1 in 150
< - 3.00	SEVERE	1 in 750
< - 4.00	VERY SEVERE	1 in 30,000

Severity classification in airflow obstruction is a two stage process. The FEV_1/FVC must be below the Lower Limit of Normal or LLN (Z-score < -1.645) to be classified as an obstructive pattern. Severity grading is then based on the FEV_1 Z-score as above, with the exception that the mild classification includes any FEV_1 Z-score ≥2.0

When results are within normal limits they should be reported as being "*within normal limits*" and not simply as "*normal*". This is important as there is a possibility that lung disease is present which has not yet caused the measured values to fall outside of normal reference range. When a result is described as reduced then it is below the Lower Limit of Normal (LLN), if described as elevated then it is above the Upper Limit of Normal (ULN). Parameters or results can also be described as "*borderline",* these results will require some careful consideration.

Lung function should never be used in isolation as a diagnostic tool. Lung function results are usually reviewed in conjunction with the larger clinical picture (clinical history, imaging, blood tests, biopsies etc.). Suggesting a specific diagnosis based only on lung function abnormalities is not recommended as the pattern seen on lung function may be seen in multiple diseases.

When writing your report; use qualifiers. Qualifiers include the following:

- "Appears to be"
- "Suggestive of"
- "May be consistent with"

For example:

"*The spirometry is consistent with a moderate airflow obstruction that is not significantly improved following the administration of a bronchodilator; the spirometry result is suggestive of the diagnosis of COPD when considering the patients smoking history and symptoms.*"

Spirometry ± bronchodilator responsiveness testing (examples B1 – B10)

Spirometry is the most commonly performed lung function test, measuring flow and volume. The test is performed using relaxed (SVC) and dynamic (forced) manoeuvres. The primary parameters used in the interpretation are the FEV_1/FVC%, the FVC and FEV_1. Some spirometers and their associated reports list multiple spirometric parameters such as PEF (Peak expiratory Flow), $FEF_{25-75\%}$ and FET (forced expiratory time) but these are not necessary for basic spirometry interpretation. Having increasing numbers of spirometry parameters will increase the chances of an abnormal finding. It is therefore best to simply use FEV_1, FVC and FEV_1/FVC% when interpreting spirometry.

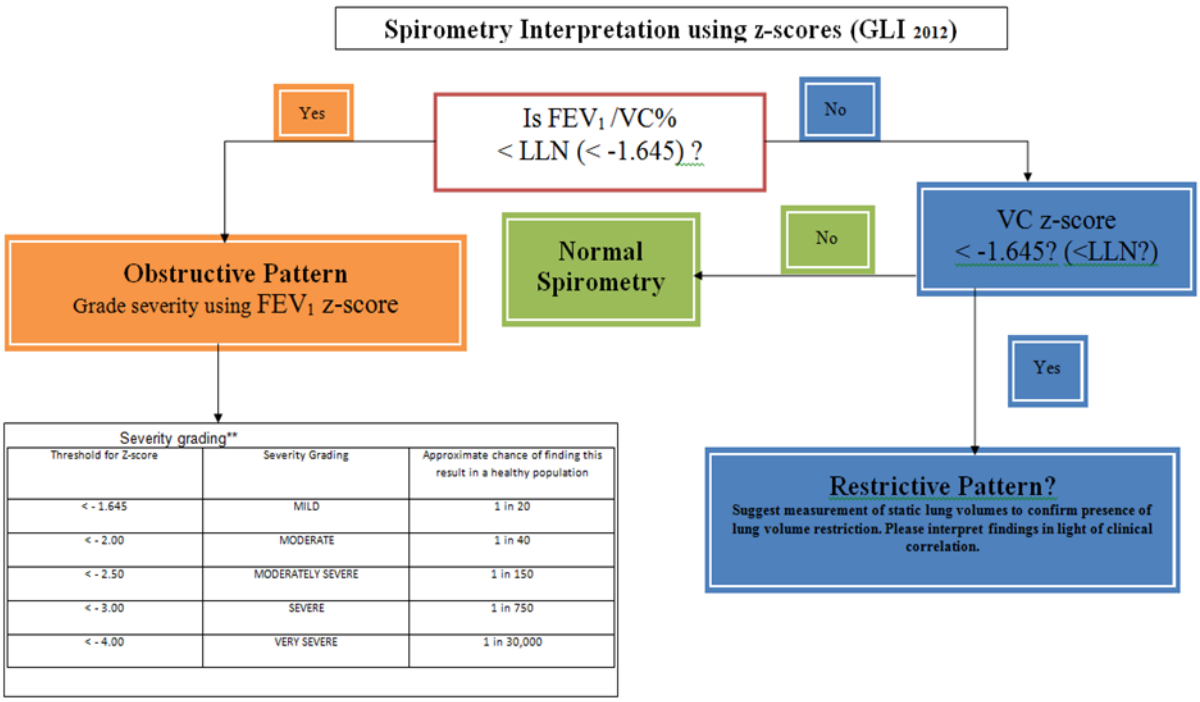
Lung disease results in abnormally low parameters for spirometry, therefore only a lower limit of normal is used and this is set at a z-score of <-1.645. Ventilatory defects found on spirometry are classified as obstructive, restrictive, mixed or a non-specific pattern. Spirometry alone can be used to identify airflow obstruction but in restrictive and mixed (obstructive and restrictive) patterns spirometry must be used in conjunction with Total Lung Capacity (TLC) from a static lung volume test. This is because the (F)VC can be reduced in spirometry due to significant airflow limitation and gas trapping, without a TLC measurement the cause of the reduced vital capacity cannot be determined or confirmed.

Obstructive spirometry generally refers to lung disease that causes airway narrowing and a limitation in airflow, whereas restrictive patterns result from pathologies either intrinsic (internal) or extrinsic (external) to the lungs. Table 2 below lists lung diseases reflected by an obstructive or restrictive pattern.

Table 2.

Obstructive	Restrictive
Airflow limitation/airway narrowing	Loss of lung volume/small lungs/reduced lung compliance
• Asthma	• Lung Fibrosis
• COPD	• Pulmonary congestion (oedema)
• Emphysema	• Chest wall disease (kyphoscoliosis)
• Chronic Bronchitis	• Neuromuscular disease/muscle weakness
• Bronchiectasis	• Lobectomy or pneumonectomy
• Cystic Fibrosis	• Pleural effusion
• Bronchiolitis	• obesity
• Foreign bodies	
• Tumour	

Below is a flowchart showing an interpretation strategy that can be employed when interpreting spirometry results



Severity grading**

Threshold for Z-score	Severity Grading	Approximate chance of finding this result in a healthy population
< - 1.645	MILD	1 in 20
< - 2.00	MODERATE	1 in 40
< - 2.50	MODERATELY SEVERE	1 in 150
< - 3.00	SEVERE	1 in 750
< - 4.00	VERY SEVERE	1 in 30,000

Severity classification in airflow obstruction is a two stage process. The FEV1/FVC must be below the Lower Limit of Normal or LLN (z-score < -1.645) to be classified as an obstructive pattern. Severity grading is then based on the FEV1 z-score as above**, **with the exception that the mild classification includes any FEV1 z-score ≥2.0**

Bronchodilator responsiveness

The indications for performing a bronchodilator responsiveness test are:

- To confirm the diagnosis of asthma;
- To determine reversibility of airflow obstruction;
- Evaluate alternative drug regimens in patients with known hyper-reactive airways;
- Disability determination when the FEV_1 is <70% of predicted;
- Pre-operative evaluation when airflow obstruction is present;
- Evaluation of new bronchodilator drugs;
- Clinical trials;
- Post bronchodilator FEV_1 is also used in the diagnosis of COPD.

Baseline or pre bronchodilator spirometry is generally used to provide an initial interpretation. After classifying the pattern and severity seen on the baseline spirometry bronchodilator responsiveness can be assessed. There are a number of definitions available (*see appendix 3*) to identify a significant response to a bronchodilator, for the purpose of this portfolio we will focus on what we have adopted locally. It is important to have an awareness of definitions that only specify a percentage increase without any absolute volume changes. This is because a small absolute volume change can result in a large percentage change. The absolute volume change may be within the normal variability of the measurement and not a true change in the result. Alternatively consider the use of the term “borderline response” when a large absolute volume change is observed (>200ml) but perhaps a >12% change is not quite achieved.

The ATS/ERS criteria for a significant response is defined as a ≥200ml and a 12% increase in FEV_1 and/or FVC between the baseline and post bronchodilator spirometry result.

Previous practice was to express the change post bronchodilator as a percent of the baseline value, leading to sex and size bias in the results. The lower the baseline value the easier it is to achieve a given threshold percentage change. The use of an absolute volume was added to the percent change. This biased outcomes towards males being significant responders. To overcome these issues it has been proposed that change should be expressed as a percent of the subjects predicted value [20] or as a change in the z-score [21] so as to be free from a sex and height bias.

A >8% increase in FEV_1 % predicted [20], favours a diagnosis of Asthma and active treatment. A change in z-score of 0.78 has been proposed as a clinically meaningful change in FEV_1. FVC post BD z-score > 0.64 was more pronounced in severe obstruction, suggesting a clinically important relief of hyperinflation. BD response can be expressed as a change in z-score for both FEV_1 and FVC with the %predicted change being an acceptable alternative [21].

If there is a significant bronchodilator response and spirometry returns to within normal limits post bronchodilator then this is described as a reversible airflow obstruction. If obstruction remains following a significant bronchodilator response then this can be classed as a fixed or irreversible airflow obstruction. Also consider the clinical relevance of an insignificant response to a bronchodilator that returns the spirometry to within normal limits.

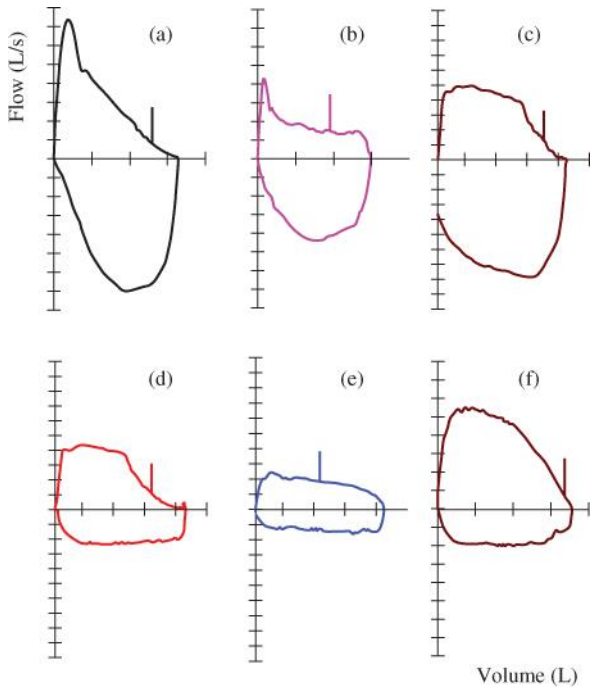
It is also important to note that patients with COPD will have little or no response in the FEV_1 post bronchodilator but may have a more detectable change in the FVC and/or VC. This is indicative of a reduction in the degree of hyperinflation, the patient may report finding it easier to breathe as the overall work of breathing is decreased.

To determine what constitutes a clinically or statistically significant response to a bronchodilator must be based upon the reproducibility of the baseline and post bronchodilator spirometry. Poor bronchodilator response may also be related to poor inhaler technique. A decreased response or worsening spirometry post bronchodilator may be related to effort fatigue from undertaking multiple forced expiratory efforts during a spirometry measurement.

Upper Airway Obstruction (UAO)

UAO cases require more specialist interpretation. This begins with looking at the overall shape of the flow volume loop and reviewing the technical comments made post testing. Good quality and reproducible expiratory and inspiratory loops are essential. The categories of UAO include variable intra-thoracic, variable extra-thoracic and a fixed upper airway obstruction.

- Variable intra-thoracic – there is a reduction in airway patency during expiration, particularly early during expiration around PEF, with little or any reduction in the inspiratory loop. This pattern is typically seen in a retro-sternal goitre or a lesion below the sternal notch (see examples B and C below);
- Variable extra-thoracic – the flow volume loop can show some decapitation/flattening of the maximal expiratory FVL but a more extreme collapse of the FVL during inspiration. This may be due to the possible collapse of the trachea (this pattern can be seen in vocal cord paralysis/goitre/tracheal lesion above sternal notch (see example F below);
- Fixed UAO-due to airway narrowing there is a fixed limitation in flow during both expiratory and inspiratory FVL (see examples D and E below).



To assist with the diagnosis of an UAO an Empey index can be calculated.

Empey index = FEV_1 (ml) / PEF (l/min)

If the Empey index is >10 then this can add diagnostic weight to the possible presence of an UAO.

A brief introduction to the lung function case examples

The spirometry examples that follow are set out in a very similar format. They include the reason for the referral and clinical information/notes, technical comments, patient demographics and the spirometry result. Some of the examples include a bronchodilator responsiveness test others simply a baseline spirometry.

The spirometry data lists the parameters measured, normal reference values, measured values and % of predicted. Dependent on which equipment was used for testing will determine if the z-score is available. Those examples which include a bronchodilator response will include the post bronchodilator measured value and the % change seen on the post bronchodilator spirometry.

When assessing examples using % predicted only- use the simple rule of thumb of <80% predicted is <LLN and >120% of predicted is >ULN.

For teaching purposes, after each example, there is a sample interpretation or report but also discussion points and any additional commentary. **Please note this sample interpretation/report is that of the author. At the point of writing the revised portfolio these sample interpretations had not been peer reviewed and therefore are open for debate and possible change by mentors and respiratory physiologists/consultants working within other hospital trusts**. The sample interpretation is split into three sections, technical and general comments (plus additional commentary if extra information is required) - includes notes on test quality. A technical interpretation – which identifies the pattern of abnormality (obstructive, restrictive etc.) and the severity and the clinical context – which provides an answer to the clinical question posed. The clinical context will also provide advice on additional testing to aid diagnosis further (if applicable).

To aid you with the basic interpretation refer to the interpretation flowcharts found in appendix 4 - spirometry interpretation and 5- bronchodilator responsiveness interpretation.

B1 Spirometry with reversibility testing

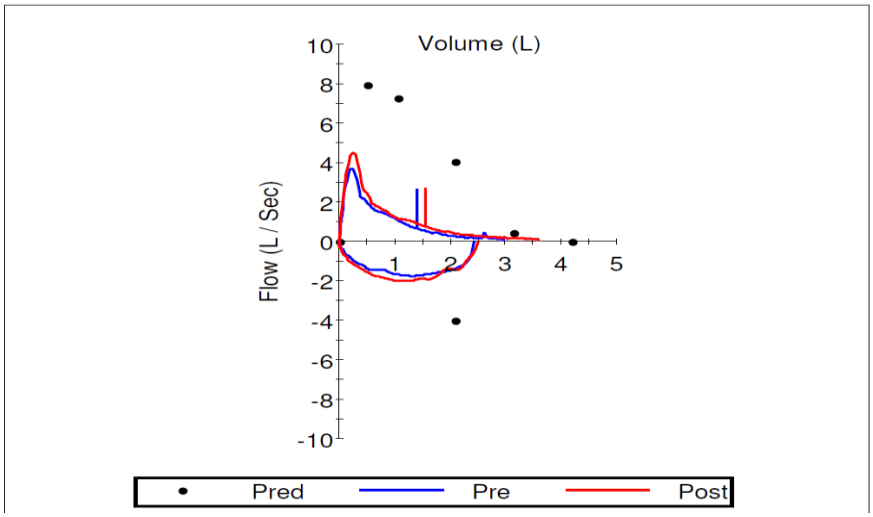
87 year old male complaining of increasing SOB and decreased exercise tolerance. Ex-smoker with a 40 pack year smoking history, quit 30 years ago. Productive cough for the last 5 years. No inhaled medication. Salbutamol 400mcgs via a spacer device administered for bronchodilator responsiveness testing. Any evidence of COPD?

Gender	Male
Age	87
Height (cm)	188
Weight (kg)	92
BMI	26
Race	Caucasian

Spirometry	Predicted Mean	Baseline	% predicted	z-score	Post BD	% predicted	% change
FEV_1	3.02	1.41	46	-2.815	1.58	52	11%
SVC	4.19	2.972	70	-1.623	3.42	81	15%
FVC	4.19	2.971	70	-1.623	3.59	85	20%
FEV_1/FVC %	72%	47%	64	-2.832	81		
FEV_1/SVC %	73%	47%	65	-2.834	46		

Royal Wolverhampton NHS Trust
New Cross Hospital
Lung Function Report
Tel:01902 695061 or Ext 5061

Patient Name	X	Hospital Number	A2	Sex	Male	Test Date	09/04/2015
Diagnosis	? COPD			Age	87	Race	Caucasian
Referrer		Height	188.00 Cms	Weight	92.00 Kgs	BMI	26.0



Interpretation B1.

Discussion points:

Good effort and technique observed on spirometry. $Sp0_2$ at rest was 96%.

There is a significant smoking history of 40 pack years. Clinical question posed - is there any evidence of COPD?

Pre-bronchodilator baseline spirometry has an FEV_1/VC% that is < LLN with a z-score of -2.832. This shows an obstructive airflow pattern. The FEV_1 pre bronchodilator is reduced to 46% of predicted with a z-score of-2.815, indicating a moderately severe airflow obstruction. The FVC and SVC are >LLN and within normal limits with z-scores >-1.645, therefore no evidence of a restrictive lung pattern.

Post bronchodilator spirometry unfortunately does not have the z-scores listed however it does show an FEV_1/VC% which is 44% indicating an airflow obstruction. Following the administration of a bronchodilator there is a significant improvement in the FVC only.

FVC increased by 20% and 622mls. Typically a significant improvement seen in the FVC can be indicative of significant relief from lung hyperinflation.

Report:

The results are indicative of a fixed moderate - severe airflow obstruction; significant improvement post bronchodilator in FVC only suggesting some relief from lung hyperinflation. The results are consistent with COPD.

B2 Spirometry with reversibility testing

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

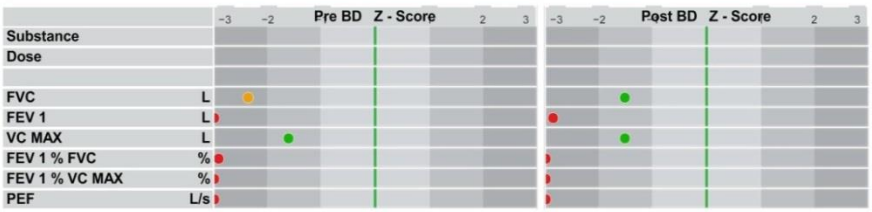
Last Name:		Identification:	
First Name:		NHS Number:	
Age:	88 Years	Date of Birth:	01/08/1928
Height:	165.0 cm	Gender:	male
Weight:	60.5 kg	BMI:	22
Operator:		Ward:	--
Race:	Caucasian	Diagnosis:	? Asthma
Physician:	Dr Gregory	Smoker:	Ex-smoker
Resting SpO2:	96%		

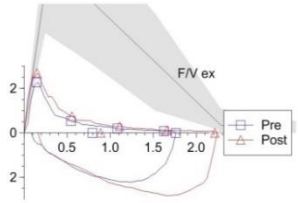
Visit date	04.10.16
Visit time	11:37

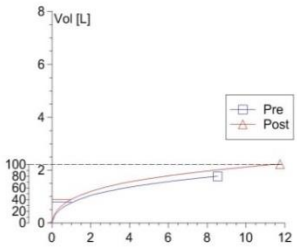
Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Pre	Pred	% Pred	Z- Score	Post	% Pred	% Change	Vol Change (ml)
Substance						Salbutamol			
Dose						400 mcg via spacer			
FVC	L	1.76	3.04	57.8	-2.37	2.21	72.7	25.9	455.00
FEV 1	L	0.79	2.25	35.2	-3.03	0.89	39.5	12.3	96.94
VC MAX	L	2.16	3.04	71.1	-1.61	2.21	72.7	2.3	49.00
FEV 1 % FVC	%	44.99	74.62	60.3	-2.92	40.12	53.8	-10.8	
FEV 1 % VC MAX	%	36.54	74.62	49.0	-3.64	40.12	53.8	9.8	
PEF	L/s	2.27	6.50	35.0	-3.49	2.70	41.5	18.6	







Physiologist Comments

Smoking History: 28 pack years (55years/10day)
Stopped: 20 years
Relevant Medications: Ventolin
Time of last inhaled medication: None on day of test.
Relative Exposures: Patient was a spray painter and builder
Good effort and cooperation during tests.

Interpretation B2

Discussion points:

Good effort and technique during test. 28 pack year smoking history, 10 per day for 55years, quit 20 years ago. Resting $Sp0_2$ 96%. Clinical question posed – asthma? Therefore it will be important to look at reversibility post bronchodilator.

On baseline, pre bronchodilator spirometry the VC_{max} is > FVC by 400mls, suggesting probable dynamic airway compression. The shape of the FVL is consistent with the church steeple silhouette seen with dynamic airway compression and significant airflow obstruction. Due to the dynamic compression of the airway during a forced effort dependant manoeuvre the FVC will be underestimated, therefore the VC_{max} will be a better indicator of the expired lung volume. As the VC_{max} is higher/greater than the FVC then it is important to use the ratio of FEV_1/VC_{max} % to assess for airflow obstruction.

Pre-bronchodilator baseline spirometry has an FEV_1/VC_{max} % that is < LLN with a z-score of -3.64. This shows an obstructive airflow pattern. The FEV_1 pre bronchodilator is reduced to 35% of predicted with a z-score of-3.03, indicating a severe airflow obstruction.

Following the administration of 400mcgs of salbutamol via a spacer device there was a significant post bronchodilator improvement in the FVC only (26% and 450mls) suggesting some clinical relief from lung hyperinflation.

?gas trapping, lung hyperinflation – consider static lung volume measurement and a chest X-ray to confirm.

Report:

Post BD spirometry is consistent with a fixed severe airflow obstruction. Significant improvement post bronchodilator in FVC only. This would be more consistent with COPD than asthma.

However the test does not rule out asthma. When making a diagnosis of asthma, this should be based on the clinical examination, history together with the results of diagnostic tests.

Suggest serial home PEF monitoring and a FeN_O test.

Consider results in light of clinical correlation.

B3 Spirometry with reversibility testing

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

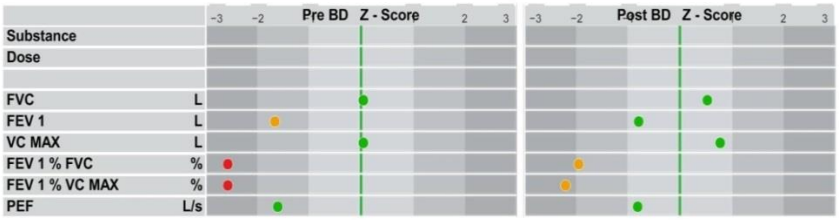
Last Name:		Identification:	
First Name:		NHS Number:	
Age:	49 Years	Date of Birth:	01/09/1966
Height:	175.0 cm	Gender:	male
Weight:	91.0 kg	BMI:	30
Operator:		Ward:	CCH
Race:	Caucasian	Diagnosis:	Cough
Physician:	Dr Rasib	Smoker:	Never smoked
Resting SpO2:	97%		

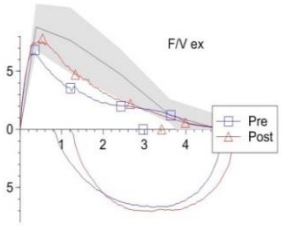
Visit date	28.04.16
Visit time	09:49

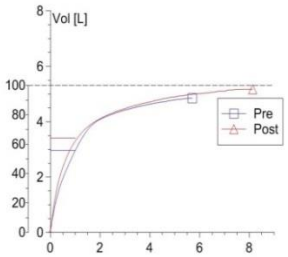
Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Pre	Pred	% Pred	Z- Score	Post	% Pred	% Change	Vol Change (ml)
Substance									
Dose									
FVC	L	4.84	4.81	100.7	0.05	5.16	107.2	6.5	315.00
FEV 1	L	2.96	3.81	77.8	-1.67	3.41	89.6	15.2	449.45
VC MAX	L	4.84	4.81	100.7	0.05	5.32	110.5	9.8	473.00
FEV 1 % FVC	%	61.14	79.36	77.0	-2.59	66.12	83.3	8.1	
FEV 1 % VC MAX	%	61.14	79.36	77.0	-2.59	64.15	80.8	4.9	
PEF	L/s	6.83	8.79	77.8	-1.61	7.80	88.8	14.1	







Physiologist Comments

Relative Exposures: Building trade for 25 years. ? asbestos exposure

Good effort and cooperation during tests.

Interpretation B3

Discussion points:

Good effort and technique on spirometry. Has never smoked and has worked within the construction industry for 25 years with possible exposure to asbestos. Clinical question is - cough what is the cause?

Pre bronchodilator, baseline spirometry shows a mild obstructive airflow pattern.

The FEV_1/FVC% has a z-score of -2.59, the FEV_1 z-score is -1.67. The FVC and VC max are within normal limits therefore no evidence of a restrictive lung pattern (loss of volume).

Following the administration of a bronchodilator there was a significant improvement in FEV_1 post bronchodilator of 15% and 449mls. Post bronchodilator spirometry is consistent with a mild airflow obstruction

This is highly suggestive of an asthmatic component. When making a diagnosis of asthma, this should be based on the clinical examination, history together with the results of diagnostic tests.

Change in FVC and VC is not significant when using ERS/ATS guidelines (significant absolute volume change of 315ml but there is a <12% increase).

Consider serial home PEF monitoring and a FeN_O measurement.

To investigate asbestos exposure – CT scan and a gas transfer measurement may be required.

Report:

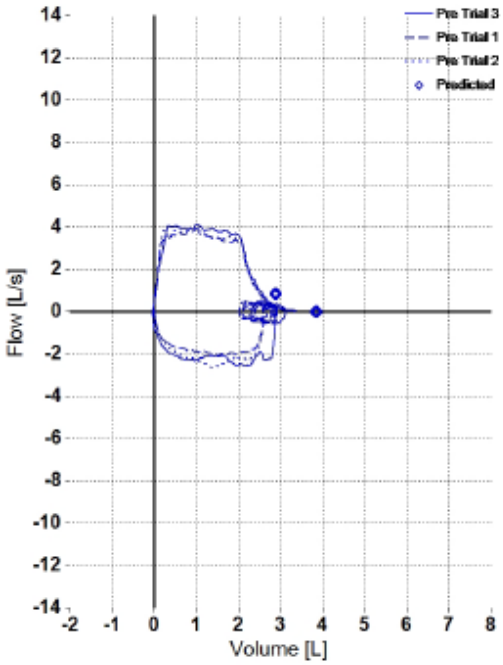
Mild airflow obstruction with a significant improvement seen post bronchodilator. This is suggestive of asthma. Consider serial home PEF monitoring and a FeNO measurement. To investigate asbestos exposure – CT scan and a gas transfer measurement may be required.

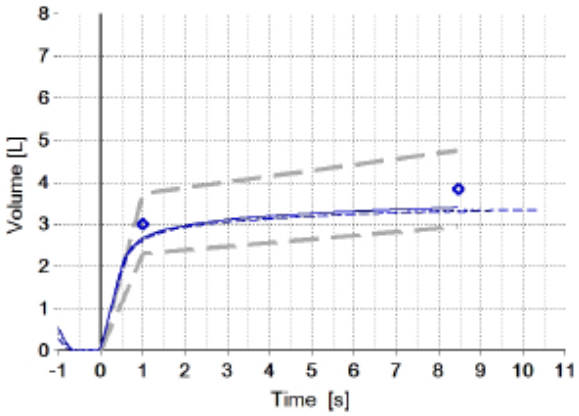
B4 Spirometry

A 57 year old female, never smoked. Bronchoscopy showed subglottic inflammation and tracheal narrowing with oedema. Symptoms include ongoing shortness of breath and wheeze for 5-10 years. Serial imaging of chest did not identify any lung parenchymal abnormalities.

Gender	female
Age	57
Height (cm)	175
Weight (kg)	81
BMI	26
Race	Caucasian

Spirometry	Reference range	Baseline	% predicted	z-score
FEV_1	>2.30	2.67	88	-0.80
FVC	>2.94	3.39	88	-0.83
FEV_1/FVC %	>67%	79%	100	-0.05
PEF (l/s)		4.11		





Interpretation B4.

Report:

Good effort and technique on spirometry.

Spirometry parameters are within normal limits. However, the shape of the Flow Volume Loop (FVL) is suggestive of a fixed Upper Airway obstruction (UAO). Fixed UAO-due to airway narrowing, there is a fixed limitation in flow during both expiratory and inspiratory FVL.

Discussion points:

Empey index = FEV_1 (mls) / PEF (L/min)

= 2670 / 247

= 11

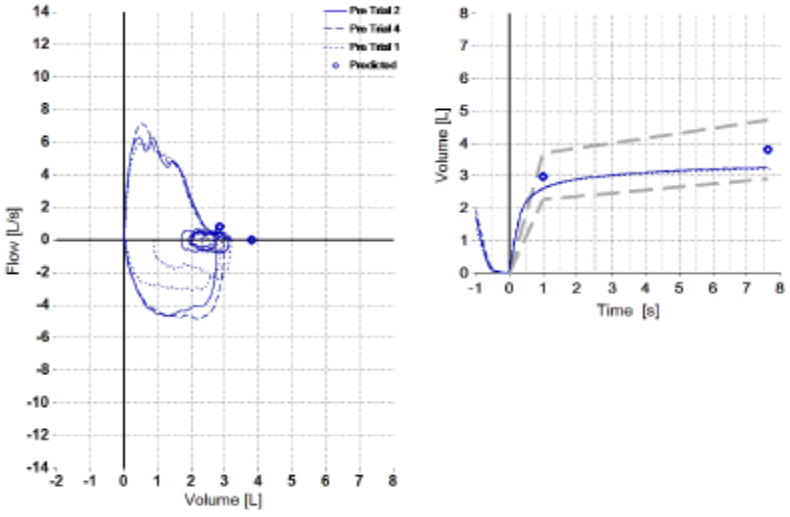
Empey index >10 adds diagnostic weight to the possible presence of UAO. No evidence of significant airflow obstruction. FVC is reduced (? loss of volume, lung restriction).

Additional commentary:

Spirometry parameters may not be affected in UAO and this example highlights the importance of reviewing the shape of the FVL, reviewing the shape should form part of the interpretation process.

The above patient was managed with tracheal stents and spirometry was repeated just over 12months later. Below is the summary of the follow up spirometry result and the associated FVL.

Spirometry	Reference range	Baseline	% predicted	z-score
FEV_1	>2.26	2.61	88	-0.85
FVC	>2.90	3.24	85	-1.02
FEV_1/FVC %	>67%	80%	102	0.20
PEF (l/s)		7.16		



The revised Empey index is now 6. Spirometry is within normal limits.

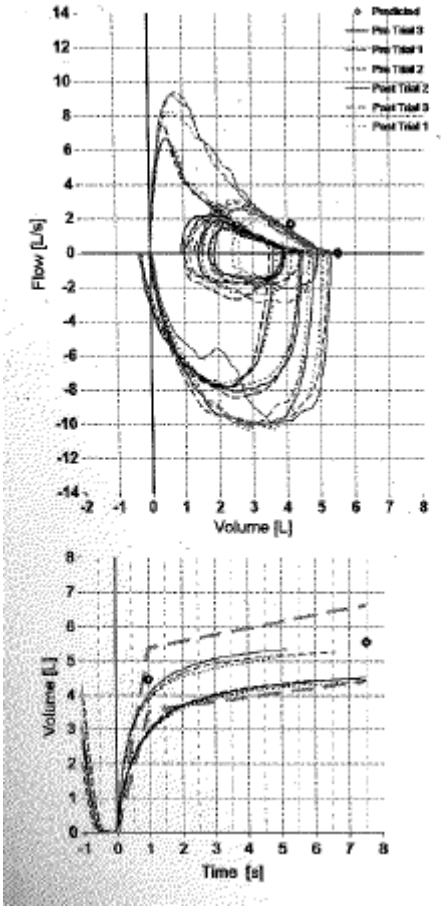
B5 Spirometry with reversibility testing

37 year old male, complaining of a chronic cough, wheeze and chest tightness. Symptoms worsening over the last 6 months, currently prescribed a salbutamol inhaler which he is using 10+ times per day. No known family history of asthma. Has never smoked. Occupation – manufacturers wedding stationary. Has a pet cat, which he has owned for < 1 year. He does report sneezing fits and runny eyes when near the cat. He suffers with hayfever in the summer and uses anti-histamines. Asthma?

Gender	male
Age	37
Height (cm)	181
Weight (kg)	119
BMI	36
Race	Caucasian

Spirometry	Predicted Mean	Baseline	LLN	% predicted	Post BD	% predicted	% change	Volume change (mls)
FEV_1	4.46	2.93*	3.54	66	3.98	89	36	1005
SVC	5.53	4.85	4.41	88	4.85	88	0	0
FVC	5.53	4.49	4.41	81	5.33	96	19	840
FEV_1/FVC %	81%	65*	71	75	75	92		
FEV_1/SVC %	81%	60*	71	81	82	101		

*<LLN



Interpretation B5.

Additional commentary:

Z-scores are sometimes not available on spirometry reports and therefore the interpretation needs to be made assessing %predicted and the use of the Lower Limit of Normal (LLN).

Discussion points:

Good effort and technique on spirometry. Cat allergy? Suffers with hayfever. Never smoked. Age 37yrs,

Baseline spirometry shows a significant airflow obstruction. Both the FEV_1/FVC% and FEV_1/VC% and FEV_1 are all below the LLN. The vital capacity is within normal limits (>LLN).

400mcgs of salbutamol via a spacer device was administered for bronchodilator responsiveness testing.

Post bronchodilator spirometry is within normal limits and demonstrates a reversible airflow obstruction.

There is a significant response seen post bronchodilator. Post BD FEV_1 improved by 36% and 1005mls, the FVC improved by 19% and 840mls. This level of reversibility is highly suggestive of asthma.

When making a diagnosis of asthma, this should be based on the clinical examination, history together with the results of diagnostic tests.

Report:

Spirometry is consistent with a reversible airflow obstruction. There is a significant improvement post bronchodilator which is highly suggestive of asthma. Post bronchodilator spirometry is within normal limits for the patient.

Suggest serial home PEF monitoring, a FeNO test and a skin prick allergy test to assist with diagnosis?

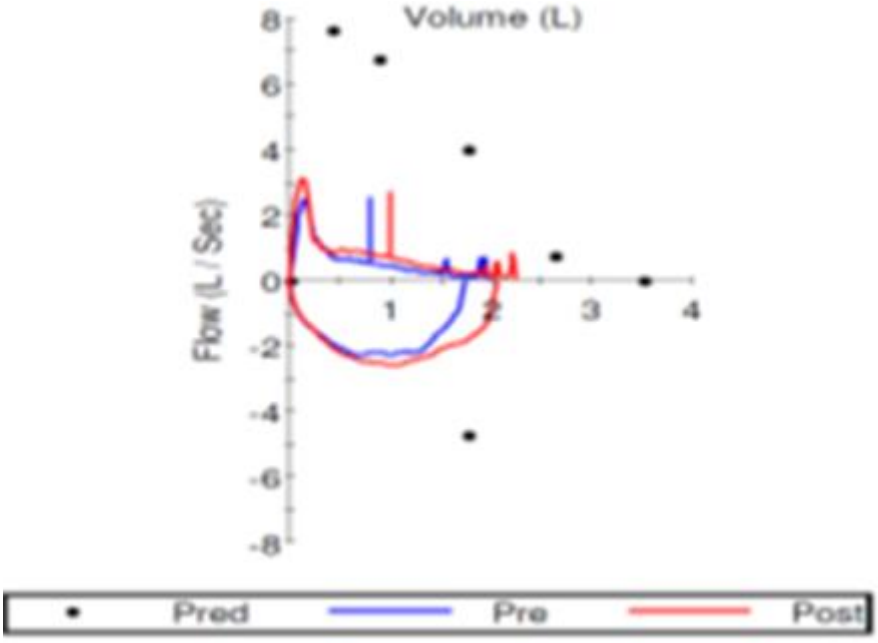
Please consider result in light of clinical correlation.

B6 Spirometry with reversibility testing

59 year old male diagnosed with asthma 30 years ago. Now presented to clinic as he feels his symptoms are deteriorating. Ex-smoker with previous factory work exposure. Good symptomatic relief when using a bronchodilator. ?element of COPD.

Gender	male
Age	59
Height (cm)	164
Weight (kg)	66
BMI	24.5
Race	Asian

Spirometry	Predicted mean	Baseline Pre BD	% predicted	z-score	Post BD	% predicted	% change
FEV_1	2.80	0.83	29	-4.82	1.04	36	+14%
FVC	3.52	1.98	56	-3.19	2.26	64	+21%
SVC	3.52	2.06	58	-3.02	2.43	69	+18%
FEV_1/FVC %	79%	42%	52	-5.92	45	45%	+6%
FEV_1/VC %	79%	40%	50		42	42%	+3%



Interpretation B6.

Discussion points:

Good effort and technique during the test. 59yr old ex-smoker (pack years would be useful to know with this patient) with some industrial exposure.

"Church steeple silhouette" shape to FVL should immediately suggest a significant airflow obstruction.

Pre bronchodilator spirometry is consistent with a mixed obstructive and restrictive lung pattern.

The FEV_1/FVC% is 42% with a z-score of -5.92. The FEV_1 has a z-score of -4.82, indicating a very severe airflow obstruction. In conjunction there is a significantly low FVC with a z-score of -3.02 suggesting a restrictive lung volume pattern.

Consider a static lung volume measurement to confirm lung restrictive pattern and possible lung hyperinflation.

There is a significant improvement post bronchodilator in the FVC only.

The post bronchodilator FEV_1 increased by 21% and 183mls – insignificant (ERS/ATS guidelines). This example highlights why it is important to have both a volumetric increase as well as a significant percentage change. This patient's baseline FEV_1 was less than a litre at 0.83L. Therefore a small change in volume will exhibit a substantial percentage change in this case a 21% change. The ERS/ATS guidelines stipulate that both a >200ml increase and a 12% change is required for a significant response. However, guidelines are just that – to aid guidance, clinical judgement is paramount. In this instance we do not know if the patient has any prior use of inhalers within 4hrs of the test – a residual effect of the bronchodilator?

The post bronchodilator FVC increased by 14% and 284mls – a significant response (ERS/ATS guidelines). This suggests some clinically significant relief from hyperinflation.

Post bronchodilator spirometry is still consistent with a severe airflow obstruction. Fixed airflow obstruction rather than a reversible obstruction.

Report:

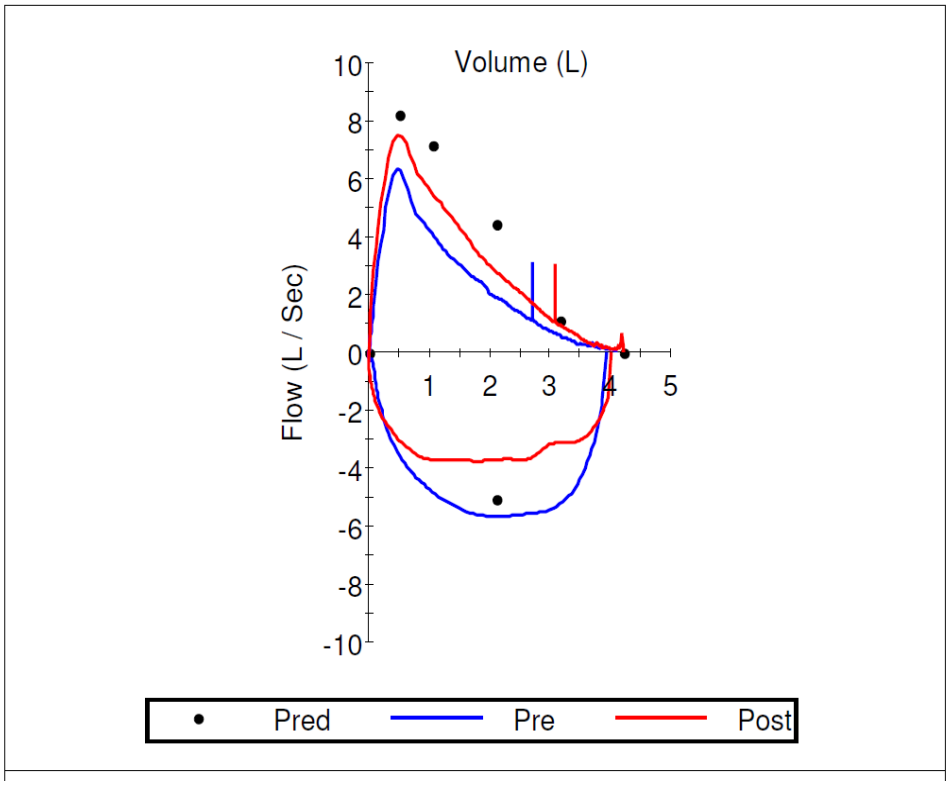
Fixed severe airflow obstruction with an element of a lung restrictive pattern (a mixed pattern), a significant response was seen in FVC only. Results are suggestive of COPD/Emphysema.

B7 Spirometry with reversibility testing

47 year old male complaining of SOB when playing with his children. On further questioning he reports having occasional wheeze and a non-productive cough. He has never smoked, suffers with hayfever, and is regularly taking antihistamines. He is unsure if his symptoms are deteriorating? He has previously used wife's inhaler and felt his breathing had improved. 400mcgs of salbutamol via a spacer administered for bronchodilator responsiveness testing. Asthma?

Gender	male
Age	47
Height (cm)	165
Weight (kg)	70
BMI	25.7
Race	caucasian

Spirometry	Predicted mean	Baseline Pre BD	% predicted	z-score	Post BD	% predicted	% change
FEV_1	3.38	2.72	80	-1.53	3.10	91%	+13%
FVC	4.22	4.10	97	-0.20	4.23	100%	+3%
FEV_1/FVC %	80%	66%	82	-2.32	73	91%	



Interpretation B7

Discussion points:

Non-smoker. Cough and wheeze, suffers with hayfever. Clinical question posed is – does the patient have asthma?

Pre bronchodilator spirometry is consistent with a mild airflow obstruction.

FEV_1/FVC% has a z-score of -2.32, FEV_1 has a z-score of -1.53. The FVC is within normal limits with a z-score of -0.20. Following administration of a bronchodilator the spirometry is now within normal limits.

There was a significant improvement in the FEV_1 of 13% and 376mls (ATS/ERS).

There is a reversible airflow obstruction, which is consistent with an asthmatic component.

Report:

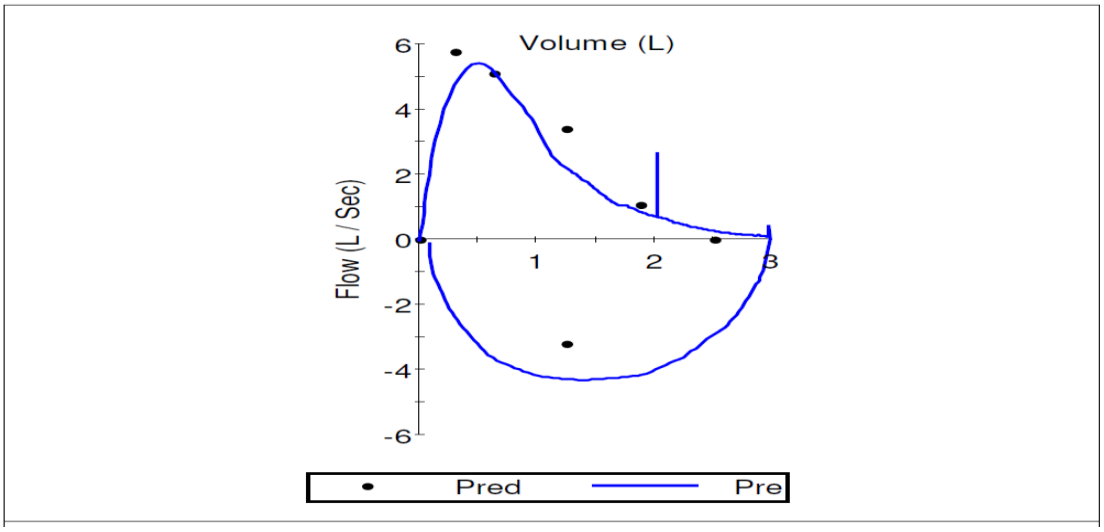
There is a reversible mild airflow obstruction (significant increase in FEV_1 post BD), which is consistent with an asthmatic component. Post bronchodilator spirometry is within normal limits. Suggest serial home PEF monitoring and a FeNO test. When making a diagnosis of asthma, this should be based on the clinical examination, medical history, together with the results of diagnostic tests.

B8 Spirometry

69 year old female with longstanding diagnosis of COPD. Feels no symptomatic relief from Seretide and Tiotropium inhalers and so rarely uses them. She does feel improvement following use of Salbutamol. Feels wheezy in the cold weather. Cough is usually non-productive and dry. Current smoker. ?evidence of Asthma.

Gender	female
Age	69
Height (cm)	163
Weight (kg)	64
BMI	24.1
Race	caucasian

Spirometry	Predicted mean	Baseline Pre BD	% predicted	z-score
FEV_1	2.10	2.05	97	-0.115
FVC	2.51	3.00	119	1.113
FEV_1/FVC %	76%	68%	89	-1.165



Interpretation B8.

Discussion points:

Good effort and technique during tests. The patient is a current smoker. Clinical question posed by the referrer is any evidence of asthma?

Spirometry is within normal limits. All parameters have z-scores >1.645.

Cannot answer clinical question posed by referrer without bronchodilator responsiveness testing.

This test does not rule out Asthma. When making a diagnosis of asthma, this should be based on the clinical examination, medical history, together with the results of diagnostic tests.

Also consider serial home PEF monitoring and a FeNO test.

Additional commentary:

As per 2019 ATS standardisation of spirometry update document a normal spirometry does not rule out a bronchodilator response. All initial baseline spirometry should be performed before and after bronchodilator administration. Thereafter the clinician may choose to perform spirometry without bronchodilator responsiveness, but it is important to consider baseline variability in lung function when making this decision.

Bronchodilator responsiveness can only be performed if it has been selected by the referring clinician on the original referral as this may fall under a patient group or specific directive (PGD/PSD)

Report:

Spirometry is within normal limits for the patient. Bronchodilator response testing is required as this test does not rule out asthma as a possible diagnosis.

B9 Spirometry with reversibility testing.

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

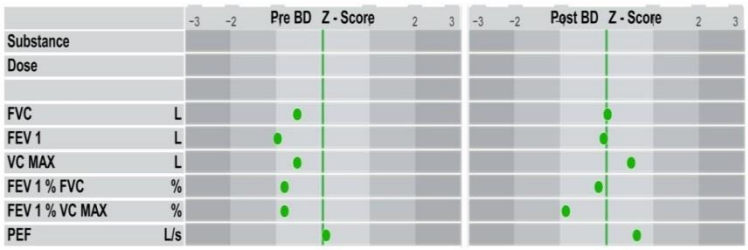
Last Name:		Identification:	
First Name:		NHS Number:	
Age:	69 Years	Date of Birth:	01/02/1947
Height:	177.0 cm	Gender:	male
Weight:	85.0 kg	BMI:	27
Operator:		Ward:	CCH
Race:	Caucasian	Diagnosis:	SOB
Physician:	Dr Dubb	Smoker:	Current smoker
Resting SpO2:	97%		

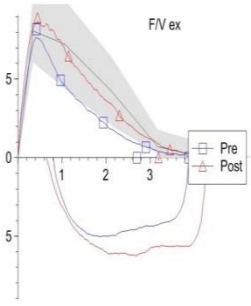
Visit date	14.04.16
Visit time	09:30

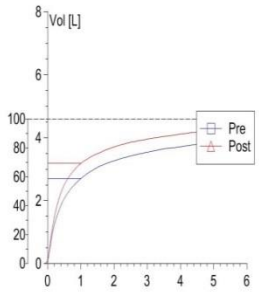
Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Pre	Pred	% Pred	Z- Score	Post	% Pred	% Change	Vol Change (ml)
Substance						Salbutamol			
Dose						400 mcg via spacer			
FVC	L	3.87	4.24	91.3	-0.55	4.26	100.4	9.9	385.00
FEV 1	L	2.70	3.22	83.9	-0.98	3.19	99.1	18.1	489.05
VC MAX	L	3.87	4.24	91.3	-0.55	4.60	108.5	18.8	729.00
FEV 1 % FVC	%	69.69	76.17	91.5	-0.83	74.87	98.3	7.4	
FEV 1 % VC MAX	%	69.69	76.17	91.5	-0.83	69.27	91.0	-0.6	
PEF	L/s	8.15	8.05	101.2	0.08	8.86	110.0	8.8	







Physiologist Comments

Smoking History: 10/day for 50 years
Relative Exposures: Factory work for 40 years. ? asbestos exposure.

Good effort and cooperation during tests.

B9 Interpretation

Discussion points:

25 pack year smoking history. The reason for the referral is shortness of breath. Resting Sp02 97%.

Pre bronchodilator baseline spirometry is within normal limits. The z scores for all spirometric parameters are all >1.645.

Additional commentary:

In the ATS/ERS standardisation of Spirometry 2019 update document it highlights that a normal baseline spirometry does not rule out a bronchodilator response test. It suggests that all initial spirometry done for diagnostic reasons should be performed before and after bronchodilator administration, thereafter the clinician may choose to perform spirometry without bronchodilator responsiveness testing.

A bronchodilator was administered - 400mcgs salbutamol via a spacer device.

Post BD spirometry is within normal limits but demonstrates a significant response to the bronchodilator in FEV_1 only.

FEV_1 increased by 18% and 489mls (ATS/ERS). Change in %predicted FEV_1 pre vs post was +15% which also suggests active treatment.

The FVC increased by 10% and 385mls – insignificant response (ERS/ATS guidelines – remember this states a >12% **and** a >200ml increase in FEV_1 and /or FVC is required).

The large significant response seen in FEV_1 would be indicative of asthma. Consider serial home PEF monitoring and a FeN_O test?

When making a diagnosis of asthma, this should be based on the clinical examination, clinical history, together with the results of diagnostic tests.

When assessing asbestos exposure – a CT scan and gas transfer measurement may be of use here.

Please interpret findings in light of clinical correlation.

Report:

Spirometry is within normal limits, significant improvement in FEV_1 observed post bronchodilator. Results are consistent with asthma. When making a diagnosis of asthma, this should be based on the clinical examination, clinical history, together with the results of diagnostic tests.

B10 Spirometry

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

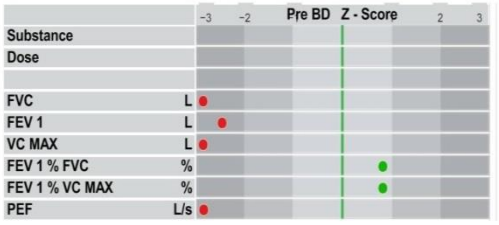
Last Name:		Identification:	
First Name:		NHS Number:	
Age:	88 Years	Date of Birth:	01/12/1927
Height:	160.0 cm	Gender:	female
Weight:	107.0 kg	BMI:	42
Operator:		Ward:	CCH
Race:	Caucasian	Diagnosis:	? Asthma
Physician:	Dr Chandra	Smoker:	Never smoked
Resting SpO2:	97%		

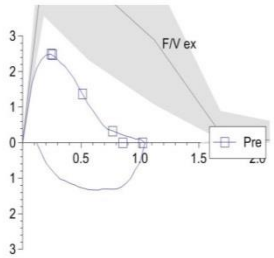
Visit date	12.04.16
Visit time	11:26

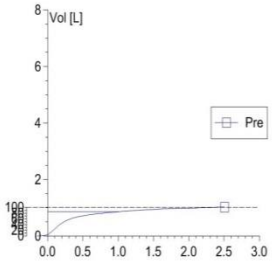
Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Pre	Pred	% Pred	Z- Score
Substance					
Dose					
FVC	L	1.02	2.24	45.5	-2.85
FEV 1	L	0.85	1.68	50.7	-2.46
VC MAX	L	1.02	2.24	45.5	-2.85
FEV 1 % FVC	%	83.53	76.32	109.4	0.83
FEV 1 % VC MAX	%	83.53	76.32	109.4	0.83
PEF	L/s	2.49	5.05	49.4	-2.84







Physiologist Comments

Patient struggled with test technique. Best results reported.

B10 Interpretation

Discussion points:

? Asthma – reversibility testing not performed. Technical comments suggest patient had difficulty performing baseline spirometry.

There is questionable accuracy of the baseline spirometry. Best effort was reported.

Available spirometry is consistent with a restrictive lung pattern (loss of volume).

The FEV_1/FVC% is within normal limits with a reduced (F)VC and FEV_1. There is no evidence to suggest a significant airflow obstruction.

FEV_1 z-score -2.46

FVC z-score -2.85

FEV_1/FVC% is within normal limits with a z-score of 0.83

To confirm restrictive lung volumes suggest measurement of total lung capacity (TLC) from a static lung volume measurement and also consider a gas transfer test.

Patient has a high BMI of 42 - ?extra-thoracic lung restriction related to obesity.

Additional commentary:

Lack of an accurate baseline test would prevent a bronchodilator responsiveness test from being undertaken. An accurate baseline test performed to quality assured standards is essential when assessing bronchodilator responsiveness.

Report:

Interpret with caution – patient had difficulty with the test. Available spirometry is consistent with a restrictive lung pattern. To confirm the presence of a restrictive lung pattern consider referring the patient for a full lung function assessment including a static lung volume measurement. High BMI. Please consider result in light of clinical correlation.

Spirometry and Gas Transfer Factor (examples B11 – B20)

The following examples from B11 – B20 not only have a spirometry measurement but also a gas transfer factor test. This is sometimes referred to as a *partial* lung function test.

Measurement of the gas transfer factor is perhaps the most physiologically and technically complex test performed within lung function.

The primary role of the lung is the exchange of gas between the atmosphere and the pulmonary circulation and hence meeting the oxygen demands of the respiring tissues. The gas exchange factors of the lungs, including those that contribute to the reaction rate of gases with haemoglobin (H_b) are assessed by the measurement.

The measurement of Transfer Factor can therefore be used to detect the presence of pulmonary vascular and parenchymal disorders.

The transfer factor or TL_{co} estimates the transfer of carbon monoxide (CO) from alveolar gas to the blood and represents the efficiency of the alveolar-capillary membrane. The measured parameters include:

- TL_{co} – the transfer of CO across the lung;
- V_A - The alveolar volume or number of lung units participating in gas exchange;
- K_{co} – The transfer coefficient or diffusion constant, the efficiency of uptake of CO in the alveoli or lung unit.

Therefore a low gas transfer (TL_{co}) is due to either a low alveolar volume (V_A-the number of contributing lung units) or the diffusion constant (K_{co}) which informs us of the efficiency per lung unit or both.

Factors to consider during interpretation

Haemoglobin (H_b) – a reduced H_b will result in a lower gas transfer factor and a higher H_b will increase the transfer factor. Where ever possible a correction for known H_b should be made.

Carboxyhaemoglobin (COH_b) – an elevated COH_b results in an underestimation of the transfer factor, smoking and exposure to secondary cigarette smoke plus air pollution may produce sufficient levels of CO to adversely affect the transfer factor measurement.

Alveolar Volume

This may be reduced due to the following:

- Incomplete expansion of the lungs (neuromuscular disease, obesity, poor inspiratory effort that results in incomplete inspiration to TLC)
- Loss of lung units (Pneumonectomy, lung collapse, localised lung destruction)
- Poor gas mixing (significant airflow obstruction – check V_A/TLC%)

It is possible that a patient may have a reduced V_A as a result of more than one of the above.

The transfer coefficient or diffusion constant (K_{CO})

K_{CO} will be affected by conditions affecting TL_{co} or the V_A. The value of K_{CO} in the interpretation is sometimes questioned [15]. Part of the reason for this is that K_{CO} is often incorrectly described as a "correction factor for alveolar volume". K_{CO} is in fact a rate constant describing the carbon monoxide transfer factor per unit alveolar volume for the alveolar volume at which the measurement is made. The relationship between TL_{co} and V_A measured as a proportion of total lung capacity (TLC) is not linear (i.e. K_{CO} changes as VA/TLC changes) and therefore cannot be described as a correction.

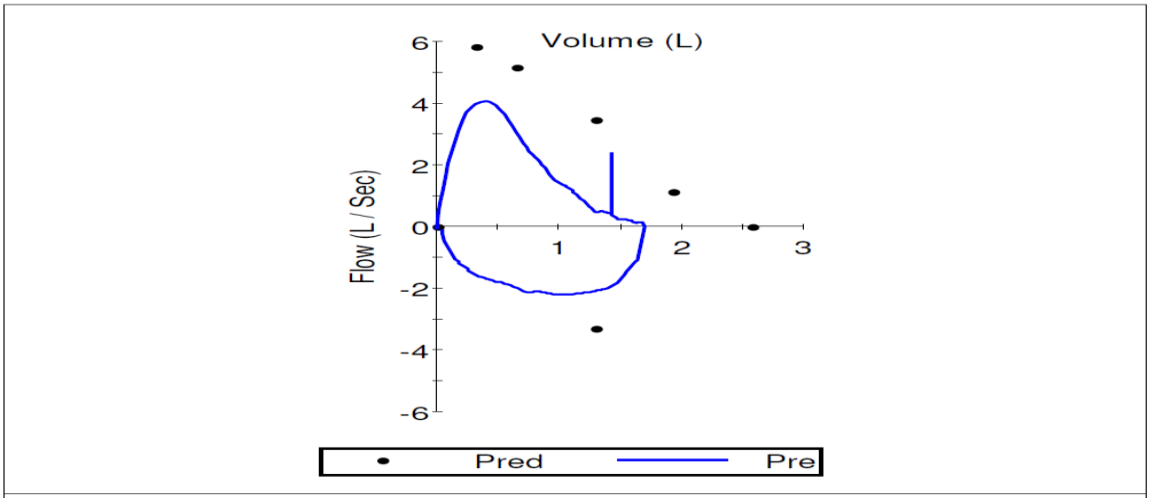
To assist with the basic interpretation of Gas Transfer Factor measurements please refer to appendix 7 – Gas Transfer Factor interpretation flowchart.

B11 Spirometry and Transfer Factor (TLco) – partial PFT

67 year old female admitted to hospital with hypoxia. On questioning, the patient feels she has always got out of breath quite easily and isn't very mobile due to RA. She has put this all down to getting older. She has never smoked and has no occupational exposures. No inhaled medication prescribed. Resting Sp02 was 87%. ?parenchymal disease.

Gender	female
Age	67
Height (cm)	163
Weight (kg)	69
BMI	26.1
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.44	2.16	1.54	66	-1.903
FVC	1.70	2.58	1.87	65	-2.049
FEV_1/FVC%	85	76	66	110	1.27
Gas Transfer					
TL_{co} (mm/min/kPa)	1.63	7.30	5.38	22	-4.85
K_{co}	0.61	1.43		42	
V_A	2.66	5.09	3.99	52	-3.62



Interpretation B11.

Discussion points:

Reason for referral is - parenchymal lung disease?

Spirometry shows a restrictive lung volume pattern. FEV_1 and FVC are reduced in the presence of a normal FEV_1/FVC%. No evidence to suggest significant airflow obstruction.

A low gas transfer factor is due to either a low alveolar volume (V_A – the number of contributing alveolar lung units) or the diffusion constant (K_{co}) which informs us of the efficiency of alveolar transfer of CO (carbon monoxide) per lung unit, **or both.**

The gas transfer factor is markedly reduced. The V_A is reduced in combination with a decreased K_{co} leading to a markedly reduced transfer factor. This pattern is seen in parenchymal (ILD) or pulmonary vascular disease (PVD).

Possible further testing: To confirm the level of lung restriction, suggest formal assessment of lung volume by measurement of static lung volumes.

$Sp0_2$ at rest was 87%? – refer for LTOT assessment and arterial blood gases?

Consider 6 minute walk test?

Is there a Sp02 desaturation on exertion?

Consider an ambulatory 02 assessment?

Additional commentary:

PVD (pulmonary hypertension), systemic sclerosis, anaemia typically has a low gas transfer factor but commonly in the presence of a normal spirometry and static lung volume measurement.

Report:

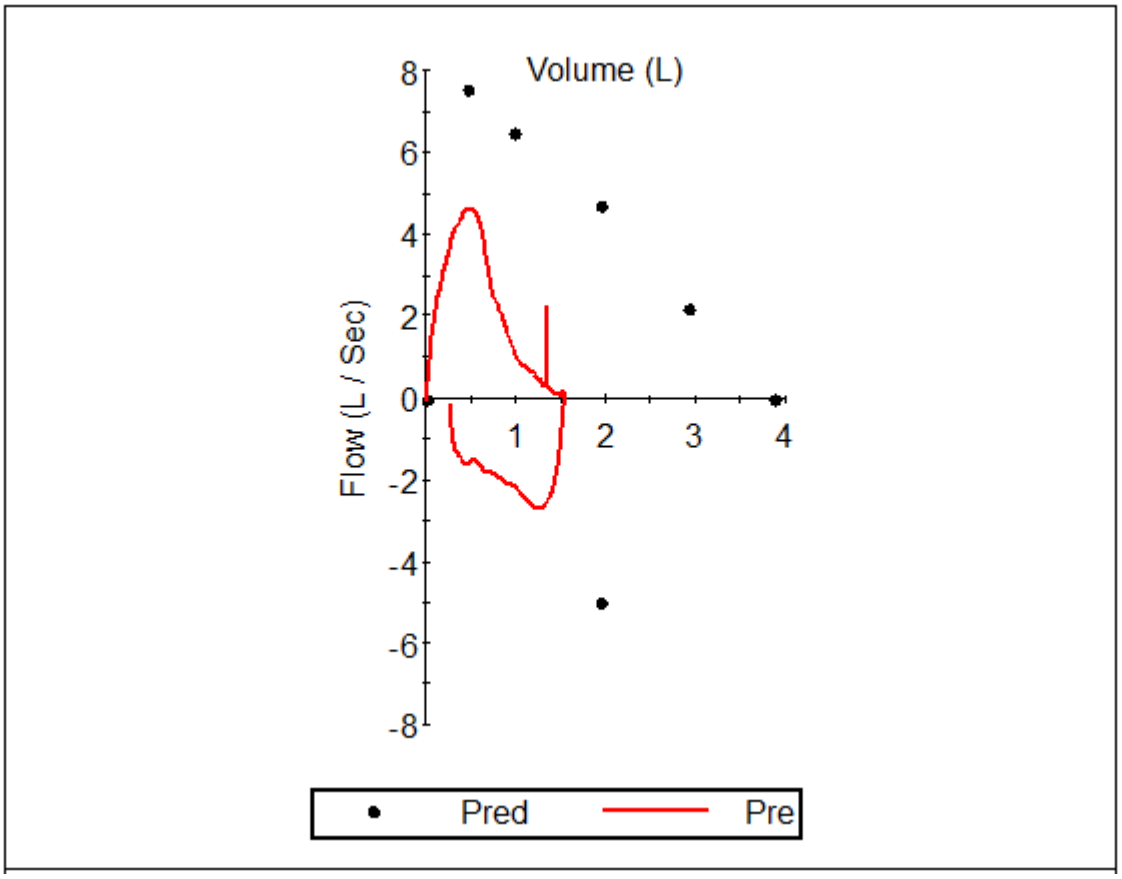
Low resting Sp02. Restrictive spirometry. Transfer factor is markedly reduced. Suggestive of ILD or pulmonary vascular disease. Consider measurement of static lung volumes and/or a referral for an LTOT assessment/arterial blood gases?

B12 Spirometry and Transfer Factor (TLco) – partial PFT

21 year old Asian female diagnosed with idiopathic pulmonary haemosiderosis, severe pulmonary hypertension due to interstitial lung disease, leptin deficiency, Type II respiratory failure, Type II diabetes and genetic obesity syndrome. Never smoked. $Sp0_2$ at rest 90%. H_b of 156gm/L.

Gender	female
Age	21
Height (cm)	174
Weight (kg)	138
BMI	46
Race	asian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.42	3.65	3.02	39	-5.862
FVC	1.60	4.17	3.46	38	-5.975
SVC	1.68	4.17	3.46	40	-5.790
FEV_1/FVC%	89	84	74	106	+0.687
FEV_1/SVC%	85	84	74	101	
Gas Transfer					
TL_{co} (mm/min/kPa)	4.69	8.61	6.68	54	-4.12
$TL_{co\ corr}$(mm/min/kPa)	4.40	8.61	6.68	51	-4.60
K_{co}	1.87	1.56	1.13	120	0.85
V_A	2.49	5.80	4.70	43	-6.46
H_b	156	120 - 180			



Interpretation B12.

Discussion points:

Good patient effort and technique. Non-smoker, low resting Sp02. BMI of 46. Complex medical history.

Baseline spirometry is consistent with a severe restrictive pattern. The FEV_1, FVC and SVC are all reduced but in the presence of a normal FEV_1/FVC%.

SVC z-score of -5.345 (↓↓)

FVC z-score of -5.975 (↓↓)

FEV_1 z-score of -4.812 (↓↓)

FEV_1/FVC% z-score of 0.687 (normal)

The gas transfer factor corrected for known H_b shows a markedly reduced TL_{co} with a z-score of -4.60. The V_A is severely reduced with a z-score of -6.46, however the K_{co} is within normal limits, z-score of 0.85.

Both TL_{co} and V_A are reduced the K_{co} is within normal limits. Pathology may be present when K_{co} is normal in the presence of a reduced TL_{co} and V_A. The result may be due to the loss of lung units (discrete or diffuse), poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these.

To formally assess for a lung restriction a static lung volume measurement of total lung capacity (TLC) is required.

Possible element of extra-thoracic lung restriction – High BMI.

Additional commentary:

Pulmonary haemosiderosis is characterized by repeated episodes of intra-alveolar bleeding that lead to abnormal accumulation of iron as hemosiderin in alveolar macrophages and subsequent development of pulmonary fibrosis and severe anaemia.

Report:

Severe restrictive spirometry. Transfer factor which is corrected for Hb is markedly reduced however this is in the presence of a normal Kco. Consider an element of extra thoracic lung restriction due to high BMI.

Consider referral into a sleep and ventilation service for blood gases and sleep studies.

NIV?

B13 Spirometry and Transfer Factor (TLco) – partial PFT

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

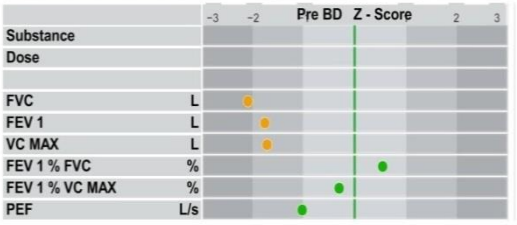
Last Name:		Identification:	
First Name:		NHS Number:	
Age:	63 Years	Date of Birth:	01/03/1953
Height:	166.0 cm	Gender:	male
Weight:	107.0 kg	BMI:	39
Operator:		Ward:	--
Race:	Caucasian	Diagnosis:	SOBOE
Physician:	Dr Spencer	Smoker:	Ex-smoker
Resting SpO2:	90%		

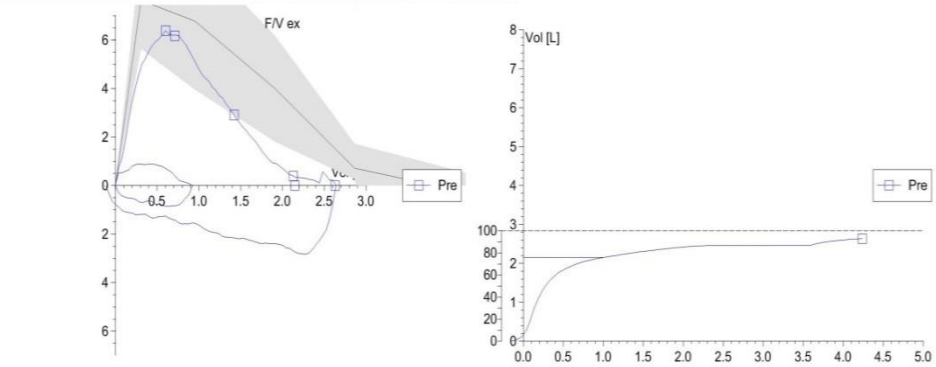
Visit date	28.09.16
Visit time	09:35

Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Pre	Pred	% Pred	Z- Score
Substance					
Dose					
FVC	L	2.63	3.82	68.9	-2.10
FEV 1	L	2.15	2.97	72.3	-1.77
VC MAX	L	2.84	3.82	74.4	-1.73
FEV 1 % FVC	%	81.68	77.79	105.0	0.56
FEV 1 % VC MAX	%	75.63	77.79	97.2	-0.30
PEF	L/s	6.38	7.63	83.6	-1.03





Physiologist Comments

Good effort and cooperation during tests , although maximal inspiration not achieved on gas transfer.
Gas transfer calculated from assumed Hb of 14.6 g/dL.

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

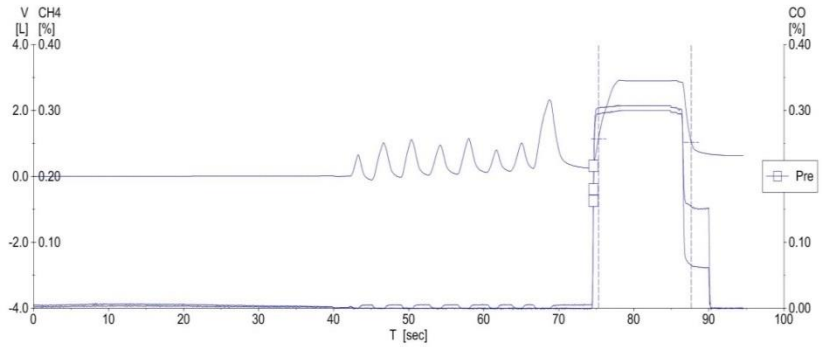
The Royal Wolverhampton NHS
NHS Trust

Last Name:
First Name:

Identification:
NHS Number:

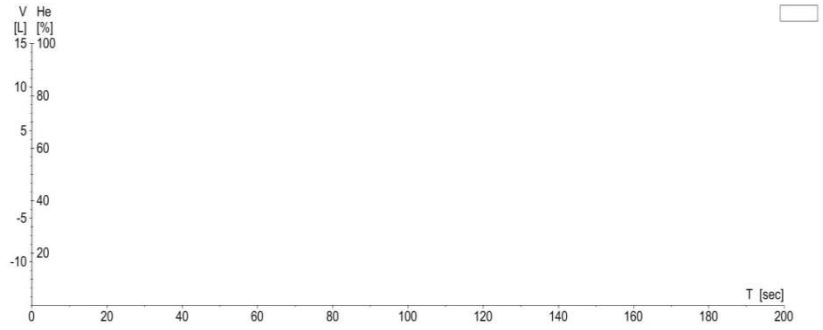
GAS TRANSFER

		Actual	Pred	% Pred	SR	Z-Score
DLCO_SB	mmol/(min*kPa)	7.15	8.25	86.6	-0.78	
DLCOcSB	mmol/(min*kPa)	7.15	8.25	86.6	-0.78	
KCO_SB	mmol/(min*kPa*L)	1.69	1.33	126.6	1.29	
KCOc_SB	mmol/(min*kPa*L)	1.69	1.33	126.6	1.29	
VA_SB	L	4.23	5.92	71.4	-2.04	
RV%TLC_SB	%	46	39	118.3	1.29	
TLC_SB	L	4.38	6.18	70.8	-2.58	
RV_SB	L	1.99	2.33	85.6	-0.82	



LUNG VOLUMES

		Actual	Pred	% Pred	SR	Z-Score
FRC-He	L		3.36			
RV	L		2.33			
TLC	L		6.18			
RV%TLC	%		38.53			



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Interpretation B13.

Discussion points:

Technical comment noted – "patient was unable to inspire fully on gas transfer test." For a quality assured gas transfer measurement the patient must achieve at least >85% of their VC_{max} during inspiration during the gas transfer factor measurement.

Resting $Sp0_2$ of 90%?

Spirometry is consistent with a mild restrictive lung pattern – a loss of lung volume. The FEV_1, VC_{max} and FVC are reduced (z-scores < -1.645) in the presence of a normal FEV_1/VC%. There is no evidence to suggest any significant airflow obstruction on spirometry.

The gas transfer is normal but in the presence of an elevated K_{co} and a reduced V_A. In this pattern we must consider incomplete alveolar expansion as per technical comment. Factors external to the lung should also be considered such as obesity (BMI 39) and chest wall restriction. The K_{co} tends to be elevated when there is incomplete expansion of alveoli to TLC (e.g. poor inspiratory effort, respiratory muscle weakness or chest wall restriction).

Report:

Spirometry is consistent with a mild restrictive pattern. Questionable test accuracy of transfer factor measurement, not a quality assured measurement. Interpret with caution. The available gas transfer factor measurement is within normal limits. Consider extra pulmonary restrictive pattern – high BMI.

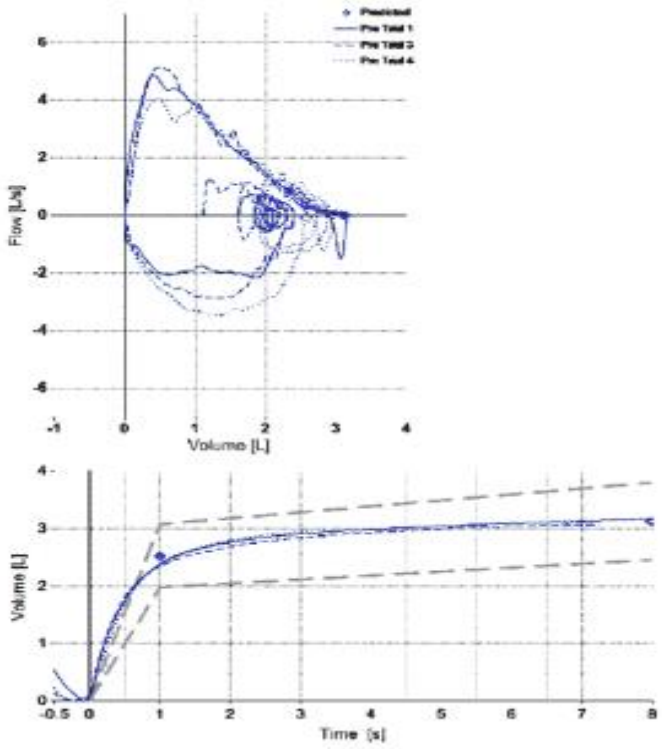
Static lung volumes are required to formally assess for lung restriction. Re-test but request a full pulmonary function test (which includes a static lung volume measurement and a repeat gas transfer factor measurement).

Suggest blood gases to investigate the low resting $Sp0_2$. Please consider result in light of clinical correlation.

B14 Spirometry and Gas transfer – partial PFT

49 year old female, current smoker, 28 pack year smoking history. Last cigarette - 30 mins prior to test. Polycythaemia H_b 180g/L. Ex pub landlord. BMI 38 obese. $Sp0_2$ at rest 94%. Good patient effort and technique on spirometry.

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	2.38	2.64	2.57	90	-0.746
VC	3.21	3.29	2.57	97	-0.029
FVC	3.15	3.29	2.57	96	-0.308
FEV_1/VC%	74	80	70	92	
PEF (L/S)	5.15	6.14	4.66	84	-1.096
$FEF_{25-75\%}$ (L/S)	1.91	2.59	1.48	74	-0.996
Gas Transfer					
TL_{co} (mm/min/kPa)	10.16	7.82	5.90	129	2.00
$TL_{co\ corr}$ (mm/min/kPa)	9.01	7.82	5.90	115	1.01
K_{co}	1.88	1.66		112	
V_A	4.80	4.83	3.73	99	-0.04
H_b	180	120 - 180			



Interpretation B14.

Discussion points:

Ex-smoker 28 pack year history.

Spirometry is within normal limits. All z-scores are >-1.645. No evidence of airflow obstruction.

Uncorrected gas transfer factor is elevated, z-score >+1.645 (or 129% of predicted). Polycythaemia. H_b 180g/L.

Gas transfer factor corrected for known H_b or $TL_{co\ corr}$ is within normal limits, z-score 1.01 (Normal K_{co} and V_A).

Report:

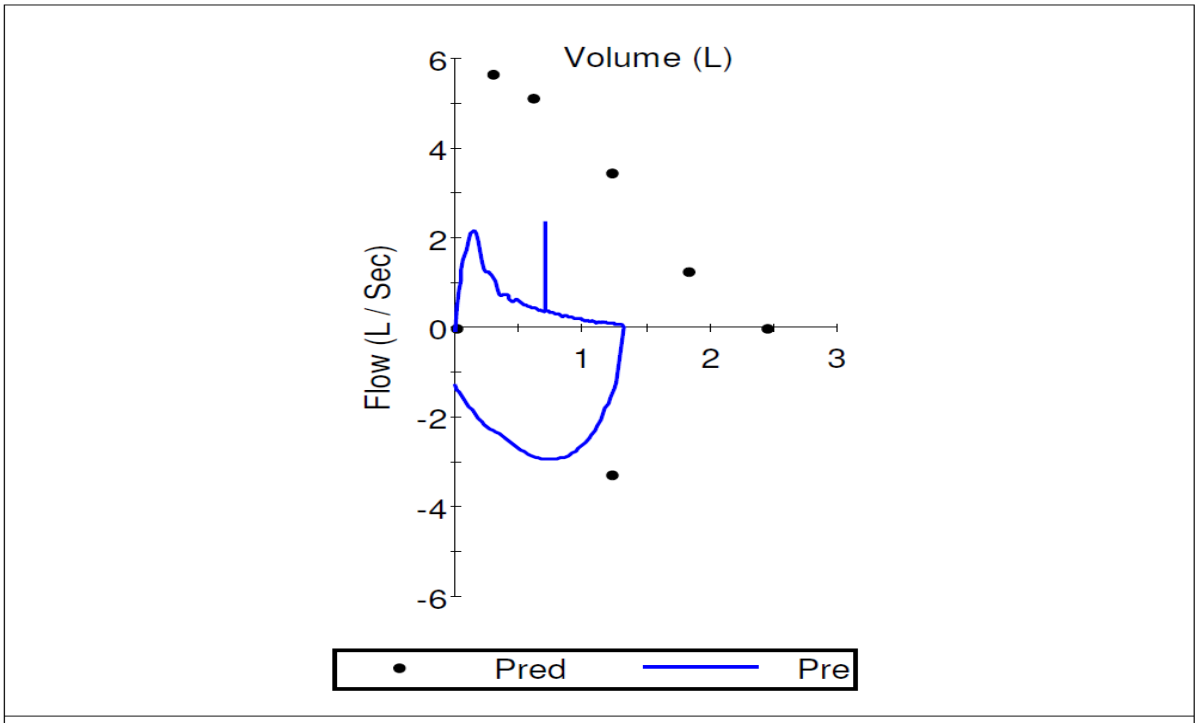
Spirometry is within normal limits, transfer factor when corrected for known Hb is within normal limits.

B15 Spirometry and Transfer Factor (TLco) – partial PFT

58 year old female admitted with recurrent chest infections causing decompensated type II respiratory failure. Suffers with a persistent, productive cough. Lung hyperinflation seen on CXR. 35 pack year smoker. Presumed exacerbation of COPD but there is no formal diagnosis through lung function. Father died aged 60 from emphysema and brother, aged 55, was given same diagnosis (emphysema) 7 years ago.

Gender	female
Age	58
Height (cm)	155
Weight (kg)	59
BMI	24.6
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	0.72	2.05	1.43	35	-3.495
FVC	1.32	2.44	1.73	54	-2.598
SVC	1.403	2.44	1.73	57	-2.411
FEV_1/FVC%	55	78	67	70	-3.586
FEV1/SVC%	51	78	67	61	
Gas Transfer					
TL_{co} (mm/min/kPa)	2.93	7.05	5.13	41	-3.52
K_{co}	0.96	1.54		62	
V_A	3.06	4.57	3.47	66	-2.26



Interpretation B15.

Discussion points:

Significant smoking history – 35 pack year history. COPD? Lung Hyperinflation on CXR

Spirometry is consistent with a mixed obstructive and restrictive lung pattern. FEV_1, FVC, SVC and FEV_1/SVC% are all significantly reduced with z-scores <-1.645.

The gas transfer factor is markedly/severely reduced, z-score of -3.52. If the V_A is also reduced then this likely reflects the poor uptake of the transfer gas in relation to the poorly ventilated air spaces. Need to check V_A against TLC from a static lung volume measurement (V_A/TLC %). This can lead to a possible underestimation in the number of contributing or accessible lung units. The low gas transfer factor and K_{co} is a result of the decreased surface area available for gas exchange and alveolar destruction.

Check V_A/TLC% (ratio) - < 80% would suggest poor gas mixing, poorly ventilated air spaces.

Additional commentary:

Smokers with airway obstruction but a normal gas transfer factor tend to have bronchitis rather than emphysema.

Report:

Mixed obstructive and restrictive spirometry. Gas transfer factor is markedly reduced. Consistent with COPD/Emphysema.

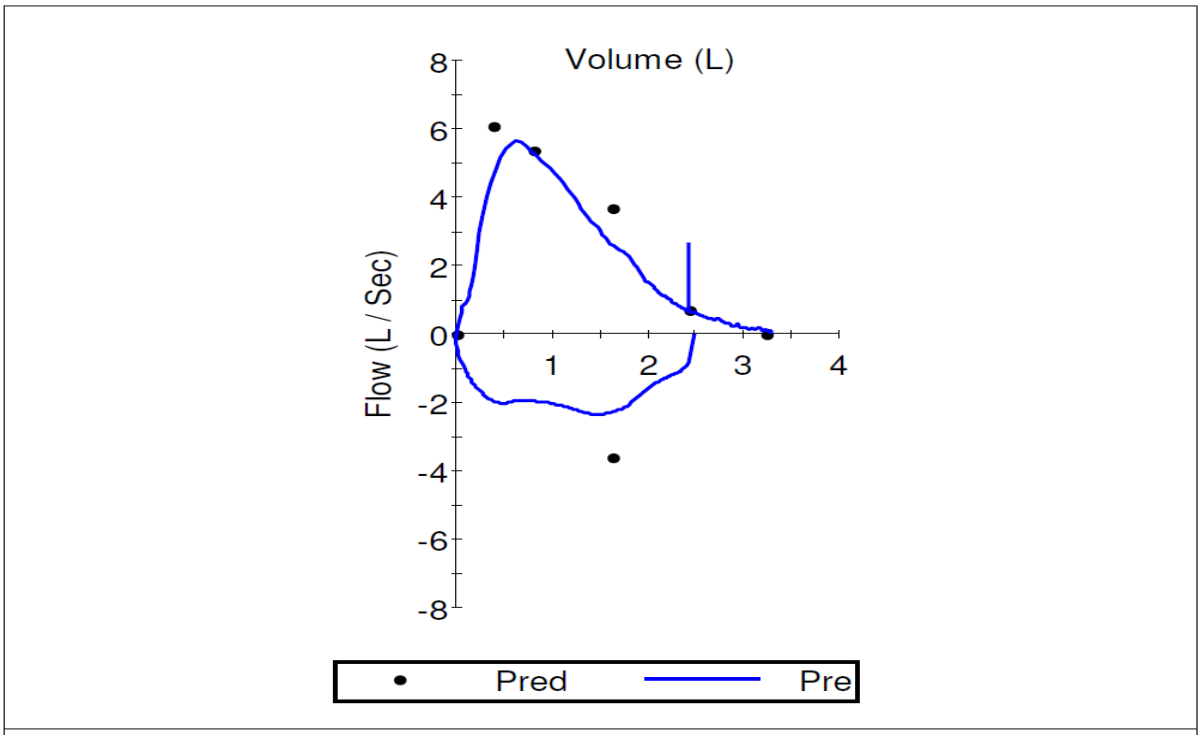
Requires a full pulmonary function test to include a static lung volume measurement to investigate lung hyperinflation/gas trapping. Look for an elevated TLC and RV/TLC% on static lung volume measurement. Also check V_A/TLC% (ratio), a ratio of < 80% would suggest poor gas mixing, poorly ventilated air spaces. Please consider result in light of clinical correlation

B16 Spirometry and Transfer Factor (TLco)

58 year old female diagnosed with Hodgkins lymphoma, awaiting BMT. H_b 95g/L. Usually fit and well but breathing has deteriorated since diagnosis 3/12 ago. Never smoked. Recent chemotherapy. Referred for assessment prior to further treatment.

Gender	female
Age	58
Height (cm)	163
Weight (kg)	80
BMI	30
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	2.44	2.56	1.96	95	-0.328
FVC	3.29	3.24	2.46	101	+0.104
SVC	3.21	3.24	2.46	99	-0.062
FEV_1/FVC%	74	79	68	93	-0.811
FEV1/SVC%	76	79	68	96	
Gas Transfer					
TL_{co} (mm/min/kPa)	6.23	7.74	5.82	80	-1.29
$TL_{co\ corr}$ (mm/min/kPa)	7.28	7.74	5.82	94	+0.39
K_{co}	1.47	1.52		96	
V_A	4.94	5.09	3.99	97	-0.23
H_b	95	120 - 180			



Interpretation B16.

Discussion points:

Never smoked. Diagnosed with Hodgkin's lymphoma, known low Hb. Recent chemotherapy.

Spirometry is within normal limits, z-scores >-1.645.

$TL_{co\ corr}$ is the corrected Gas Transfer factor for the known H_b of 95 g/L.

The corrected gas transfer factor is within normal limits.

Report:

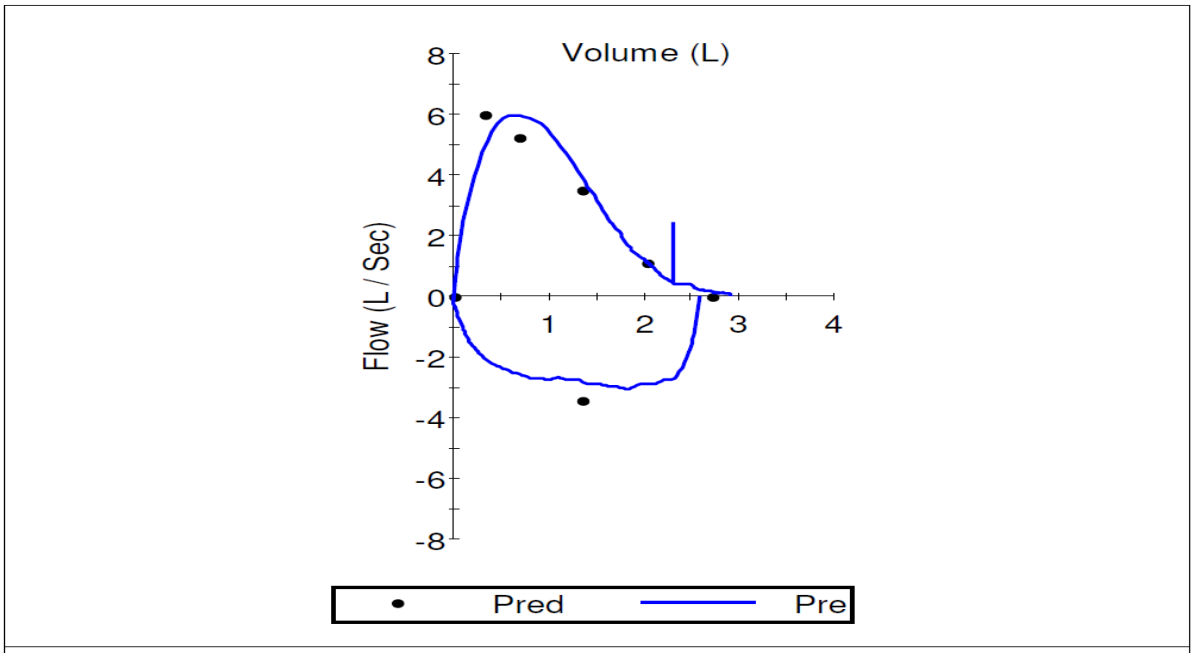
Spirometry is within normal limits for the patient. The transfer factor corrected for the patients known H_b is also within normal limits.

B17 Spirometry and Transfer Factor (TLco) – partial PFT

70 year old female, under the care of the rheumatology team for Rheumatoid Arthritis (RA). Started on Methotrexate 6/12 ago and is now complaining of increasing SOB and cough. Ex-smoker with 45 pack year history. ? lung toxicity.

Gender	female
Age	70
Height (cm)	168
Weight (kg)	82
BMI	29
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	2.32	2.27	1.64	102	0.142
FVC	2.92	2.71	2.00	107	0.481
SVC	3.17	2.71	2..00	116	1.064
FEV_1/FVC%	79	76	64	105	0.589
FEV1/SVC%	73	76	64	96	
Gas Transfer					
TL_{co} (mm/min/kPa)	4.61	7.54	5.62	61	-2.50
K_{co}	0.98	1.39		70	
V_A	4.72	5.30	4.31	87	-1.02



Interpretation B17.

Discussion points:

Significant smoking history – 45 pack year history. Known RA, has been taking Methotrexate (MTX) for approximately 6 months. Clinical question posed by referrer is there any evidence of possible lung toxicity?

Although patient has an extensive smoking history the spirometry is within normal limits. No evidence to suggest a significant airflow obstruction.

The gas transfer factor however is moderately reduced. The K_{co} is low but in the presence of a normal V_A. Both TL_{co} and V_A are reduced. As the K_{co} is within normal limits, pathology may be present when K_{co} is normal in the presence of a reduced TL_{co} and V_A. The result may be due to the loss of lung units (discrete or diffuse), poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these.

Further testing: CT scan?

Additional commentary:

Methotrexate use is associated with an acute hypersensitivity pneumonitis in patients with RA and usually goes away if methotrexate is stopped. Kiely P et al. Rheumatology. 2019; 58 (suppl 3),

Report:

Spirometry is within normal limits. There is a moderately reduced gas transfer factor. The result may be due to the loss of lung units (discrete or diffuse), poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these. Correlate clinically – discuss result with rheumatology team?

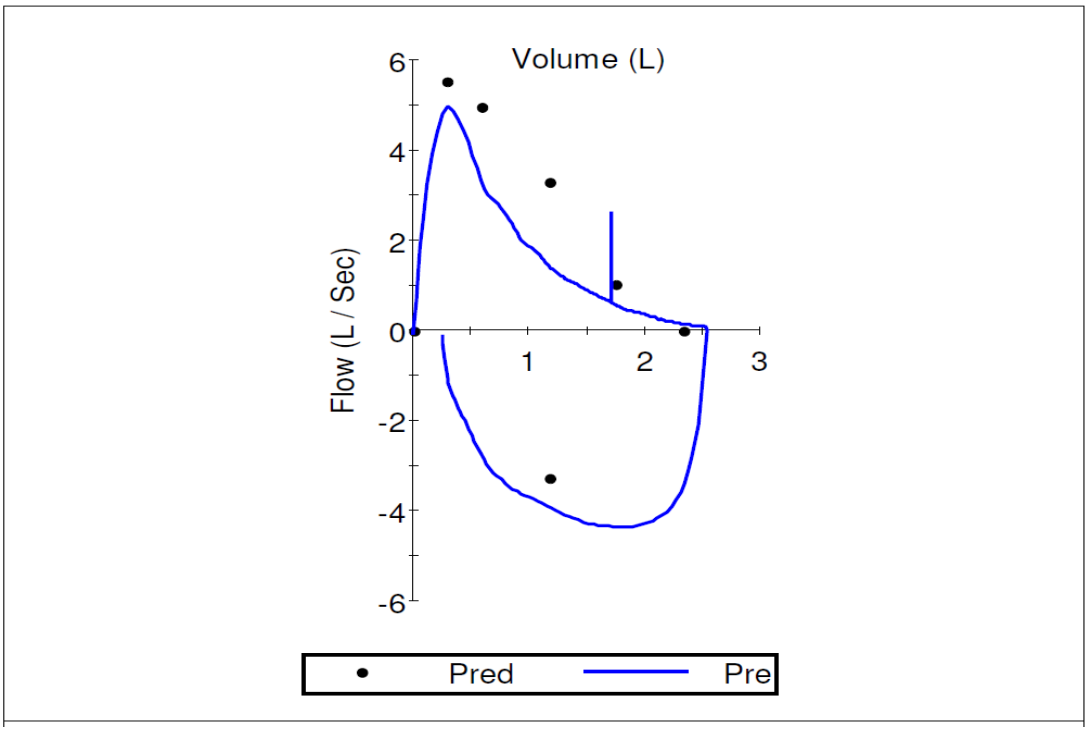
Repeat full lung function in 3-6 months to assess for any serial change?

B18 Spirometry and Transfer Factor (TLco) – partial PFT

69 year old female attended clinic complaining of a persistent cough. Usually dry however becomes more productive when she gets a cold. Ex-smoker with a 10 pack year history. Prescribed Salbutamol, Seretide and Tiotropium by GP. Does feel symptoms improved since then. No previous spirometry available ? COPD.

Gender	female
Age	69
Height (cm)	159
Weight (kg)	73
BMI	29
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.72	1.93	1.31	89	0.544
FVC	2.55	2.34	1.63	109	0.489
SVC	2.81	2.34	1.63	116	1.110
FEV_1/FVC%	68	75	65	91	-1.267
FEV1/SVC%	61	75	64	81	
Gas Transfer					
TL_{co} (mm/min/kPa)	7.09	6.84	4.92	104	0.21
K_{co}	1.45	1.42		102	
V_A	4.89	4.83	3.73	101	0.10



Interpretation B18.

Discussion points:

Clinical question posed is – COPD?

The Sp02 at rest 97%.

10 pack year smoking history (not significant?).

The FVL by its appearance looks obstructive with a noticeable concavity on the expiratory limb.

If we were to interpret the results using a fixed cut-off of <70% for the FEV_1/FVC % as per NICE COPD guidelines the spirometry would be interpreted as showing a mild airflow obstruction.

However, when interpreting spirometry results using z-scores (standard deviation from the predicted mean) the spirometry is within normal limits and does not suggest any significant airflow obstruction. The FEV_1/VC% is > LLN.

Therefore no evidence of significant airflow obstruction.

The patient is 69 years of age. The spirometry is normal for her age.

Report:

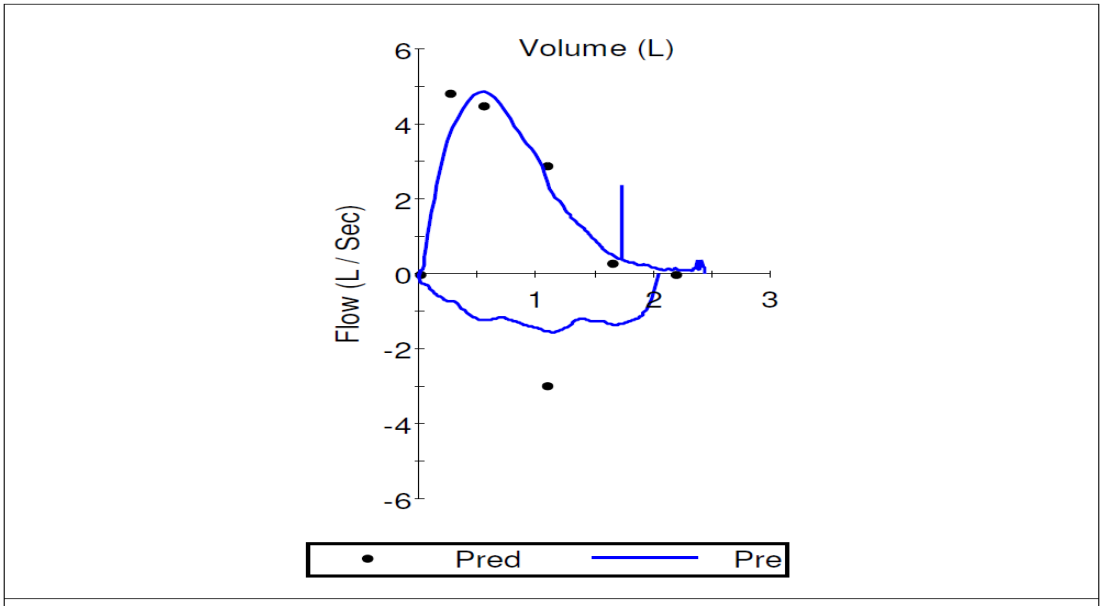
Normal spirometry and gas transfer factor. Not suggestive of significant COPD. Bronchitis?

B19 Spirometry and Transfer Factor (TLco)

77 year old female with mild fibrotic changes on CXR. Current smoker with a 30 pack year history. SOBOE but still very active – walks around 2 miles daily. No symptoms at rest. CABG x3, previous PAH. ?lung disease.

Gender	female
Age	77
Height (cm)	150
Weight (kg)	67.8
BMI	30
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.75	1.69	1.21	103	0.214
FVC	2.45	2.19	1.53	112	0.662
SVC	2.62	2.19	1.53	119	1.082
FEV_1/FVC%	71	77	64	92	-0.797
FEV1/SVC%	67	77	64	87	
Gas Transfer					
TL_{co} (mm/min/kPa)	3.43	5.74	3.82	59	-1.98
K_{co}	0.86	1.35		64	
V_A	3.96	4.26	3.16	93	0.44



Interpretation B19.

Discussion points:

Significant smoking history – 30 pack year history. She is a current smoker. Spirometry is within normal limits. No evidence of a significant airflow obstruction.

Mildly reduced gas transfer factor (TL_{co}). The K_{co} is mildly reduced with a normal V_A. Results are consistent with findings on CXR. ? Early pulmonary fibrosis or emphysema?

Repeat test in 6/12 to assess for any further significant serial lung function changes?

Are symptoms impacting significantly on the patient quality of life at this stage?

Report:

Spirometry is within normal limits, mildly reduced gas transfer factor. Repeat test in 6 months to assess for any serial changes in lung function. Suggest smoking cessation.

B20 Spirometry and Transfer Factor (TLco)

47 year old male attended following on-going SOB, SOB particularly worse when supine or bending forward. Symptoms present since car accident 3 months prior. CXR shows raised hemi diaphragm. Never smoked. ? diaphragm dysfunction.

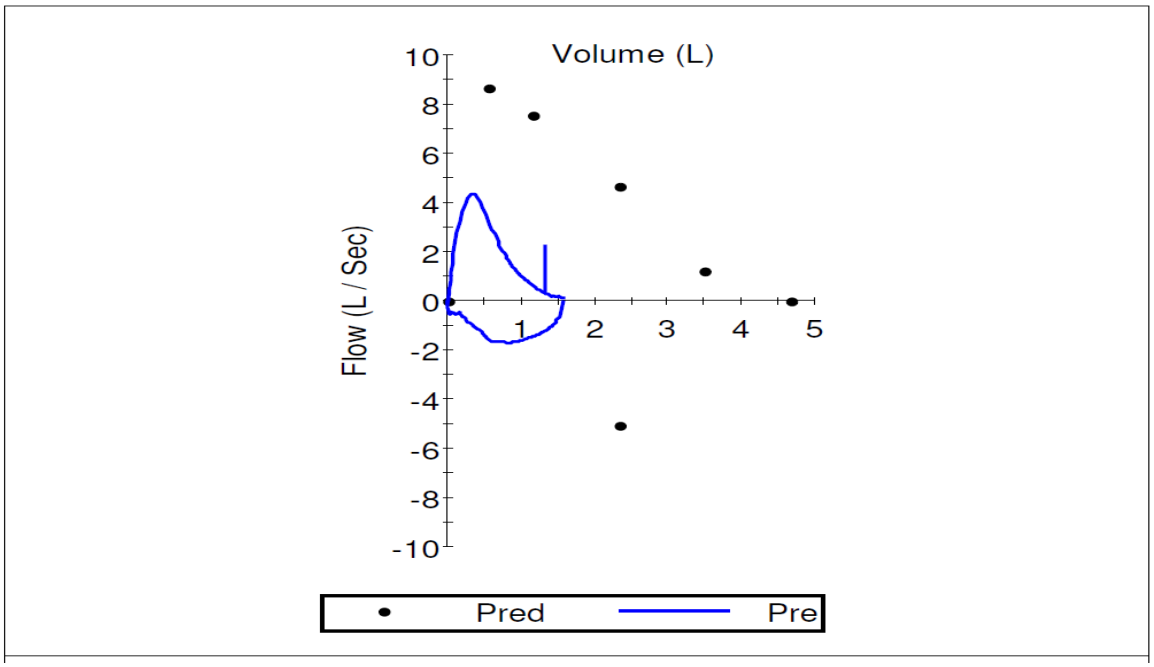
Royal Wolverhampton NHS Trust
New Cross Hospital
Lung Function Report
Tel:01902 695061 or Ext 5061

Patient Name	X	Hospital Number	A14	Sex	Male	Test Date	22/01/2016
Diagnosis	Raised Hemi diaphragm and phrenic nerve palsy.			Age	47	Race	Caucasian
Referrer		Height	172.00 Cms	Weight	104.00 Kgs	BMI	35.2

Tobacco product: Never Smoked Years smoked: Pack years: Quit smoking: yrs
Medications:
pre test comments:
Sp02 at rest: 95% Occupation:
Post test comments: Good patient effort & cooperation. Gas Transfer calculated from an assumed Hb of 14.6 g/dl Good Technique.
Physiologist:

Spirometry reference ranges GLI 2012
Transfer Factor / Lung Volumes ECCS

	Actual	Pred	LLN	%Pred	#SD
---- SPIROMETRY ----					
FVC (L)	1.619	4.666	3.658	34	-4.970
FEV1 (L)	1.353	3.716	2.935	36	-4.975
SVC (L)	1.547	4.666	3.655	33	-5.088
FEV1/FVC (%)	83.557	79.869	69.971	104	0.613
FEV1/SVC (%)	87.452	79.640		109	
FEF Max (L/sec)	4.455	8.658	6.668	51	-3.474
---- GAS TRANSFER ----					
DLCOunc (mM/min/kPa)	6.32	9.93	7.61	63	-2.56
DLCOcor (mM/min/kPa)		9.93	7.61		
DL/VA (mM/min/kPa/L)	2.31	1.56		148	
VA (L)	2.73	6.38	5.01	42	-4.39
RV/TLC (SB) (%)	52.62	32.57	21.65	161	3.67
TLC (SB) (L)	2.88	6.66	5.51	43	-5.39
RV (SB) (L)	1.52	2.07	1.40	73	-1.35



Interpretation B20.

Discussion points:

Severe restrictive lung pattern on spirometry (small lung volume) with a significantly reduced peak expiratory flow. Never smoked. $Sp0_2$ at rest 95%. BMI 35.

The gas transfer factor is reduced. The K_{co} (DL/V_A) is elevated and the V_A is significantly reduced.

When K_{co} is elevated (>upper limit of normal) in the presence of a reduced V_A consider incomplete alveolar expansion. Factors external to the lungs should be considered. K_{co} tends to be elevated when there is incomplete expansion of alveoli to TLC (e.g. poor inspiratory effort, respiratory muscle weakness or a chest wall restriction).

Additional commentary:

Check test quality - ? poor inspiratory effort on the gas transfer test can show same result i.e. when inspiratory capacity is <85% of the patients VC. Technical comments however confirm good technique.

Report:

Extra-pulmonary, restrictive, lung pattern. Restrictive spirometry. Reduced gas transfer factor in the presence of an elevated diffusion constant (Kco).

CXR shows a raised hemi-diaphragm. Symptoms have worsened since having a car accident 3 months prior. SOB worse when supine. Consider respiratory muscle weakness – suggest simple respiratory muscle assessment by MIP/MEP and SNIP? Consider supine vs erect spirometry to assess diaphragmatic function.

Full Pulmonary Function Test (examples B21 – B30)

The following examples from B21 – B30 not only have a spirometry measurement and a gas transfer factor test but also a static lung volume measurement. This is referred to as a full lung or pulmonary function test.

Static lung volumes can be measured by the following methods:

- Body Plethysmography;
- Helium Dilution;
- Nitrogen washout.

In patients without any significant airflow limitation the three methods above will correlate relatively closely with each other, in significant airflow obstruction significant methodological differences are seen. Dilution and washout methods may underestimate lung volumes due to non-communicating airspaces, poorly ventilated lung. Plethysmography may overestimate results.

The parameters below are typically used to interpret static lung volume measurements:

- Total Lung Capacity (TLC);
- Thoracic Gas volume – TGV (plethysmography) or Functional Residual Capacity – FRC (dilution and washout);
- Residual Volume (RV);
- RV/TLC%.

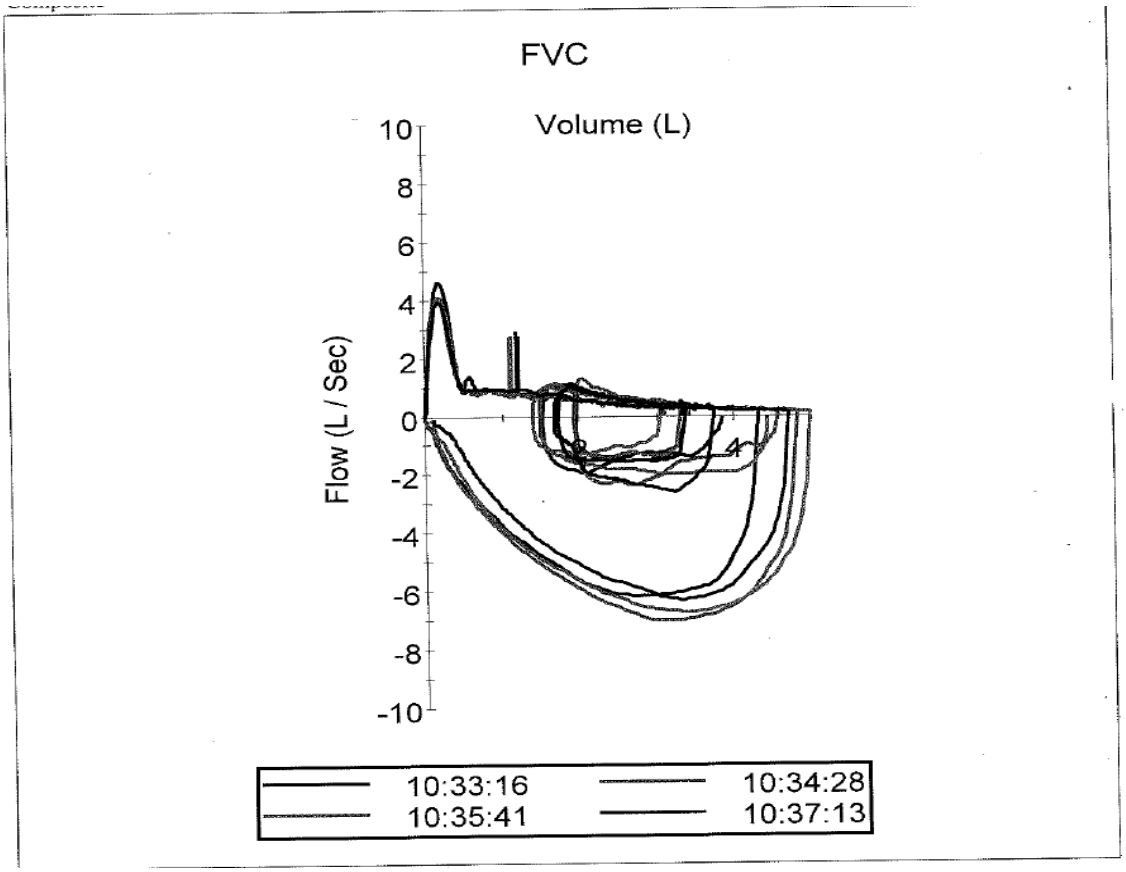
For the RV and RV/TLC% generally only abnormally high results are of interest. For TGV or FRC and TLC the results can be abnormally high or low.

To assist with full lung function interpretation refer to interpretation flowcharts in appendices 4,5,6 and 7.

B21 Full Pulmonary Function test.

69 year old male, ex-smoker, 38 year pack history. Pre assessment for LVRS/EBV. Occupation retired plasterer.

Spirometry	Actual	Predicted	LLN	%Predicted	Z-score
FEV_1	1.226	3.435	2.484	35	-3.579
VC	6.37	4.56	3.386	139	0.41
FVC	4.986	4.56	3.386	109	0.584
FEV_1/FVC%	25	75.66	62.340	32	-4.949
FEV_1/VC%	19	75.33			
PEF (L/S)	4.59	8.384	6.394	54	-3.134
$FEF_{25-75\%}$ (L/S)	0.393	2.583	1.135	15	-2.978
Gas Transfer					
TL_{co} (mm/min/kPa)	4.75	9.69	7.37	48	-3.51
K_{co}	0.61	1.29		47	
V_A	7.65	7.22	5.85	106	0.52
IVC	6.05				
Lung Volumes (plethysmography)					
TGV	8.56	3.82	2.83	224	7.90
RV	5.20	2.70	2.03	192	6.09
TLC	10.65	7.54	6.39	141	4.45
RV/TLC%	48.78	41.19	30.27	118	1.39



B21 Interpretation.

Discussion points:

Severe airflow obstruction on spirometry. Pattern on FVL is suggestive of dynamic airway collapse typically seen in emphysema.

Dynamic airway collapse confirmed by SVC > FVC by > 500ml.

The reduced V_A when compared to the elevated TLC likely reflects poor gas mixing/transfer gas uptake – poorly ventilated air spaces. V_A/TLC% = 72% (ref >80%).

This may lead to a possible underestimation in the number of contributing or accessible lung units. The reduced gas transfer factor is a result of the decreased surface area available for gas exchange and alveolar destruction. Gas transfer factor shows a marked reduction in TL_{co} and K_{co}, typically seen in emphysema.

Lung volumes show hyperinflation with a marked elevation in TLC, TGV and RV.

Report:

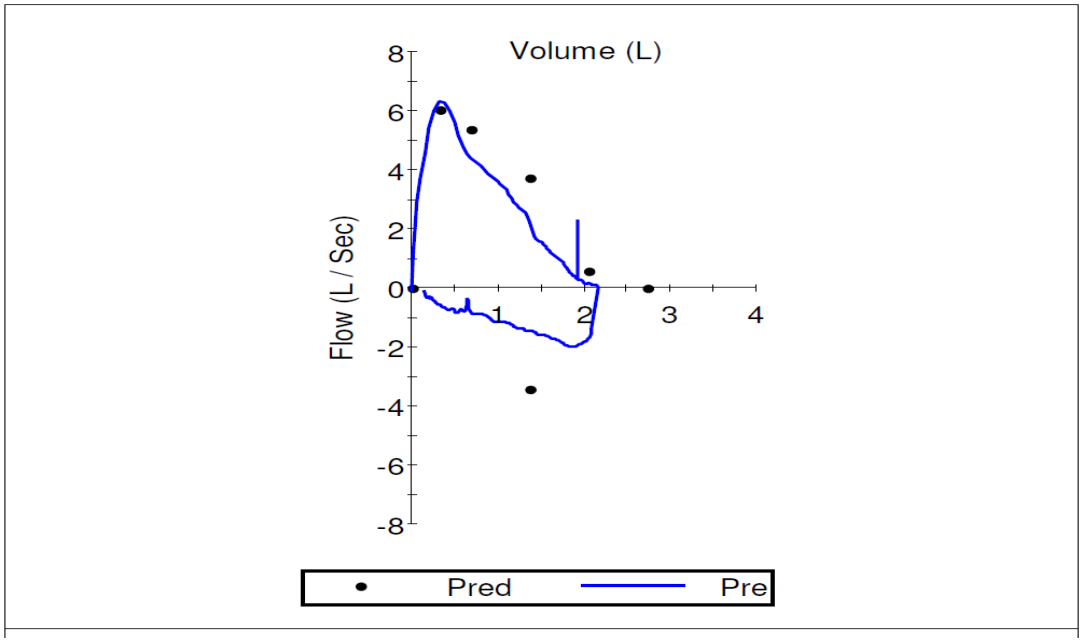
Severe airflow obstruction, lung volumes are consistent with lung hyperinflation. Marked reduction in the gas transfer factor which likely reflects poor gas mixing/poorly ventilated airspaces which in turn can lead to an underestimation of the gas transfer factor (decreased surface area, alveolar destruction). Results are consistent with COPD/Emphysema.

B22 Full Pulmonary Function Test

52 year old female referred with increasing SOB over last 12/12. Known Sickle Cell Anaemia. Never smoked. Previous TB as child and worked in various factories for last 25 years. ? lung disease.

Gender	female
Age	52
Height (cm)	158
Weight (kg)	57.3
BMI	23
Race	black

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.94	2.20	1.66	87	-0.812
VC	2.17	2.73	2.055	79	-1.388
FVC	2.16	2.73	2.055	79	-1.360
FEV_1/FVC%	89	81	71	110	1.418
FEV_1/VC%	89	81	71	110	1.418
Gas Transfer					
TL_{co} (mm/min/kPa)	5.02	7.64	5.72	65	-2.24
$TL_{co\ corr}$ (mm/min/kPa)	6.00	7.64	5.72	78	-1.40
K_{co}	1.88	1.59		118	
V_A	3.18	4.79	3.69	66	-2.40
Lung Volumes (plethysmography)					
TGV	1.85	2.60	1.78	71	-1.50
RV	1.04	1.70	1.12	61	-1.88
TLC	3.22	4.66	3.67	68	-2.41
RV/TLC%	32	37	25	88	-0.75



Interpretation B22.

Discussion points:

Spirometry is within normal limits. FEV_1, FVC and FEV_1/FVC% are all > LLN. Patient has never smoked. Patient is diagnosed with Sickle cell anaemia. Previous TB.

Spirometry shows a borderline restrictive pattern. Both FVC and SVC are sitting proportionately closer to the lower limits of normal.

Ethnic correction has been applied to spirometry measurements. BMI 23

The uncorrected gas transfer factor is moderately reduced, z-score -2.24. The gas transfer factor corrected for the known H_b is within normal limits. However the V_A on gas transfer is reduced suggesting a restrictive lung volume involvement?

Static lung volumes show a significantly reduced TLC and RV (< LLN). This is consistent with a reduced lung volume commonly seen in restrictive lung patterns. However, the static lung volume measurements have not been adjusted for ethnic correction. Applying a 12% correction to the predicted mean TLC improves the %predicted TLC to 78%. Suggesting a borderline/mild lung restrictive pattern.

Additional commentary:

A low V_A from gas transfer factor testing should not be used or seen as evidence of lung restriction. This is based on the methodology of how the V_A is derived – it is estimated from a single breath lung dilution of a tracer gas. To formally assess for a restrictive lung pattern use a static lung volume measurement.

Report:

Spirometry is within normal limits. Transfer factor corrected for the known Hb is within normal limits. Static lung volumes when corrected for ethnicity are consistent with a borderline mild restrictive pattern. BMI of 23.

B23 Full Lung Function Test

67 year old male with cardiomyopathy. Ex smoker, 30 per day for 20 years, stopped 30 years ago. Relevant medications – Bisoprolol, Ramipril, statin. Occupational exposures – HGV mechanic (brake dust exposure). Sp02 at rest 96%

Gender	male
Age	67
Height (cm)	173.5
Weight (kg)	89
BMI	30
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	2.27	3.15	2.30	72	-1.70
VC	2.95	4.11	3.08	72	-1.86
FVC	2.94	4.11	3.08	72	-1.85
FEV_1/FVC%	77	77	64	101	0.08
FEV_1/VC%	77	77	64	101	0.05
Gas Transfer					
TL_{co} (mm/min/kPa)	5.91	8.82	6.50	67	-2.07
K_{co}	1.40	1.30		108	
V_A	4.21	6.49	5.13	65	-2.75
Lung Volumes (plethysmography)					
FRC	2.22	3.57	2.59	62	-2.25
RV	1.57	2.52	1.84	62	-2.31
TLC	4.43	6.78	5.63	65	-3.35
RV/TLC%	35	40	31	88	-0.86

B23 Interpretation.

Discussion points:

Ex-smoker – 30 pack year history. BMI 30. $Sp0_2$ at rest 96%. Mild Restrictive lung pattern on spirometry. FEV_1 and VC <LLN. FEV_1/FVC% is within normal limits. Gas transfer factor is moderately reduced in the presence of a normal K_{co} and a reduced V_A.

Lung disease may be present when the K_{co} is normal in the presence of a reduced gas transfer factor and V_A. The result may be due to loss of lung units, poor gas mixing (Check V_A/TLC %), parenchymal or pulmonary vascular dysfunction or a combination of these.

The V_A/TLC ratio is 95% (normal reference >80%). No suggestion of poor gas mixing.

Static lung volumes are consistent with a restrictive lung volume. The TLC is significantly reduced (<LLN).

Report:

Spirometry and lung volumes are consistent with a restrictive lung pattern (reduced lung volumes). Gas transfer factor is moderately reduced. Reason for referral is SOBOE, medical history of cardiomyopathy. Is there a cardiac or respiratory limitation to exercise? Consider referral for CPET?

B24 Full Pulmonary Function Test

38 year old male, diagnosed and treated in the community for asthma. Attended A&E twice in last month with difficulty breathing. Unsure of triggers. FeN_O = 35ppb ?well controlled.

Gender	male
Age	38
Height (cm)	180
Weight (kg)	81
BMI	25
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	5.15	4.40	3.51	117	+1.40
VC	6.60	5.45	4.34	121	+1.71
FVC	6.35	5.45	4.34	116	+1.33
FEV_1/FVC%	81	81	71	100	+0.032
FEV_1/VC%	77	81	71	95	
Gas Transfer					
TL_{co} (mm/min/kPa)	13.29	11.45	9.13	116	+1.30
K_{co}	1.74	1.64		105	
V_A	7.65	7.00	5.63	109	+0.78
Lung Volumes (plethysmography)					
TGV	4.57	3.47	2.48	131	+1.83
RV	2.17	1.97	1.30	110	+0.48
TLC	8.78	7.31	6.16	120	+2.10
RV/TLC%	25	29	18	86	-0.77

Interpretation B24.

Report:

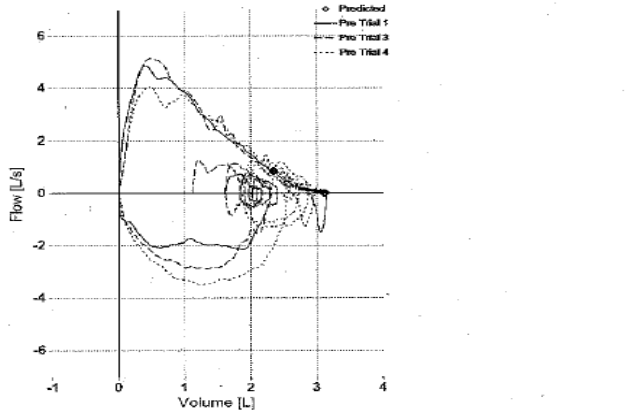
Spirometry and gas transfer factor are within normal limits.

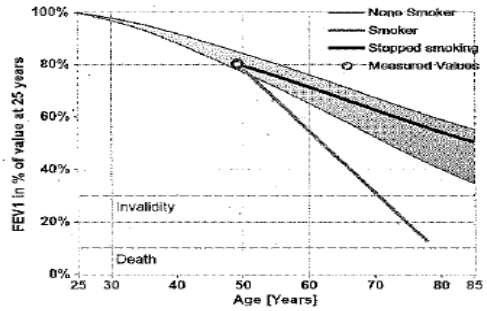
Static lung volumes show an elevated TLC however this is within normal limits.

B25 Full Pulmonary Function Test

49 year old female. Current smoker, 10 per day for 21 years. Last cigarette 30mins prior to test. BMI 36. Polycythaemia. Occupation - runs a pub.

Spirometry	Actual	Predicted	LLN	%Predicted	Z-score
FEV_1	2.380	2.640	2.061	90	-0.746
VC	3.270	2.571	3.286	97	-0.029
FVC	3.150	2.571	3.286	95	-0.308
FEV_1/FVC%	76	69.6	81	93	-0.809
FEV_1/VC%	74	69.6	81	92	
Gas Transfer					
TL_{co} (mm/min/kPa)	10.16	7.82	5.90	129	2.00
$TLco_{cor}$ (mm/min/kPa)	9.01	7.82	5.90	115	1.01
K_{co}	1.88	1.66		112	
V_A	4.80	4.83	3.73	99	-0.04
Hgb (gm/L)	180	120 - 180			
Lung Volumes (plethysmography)					
TGV	3.00	2.61	1.79	114	0.78
RV	2.00	1.68	1.10	119	0.91
TLC	5.12	4.70	3.71	108	0.70
RV/TLC%	39.06	35.95	24.29	108	0.53





Interpretation B25.

Discussion points:

Current smoker, 27 pack year history. BMI 36. Polycythaemia

Spirometry and lung volume measurements are within normal limits. Z-scores are all > -1.645

No evidence to suggest significant airflow obstruction. FEV_1/FVC% > LLN.

Uncorrected gas transfer factor (TL_{co}) is elevated (Polycythaemia Hb 180g/L), z-score +2.00 (129% predicted). When corrected for known H_b gas transfer factor ($TL_{co\ cor}$) is within normal limits for the patient (z-score +1.01, 115% predicted).

Report:

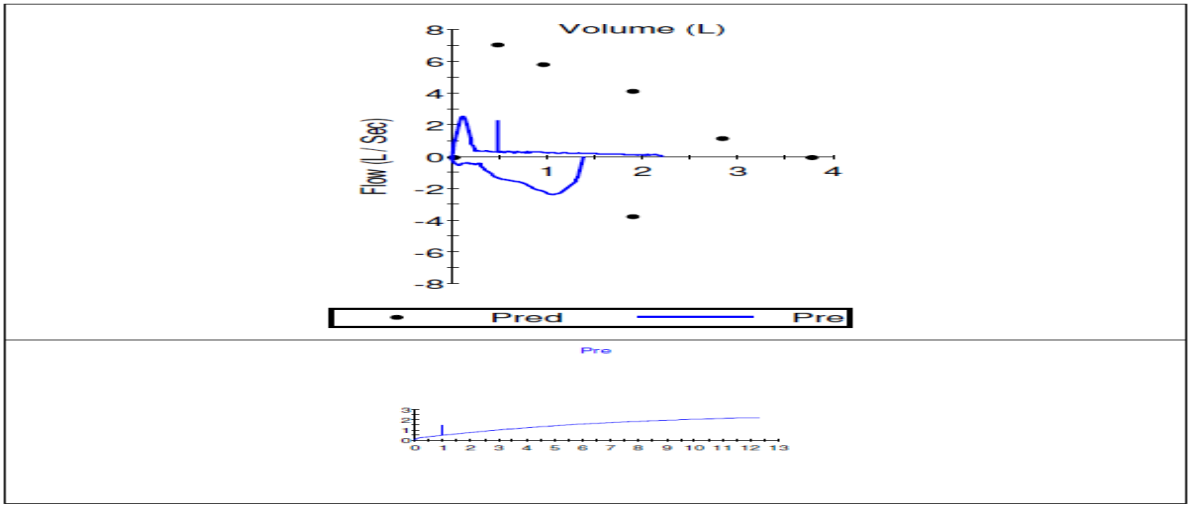
Spirometry and lung volumes are within normal limits. The corrected gas transfer factor for the known Hb is within normal limits for the patient

B26 Full Lung Function Test

42 year old female. Diagnosed with COPD and Bronchiectasis. Recently completed pulmonary rehabilitation. Repeat CT scan reported as showing stable emphysema however the referring consultant has asked for a second opinion as he felt that the CT was more consistent with localised areas of saccular bronchiectasis. Ex-smoker-quit 7 months ago, reports only smoking for 15 years with a 7.5 pack year history. She has also reported minor relapses in smoking recently. She is prescribed SABA, LAMA and LABA inhalers plus nebulised salbutamol and rescue medication (antibiotics and oral steroids). Normal echocardiogram, Normal F_eN_O levels, normal alpha-1 antitrypsin levels and normal I_gE and RAST to common allergens. SABA was used 1 hour prior to test. $Sp0_2$ at rest was 92%. The patient was breathless throughout the tests and found the tests difficult to complete.

Gender	female
Age	42
Height (cm)	165
Weight (kg)	63.5
BMI	23.3
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	0.50	3.05	2.42	16	-6.17
FVC	2.20	3.76	2.99	58	-3.40
SVC	2.16	3.76	2.99	57	-3.50
FEV_1/FVC%	23	81	71	27	-5.18
FEV1/SVC%	23	81	71	27	
Gas Transfer					
TL_{co} (mm/min/kPa)	6.23	8.67	6.75	71	-2.08
K_{co}	1.34	1.70		78	
V_A	4.62	5.22	4.12	88	-0.89
Lung Volumes (body plethysmography)					
TGV	6.74	2.74	1.92	246	+8.00
RV	6.24	1.67	1.09	373	+13.1
TLC	7.95	5.10	4.11	155	+4.75
RV/TLC%	79	33	22	234	+7.74



Interpretation B26.

Discussion points:

Good effort and technique. Resting $Sp0_2$ of 92%. Diagnosed with COPD and Bronchiectasis.

The FVL shows a very clear "church silhouette pattern" which is seen in severe airflow obstruction and is described as dynamic airway collapse.

All spirometric parameters (FEV_1, FVC and FEV_1/FVC %) are all reduced <LLN, consistent with a mixed obstructive and restrictive lung pattern.

Baseline spirometry is consistent with a very severe airflow obstruction with an element of a restrictive lung pattern.. FEV_1/FVC z-score of -5.18 with an FEV_1 z-score of -6.17. The FVC has a z-score of -3.40.

The gas transfer factor TL_{co} is reduced with a z-score of -2.08 in the presence of a mildly reduced K_{co} and a normal V_A. This pattern is seen in parenchymal or pulmonary vascular disease. The V_A/TLC% is 58% indicating impaired gas mixing. This leads to a possible underestimation of the number of contributing or accessible lung units.

The static lung volume measurement is consistent with severe lung hyperinflation with a significantly elevated (>ULN) TLC, TGV and RV/TLC%. TLC z-score is +4.75, TGV z-score is +8.00 and the RV/TLC% z-score is +7.74. All parameters are significantly elevated above the Upper Limit of Normal (ULN). Lung volumes rule out any significant lung restrictive pattern. The restrictive element seen on spirometry is a result of the dynamic airway collapse caused by the forced effort manoeuvre.

Report:

There is a very severe airflow obstruction seen on the spirometry. The lung volume measurement shows a significant lung hyperinflation. Gas transfer factor is reduced and is likely due to poor gas mixing/poorly ventilated airspaces leading to an underestimation of the gas transfer factor.

Result is consistent with very severe COPD/Bronchiectasis.

Consider blood gas assessment for oxygen therapy – low resting $Sp0_2$?

B27 Full Pulmonary Function Test

77 year old male attended following several chest infections and worsening cough. Ex-smoker. Exercise tolerance still around 2 miles although pace has slowed. Pneumonectomy 15 years ago. ?COPD. Resting $Sp0_2$ 92%.

Gender	male
Age	77
Height (cm)	180
Weight (kg)	83
BMI	25.6
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	1.48	3.04	2.17	49	-2.94
FVC	2.23	4.10	2.97	54	-2.73
SVC	2.28	4.10	2.97	57	-2.65
FEV_1/FVC%	67	74	61	91	-1.00
FEV1/SVC%	65	74	61	87	
Gas Transfer					
TL_{co} (mm/min/kPa)	5.73	8.86	6.54	64	-2.22
K_{co}	1.42	1.27		112	
V_A	4.03	6.99	5.62	57	-3.57
Lung Volumes (body plethysmography)					
TGV	2.91	3.82	2.83	76	-1.52
RV	2.26	2.83	2.16	76	-1.39
TLC	4.48	7.30	6.15	64	-4.00
RV/TLC%	50	44	33	114	1.16

Interpretation B27.

Discussion points:

Resting $Sp0_2$ 92%. Ex heavy smoker. Pneumonectomy 15 years ago. COPD? BMI 26.

Spirometry shows a lung restrictive pattern (reduced FVC and SVC with a normal FEV_1/FVC% which is > LLN).

Gas transfer factor is moderately reduced with a normal K_{co} and a significantly reduced V_A. Lung disease may be present when the K_{co} is normal in the presence of a reduced gas transfer factor and VA. The result may be due to loss of lung units, poor gas mixing (Check V_A/TLC % - is this <80%?), parenchymal or pulmonary vascular dysfunction or a combination of these.

The static lung volume measurement is consistent with a severe restrictive lung volume pattern. TLC z – score of -4.00 (64% predicted).

Report:

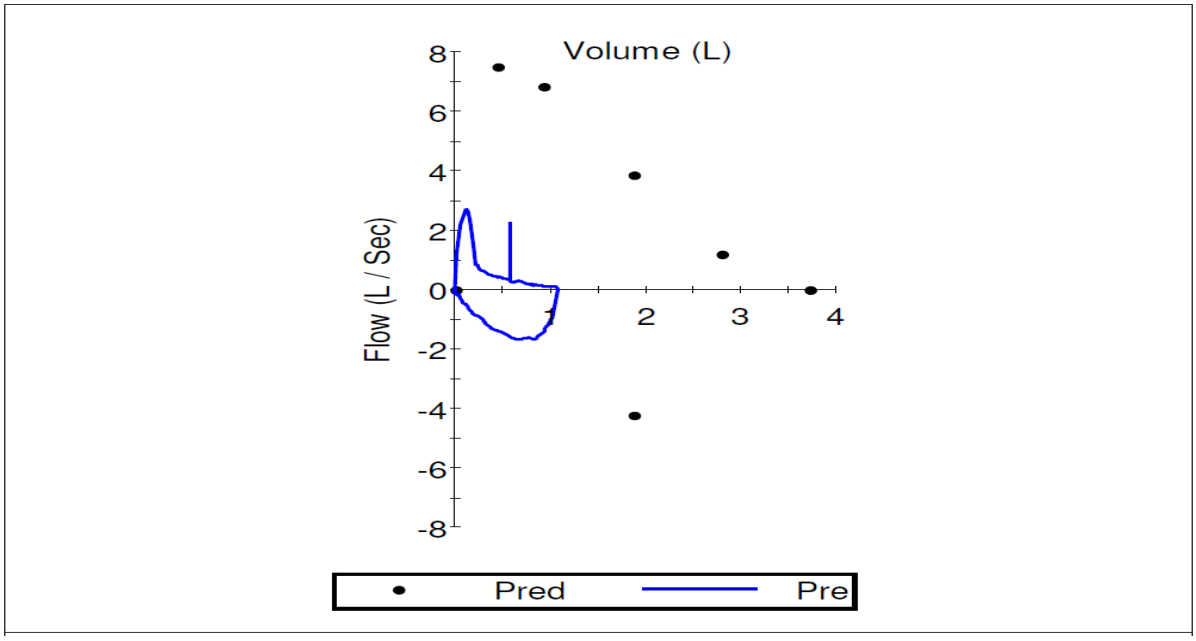
There is a restrictive spirometry and lung volume measurement indicating a loss of volume. Gas transfer factor is reduced and may be due to a loss of lung units, parenchymal or pulmonary vascular dysfunction (or a combination of these). Result is not consistent with COPD.

B28 Pulmonary Function Test

79 year old male attended with history of frequent chest infections and increasing amounts of sputum. Never smoked but spent long periods of time in pubs throughout working life and therefore exposed to passive smoking. Currently being treated with Seretide and Salbutamol inhalers. ?COPD ?Bronchiectasis.

Gender	male
Age	79
Height (cm)	176
Weight (kg)	73.5
BMI	23.7
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	0.600	2.76	1.925	22	-4.243
FVC	1.077	3.72	2.720	29	-4.337
SVC	1.395	3.72	2.720	38	-3.816
FEV_1/FVC%	56	72	61	77	-2.390
FEV1/SVC%	43	72	61	60	
Gas Transfer					
TL_{co} (mm/min/kPa)	3.85	8.26	5.94	46	-3.13
K_{co}	1.33	1.24		107	
V_A	2.96	6.68	5.31	43	-4.56
Lung Volumes (body plethysmography)					
TGV	2.82	3.75	2.76	75	-1.54
RV	2.68	2.83	2.16	94	-0.37
TLC	4.07	6.95	5.83	58	-4.15
RV/TLC%	65.76	45	34	145	3.79



Interpretation B28.

Discussion points:

?COPD ?Bronchiectasis.

Patient has a history of recurrent chest infections. Never smoked although significant exposure to secondary/passive smoking.

Mixed obstructive and restrictive spirometry all parameters are <LLN. Baseline spirometry is consistent with a very severe airflow obstruction (FEV_1/FVC % <LLN, FEV_1 z-score -4.243).

Unable to formally grade the severity of COPD without a post bronchodilator spirometry result, (as per NICE COPD guidelines).

Severely reduced gas transfer factor. Normal K_{co} with a reduced V_A.

V_A/TLC% = 71%. Suggests evidence of poor gas mixing.

Pathology may be present when K_{co} is normal in the presence of a reduced TL_{co} and V_A. The result may be due to the loss of lung units (discrete or diffuse), poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these.

The Total Lung Capacity (TLC) is significantly reduced. This is consistent with a reduced lung volume commonly seen in restrictive lung patterns (TLC z-score -4.15).

Report:

There is a significant airflow obstruction seen on spirometry. Static lung volumes are consistent with a severe restrictive lung volume pattern. Gas transfer factor is severely reduced. There is evidence of poor gas mixing which leads to an underestimation of the accessible lung units available for gas exchange.

Suggest a bronchodilator responsiveness test to assess airflow obstruction post bronchodilator, any reversibility?

Results are suggestive of COPD/Bronchiectasis.

B29 Full Pulmonary Function Test

66 year old female treated for COPD. Exercise tolerance down to 100m. Frequent exacerbations requiring hospitalisation and acute NIV. Under consideration for LVRS. Sp02 at rest 94%.

Gender	female
Age	66
Height (cm)	170
Weight (kg)	82
BMI	28.4
Race	caucasian

Spirometry	**Actual**	**Predicted**	**LLN**	**%Predicted**	**Z-score**
FEV_1	0.88	2.55	1.90	35	-4.22
FVC	1.96	3.29	2.41	59	-2.50
SVC	2.45	3.29	2.41	74	-1.58
FEV_1/FVC%	45	78	66	57	-4.67
FEV1/SVC%	36	78	66	46	
Gas Transfer					
TL_{co} (mm/min/kPa)	4.46	7.92	6.00	56	-2.96
K_{co}	1.04	1.43		72	
V_A	4.27	5.54	4.44	77	-1.89
Lung Volumes (body plethysmography)					
TGV	5.20	2.87	2.05	181	+4.66
RV	4.55	2.14	1.56	212	+6.88
TLC	7.00	5.43	4.44	128	+2.61
RV/TLC%	65	41	30	156	+4.04

Interpretation B29.

Discussion points:

30 pack year smoking history. $Sp0_2$ at rest 94%. Poor exercise tolerance, frequent exacerbations and hospital admissions and acute NIV. Smoking history?

Very severe airflow obstruction on spirometry. FEV_1/FVC% <LLN, FEV_1 z-score -4.22.

Gas transfer factor is moderate to severely reduced. Both K_{co} and V_A are reduced. The reduced V_A likely reflects the poor uptake of the transfer gas in relation to poorly ventilated air spaces (V_A/TLC% =61%, indicating impaired gas mixing). This leads to a possible underestimation of the number of contributing or accessible lung units. The low transfer factor and K_{co} is a result of the decreased surface area available for gas exchange and alveolar destruction. Typically seen in Emphysema.

Static lung volumes show a significantly elevated TLC, RV, TGV and RV/TLC%. This is consistent with lung hyperinflation and airflow obstruction. Consider bronchodilator responsiveness testing.

Report:

Spirometry is consistent with a severe airflow obstruction. There is evidence of lung hyperinflation on the static lung volume measurement. Markedly reduced gas transfer factor which likely reflects poor gas mixing and the possible underestimation of the number of contributing or accessible lung units. Typically seen in COPD/Emphysema.

B30 Full Pulmonary Function Test

Wolverhampton Respiratory Centre

Cannock Chase Hospital
Lung Function Report
Tel : 01902 695061 x 5061

The Royal Wolverhampton NHS
NHS Trust

Last Name:		Identification:	
First Name:		NHS Number:	
Age:	63 Years	Date of Birth:	01/08/1953
Height:	175.0 cm	Gender:	male
Weight:	75.0 kg	BMI:	24
Operator:		Ward:	--
Race:	Caucasian	Diagnosis:	? COPD
Physician:		Smoker:	Ex-smoker
Resting SpO2:	94%		

Visit date	14.02.17
Visit time	10:16

Spirometry reference ranges GLI 2012
Transfer Factor and Lung Volumes ECCS 1993

SPIROMETRY

		Actual	Pred	LLN	% Pred	Z- Score	Z-Score Graph
FVC	L	4.23	4.34	3.28	97.5	-0.17	
FEV 1	L	1.16	3.34	2.48	34.8	-3.90	
VC MAX	L	4.51	4.34	3.28	104.0	0.27	
FEV 1 % FVC	%	27.50	77.14	64.64	35.6	-4.99	
FEV 1 % VC MAX	%	25.76	77.14	64.64	33.4	-5.09	
PEF	L/s	3.70	8.19	6.20	45.2	-3.71	

GAS TRANSFER

DLCO_SB	mmol/(min*kPa)	3.71	9.25	6.93	40.0	-3.93
DLCOcSB	mmol/(min*kPa)	3.71	9.25	6.93	40.0	-3.93
KCO_SB	mmol/(min*kPa*L)	0.61	1.34	0.94	45.2	-2.99
KCOc_SB	mmol/(min*kPa*L)	0.61	1.34	0.94	45.2	-2.99
VA_SB	L	6.12	6.61	5.24	92.6	-0.59
RV%TLC_SB	%	37	39	30	97.3	-0.19
TLC_SB	L	6.28	6.90	5.75	91.0	-0.89
RV_SB	L	2.35	2.45	1.77	96.2	-0.23

LUNG VOLUMES

FRC-He	L	5.93	3.57	2.59	166.0	3.93
RV	L	3.82	2.45	1.77	156.1	3.35
TLC	L	8.00	6.90	5.75	115.8	1.56
RV%TLC	%	47.80	38.53	29.55	124.1	1.70

Physiologist Comments

Smoking History: 40 pack years.
Relevant Medications: Salbutamol and Spiriva not taken.
Relative Exposures: Exposure to dusts and diesel fumes for significant period of time.
Good effort and cooperation during tests. Gas transfer calculated from assumed Hb of 14.6 g/dL.

Interpretation B30.

Discussion points:

$Sp0_2$ at rest 94%. 63yr old, 40 pack year smoking history. Exposure to dusts and diesel fumes.

Severe airflow obstruction on spirometry FEV_1/VC_{max}% z-score -5.09 (↓↓), FEV_1 z-score -3.90 (↓↓), VC_{max} z-score 0.27 (within normal limits), FVC z-score -0.17 (within normal limits).

Gas transfer factor is markedly reduced. This is in the presence of a reduced K_{co} and a normal V_A.

The V_A/TLC ratio is 77%.

Gas transfer factor is severely reduced in the presence of a significantly reduced K_{co} and a normal V_A

As the V_A/TLC ratio is reduced this would suggest poor gas mixing, leading to an underestimation of the V_A.

Static lung volumes show a significantly raised RV (z-score +3.35); in conjunction with an increased RV/TLC % ratio (above the upper limit of normal) this may suggest an element of lung hyperinflation/gas trapping.

Result is consistent with COPD, however bronchodilator responsiveness testing is required to assess post bronchodilator airway obstruction and to grade severity of COPD.

Report:

Severe airflow obstruction, severely reduced gas transfer factor which is likely reduced due to poor gas mixing/poorly ventilated air spaces leading to an underestimation of the alveolar volume. There is a suggestion of gas trapping/hyperinflation on lung volumes. Result is consistent with COPD. Bronchodilator responsiveness testing would be required to grade the severity of COPD.

Simple Respiratory Muscle assessments (example B31 – B32

The following examples are simple respiratory muscle assessments. The measured parameters used for interpretation of respiratory muscle strength are MIP, MEP, SNIP and a supine versus erect vital capacity (VC) measurement.

Maximal Inspiratory Pressure (MIP or $P_I$max) and Maximal expiratory Pressure (MEP or $P_E$max) reflect the maximal pressure generated by the respiratory muscles as well as the lung elastic recoil pressure. The pressure is generated against an occluded airway and measured at RV or maximal exhalation (MIP) and TLC, maximal inspiration (MEP).

SNIP (P_{nasal}) or sniff nasal inspiratory pressure is a more dynamic measure of inspiratory muscle strength. It is the maximal pressure that is generated from a short and sharp inspiratory effort via the nose (unobstructed nostril). This is generally performed at FRC or the end of a normal tidal breath. The SNIP pressure is measured via a nasal probe inserted into one nostril.

Simple measurements of respiratory muscle strength provide a global assessment of respiratory muscles rather than pinpoint a specific muscle. A normal result will assist with excluding significant respiratory muscle weakness. The tests are very much effort dependant so ensuring good test quality is imperative. Check the technical comments before proceeding with the interpretation. An abnormal result may reflect poor test performance rather than reflecting true respiratory muscle weakness.

The primary muscles used during inspiration are the diaphragm, inspiratory intercostal muscles, scalene and sterno-mastoid muscles. During expiration the muscles of the abdominal wall and expiratory intercostal muscles are used. MIP may be reduced in isolation where airflow obstruction with lung hyperinflation is present; in this case the flattened diaphragm is at a mechanical disadvantage to generate maximal pressures.

Only abnormally low results are of interest. On the following reports the measured values are also compared against a reference value and a lower limit of normal (LLN).

Other tests from lung function measurements can be used to assess for clinically significant muscle weakness. A reduced vital capacity (VC) is a common finding in significant muscle weakness. A reduced TLC with an elevated RV/TLC% particularly when there is no significant airflow obstruction observed on spirometry may reflect the inability to fully inflate the lungs due to muscle weakness.

Simple Respiratory Muscle Assessment Interpretation Guidance

Comparing test results to a reference range allows respiratory muscle weakness to be identified. While a normal MIP, SNIP and MEP excludes clinically significant respiratory muscle weakness, low values can be difficult to interpret and do not confirm respiratory muscle weakness. Low test values can occur as a result of poor patient effort or difficulties performing the test. Please check technical comments.

MIP of > - 80cmH_20 excludes clinically significant respiratory muscle weakness in both males and females

MEP of > +80cmH_20 (males) and > +60cmH_20 (females) excludes clinically significant muscle weakness.

SNIP of > - 70cmH_20 (males) and > - 60cmH_20 (females) excludes clinically significant muscle weakness

A normal MEP with a low MIP suggests isolated diaphragmatic weakness. When assessing serial mouth pressure measurements a change in excess of 25cmH_20 can be used as a threshold to identify true change in respiratory muscle strength.

Upright or erect Vital Capacity vs Supine Vital Capacity:

A low vital capacity; or a drop in excess of 30% [7] when changing from upright to supine in the vital capacity (VC) and a reduced TL_{co} and V_A with an elevated K_{co} can all be suggestive of respiratory muscle weakness although concomitant lung disease must be considered when interpreting the test results.

If simple muscle assessment is inconclusive, a referral for more complex specialist muscle testing should be considered.

Below are the thresholds for referral for NIV for Motor Neurone Disease as per NICE Guideline [NG42]: Motor Neurone Disease- Assessment and management.

Forced Vital Capacity (FVC) or Vital Capacity (VC)	**Sniff nasal inspiratory pressure (SNIP) and/or maximal inspiratory pressure (MIP)** *(if both tests are performed, base the assessment on the better respiratory function reading)*
FVC or VC < 50% of predicted value FVC or VC < 80% of predicted value plus any symptoms or signs of respiratory impairment, particularly orthopnoea	SNIP or MIP < 40cmH_20 SNIP or MIP < 65cmH_20 for men or 55cmH_20 for women plus any symptoms or signs of respiratory impairment, particularly orthopnoea. Repeated regular tests show a rate of decrease of SNIP or MIP of more than 10cmH_20 per 3 months

B31 Simple Respiratory Muscle Assessment

67 year old female diagnosed with MND 9/12 ago. Mainly bulbar symptoms. Referred for consideration of NIV. ABG's show compensated type II respiratory failure. ? degree of muscle weakness. Patient had difficulty maintaining a tight seal around the mouthpiece.

Gender	female
Age	67
Height (cm)	163
Weight (kg)	69

	Measured value (cmH_20)	Reference range or LLN (cmH_20)
MEP	+17	>57
MIP	-9	>29
SNIP	-21	>29

	Measured	%Predicted
VC upright (L)	1.48	48%
VC supine (L)	0.95	
% Change in VC	-36%	

Interpretation B31.

Report:

Known MND, mainly bulbar symptoms.

Results should be interpreted with caution. Patient had difficulty maintaining a tight seal around mouthpiece (Bulbar symptoms).

Results would suggest a possible global respiratory muscle weakness as MIP. MEP and SNIP are markedly < LLN for this patient. There was also a significant fall in VC when measured in supine position (-36% fall) suggesting a diaphragmatic weakness.

As per NICE guidelines patient should be considered for NIV (VC < 50% predicted, SNIP < 40cmH_20).

Additional commentary:

Bulbar Signs and symptoms can include progressive difficulty with talking and swallowing. Patients can also exhibit reduced gag reflexes, weak palatal movements, fasciculation's (a brief spontaneous contraction affecting a small number of muscle fibres, often causing a flicker of movement under the skin), and weak movement of the facial muscles and tongue

B32 Simple Respiratory Muscle Assessment

60 year old male with possible diaphragm palsy – raised right hemi-diaphragm on CXR. On-going SOB. Moderate airflow obstruction on Spirometry. Ex-smoker-quit 2011, COPD, IHD, MI 2013. $Sp0_2$ on air 95%. Works as a carpenter has had significant exposure to asbestos. Good effort and technique during measurement.

Gender	male
Age	60
Height (cm)	191
Weight (kg)	113

	Measured value (cmH_20)	Reference range or LLN (cmH_20)
MEP	+103	>67
MIP	-49	>53
SNIP	-54	>62

	Measured
VC upright (L)	4.66
VC supine (L)	3.27
% Change in VC	-30%

Interpretation B32.

Report:

Good effort and technique.

MEP is within normal limits (>LLN) also >+80cmH_20.

Significantly reduced MIP and SNIP. A normal MEP with a low MIP suggests isolated diaphragmatic weakness

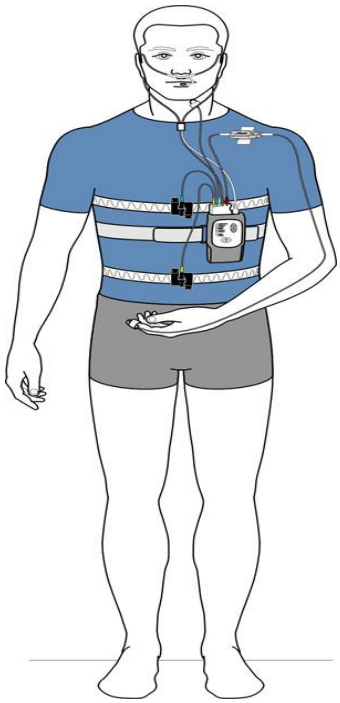
Supine vs erect VC measurement shows a -30% fall when in supine position. Result is consistent with diaphragmatic weakness.

What is a Respiratory Sleep study?

The high prevalence of Obstructive Sleep Apnoea requires the need for effective strategies with simple and relatively fast tests to identify patients with significant sleep disordered breathing. It is estimated that 75% of outpatients with a suspected diagnosis of OSA are investigated using a limited respiratory sleep study, sometimes referred to as a respiratory sleep polygraphy.

What is measured?

The equipment is worn overnight by the patient typically at home and records oxygen levels ($Sp0_2$), breathing movements (Chest and abdomen belts), Nasal airflow or pressure (nasal cannula or thermistor), sleep position (supine, right, left, upright), heart rate and snoring (audio). A limited sleep study does not have EEG signals and is therefore different to a polysomnography.



How is the data analysed?

Current evidence suggests that the patient needs to have at least 5 hrs of good quality sleep with the equipment for an accurate analysis and interpretation to be made. The data is either "scored" automatically by the associated analysis software or manually by a senior respiratory physiologist or competent practitioner. Guidelines suggest that competently trained practitioners perform manual analysis or scoring because of its greater diagnostic accuracy. The data and events are scored in line with the American Academy of Sleep Medicine (AASM) guidelines.

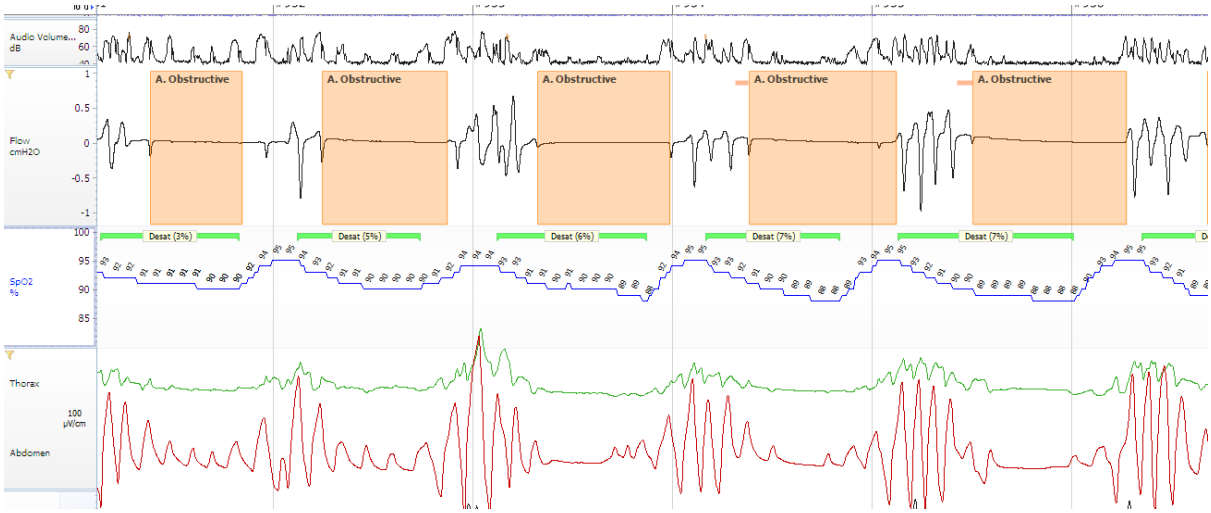
What are the respiratory event types?

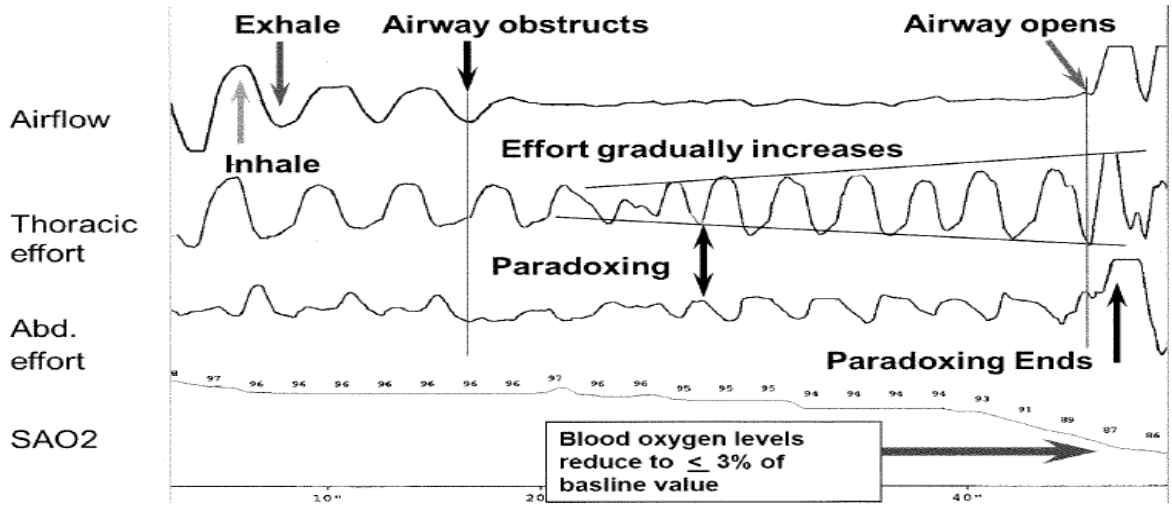
- Obstructive apnoea
- Central apnoea
- Mixed apnoea
- Hypopnoea

All respiratory events need to be at least 10 seconds long.

What is an Obstructive apnoea?

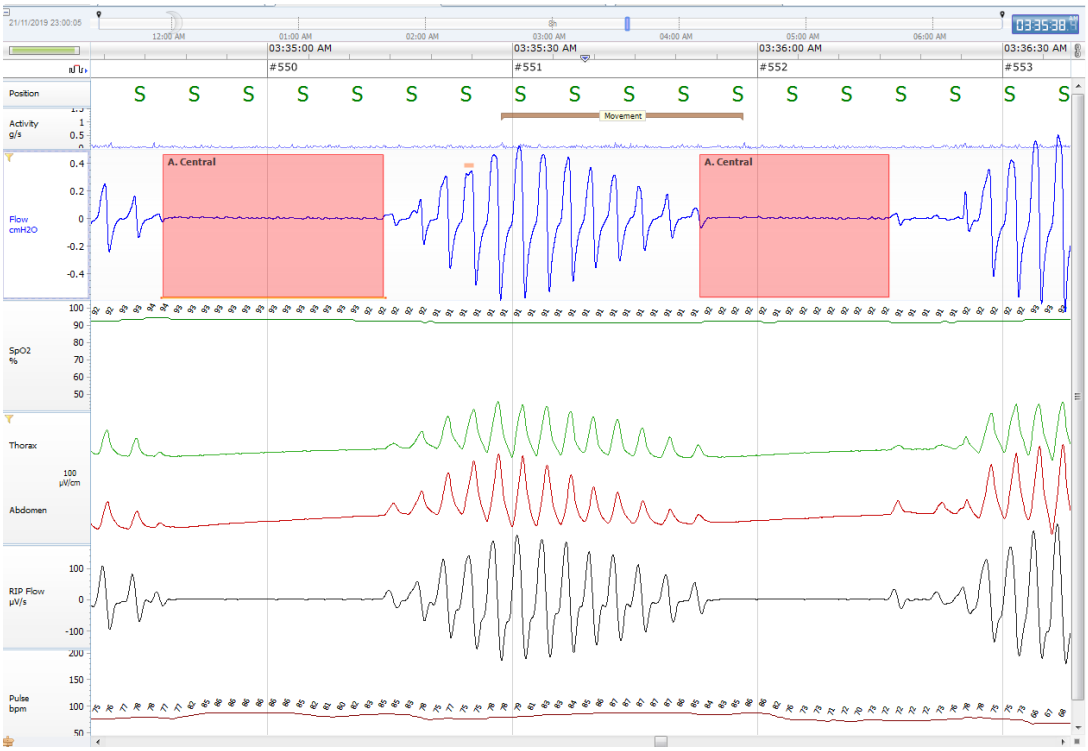
No airflow for a minimum of 10 seconds with an associated increase in respiratory effort, which can present as paradoxical chest and abdomen movement. Paradoxical breathing is sometimes referred to as diaphragmatic loading and describes when the chest and abdomen move in opposition to each other rather than together during normal breathing. A ≥3% desaturation is not required to score an obstructive apnoea. The events are measured either using the nadir or peak to peak methods. The nadir method starts at the end of the last breath prior to the obstructive apnoea to the beginning of the next breath. The automatic scoring method employed by the Noxturnal© T3 sleep system employs this method. Peak to peak looks at the peak of the last breath to the peak of the next breath following the obstructive apnoea and this is the preferred method when manually scoring.





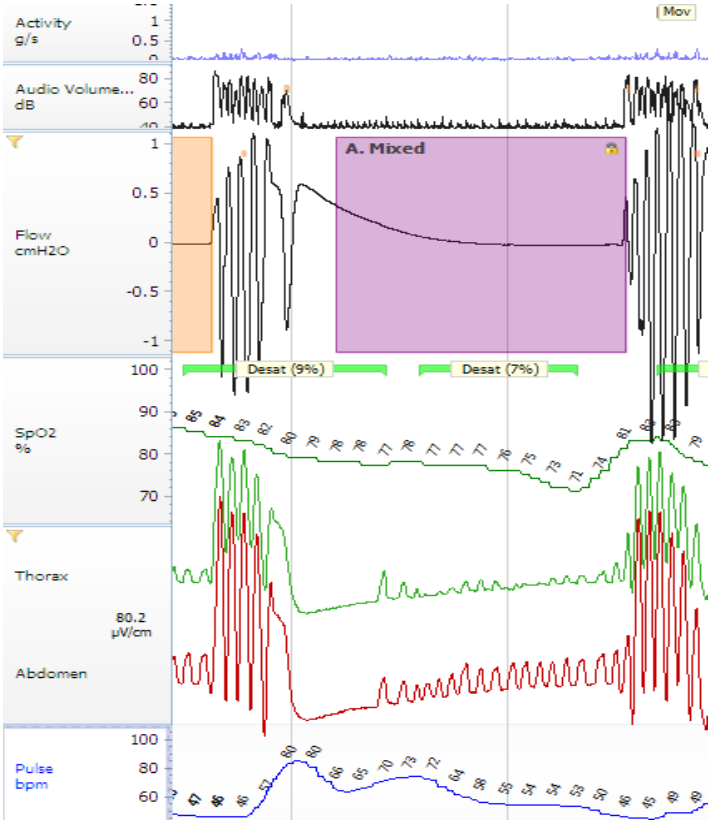
What is a Central apnoea?

Absence of airflow at the nose and mouth for a minimum of 10 seconds with a complete absence of respiratory effort as measured by chest and abdomen belts. No desaturation is required but can be seen in excessively long central apnoea events.



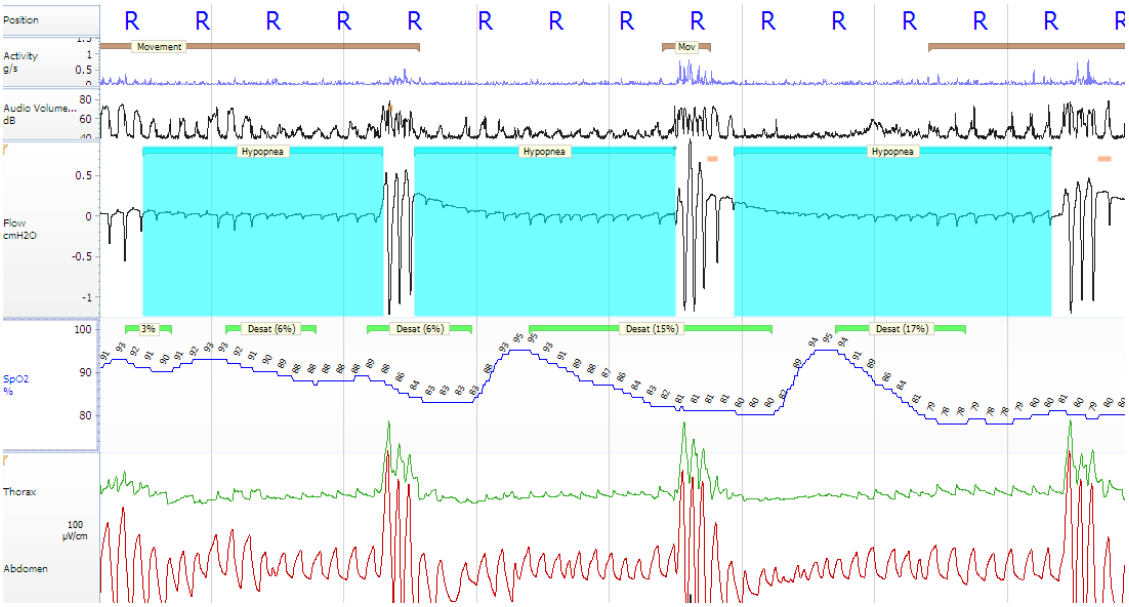
What is a mixed apnoea?

Complete absence of nasal or oral flow, total absence of respiratory effort at the beginning of the event followed by a gradual increase in effort. No desaturation is needed but can be present. It is termed mixed as it refers to a mixture of a central and an obstructive apnoea. The mixed apnoea may have a short central component or a larger one, for example a 30 second central apnoea and a 10 second hypopnoea. The example below shows a shorter central component and a longer hypopnoea. Physiologically during the central portion of the mixed apnoea there is a gradual increase in $C0_2$ which subsequently acts as a stimulus to breathe and leads to the gradual increase in respiratory effort. As with all respiratory events a mixed apnoea may be longer during REM sleep. Mixed apnoea's can be seen as a sign of a complex sleep disordered breathing patient.



What is a Hypopnoea?

A Hypopnoea is defined by the AASM as a reduction in airflow of about 30% from baseline. To assess if a 30% fall in airflow is present it is important to look at airflow on the page or epoch before and after the identified event. A hypopnoea must have an associated ≥ 3% desaturation which can occur during the event or in the lag period following the event. The AASM guidelines state that the 3% desaturation does not need to be during or after a hypopnoea event. The Noxturnal© T3 system software uses within 20 seconds of an event. When scoring hypopnea's manually- it is advised to use a 25-30 second lag, if any longer then the desaturation is not likely attributed to the event. A hypopnoea may be scored as an obstructive apnoea when the nasal pressure signal is ≤ 10% from baseline. A hypopnoea has the same physiological consequence as an apnoea.

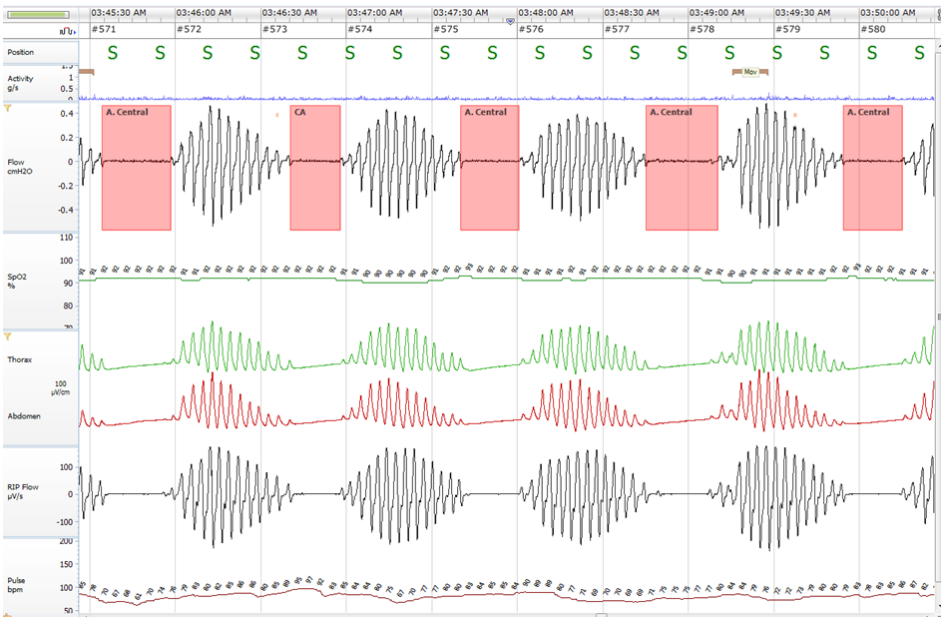


What is Cheyne - Stokes respiration (CSR)?

This is a crescendo-decrescendo respiratory breathing pattern usually associated with congestive heart failure. Atrial fibrillation may be present. It is defined as three consecutive cycles of crescendo – decrescendo pattern in breathing signal with a cycle length of a minimum of 40 seconds and at least one of the following:

- 5 or more central apnoea's per hour of sleep
- 5 or more hypopnea's per hour of sleep

The scoring criteria are defined as a 50% change in amplitude, diagnostic criteria – 33% of the night spent in CSR.



Apnoea-Hypopnoea index (AHI) severity grading ($SIGN_{2003}$, NICE $_{2008}$).

- <5 Normal
- 5 – 15 Mild
- 15- 30 Moderate
- >30 Severe

Writing a sleep study report.

Below is a summary report for a limited respiratory sleep study. This has all the data required to report the sleep study. The summary report would be produced after the sleep study was either autoscored or manually scored by a competent practitioner (this is dependent upon local practice).

When writing a sleep study report it is important to firstly comment on how the study was reviewed/scored (i.e. autoscored or manually scored?). Who scored the sleep study? Comment on the study quality and to ascertain whether there is enough usable information for an interpretation. In general the supine time ideally needs to be >30% of the total recording time. If <30% then consider repeating the sleep study. Comment on the recording time, was this >5hrs? Is the signal quality acceptable? Was there any loss of flow or oximetry throughout the recording?

State the AHI and grade this using the grading criteria listed above. It is also good practice to also state the ODI or oxygen desaturation index. If the ODI is significantly greater than the AHI then this may indicate a loss of flow signal during the recording. If the AHI is significantly greater than the ODI then this may indicate a higher number of apnoea's without an associated oxygen desaturation. Do the respiratory events appear positional in nature? As an example do more events occur on perhaps the patients right side or when in supine position, suggesting positional OSA?

Comment on the snore index, the snore index is % of the study spent in snore train, a snore train is defined as a period of 3 or more snores in a continuous row.

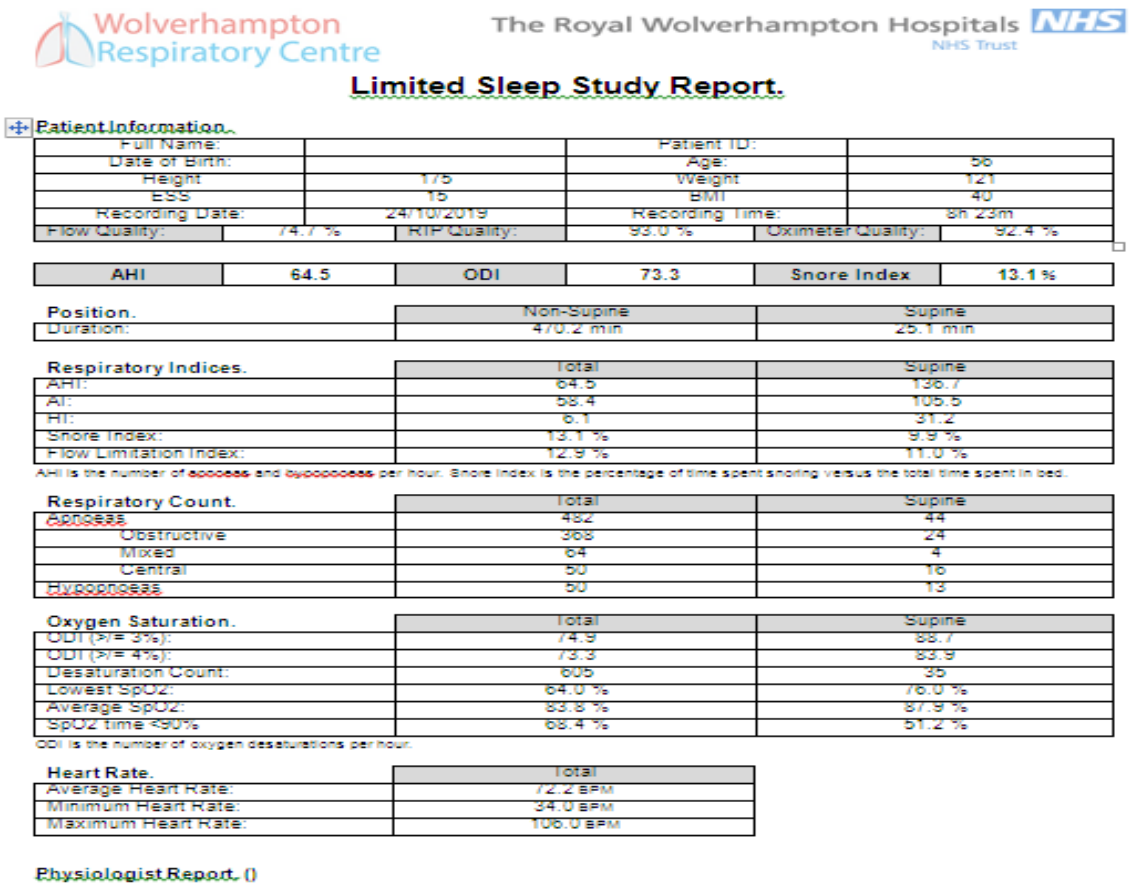
Comment on the flow limitation index (FLI), excessive flow limitation alone i.e. >30% can lead to excessive daytime tiredness.

Summarise the number and type of respiratory events (hypopnoea, obstructive apnoea, mixed, or central), which event was most prominent throughout the recording?

What was the mean $Sp0_2$ throughout the night? What was the minimum Sp02? What % of the study time was spent <90% $Sp0_2$?

Does the patient need to inform the DVLA? If the Epworth sleepiness score is high then the patient may have obstructive sleep apnoea syndrome (OSAS). Is CPAP treatment to be considered?

Finally consider adding some technical comments especially if there was some signal artefact during the recording. Consider adding to your report "Due to signal artefact please interpret with caution. Please use clinical judgement" or "Please interpret findings in light of clinical correlation"



Wolverhampton Respiratory Centre

The Royal Wolverhampton Hospitals NHS
NHS Trust

Limited Sleep Study Report.

Patient Information.

Full Name:		Patient ID:	
Date of Birth:		Age:	56
Height	175	Weight	121
ESS	15	BMI	40
Recording Date:	24/10/2019	Recording Time:	8h 23m

Flow Quality:	74.7 %	RIP Quality:	93.0 %	Oximeter Quality:	92.4 %

AHI	64.5	ODI	73.3	Snore Index	13.1 %

Position.	Non-Supine	Supine
Duration:	470.2 min	25.1 min

Respiratory Indices.	Total	Supine
AHI:	64.5	136.7
AI:	58.4	105.5
HI:	6.1	31.2
Snore Index:	13.1 %	9.9 %
Flow Limitation Index:	12.9 %	11.0 %

AHI is the number of apnoeas and hypopnoeas per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Count.	Total	Supine
Apnoeas	482	44
Obstructive	368	24
Mixed	64	4
Central	50	16
Hypopnoeas	50	13

Oxygen Saturation.	Total	Supine
ODI (>/= 3%):	74.9	88.7
ODI (>/= 4%):	73.3	83.9
Desaturation Count:	605	35
Lowest SpO2:	64.0 %	76.0 %
Average SpO2:	83.8 %	87.9 %
SpO2 time <90%	68.4 %	51.2 %

ODI is the number of oxygen desaturations per hour.

Heart Rate.	Total
Average Heart Rate:	72.2 BPM
Minimum Heart Rate:	34.0 BPM
Maximum Heart Rate:	106.0 BPM

Physiologist Report. ()

Below you will find a number of limited respiratory sleep study reports, the default sleep reports have been used rather than those customised locally as seen above. The data provided is the same and perhaps a little bit more detailed.

Write a sleep study report for each of these using the guidance notes above. *See appendix 4 for an example of a sleep study reporting template to assist in formulating a report.*

B33 Respiratory Sleep Study

A 57 year old male attended the sleep clinic complaining of excessive daytime sleepiness, loud snoring and witnessed breath holding. His wife also suggests that there is sometimes very little chest movement from him during sleep. No morning headaches. BMI 31, ESS 14 ?OSA.

Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E1	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	09/12/2014	Bed Time Starts	23:13
Recording Time	23:00	Bed Time Ends	05:25
Recording Duration	7h 59m 59s	Time in Bed	6h 11m (371.8m)

Respiration Overview

AHI 62.8 ODI 60.8 Snore Index 16.5%

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices	total	supine
Apnea/Hypopnea Index	62.8 /h	64.9 /h
Apnea Index	59.5 /h	62.6 /h
Hypopnea Index	3.2 /h	2.3 /h
Snore Index	16.5 %	15.7 %
Flow Limitation Index	24.7 %	19.8 %
Longest Apnea	79 s	79 s
Longest Hypopnea	47 s	36 s

Respiratory Count	total	supine
Apneas	369	188
Obstructive	203	91
Mixed	166	97
Central	0	0
Hypopneas	20	7
Average Apnea	38 s	39 s
Average Hypopnea	30 s	27 s

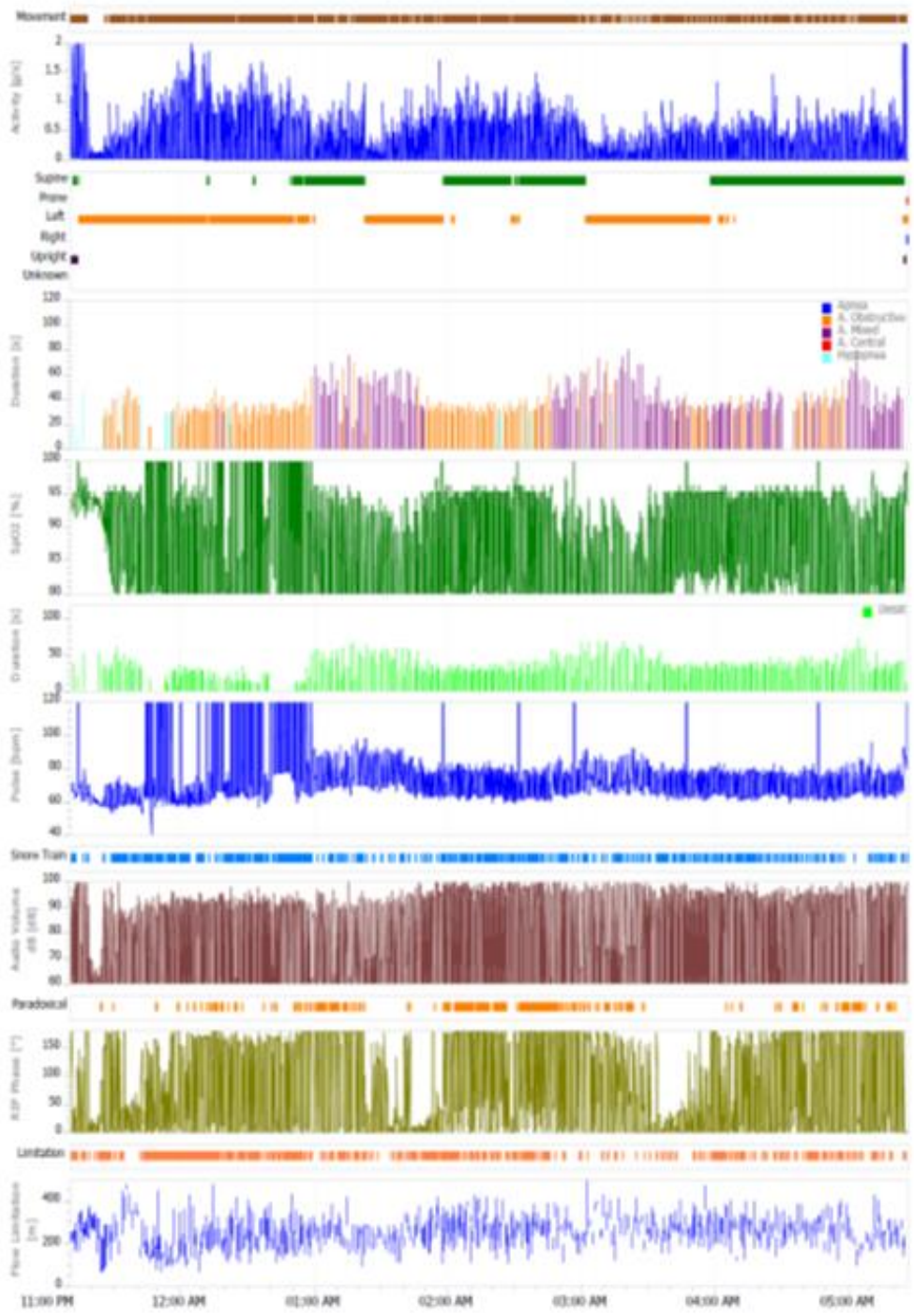
Saturation	total	supine
Desaturation Index	60.8 /h	65.9 /h
Desaturation Count	377	198
Lowest SpO2	52.0 %	54.0 %
Average SpO2	81.9 %	82.9 %
Baseline SpO2	84.6 %	82.9 %
Desaturation < 90%:	60.0 /h	65.6 /h
Desaturation < 85%:	58.7 /h	64.2 /h
SpO2 time < 90%:	68.7 %	69.4 %
SpO2 time < 85%:	52.8 %	51.4 %

Pulse	total	supine
Average Pulse	67 bpm	68 bpm
Highest Pulse	96 bpm	96 bpm
Lowest Pulse	38 bpm	57 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	5.4 bpm	5.6 bpm
Average Desat Drop	19.2 %	17.9 %
Average Low Desat	73.7 %	75.3 %

Position and Activity		
Supine Time	180.7 m	48.0 %
Non-Supine Time	192.8 m	51.2 %
Upright Time	3.2 m	0.9 %
Activity Time	221.9 m	58.9 %
Invalid Data Time	0 m	0.0 %

Other	total	supine
Oximeter Quality	94.7 %	Fair
Flow Quality	100.0 %	Good
RIP Quality	99.6 %	Good
Paradoxical Index	28.3 %	43.8 %
Est. Sleep Efficiency	41.6 %	40.1 %
Respiration Rate	21.5	21.6

Trend Overview



Interpretation B33.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist.

Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The supine time was >30% of the total recording time (48%). *If <30% then consider repeating the sleep study*. The time in bed was 6hrs and 11minutes. Oximeter quality was 95%; flow signal quality was 100%.

The results indicate severe sleep disordered breathing (SDB) with an AHI of 62.8 and an ODI of 60.8. The slight difference seen in AHI and ODI would suggest a slightly higher significance of apnoea's without an associated desaturation. The patient had an Epworth score of 14 (normal ref <12).

Severe Obstructive sleep apnoea syndrome (OSAS), DVLA advice to be given – consider trial of CPAP.

The patient had a snore index of 16.5%. The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row).

The flow limitation index was 24.7% (normal reference <30%*). Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness*.

The majority of events were obstructive apnoea's.

There were 203 obstructive apnoea's, 166 mixed apnoea's, 20 hypopneas and no central events.

The average Sp02 was 82%, with 69% of the recording being spent <90%. The minimum Sp02 was 52%.

Please interpret findings in light of clinical correlation.

AHI severity grading – SIGN 2003, NICE 2008, Powell et al 2010

<5 normal

5-15 mild

15-30 moderate

>30 severe

B34 Respiratory Sleep Study

81 year old male referred from cardiology regarding on-going orthopnoea and daytime sleepiness. Diagnosed with heart failure 15 years ago – last ejection fraction 21%. Non snorer. BMI 24, ESS 9.

Respiration Report

Patient Information

Full Name		Date of Birth	22/02/1935
Patient ID	E2	Height	169 cm
Address		Weight	72 kg
ZIP/Postal Code		BMI	25.2
City		Age	81
Phone/Mobile			

Recording Information

Recording Date	**12/06/2014**	Bed Time Starts	22:44
Recording Time	22:00	Bed Time Ends	05:59
Recording Duration	7h 59m 58s	Time in Bed	7h 12m (432.6m)

Respiration Overview

AHI **37.3** ODI **39.8** Snore Index **5.6%**

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices	total	supine
Apnea/Hypopnea Index	37.3 /h	33.7 /h
Apnea Index	32.3 /h	29.5 /h
Hypopnea Index	5.0 /h	4.2 /h
Snore Index	5.6 %	7.6 %
Flow Limitation Index	4.6 %	4.5 %
Longest Apnea	50 s	50 s
Longest Hypopnea	87 s	87 s

Respiratory Count	total	supine
Apneas	233	134
Obstructive	31	27
Mixed	40	35
Central	162	72
Hypopneas	36	19
Average Apnea	24 s	27 s
Average Hypopnea	30 s	29 s

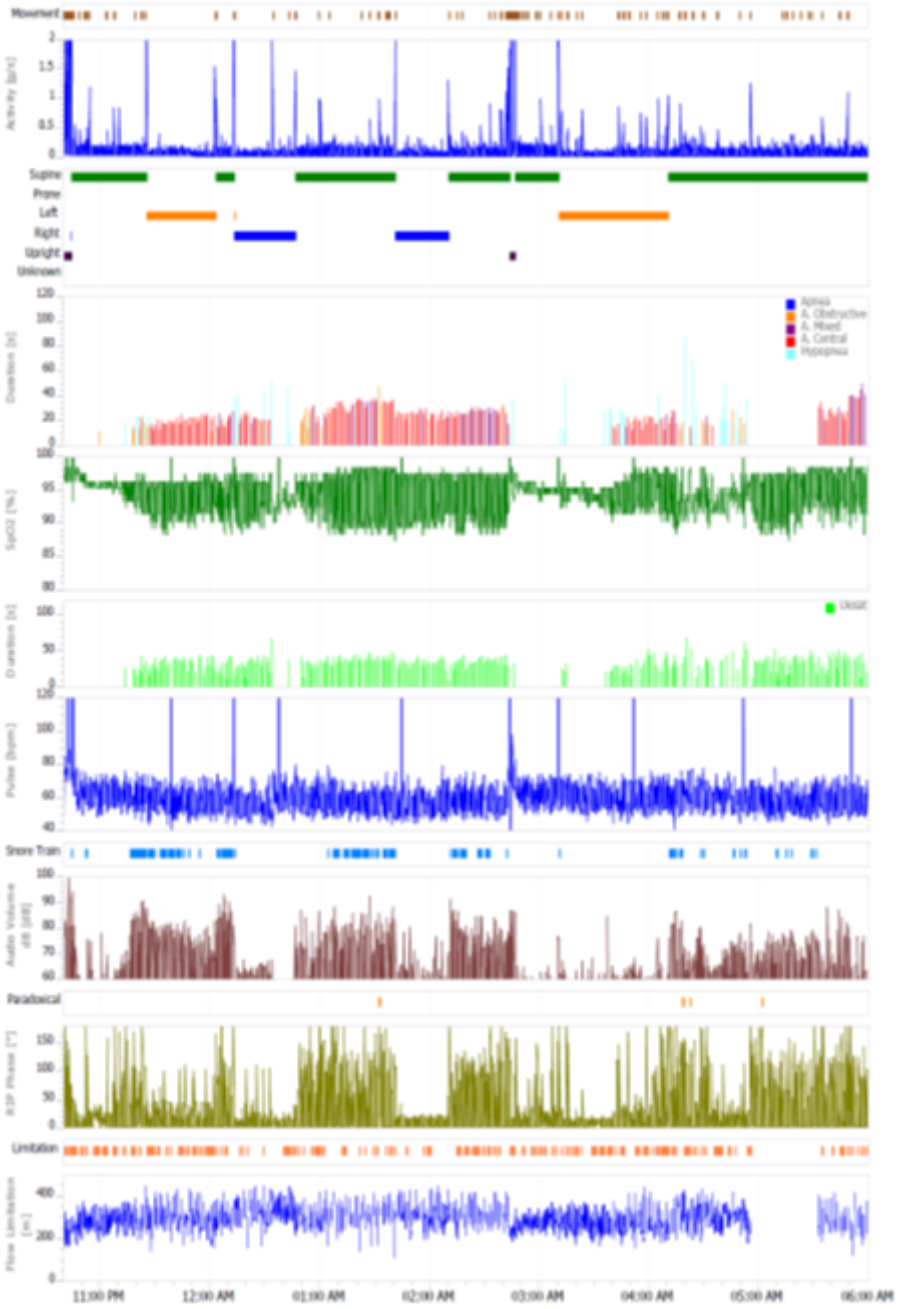
Saturation	total	supine
Desaturation Index	39.8 /h	39.2 /h
Desaturation Count	287	178
Lowest SpO2	87.0 %	87.0 %
Average SpO2	94.0 %	94.2 %
Baseline SpO2	94.7 %	95.0 %
Desaturation < 90%:	15.4 /h	17.4 /h
Desaturation < 85%:	0.0 /h	0.0 /h
SpO2 time < 90%:	3.3 %	3.6 %
SpO2 time < 85%:	0.0 %	0.0 %

Pulse	total	supine
Average Pulse	58 bpm	58 bpm
Highest Pulse	83 bpm	83 bpm
Lowest Pulse	40 bpm	40 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	5.5 bpm	5.5 bpm
Average Desat Drop	6.8 %	7.0 %
Average Low Desat	90.1 %	90.0 %

Position and Activity		
Supine Time	272.3 m	61.8 %
Non-Supine Time	160.3 m	36.4 %
Upright Time	7.7 m	1.8 %
Activity Time	27.1 m	6.2 %
Invalid Data Time	0 m	0.0 %

Other	total	supine
Oximeter Quality	99.8 %	Good
Flow Quality	93.7 %	Fair
RIP Quality	100.0 %	Good
Paradoxical Index	0.5 %	0.8 %
Est. Sleep Efficiency	95.5 %	93.7 %
Respiration Rate	18.7	19.1

Trend Overview



Interpretation B34.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist.

Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The supine time was >30% of the total recording time (62%). *If <30% then consider repeating the sleep study*. The time in bed was 7hrs and 12minutes. Oximeter quality was 100%; flow signal quality was 94%.

The results indicate severe sleep disordered breathing (SDB) with an AHI of 37.3 and an ODI of 39.8. The patient had an Epworth score of 9 (normal ref <12).

The patient had a snore index of 5.6%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row).*

The flow limitation index was 4.6% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness.*

The majority of events were central sleep apnoea's (162).

There were also 31 obstructive apnoea's, 40 mixed apnoea's and 36 hypopneas.

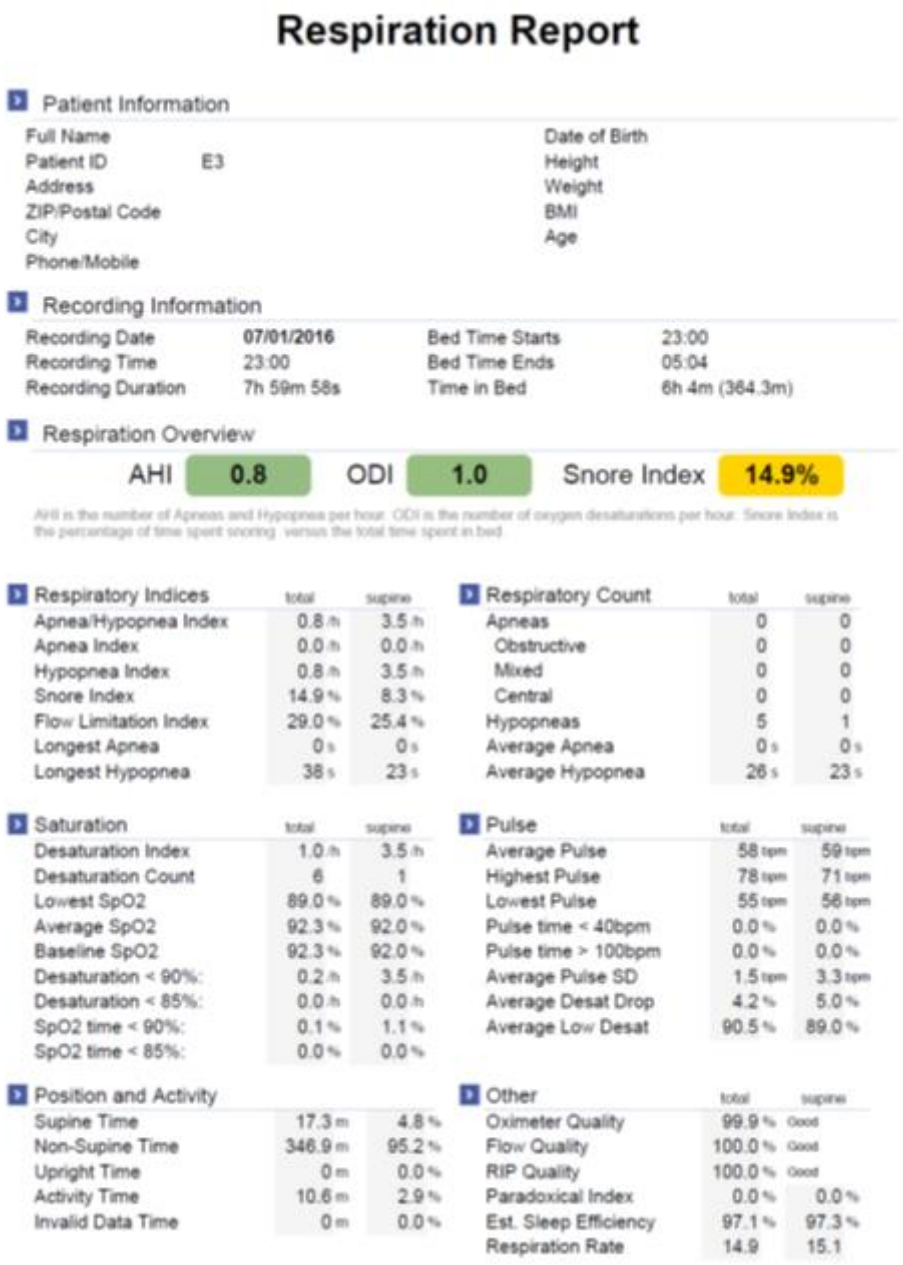
The average Sp02 was 94%, with 3.3% of the recording being spent <90%. The minimum Sp02 was 87%.

Central sleep apnoea (CSA) is a manifestation of respiratory control instability in patients with heart failure. While recent evidence suggests a decrease in its prevalence in patients with heart failure, CSA remains a relatively common disorder in this population. Central sleep apnoea (CSA) occurs in 25-40% of patients with HF with reduced ejection fraction and often may manifest with Cheyne-Stokes respiration. However, sleep apnoea-targeted therapies (CPAP) have not previously been shown to improve cardiovascular outcomes in patients with HF.

Please interpret findings in light of clinical correlation.

B35 Respiratory Sleep Study

31 year old female attended clinic complaining of excessive daytime sleepiness and trouble sleeping at night. Takes around 90 minutes to fall asleep and wakes frequently during the night. She sleeps alone and unaware of snoring. Also suffers from vivid dreams when very stressed. ?any sleep disordered breathing



Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E3	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	07/01/2016	Bed Time Starts	23:00
Recording Time	23:00	Bed Time Ends	05:04
Recording Duration	7h 59m 58s	Time in Bed	6h 4m (364.3m)

Respiration Overview

AHI 0.8 ODI 1.0 Snore Index 14.9%

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed

Respiratory Indices

	total	supine
Apnea/Hypopnea Index	0.8 /h	3.5 /h
Apnea Index	0.0 /h	0.0 /h
Hypopnea Index	0.8 /h	3.5 /h
Snore Index	14.9 %	8.3 %
Flow Limitation Index	29.0 %	25.4 %
Longest Apnea	0 s	0 s
Longest Hypopnea	38 s	23 s

Respiratory Count

	total	supine
Apneas	0	0
Obstructive	0	0
Mixed	0	0
Central	0	0
Hypopneas	5	1
Average Apnea	0 s	0 s
Average Hypopnea	26 s	23 s

Saturation

	total	supine
Desaturation Index	1.0 /h	3.5 /h
Desaturation Count	6	1
Lowest SpO2	89.0 %	89.0 %
Average SpO2	92.3 %	92.0 %
Baseline SpO2	92.3 %	92.0 %
Desaturation < 90%:	0.2 /h	3.5 /h
Desaturation < 85%:	0.0 /h	0.0 /h
SpO2 time < 90%:	0.1 %	1.1 %
SpO2 time < 85%:	0.0 %	0.0 %

Pulse

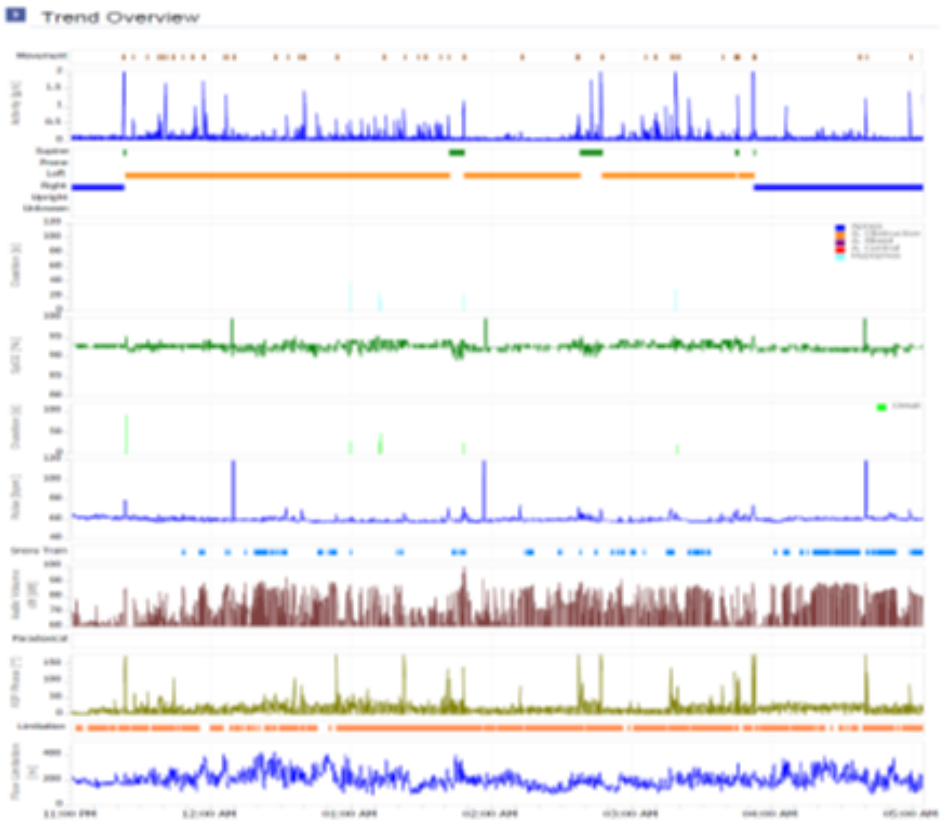
	total	supine
Average Pulse	58 bpm	59 bpm
Highest Pulse	78 bpm	71 bpm
Lowest Pulse	55 bpm	56 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	1.5 bpm	3.3 bpm
Average Desat Drop	4.2 %	5.0 %
Average Low Desat	90.5 %	89.0 %

Position and Activity

Supine Time	17.3 m	4.8 %
Non-Supine Time	346.9 m	95.2 %
Upright Time	0 m	0.0 %
Activity Time	10.6 m	2.9 %
Invalid Data Time	0 m	0.0 %

Other

	total	supine
Oximeter Quality	99.9 %	Good
Flow Quality	100.0 %	Good
RIP Quality	100.0 %	Good
Paradoxical Index	0.0 %	0.0 %
Est. Sleep Efficiency	97.1 %	97.3 %
Respiration Rate	14.9	15.1



Interpretation B35.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist.

Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The time in bed was 6hrs and 4minutes. Oximeter quality was 100%; flow signal quality was 100%.

The results indicate no evidence to suggest significant sleep disordered breathing (SDB) with an AHI of 0.8 and an ODI of 1.0.

The patient had a snore index of 15%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row)*.The flow limitation index was 29% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness*.

There were 5 hypopnoeas and no central events.

The average Sp02 was 92.3%, with 0.1% of the recording being spent <90%. The minimum Sp02 was 89%.

Please interpret findings in light of clinical correlation.

B36 Respiratory Sleep Study

37 year old female attended clinic complaining of sleepiness and lack of energy during the day. Partner has witnessed apnoea's. Snores in all positions. Has two children under age of 4. BMI 29, ESS 15

Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E4	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	**16/04/2015**	Bed Time Starts	23:00
Recording Time	23:00	Bed Time Ends	04:14
Recording Duration	7h 55m 18s	Time in Bed	5h 10m (310.2m)

Respiration Overview

AHI **13.5** ODI **14.7** Snore Index **57.2%**

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices	total	supine
Apnea/Hypopnea Index	13.5 /h	25.4 /h
Apnea Index	4.4 /h	16.9 /h
Hypopnea Index	9.1 /h	8.5 /h
Snore Index	57.2 %	44.8 %
Flow Limitation Index	28.9 %	14.5 %
Longest Apnea	37 s	20 s
Longest Hypopnea	88 s	19 s

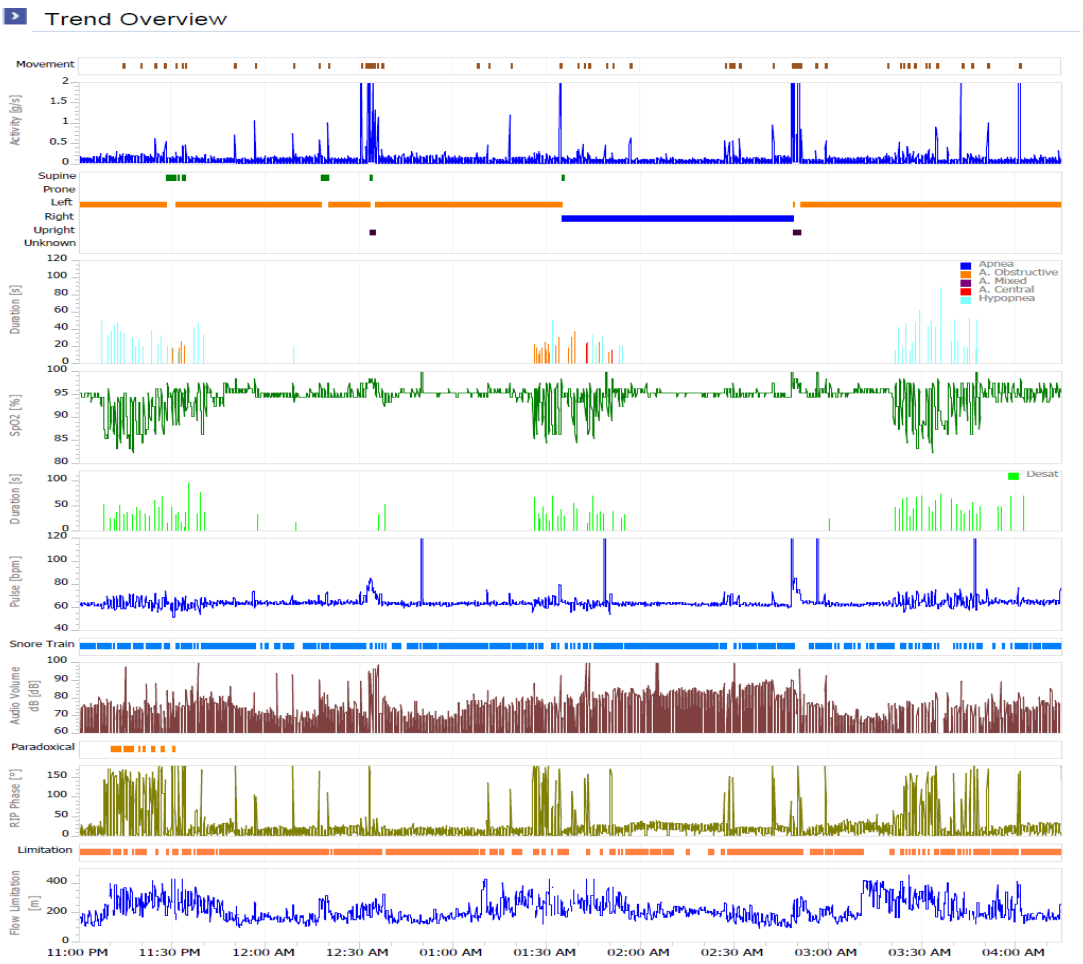
Respiratory Count	total	supine
Apneas	23	2
Obstructive	21	2
Mixed	0	0
Central	2	0
Hypopneas	47	1
Average Apnea	21 s	19 s
Average Hypopnea	34 s	19 s

Saturation	total	supine
Desaturation Index	14.7 /h	42.4 /h
Desaturation Count	76	5
Lowest SpO2	82.0 %	87.0 %
Average SpO2	94.1 %	94.2 %
Baseline SpO2	94.8 %	94.8 %
Desaturation < 90%:	10.1 /h	16.9 /h
Desaturation < 85%:	1.7 /h	0.0 /h
SpO2 time < 90%:	7.8 %	3.8 %
SpO2 time < 85%:	0.8 %	0.0 %

Pulse	total	supine
Average Pulse	62 bpm	61 bpm
Highest Pulse	79 bpm	73 bpm
Lowest Pulse	50 bpm	50 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	2.1 bpm	bpm
Average Desat Drop	7.9 %	3.2 %
Average Low Desat	88.1 %	90.7 %

Position and Activity		
Supine Time	7.2 m	2.3 %
Non-Supine Time	303.4 m	96.5 %
Upright Time	3.8 m	1.2 %
Activity Time	12.7 m	4.0 %
Invalid Data Time	0 m	0.0 %

Other	total	supine
Oximeter Quality	99.8 %	Good
Flow Quality	100.0 %	Good
RIP Quality	100.0 %	Good
Paradoxical Index	2.3 %	8.5 %
Est. Sleep Efficiency	97.2 %	97.9 %
Respiration Rate	14.3	15.8



Interpretation B36.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist.

Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The time in bed was 5hrs and 10minutes. Oximeter quality was 100%; flow signal quality was 100%. Epworth Sleepiness score of 15/24. The results indicate evidence of mild sleep disordered breathing (SDB) with an AHI of 13.5 and an ODI of 14.7.

The patient had a snore index of 57%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row).*The flow limitation index was 28.9% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness.*

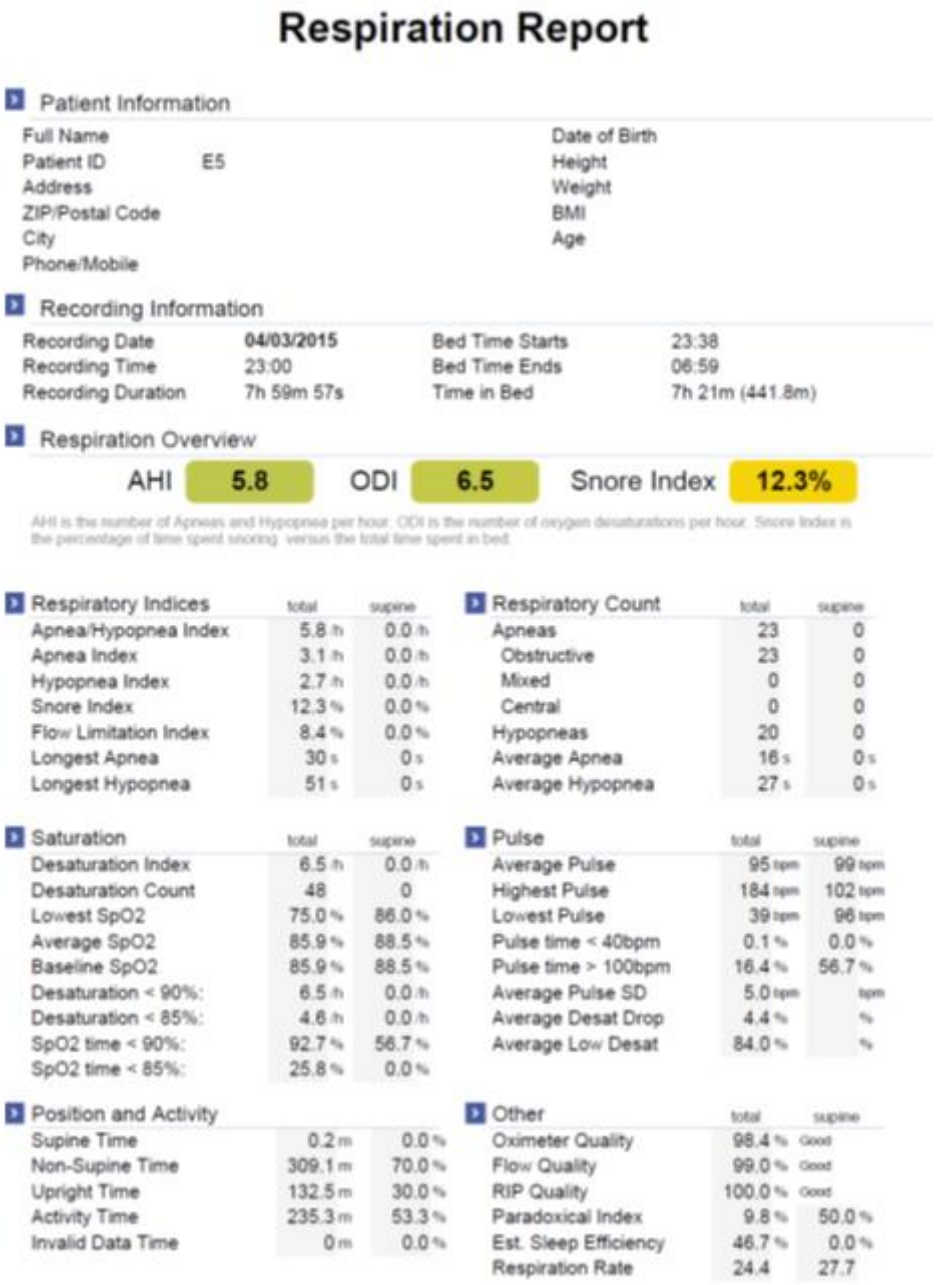
There were 21 obstructive apnoea's, 2 central events and 47 hypopneas.

The average Sp02 was 94%, with 8% of the recording being spent <90%. The minimum Sp02 was 82%. Consider trial of CPAP.

Please interpret findings in light of clinical correlation.

B37 Respiratory Sleep Study

75 year old male attended with difficulty sleeping throughout the night. Occasionally snores when on his back or after drinking alcohol. Naps each afternoon and wakes unrefreshed. Suffers with RA for which he takes paracetamol and occasional co-codamol. ?sleep disordered breathing



Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E5	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	04/03/2015	Bed Time Starts	23:38
Recording Time	23:00	Bed Time Ends	06:59
Recording Duration	7h 59m 57s	Time in Bed	7h 21m (441.8m)

Respiration Overview

AHI 5.8 ODI 6.5 Snore Index 12.3%

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices	total	supine
Apnea/Hypopnea Index	5.8 /h	0.0 /h
Apnea Index	3.1 /h	0.0 /h
Hypopnea Index	2.7 /h	0.0 /h
Snore Index	12.3 %	0.0 %
Flow Limitation Index	8.4 %	0.0 %
Longest Apnea	30 s	0 s
Longest Hypopnea	51 s	0 s

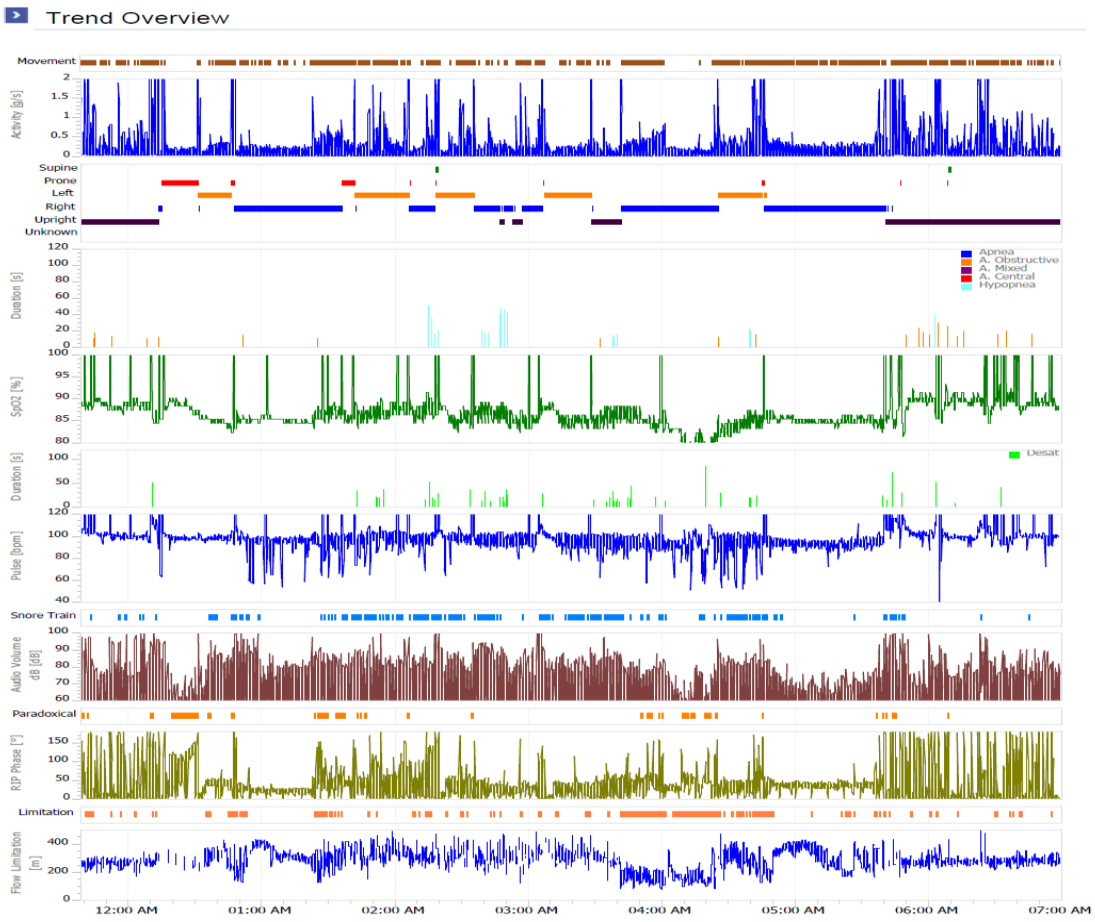
Respiratory Count	total	supine
Apneas	23	0
Obstructive	23	0
Mixed	0	0
Central	0	0
Hypopneas	20	0
Average Apnea	16 s	0 s
Average Hypopnea	27 s	0 s

Saturation	total	supine
Desaturation Index	6.5 /h	0.0 /h
Desaturation Count	48	0
Lowest SpO2	75.0 %	86.0 %
Average SpO2	85.9 %	88.5 %
Baseline SpO2	85.9 %	88.5 %
Desaturation < 90%:	6.5 /h	0.0 /h
Desaturation < 85%:	4.6 /h	0.0 /h
SpO2 time < 90%:	92.7 %	56.7 %
SpO2 time < 85%:	25.8 %	0.0 %

Pulse	total	supine
Average Pulse	95 bpm	99 bpm
Highest Pulse	184 bpm	102 bpm
Lowest Pulse	39 bpm	96 bpm
Pulse time < 40bpm	0.1 %	0.0 %
Pulse time > 100bpm	16.4 %	56.7 %
Average Pulse SD	5.0 bpm	bpm
Average Desat Drop	4.4 %	%
Average Low Desat	84.0 %	%

Position and Activity		
Supine Time	0.2 m	0.0 %
Non-Supine Time	309.1 m	70.0 %
Upright Time	132.5 m	30.0 %
Activity Time	235.3 m	53.3 %
Invalid Data Time	0 m	0.0 %

Other	total	supine
Oximeter Quality	98.4 %	Good
Flow Quality	99.0 %	Good
RIP Quality	100.0 %	Good
Paradoxical Index	9.8 %	50.0 %
Est. Sleep Efficiency	46.7 %	0.0 %
Respiration Rate	24.4	27.7



Interpretation B37

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist.

Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The time in bed was 7hrs and 21minutes. Oximeter quality was 98%; flow signal quality was 99%. The results indicate evidence of borderline mild sleep disordered breathing (SDB) with an AHI of 5.8 and an ODI of 6.5.

The patient had a snore index of 12.3%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row)*.The flow limitation index was 8.4% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness.*

There were 23 obstructive apnoea's, 0 central events and 20 hypopneas. They appear to be positional in nature, occurring predominantly on the right side.

The average Sp02 was 86%, with 93% of the recording being spent <90%. The minimum Sp02 was 75%.

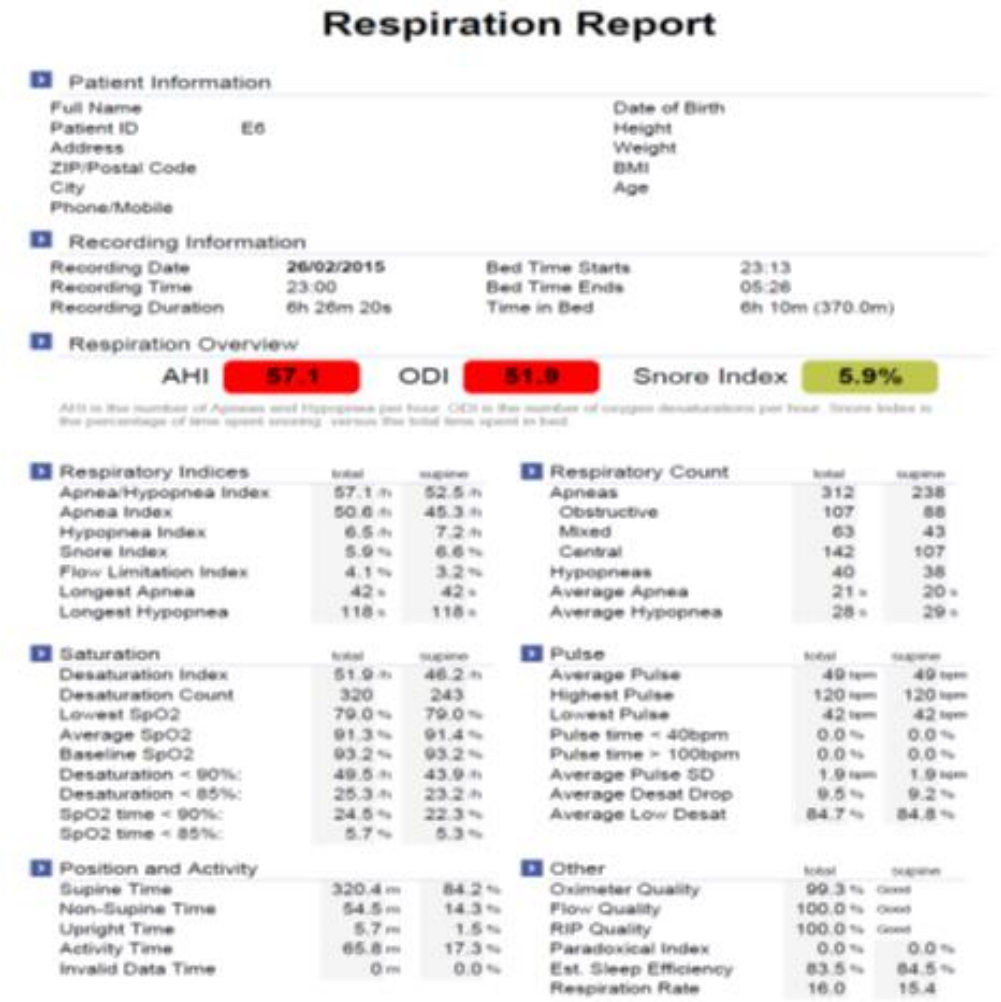
Need Epworth sleepiness score, consider trial of CPAP if patient is excessively sleepy during the daytime or if he drives for a living?

? BMI, lifestyle changes, Weight loss

Please interpret findings in light of clinical correlation.

B38 Respiratory Sleep Study

19 year old male attended clinic complaining or excessive snoring and difficulty staying awake during afternoon lectures at university. Snores in all positions. Sleeps around 10 hours per night, waking once to urinate. BMI 33. Mallampati 4 with “kissing” tonsils. ? OSA



Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E6	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	26/02/2015	Bed Time Starts	23:13
Recording Time	23:00	Bed Time Ends	05:26
Recording Duration	6h 26m 20s	Time in Bed	6h 10m (370.0m)

Respiration Overview

AHI 57.1 ODI 51.9 Snore Index 5.9%

AHI is the number of Apneas and Hypopneas per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices	total	supine
Apnea/Hypopnea Index	57.1 /h	52.5 /h
Apnea Index	50.6 /h	45.3 /h
Hypopnea Index	6.5 /h	7.2 /h
Snore Index	5.9 %	6.6 %
Flow Limitation Index	4.1 %	3.2 %
Longest Apnea	42 s	42 s
Longest Hypopnea	118 s	118 s

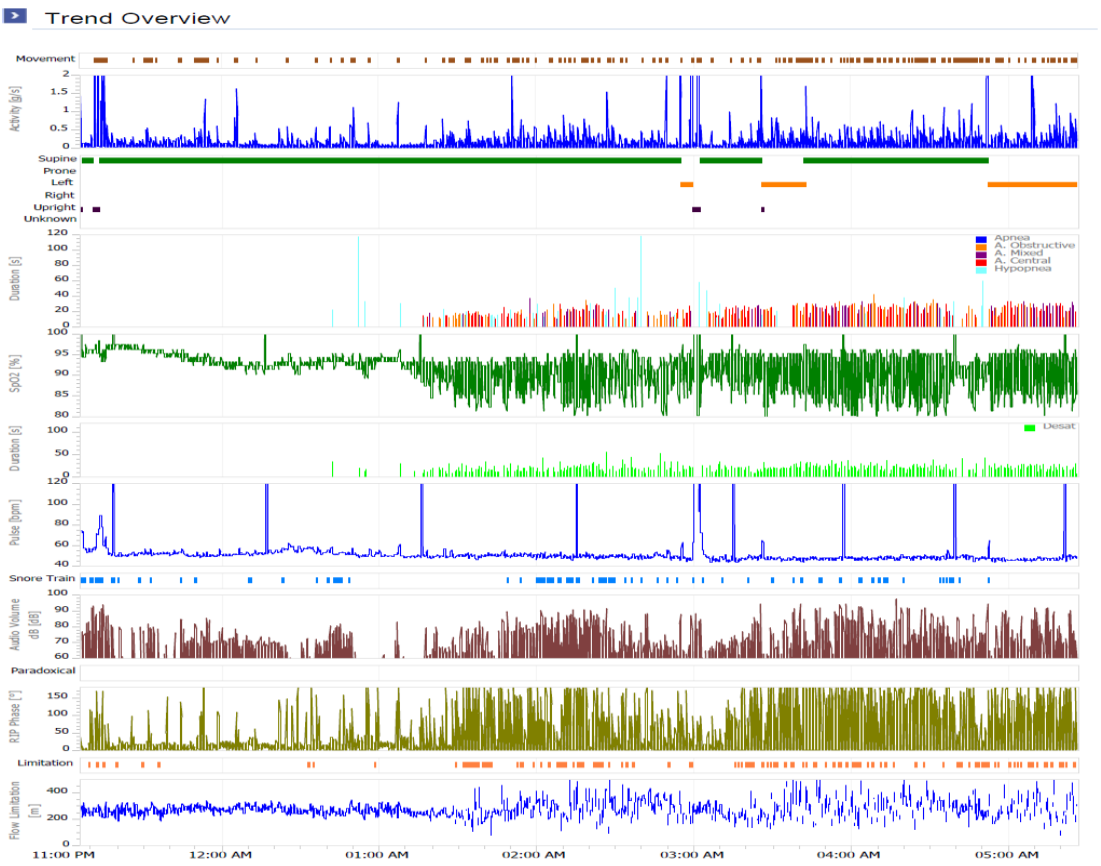
Respiratory Count	total	supine
Apneas	312	238
Obstructive	107	88
Mixed	63	43
Central	142	107
Hypopneas	40	38
Average Apnea	21 s	20 s
Average Hypopnea	28 s	29 s

Saturation	total	supine
Desaturation Index	51.9 /h	46.2 /h
Desaturation Count	320	243
Lowest SpO2	79.0 %	79.0 %
Average SpO2	91.3 %	91.4 %
Baseline SpO2	93.2 %	93.2 %
Desaturation < 90%:	49.5 /h	43.9 /h
Desaturation < 85%:	25.3 /h	23.2 /h
SpO2 time < 90%:	24.5 %	22.3 %
SpO2 time < 85%:	5.7 %	5.3 %

Pulse	total	supine
Average Pulse	49 bpm	49 bpm
Highest Pulse	120 bpm	120 bpm
Lowest Pulse	42 bpm	42 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	1.9 bpm	1.9 bpm
Average Desat Drop	9.5 %	9.2 %
Average Low Desat	84.7 %	84.8 %

Position and Activity		
Supine Time	320.4 m	84.2 %
Non-Supine Time	54.5 m	14.3 %
Upright Time	5.7 m	1.5 %
Activity Time	65.8 m	17.3 %
Invalid Data Time	0 m	0.0 %

Other	total	supine
Oximeter Quality	99.3 %	Good
Flow Quality	100.0 %	Good
RIP Quality	100.0 %	Good
Paradoxical Index	0.0 %	0.0 %
Est. Sleep Efficiency	83.5 %	84.5 %
Respiration Rate	16.0	15.4



Interpretation B38.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist. Overall the study is of good quality (>4hrs) and is acceptable for interpretation and reporting. The supine time was >30% of the total recording time (84%). *If <30% then consider repeating the sleep study*. The time in bed was 6hrs and 10minutes.

Oximeter quality was 99%; flow signal quality was 100%.

The results indicate severe sleep disordered breathing (SDB) with an AHI of 57.1 and an ODI of 51.9. The slight difference seen in AHI and ODI would suggest a slightly higher significance of apnoea's without an associated desaturation. There was a significant change in the frequency of sleep disordered breathing events from approximately 1.00am?

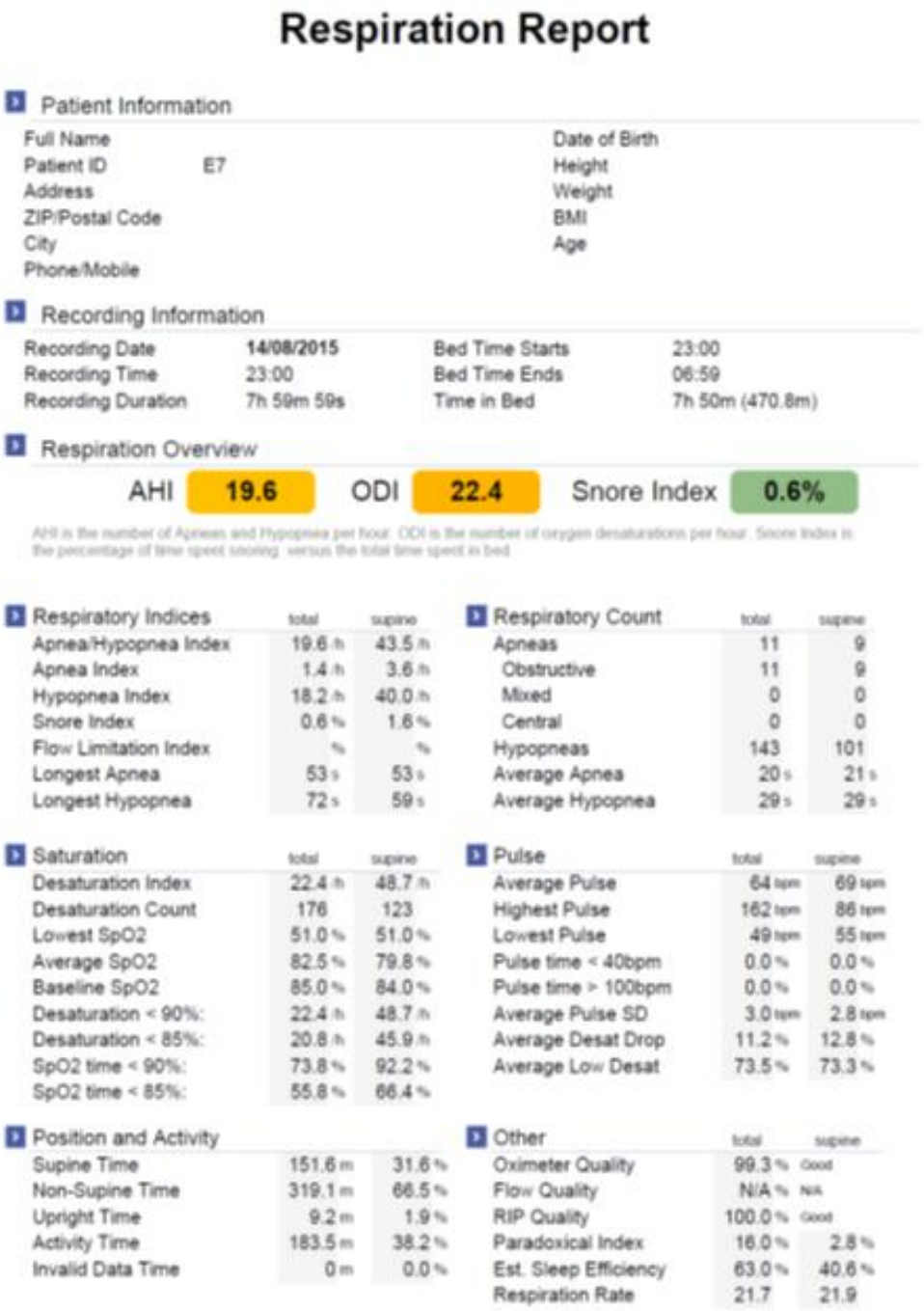
Severe Obstructive sleep apnoea (OSA), please consider a trial of CPAP? Consider tonsillectomy and repeat LSS (ENT review?).

An Epworth score is required to assess daytime tiredness. The patient had a snore index of 6%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row)*. The flow limitation index was 4% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness*. The majority of events were central apnoea's (142). There were 107 obstructive apnoea's, 63 mixed apnoea's and 40 hypopneas. The average Sp02 was 91%, with 25% of the recording being spent <90%. The minimum Sp02 was 79%.

Please interpret findings in light of clinical correlation. Consider polysomnography to assess central sleep apnoea?

B39 Respiratory Sleep Study

59 year old female with known severe OSA. AHI 93, mean sats 84%. ESS improved from 22 to 14 on treatment in last 4 weeks. BMI 54. Still snoring at times during the night. No excessive mask leak. Takes morphine and occasional Tramadol for back pain. Morning headaches a couple of times per month. CPAP pressure is fixed at 16cmH2O. ? adequate treatment.



Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E7	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	14/08/2015	Bed Time Starts	23:00
Recording Time	23:00	Bed Time Ends	06:59
Recording Duration	7h 59m 59s	Time in Bed	7h 50m (470.8m)

Respiration Overview

AHI 19.6 ODI 22.4 Snore Index 0.6%

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices

	total	supine
Apnea/Hypopnea Index	19.6 /h	43.5 /h
Apnea Index	1.4 /h	3.6 /h
Hypopnea Index	18.2 /h	40.0 /h
Snore Index	0.6 %	1.6 %
Flow Limitation Index	%	%
Longest Apnea	53 s	53 s
Longest Hypopnea	72 s	59 s

Respiratory Count

	total	supine
Apneas	11	9
Obstructive	11	9
Mixed	0	0
Central	0	0
Hypopneas	143	101
Average Apnea	20 s	21 s
Average Hypopnea	29 s	29 s

Saturation

	total	supine
Desaturation Index	22.4 /h	48.7 /h
Desaturation Count	176	123
Lowest SpO2	51.0 %	51.0 %
Average SpO2	82.5 %	79.8 %
Baseline SpO2	85.0 %	84.0 %
Desaturation < 90%:	22.4 /h	48.7 /h
Desaturation < 85%:	20.8 /h	45.9 /h
SpO2 time < 90%:	73.8 %	92.2 %
SpO2 time < 85%:	55.8 %	66.4 %

Pulse

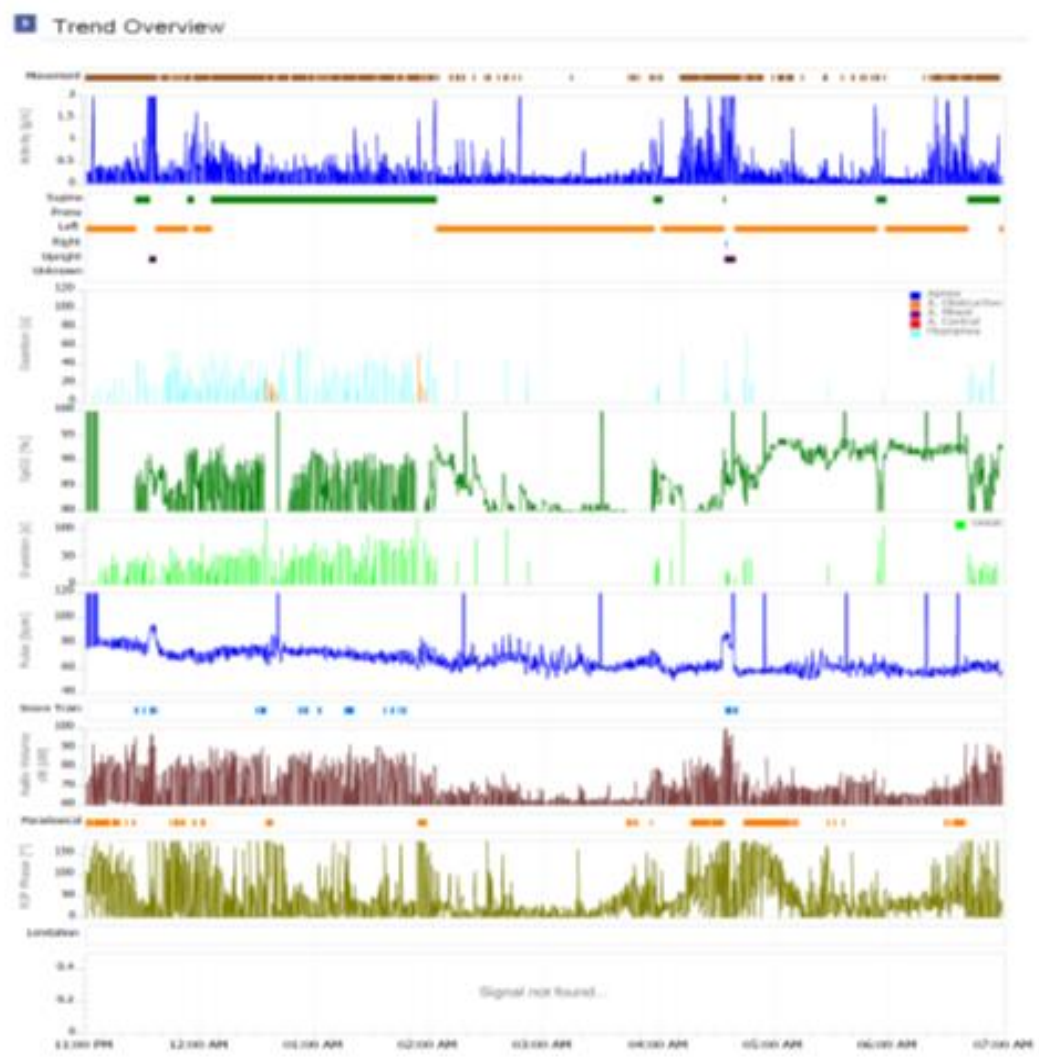
	total	supine
Average Pulse	64 bpm	69 bpm
Highest Pulse	162 bpm	86 bpm
Lowest Pulse	49 bpm	55 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	3.0 bpm	2.8 bpm
Average Desat Drop	11.2 %	12.8 %
Average Low Desat	73.5 %	73.3 %

Position and Activity

Supine Time	151.6 m	31.6 %
Non-Supine Time	319.1 m	66.5 %
Upright Time	9.2 m	1.9 %
Activity Time	183.5 m	38.2 %
Invalid Data Time	0 m	0.0 %

Other

	total	supine
Oximeter Quality	99.3 %	Good
Flow Quality	N/A %	N/A
RIP Quality	100.0 %	Good
Paradoxical Index	16.0 %	2.8 %
Est. Sleep Efficiency	63.0 %	40.6 %
Respiration Rate	21.7	21.9



Interpretation B39.

LSS repeated at home. Known severe sleep disordered breathing/ severe OSAS.

Sleep study recorded whilst on CPAP with a fixed pressure of 16cmH20.

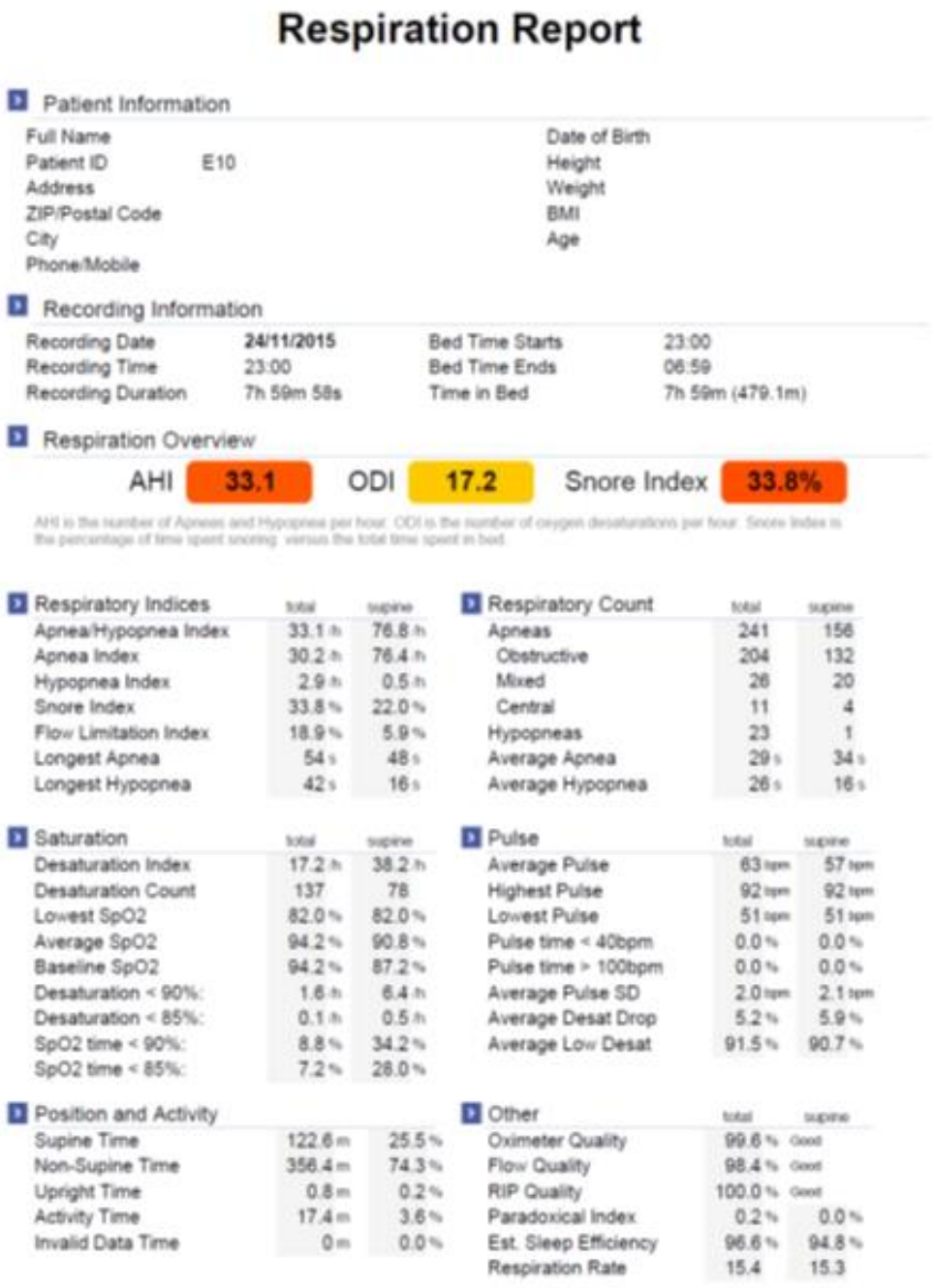
AHI has improved from 93 to 19.6. Change in ESS from 22 to 14.

Suggests in-effective treatment of SDB, evidence of continued daytime tiredness. However there is a question as to whether the CPAP was only used for part of the night (split night study)? Significant reduction in sleep disordered breathing events from 2.00am? Positional sleep apnoea (supine)? Need to ascertain more information from the patient. Reassess sleep study and score (AHI) from 2.00am onwards? Consider CPAP titration study or initiating autoCPAP rather than fixed pressure treatment.

Please interpret findings in light of clinical correlation.

B40 Respiratory Sleep Study

44 year old male attended clinic complaining of excessive tiredness and loud snoring. Has been getting progressively worse for 6 months resulting in him falling asleep at the wheel 4 weeks ago and crashing into a tree. Now only drives locally with window open to improve alertness. Snorer in all positions. No morning headaches ?OSA. ESS 12/24. BMI 38. Collar size 20".



Respiration Report

Patient Information

Full Name		Date of Birth	
Patient ID	E10	Height	
Address		Weight	
ZIP/Postal Code		BMI	
City		Age	
Phone/Mobile			

Recording Information

Recording Date	24/11/2015	Bed Time Starts	23:00
Recording Time	23:00	Bed Time Ends	06:59
Recording Duration	7h 59m 58s	Time in Bed	7h 59m (479.1m)

Respiration Overview

AHI 33.1 ODI 17.2 Snore Index 33.8%

AHI is the number of Apneas and Hypopnea per hour. ODI is the number of oxygen desaturations per hour. Snore Index is the percentage of time spent snoring versus the total time spent in bed.

Respiratory Indices

	total	supine
Apnea/Hypopnea Index	33.1 /h	76.8 /h
Apnea Index	30.2 /h	76.4 /h
Hypopnea Index	2.9 /h	0.5 /h
Snore Index	33.8 %	22.0 %
Flow Limitation Index	18.9 %	5.9 %
Longest Apnea	54 s	48 s
Longest Hypopnea	42 s	16 s

Respiratory Count

	total	supine
Apneas	241	156
Obstructive	204	132
Mixed	26	20
Central	11	4
Hypopneas	23	1
Average Apnea	29 s	34 s
Average Hypopnea	26 s	16 s

Saturation

	total	supine
Desaturation Index	17.2 /h	38.2 /h
Desaturation Count	137	78
Lowest SpO2	82.0 %	82.0 %
Average SpO2	94.2 %	90.8 %
Baseline SpO2	94.2 %	87.2 %
Desaturation < 90%:	1.6 /h	6.4 /h
Desaturation < 85%:	0.1 /h	0.5 /h
SpO2 time < 90%:	8.8 %	34.2 %
SpO2 time < 85%:	7.2 %	28.0 %

Pulse

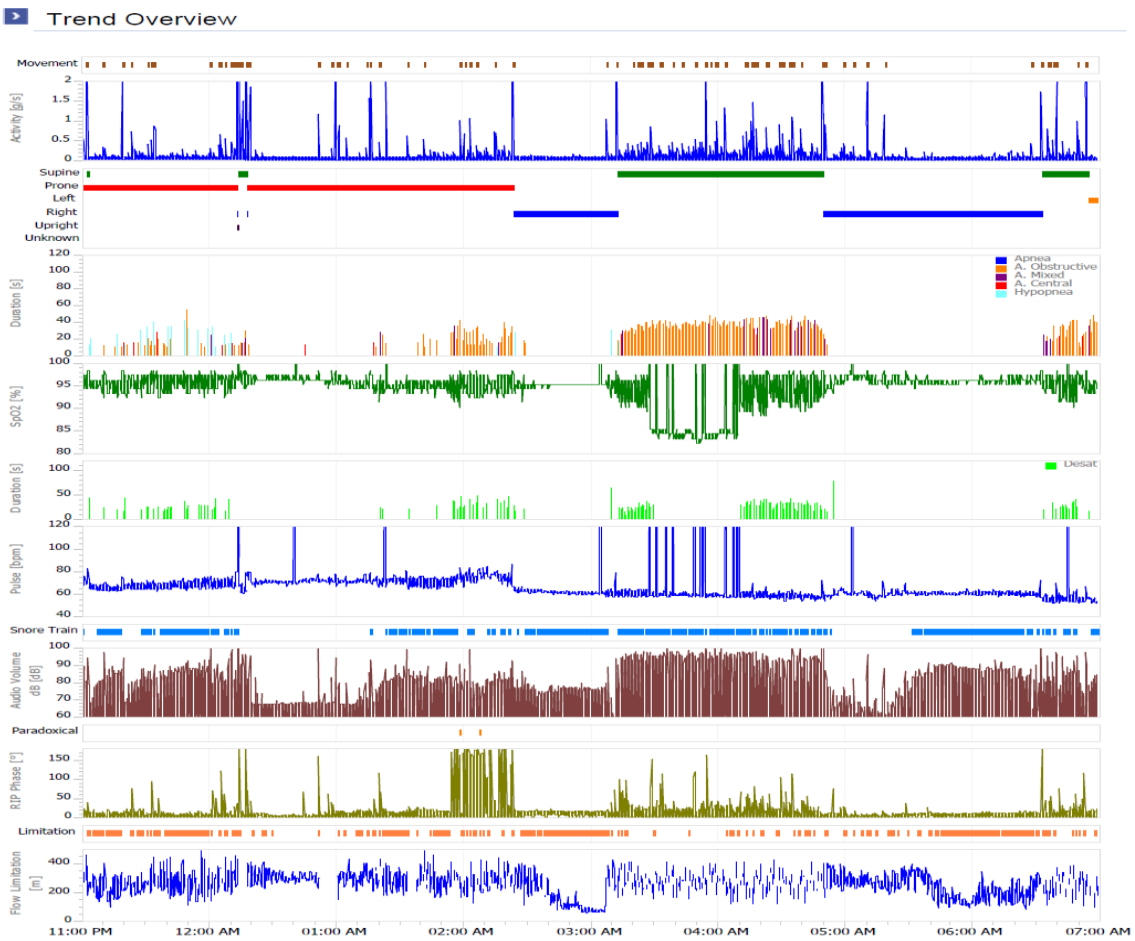
	total	supine
Average Pulse	63 bpm	57 bpm
Highest Pulse	92 bpm	92 bpm
Lowest Pulse	51 bpm	51 bpm
Pulse time < 40bpm	0.0 %	0.0 %
Pulse time > 100bpm	0.0 %	0.0 %
Average Pulse SD	2.0 bpm	2.1 bpm
Average Desat Drop	5.2 %	5.9 %
Average Low Desat	91.5 %	90.7 %

Position and Activity

Supine Time	122.6 m	25.5 %
Non-Supine Time	356.4 m	74.3 %
Upright Time	0.8 m	0.2 %
Activity Time	17.4 m	3.6 %
Invalid Data Time	0 m	0.0 %

Other

	total	supine
Oximeter Quality	99.6 %	Good
Flow Quality	98.4 %	Good
RIP Quality	100.0 %	Good
Paradoxical Index	0.2 %	0.0 %
Est. Sleep Efficiency	96.6 %	94.8 %
Respiration Rate	15.4	15.3



<u>Interpretation B40</u>.

The sleep study was autoscored in line with local protocol and then formally reviewed by a senior respiratory physiologist. The supine time was <30% of the total recording time (26%) <u>consider repeating the sleep study, questionable study quality?</u> However, the time in bed was 7hrs and 59minutes. The patient may be sleeping upright or propped up with pillows – no excessive movement. Oximeter quality was 100%; flow signal quality was 98%. The available results indicate severe sleep disordered breathing (SDB) with an AHI of 33.1 and an ODI of 17.2, which appears to be positional in nature (Supine).

Significant increase in SDB events when in supine position. The difference seen in AHI and ODI would suggest a higher significance of apnoea's without an associated desaturation. The patient had an Epworth score of 12 (normal ref <12). Severe Obstructive sleep apnoea syndrome (OSAS), **DVLA advice to be given, patient should not drive until treated, recent RTA – consider urgent trial of CPAP**.

The patient had a snore index of 34%. *The snore index is classed as the % of the study in snore train (A snore train is defined as a period of 3 or more snores in a continuous row)*. The flow limitation index was 19% (normal reference <30%). *Excessive flow limitation alone i.e. >30% can lead to excessive daytime sleepiness*. The majority of events were obstructive apnoea's (204). There were 26 mixed apnoea's, 23 hypopneas and 11 central events. The average Sp02 was 94%, with 9% of the recording being spent <90%. The minimum Sp02 was 82%. Please interpret findings in light of clinical correlation.

What is Cardiopulmonary Exercise testing (CPET)?

CPET is a relatively non-invasive objective test which provides a direct global measurement of the integrative exercise responses of the pulmonary, cardiovascular and metabolic systems during incremental exercise.

As a diagnostic test, CPET is used to assess exercise intolerance and its contributing factors. Due to the dynamic nature of this test, organ function is assessed at rest and during exercise, a factor which provides good description of a subject's physiological reserve.

The test is usually performed on a cycle ergometer, or sometimes a treadmill, whilst the individual wears a face mask for breath by breath measurements and usually comprises four stages – baseline phase, warm up phase, incremental exercise phase and recovery phase.

When is CPET indicated?

It is widely accepted that the use of CPET as a diagnostic test is specifically indicated in a wide variety of clinical situations including,

- Evaluation of exercise tolerance
- Evaluation of undiagnosed exercise intolerance and its functional correlates
- Evaluation of cardiovascular disease
- Evaluation of respiratory disease or symptoms
- Preoperative evaluation and stratification of surgical risk
- Evaluation and prescription of exercise rehabilitation or pre-surgical optimisation

What is measured during CPET?

CPET equipment employs a 'metabolic cart', comprising an oxygen analyser, carbon dioxide analyser and a flowmeter to measure respiratory gas exchange including oxygen uptake (VO_2), carbon dioxide output (VCO_2), minute ventilation (V_E) and end tidal partial pressures of oxygen and carbon dioxide ($P_{ET}O_2$ & $P_{ET}CO_2$). Signals are continuously measured to provide real time breath by breath analysis.

Measurements of cardiac function and circulation are also made via 12 lead electrocardiography, non-invasive arterial blood pressure and pulse oximetry.

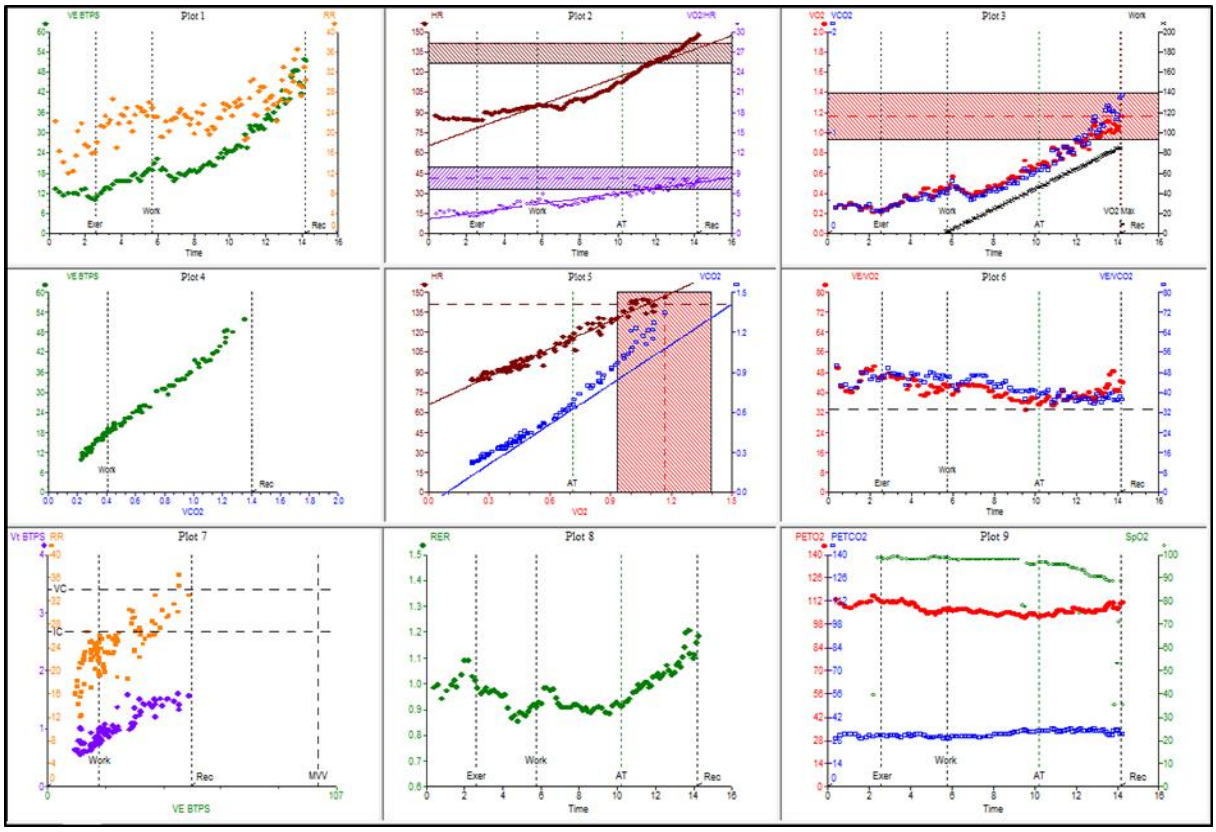
Data presentation and 9 panel plots

Two approaches are commonly used for CPET data presentation, tabular and graphical display. Both approaches are useful in isolation, but it is particularly advantageous to use both displays in combination for interpretation and analysis.

Summary data is usually presented in a simple table and provides physiological measurements from key points in the incremental exercise test, including values at rest, at the anaerobic threshold (AT) and height of exercise. Data should include Exercise duration, Work rate (Watts), RER, VO_2Peak, AT,

$P_{ET}O_2$, $P_{ET}CO_2$, V_E/VO_2, V_E/VCO_2, Heart rate, Heart rate reserve, O_2 Pulse, Blood pressure, V_E, V_E/MVV, Breathing reserve and SpO_2.

CPET data is usually displayed graphically in the format of a nine-panel plot, the most common of which is the Harbor-UCLA plot. Other variants of the nine panel plot are sometimes utilised and it is imperative to confirm which version is in use before any attempt to interpret is made.



The Harbor-UCLA nine panel plot is arranged from top left and proceeds to the right and describes the following information:

- Plot 1: V_E vs Time (or work rate)
- Plot 2: HR and O_2Pulse vs Time (or work rate)
- Plot 3: VO_2 and VCO_2 vs Time (or work rate)
- Plot 4: V_E vs VCO_2
- Plot 5: VCO_2 and HR vs VO_2
- Plot 6: V_E/VO_2 and V_E/VCO_2 vs Time (or work rate)
- Plot 7: V_T vs V_E (RR added to above example)
- Plot 8: RER vs Time (or work rate)
- Plot 9: $P_{ET}O_2$ and $P_{ET}CO_2$ vs Time (or work rate) (SpO_2 added to above example)

Each plot is interpreted in isolation and in combination with other plots to describe the physiological response to incremental exercise.

Plot 3 is used to describe aerobic capacity.

Plot 3, 6 and 9 are used to identify the anaerobic threshold.

Plot 2, 3 and 5 are used to describe cardiovascular responses.

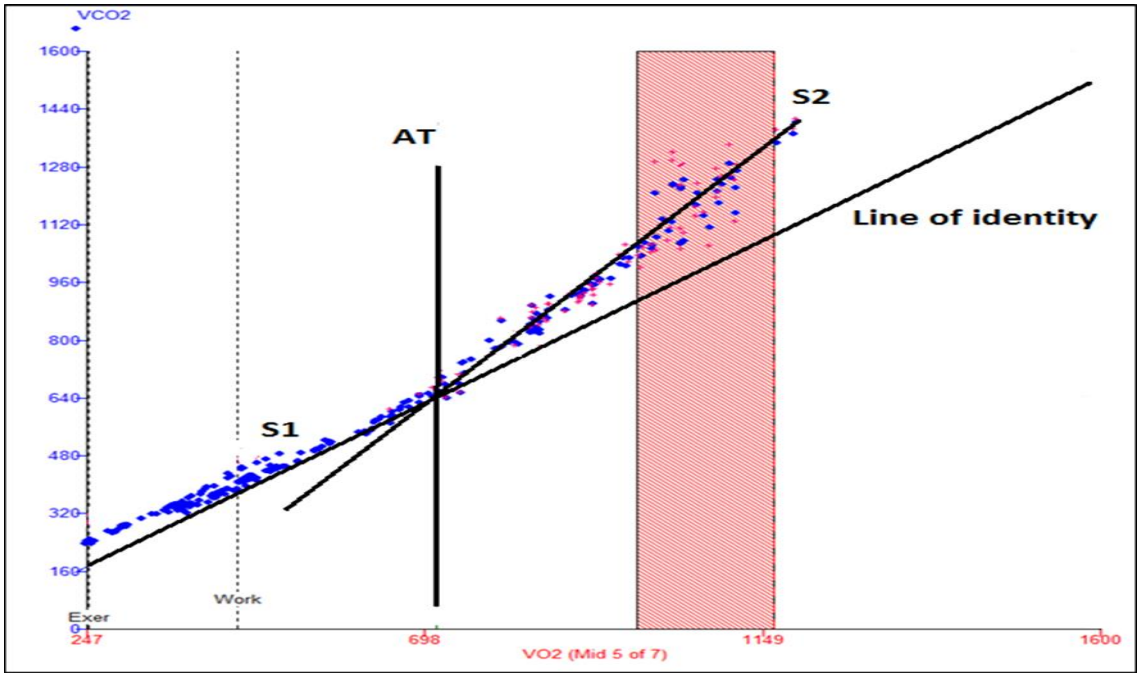
Plot 1, 4 and 7 are used to describe the ventilatory responses.

Plot 3 and 8 are used to identify metabolic abnormalities.

Non-invasive estimation of the anaerobic threshold (AT point)

The anaerobic threshold is the physical demarcation point during incremental exercise testing beyond which the skeletal muscle oxygen demand exceeds the ability of aerobic energy production and energy supplementation by anaerobic metabolism is required. Below the anaerobic threshold exercise is sustainable; above the anaerobic threshold, accumulation of lactic acid will eventually result in muscle fatigue and exercise termination. The AT point usually occurs between 40-60% of the predicted VO_2Peak in health; it is independent of patient motivation and is a reliable, repeatable patient specific measurement of dynamic functional capacity.

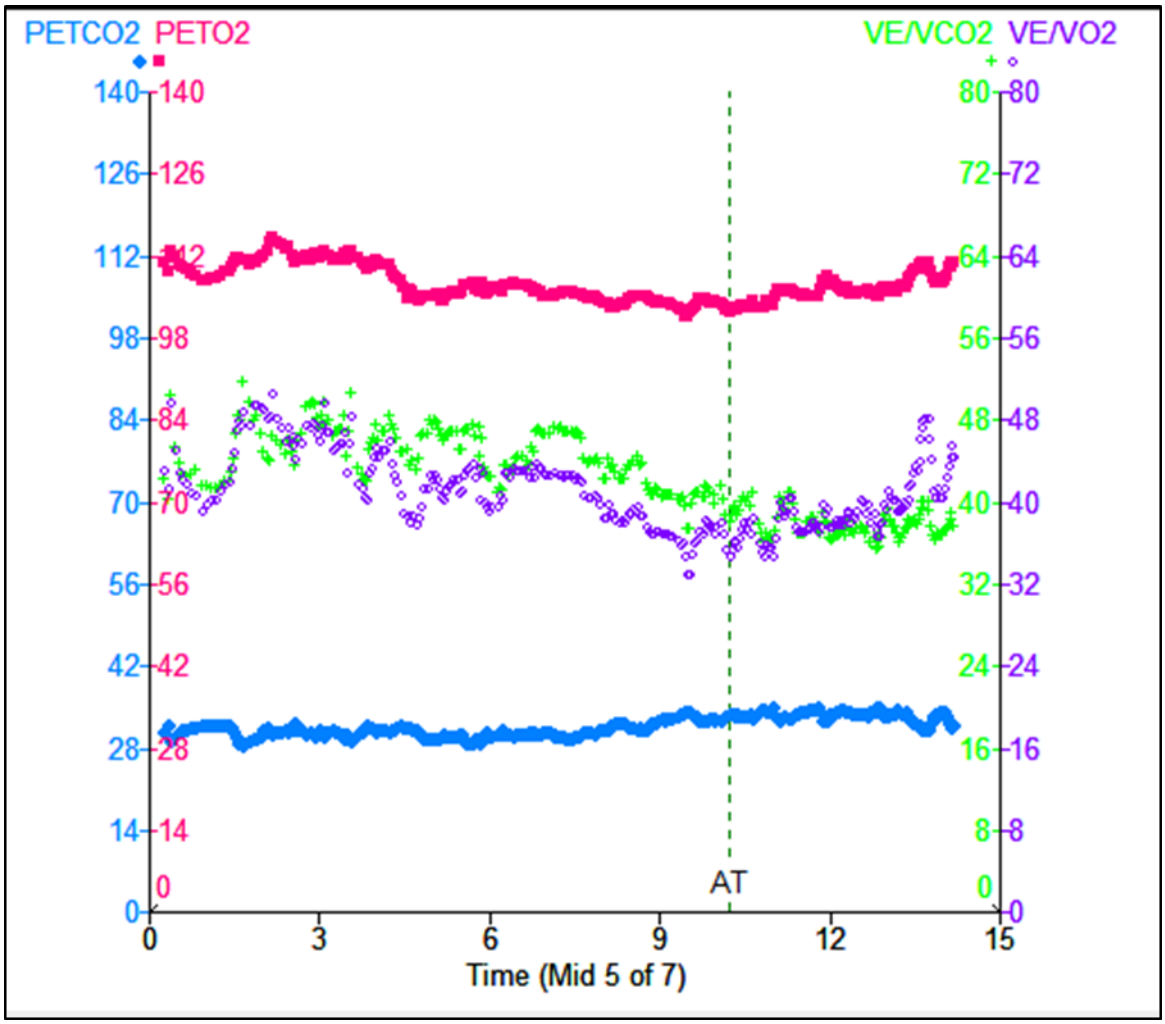
The estimation of AT point can be made non-invasively by interpreting the relationship between VCO_2 and VO_2. This is often termed the 'v-slope' method and is considered the primary method for AT identification. Below the AT point, VCO_2 increases in a linear relationship with VO_2, the slope of this relationship is termed the 'S1 slope' and typically demonstrates a value very close to 1.0. For this reason, it is often useful to include a 'line of identity' (a slope of 1.0) for reference when plotting a v-slope graph.



Above the AT point, additional CO_2 is produced as a by-product of bicarbonate buffering of accumulated lactate; as a result, the VCO_2- VO_2 relationship becomes steeper. This steeper slope is referred to as the 'S2 slope'. The VO_2 value at the intersection (or 'break point') of the S1-S2 slopes coincides with initial increase in arterial lactate.

In some individuals, the 'v'slope' relationship is not always easily and clearly partitioned into linear S1 and S2 segments. In this instance, moving the line of identity from right to left until it impacts upon the 'v-slope' is a suitable alternative method for AT identification, with the data point of impact being a suitable estimation of AT. This is known as the 'modified v-slope' method.

An alternate (or confirmatory) method for identification of the AT point is often referred to as the 'dual criteria' or 'integrated criteria' method. This involves plotting end tidal gas tensions and ventilatory equivalents against time, work rate or VO_2.



At the AT point, increases in ventilation, due to additional CO_2 as a by-product of bicarbonate buffering of accumulated lactate, will result in the onset of alveolar hyperventilation with respect to oxygen uptake. At this point, systematic increases in both V_E/VO_2 and $P_{ET}O_2$ whilst V_E/VCO_2 and $P_{ET}CO_2$ remain constant, is observed. Whilst the 'v-slope' is the primary method for identifying the

AT point, application of the 'dual criteria' method may be used to increase confidence in AT estimation.

What is the Chronotropic index?

The chronotropic index relates the change in heart rate to the change in oxygen consumption. A chronotropic index > 1.30 indicates a steep heart rate response and can suggest an increased dependence on heart rate to increase cardiac output secondary to a low stroke volume. A chronotropic index < 0.8 can indicate a blunted heart rate response (possible chronotropic incompetence) which in turn can suggest a variety of cardiac dysfunctions but can also be caused by medication such as beta blockers. A low chronotropic index can also be seen in exceptionally fit individuals (elevated V02max, elevated oxygen uptake at anaerobic threshold) and in these cases, is normal. In an exceptionally fit individual a normal chronotropic index is likely abnormal.

The formula for calculating the Chronotropic index is:

$$CI = [\frac{(Peak\ HR - baseline\ HR)}{(predicted\ HR - baseline\ HR)}] / [\frac{(Peak\ VO2 - baseline\ VO2)}{(predicted\ VO2 - baseline\ VO2)}]$$

Normal response to incremental exercise

Interpretation of CPET is a complex and skilled procedure, which relies on good levels of experience and competency. As a minimum, it is important to understand the expected normal responses to an incremental cardiopulmonary exercise protocol, before an abnormality can be identified.

Measured exercise response variables can be compared to normal reference values for assessment of normalcy, but it is more often the pattern of responses which we are most interested in interpreting.

Before any analysis of exercise responses can be made, it is important to ascertain the quality of the test by considering three questions. Was it a maximal effort test? What was the reason for stopping the test? Are there any other technical comments provided by the test operator?

- Test effort: Suboptimal effort results in submaximal physiological test variables and can be due to poor motivation, poor perception of effort/symptoms or deliberate suboptimal effort in order to present an image of reduced exercise tolerance. Misidentification of submaximal effort may lead to misdiagnosis. It is important to evidence maximal effort by identifying one or more of the following parameters.
    - Plateau at VO_2Peak (this will be rarely seen in clinical patients)
    - RER >1.1
    - HR and/or V_E attains predicted maximum
    - AT point reached
    - Arterial lactate >8mmol
- Reason for test termination: It is important to ascertain if the test was stopped by the patient or the operator. If the test was stopped by the operator, it is likely that the test was

terminated early due to a technical issue or a change in the clinical status of the patient. Did the patient terminate the test due to symptom limitation (dyspnoea, chest pain etc.)? It is usual for the patient to terminate the test due to leg fatigue in non-symptom limited incremental exercise testing.

- Other technical comments: It is important to consider any technical comments made by the test operator as these may provide information which may impact on the validity of the test.

Initially, it is important to consider exercise tolerance by assessing the aerobic (functional) capacity. Here we are concerned with describing the VO_2Peak. VO_2Peak is the highest VO_2 recorded during the incremental exercise test and is dependent on patient effort/motivation. VO_2Peak should not be confused with the physiological maximum rate of oxygen uptake (VO_2Max), as this is not regularly seen in clinical practice. In health, we would expect the patient to achieve at least 80% of their predicted VO_2. Failure to achieve this during a maximal effort test is an indication of exercise intolerance/ reduced functional capacity.

Generally, there is a linear relationship between VO_2 and work rate (watts) and the slope of the relationship reflects oxygen delivery and utilisation at the skeletal muscle. A normal slope describes an increase of 10.3ml/minute for every watt increase in work rate and values below this would be evident in heart and lung disease as well as some metabolic disorders.

The AT point should be considered next. The AT is related to the point at which anaerobic metabolism increases as an extra source of energy for exercising muscles to sustain work when aerobic metabolism is no longer sufficient. The AT is a useful marker of the patient's ability to perform daily activities, performing activities beyond the AT is unsustainable due to lactic acidosis and will result in activity termination due to fatigue. In health, the AT occurs at a point which is greater than 40% of the predicted VO_2Peak.

Performing the incremental exercise will increase the metabolic demand and increased oxygen supply is required to sustain activity. We would therefore expect heart rate to rise and exceed 90% of the age predicted maximum. The normal heart rate response describes a heart rate which increases steadily from rest and is highest at the point at which the test ends, increases in heart rate are proportionate to increases in exercise intensity. O_2Pulse (VO_2/HR) is used as a surrogate marker for stroke volume and can be used to assess the expected increases in systolic function. In the normal subject, the O_2Pulse increases during the early stages of incremental exercise up to a plateau as maximum stroke volume is achieved, further increases in cardiac output are achieved through increases in heart rate.

Cardiovascular limitation is expected in normal individuals, but in conjunction with normal or high VO_2Peak. A cardiovascular limitation in the presence of exercise intolerance is abnormal and would suggest evidence of a cardiovascular limitation to exercise. Conversely, an absence of cardiovascular limitation is abnormal and would be observed in early test termination or exercise limitation due to a pulmonary defect.

Skeletal muscle metabolism during incremental exercise results in increased intramuscular carbon dioxide production. In health, partial pressure of carbon dioxide in the blood is maintained by efficient increase of minute ventilation (V_E) as a product of increasing tidal volume and respiratory

rate. During CPET, V_E is analysed relative to maximum voluntary ventilation (V_E/MVV). In health, exercise tolerance is not limited by the pulmonary system and the V_E/MVV does not exceed 85%.

Gas exchange can be assessed initially by observing the SpO_2 values and their trend during incremental exercise. In health oxygen saturation will remain consistent as work rate increases. We can measure ventilatory efficiency by assessing the ventilatory equivalents; this is minute ventilation relative to oxygen consumption (V_E/VO_2) or carbon dioxide exhalation (V_E/VCO_2). During early exercise onset, the increases in tidal volume and lung perfusion result in an improvement in ventilatory efficiency. As a result, the ventilatory equivalents tend to fall to a nadir before rising again after the AT. The nadir point represents the point at which the lungs are operating at their best. In health, V_E/VO_2 is less than 31 and V_E/VCO_2 is less than 34. Values higher than this suggest a degree of ventilatory inefficiency.

Respiratory limitation to exercise

Respiratory disease can impact on exercise tolerance in several ways and involves the inability to efficiently eliminate carbon dioxide, either through limitations in gas exchange or mechanical ventilatory efficiency. As a result, it is usual to see a reduction in the VO_2Peak.

In severely impaired patients, the test is often terminated before the AT point, often the RER value fails to exceed 1.0. This is due to the degree of mechanical ventilatory limitation curtailing exercise duration before sufficient cardiac response generates significant lactic acidosis. As a result, evidence of good heart rate reserve can be seen. In patients with less severe respiratory impairment, the AT point is usually low and reflects associated deconditioning.

We would expect ventilatory reserve to be significantly reduced (V_E/MVV >85%) as the ability to augment tidal volume (V_t) and respiratory rate is impacted upon as a result of volume and/or flow limitation. Ventilatory efficiency is also low in many lung conditions; this is evidenced by elevated ventilatory equivalents. Oxygen desaturation is expected in patients with diffusion impairment due to progressive widening of the alveolar-arterial oxygen partial pressure difference. Upon stopping the test, patients may report excessive dyspnoea.

Summary:

- Low VO_2Peak
- High HR reserve
- Low V_E reserve
- Flat V_t/V_E relationship
- High ventilatory equivalents
- Oxygen desaturation

Cardiac limitation to exercise

A reduction in VO_2Peak is often evident in those patients with cardiac limitation to exercise tolerance. This is usually due to reductions in cardiac output and subsequent limitation of the

cardiovascular system to transport oxygen to skeletal muscle. Skeletal muscles then rely more heavily on energy production through anaerobic processes, this occurs earlier than normal. The AT point is therefore typically low, in both absolute terms and when expressed as a percentage of the predicted VO_2Peak. An AT point <40% of predicted VO_2Peak is associated with significant pathology. VO_2/Work rate relationship is <8.3 ml/min/watt in those patients with impaired oxygen delivery to working muscles.

Heart rate response will usually demonstrate a rapid and early rise at submaximal exercise intensities and may exceed their heart rate reserve before achieving sufficient VO_2Peak. This steeper heart rate response is also evident in deconditioning and is often difficult to distinguish from early cardiovascular disease. Conversely, patients with chronotropic incompetence, either through medications or heart disease, demonstrate a shallow heart rate response. Obviously, 12 lead ECG should be closely scrutinised for arrhythmias or myocardial ischaemia.

Interpretation of the O_2Pulse will describe the stroke volume during incremental exercise. Where stroke volume is decreased due to cardiac disease, the O_2Pulse is also usually low. Attention should be paid to the response pattern; an O_2Pulse which starts low and fails to rise significantly suggests poor left ventricular function whereas an O_2Pulse which plateaus early, or falls, may be an indication of onset of cardiac ischaemia.

Ventilatory reserve tends to be normal or elevated, but ventilatory efficiency may be reduced due to elevated dead space/ tidal volume ratio. As a result, ventilatory equivalents are often elevated in cardiac failure. Oxygen desaturation is often not expected in cardiac patients but is evident in patients with pulmonary hypertension.

Summary:

- Low VO_2Peak
- Steep HR response
- Low/absent HR reserve
- Low O_2Pulse, early plateau
- Low AT
- High ventilatory equivalents

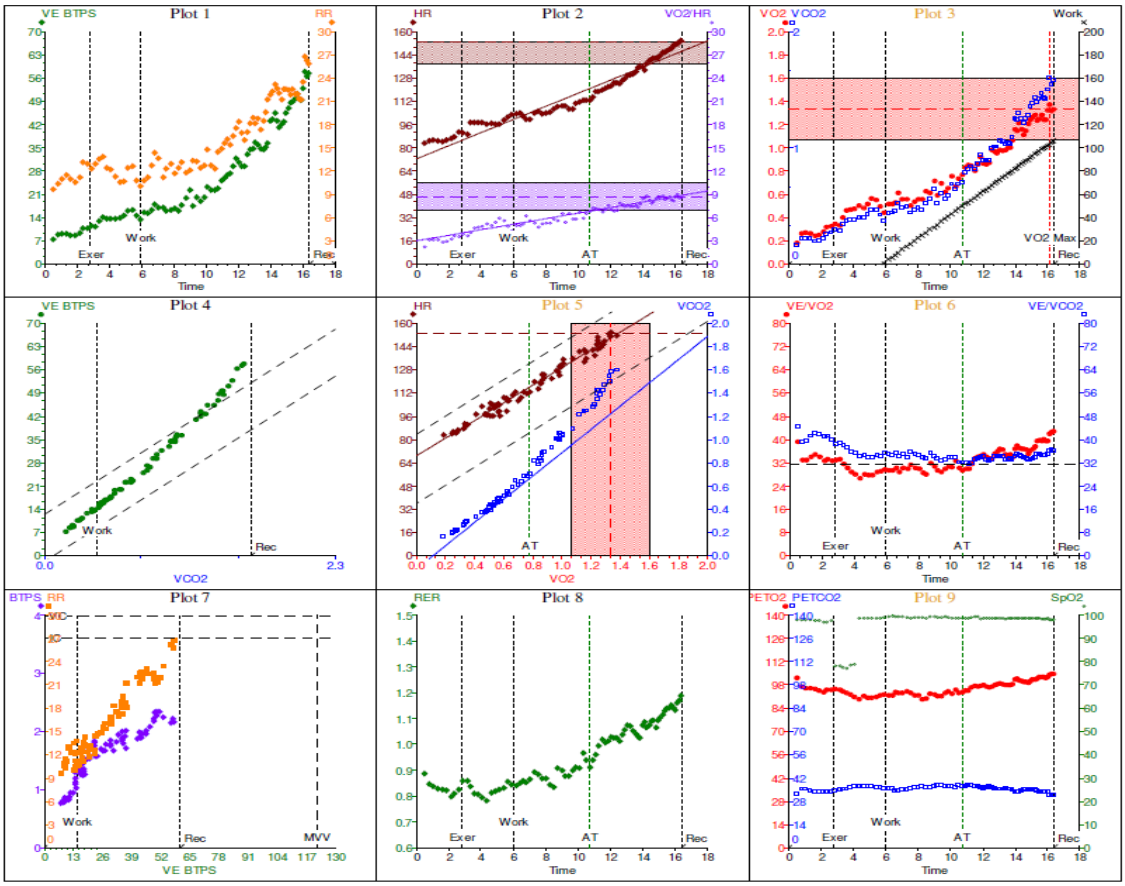
See appendix 5 for a simple guide on CPET normal reference values.

See appendix 6 for a suggested reporting template to assist reporting CPET results [36]

B41 Cardiopulmonary Exercise test

67 year old female, pre-op assessment-for right robotic partial nephrectomy. Medical History: CVA 12 years ago, previous hip replacement, ex-smoker ?arthritis. Relevant medications: Symbicort, Salbutamol, Sertraline, statin. Tested using a cycle ergometer with an incremental work rate of 10 watts per minute. Extra small Hans Rudolph mask, saddle height 16. Pre-test spirometry was within normal limits. Resting ECG showed NSR (ventricular ectopic beats at rest), BP 138/90, $Sp0_2$ 98%. The $V0_2$/work rate response was 9.3ml/min/watt. Test was terminated by the patient due to leg fatigue. Patient c/o some chest tightness experienced throughout exercise. The ECG during exercise showed frequent ventricular ectopic beats (137 in total) throughout exercise and at rest. No significant ischaemic changes observed.

	Rest	AT	V02 Max	Pred	VO2 Max/Pred (%)
---- WORK ----					
Work (Watts)	0	50	104	69	151
Ex Time (min)		7:55	13:21		
---- VENTILATION ----					
Vt BTPS (mL)	839	1575	2137		
RR (br/min)	13	15	26		
VE BTPS (L/min)	10.9	22.9	55.9	122.0	46
VE/MVV (%)	9	19	46		
BR (L/Min)	110.9	98.9	65.9		
---- OXYGEN CONSUMPTION ----					
VO2 (mL/kg/min)	3.8	9.2	15.3	15.8	97
VO2 (mL/min)	321	774	1290	1333	97
RER	0.83	0.91	1.17		
---- CARDIAC ----					
HR (BPM)	91	113	153	153	100
HRR (BPM)	62	40	0		
VO2/HR (mL/beat)	4	7	8	9	97
---- V/Q ----					
VE/VCO2	41	32	37	53	70
VE/VO2	34	30	43	64	68
PETCO2 (mmHg)	34	37	32		
PETO2 (mmHg)	96	94	105		
----------					
sysBP (mmHg)	138	149	183		
diaBP (mmHg)	90	79	88		
SpO2 (%)	98	99	98		
METS	1.1	2.6	4.4	4.5	97



Interpretation B41

Patient referred by the Urology team, to assess for pre-op right robotic partial nephrectomy. Test protocol: tested using a cycle ergometer with an incremental work rate of 10 watts per minute. Extra small Hans Rudolph mask, saddle height 16. Test was terminated by the patient due to leg fatigue. Patient c/o some chest tightness experienced throughout exercise.

Pre-test spirometry was within normal limits. Resting ECG: NSR (ventricular ectopic beats at rest), BP 138/90, $Sp0_2$ 98%.

The patient exercised for 13mins and 21secs achieving a maximum workload of 104 watts (151% of predicted). RER at the height of exercise was 1.17, maximal effort test. Aerobic capacity was normal at 97% of predicted (normal reference >80%). $V0_2$ peak was measured at 1290 ml/min or 15.3ml/kg/min when corrected for body weight.

The $V0_2$/work rate response was normal at 9.3ml/min/watt (normal reference 8.3 - 12.3). The anaerobic threshold was identified confidently using the modified V-slope and confirmed using the dual criteria.

0_2 uptake measured at anaerobic threshold was recorded as 9.2ml/kg/min which is 58% of predV02peak. This suggests a sedentary fitness status. Maximum heart rate at the height of exercise was 153bpm which was 100% of predicted (normal reference >90%). There was a heart rate reserve of 0bpm (normal reference <15bpm). The 02 pulse at peak exercise was measured as 8ml/beat which was 97% of predicted and plateaued appropriately. The $HR/V0_2$ relationship was relatively normal. The ECG during exercise showed frequent ventricular ectopic beats (137 in total) throughout exercise and at rest. No significant ischaemic changes observed.

Normal cardiac limitation to exercise.

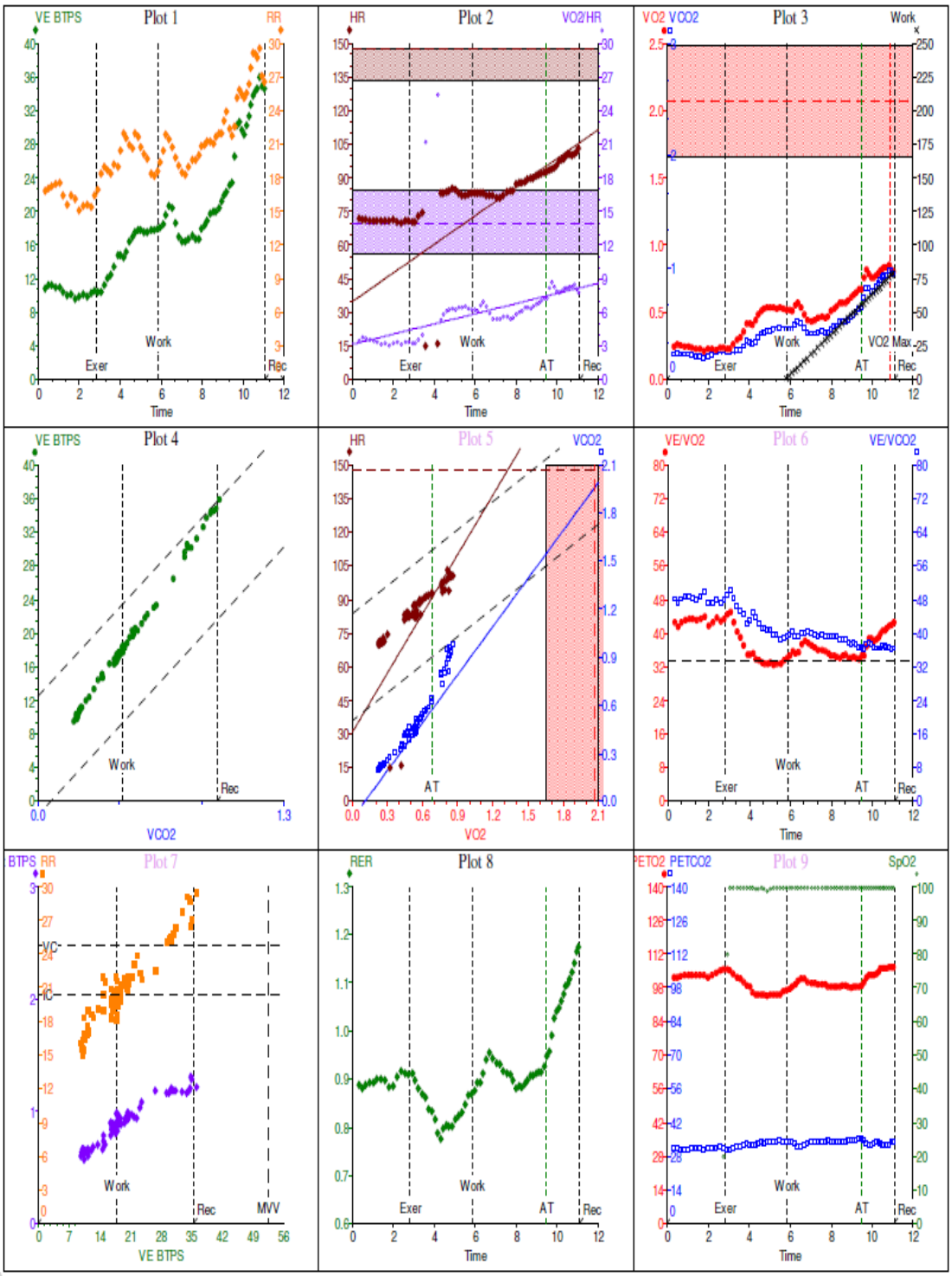
Ventilatory responses were as expected. VE_{max} was 56 L/min at the height of exercise which when referenced to the MVV was 46% (normal reference <85%).There was a breathing reserve of 66L/min (normal reference > 11 L/min). Gas exchange responses were within normal parameters, The $V_E/VC0_2$ and $V_E/V0_2$ measured at anaerobic threshold were normal at 32 (ref <34) and 30 (ref <31) respectively. $Sp0_2$ trended normally throughout exercise.

Please interpret findings in light of clinical correlation.

B42 Cardiopulmonary Exercise test

72 year old male. Pre-op assessment for colorectal surgery - pre-op laproscopic anterior resection. Medical History: PVD, ?IHD, ex-smoker, TIA, both knees replaced, groin stents. Relevant medications: GTN spray, hypertension meds, anticoagulant. Pre-test spirometry was consistent with a mixed obstructive (moderate) and restrictive (mild) ventilatory pattern. ? COPD - ex smoker - no formal diagnosis, not currently prescribed any inhaled medication. Resting ECG: NSR, BP 110/76, Sp02 100%. Patient tested using a cycle ergometer with an incremental work rate of 15 watts per minute. Small Hans Rudolph mask, saddle height 25. Test was terminated by the patient due to leg pain and dyspnoea. $V0_2$/work rate response was 7.7 ml/min/watt. The ECG during exercise showed periods of movement artefact, available data showed no significant evidence of ischaemic changes.

	Rest	AT	V02 Max	Pred	VO2 Max/Pred (%)
---- WORK ----					
Work (Watts)	0	56	76	149	51
Ex Time (min)		6:42	8:04		
---- VENTILATION ----					
Vt BTPS (mL)	648	1079	1264		
RR (br/min)	16	22	29		
VE BTPS (L/min)	10.6	23.5	36.1	56.0	64
VE/MVV (%)	20	45	69		
BR (L/Min)	45.2	32.4	19.8		
---- OXYGEN CONSUMPTION ----					
VO2 (mL/kg/min)	3.4	9.4	11.9	28.8	41
VO2 (mL/min)	244	676	853	2071	41
RER	0.91	0.95	1.15		
---- CARDIAC ----					
HR (BPM)	71	93	100	148	68
HRR (BPM)	77	55	48		
VO2/HR (mL/beat)	3	7	9	14	61
---- V/Q ----					
VE/VCO2	48	37	37	16	235
VE/VO2	44	35	42	19	224
PETCO2 (mmHg)	31	35	33		
PETO2 (mmHg)	106	99	107		
----------					
sysBP (mmHg)		116	116		
diaBP (mmHg)		85	85		
SpO2 (%)	20	100	100		
METS	1.0	2.7	3.4	8.2	41


VE BTPS
Plot 1
RR
Exer
Work
Rec
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Plot 2
VO2/HR
Exer
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Time
VO2 VCO2
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Work
Exer
Work
AT
VO2 Max
Rec
Time
VE BTPS
Plot 4
Work
Rec
VCO2
HR
Plot 5
VCO2
AT
VO2
VE/VO2
Plot 6
VE/VCO2
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BTPS RR
Plot 7
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MVV
VE BTPS
RER
Plot 8
Exer
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Rec
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PETO2 PETCO2
Plot 9
SpO2
Exer
Work
AT
Rec
Time

B42 Interpretation

Patient referred by the colorectal surgical team, to assess for pre-op laparoscopic anterior resection.

Test protocol: tested using a cycle ergometer with an incremental work rate of 15 watts per minute. Small Hans Rudolph mask, saddle height 25. Test was terminated by the patient due to leg pain and dyspnoea.

Pre-test spirometry was consistent with a mixed obstructive (moderate) and restrictive (mild) ventilatory pattern. ? COPD - ex smoker - no formal diagnosis, not currently prescribed any inhaled medication. ?needs formal respiratory assessment. Resting ECG: NSR, BP 110/76, Sp02 100%.

The patient exercised for 8mins and 4secs achieving a maximum workload of 76 watts (51% of predicted). RER at the height of exercise was 1.15, maximal effort test. Aerobic capacity was severely reduced at 41% of predicted (normal reference >80%). $V0_2$ peak was measured at 853 ml/min or 11.9ml/kg/min when corrected for body weight. The $V0_2$/work rate response was shallow at 7.7 ml/min/watt (normal reference 8.3 - 12.3). Abnormal/shallow responses suggest inadequate 0_2 delivery to exercising muscles.

The anaerobic threshold was identified with fair confidence using the modified V-slope and confirmed using the dual criteria. 0_2 uptake measured at anaerobic threshold was recorded as 9.4ml/kg/min which is 33% of pred$V0_2$peak and occurred abnormally (<40%) suggesting early onset metabolic acidosis.

Maximum heart rate at the height of exercise was 100bpm which was 68% of predicted (normal reference >90%). There was a heart rate reserve of 48bpm (normal reference <15bpm). The 0_2 pulse at peak exercise was measured as 9ml/beat which was 61% of predicted. The HR/$V0_2$ relationship was relatively normal.

Absence of expected normal cardiac limitation to exercise.

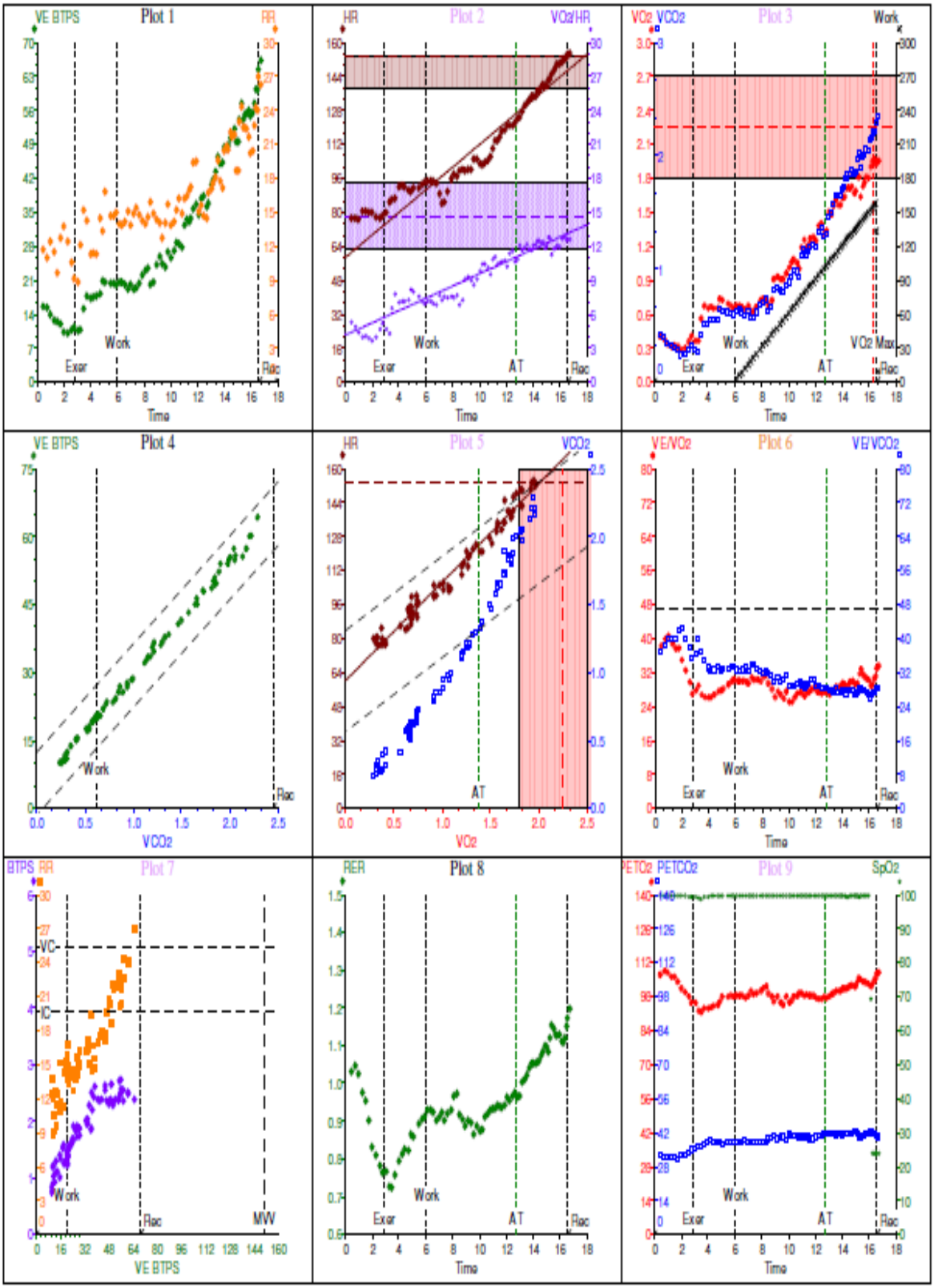
Ventilatory responses were as expected. VE_{max} was 36.1 L/min at the height of exercise which when referenced to the MVV was 69% (normal reference <85%).There was a breathing reserve of 19.8L/min (normal reference > 11 L/min). Gas exchange responses were abnormal, The $V_E/VC0_2$ and $V_E/V0_2$ measured at anaerobic threshold were elevated at 37 (ref <34) and 35 (ref <31) respectively. Suggesting a degree of ventilatory inefficiency. $Sp0_2$ trended normally throughout exercise.

Please interpret findings in light of clinical correlation.

B43 Cardiopulmonary Exercise testing

66 year old male. Patient referred by urology surgical team for CPET assessment of fitness for surgery. The patient had a normal pre-test spirometry. Resting ECG showed LBBB with NSR. Exercised on a 15w/min protocol, small (Hans Rudolph) mask and seat height of 28. No significant ECG changes observed during exercise. $V0_2$/Work rate relationship = 9.8ml/min/watt.

	Rest	AT	V02 Max	Pred	VO2 Max/Pred (%)
---- WORK ----					
Work (Watts)	0	103	155	153	101
Ex Time (min)		9:54	13:26		
---- VENTILATION ----					
Vt BTPS (mL)	1220	2331	2591		
RR (br/min)	9	16	23		
VE BTPS (L/min)	11.2	37.4	60.4	151.0	40
VE/MVV (%)	7	25	40		
BR (L/Min)	139.7	113.5	90.4		
---- OXYGEN CONSUMPTION ----					
VO2 (mL/kg/min)	4.3	14.3	21.4	23.5	91
VO2 (mL/min)	414	1370	2054	2252	91
RER	0.76	0.97	1.11		
---- CARDIAC ----					
HR (BPM)	78	124	152	154	99
HRR (BPM)	76	30	2		
VO2/HR (mL/beat)	5	11	14	15	93
---- V/Q ----					
VE/VCO2	35	28	27	39	69
VE/VO2	27	27	29	47	63
PETCO2 (mmHg)	35	42	42		
PETO2 (mmHg)	96	98	104		
----------					
sysBP (mmHg)	131	184	208		
diaBP (mmHg)	85	89	84		
SpO2 (%)	99	100	24		
METS	1.2	4.1	6.1	6.7	91


VE BTPS
Plot 1
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Plot 2
VO2/HR
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VO2 VCO2
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VO2 Max
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VCO2
Plot 5
VO2
VE/VO2
Plot 6
VE/VCO2
BTPS RR
Plot 7
VC
IC
MVV
RER
Plot 8
PETO2 PETCO2
Plot 9
SpO2

B43 Interpretation

Patient referred by urology surgical team for CPET assessment of fitness for surgery. Patient exercised on a 15w/min protocol, small (Hans Rudolph) mask and seat height of 28.

Pre-test spirometry was within normal limits. Patient exercised for approximately 13min 26seconds, achieving a peak work load of 155watts (101%pred). Patient made a good effort during test, RER at height of exercise was 1.11 - this was a maximal effort test to volitional fatigue. Test was stopped by patient due to leg fatigue - no palpitations or chest pain reported.

Aerobic capacity was normal (91%pred), VO2peak was measured at 2054mL/min or 21.4mL/kg/min. VO_2/WR relationship was 9.8ml/min/watt and within normal limits (normal - 8.3-12.3). Anaerobic threshold was identified confidently using the v-slope method and confirmed using dual criteria. AT was measured at 14.3mL/kg/min and occurred at 61%predVO_2Peak and is consistent with active fitness levels.

ECG showed LBBB with NSR at rest. Max heart rate was measured at 152bpm (99%pred). Heart rate reserve at height of exercise was 2bpm (normal reference <15bpm). HR/VO_2 slope was a relatively normal response to exercise. O_2 Pulse at height of exercise was 14mL/beat (93%pred) and plateaued appropriately. Ventilatory responses were normal. V_E at height of exercise was 60.4L/Min, 40% when referenced to MVV (normal reference <85%), breathing reserve at height of exercise was 90.4L/Min (normal >11L/Min). Gas exchange responses were within normal parameters. The $V_E/VC0_2$ and $V_E/V0_2$ measured at anaerobic threshold were normal at 28 (ref <34) and 27 (ref <31) respectively. Sp02 trended normally throughout exercise.

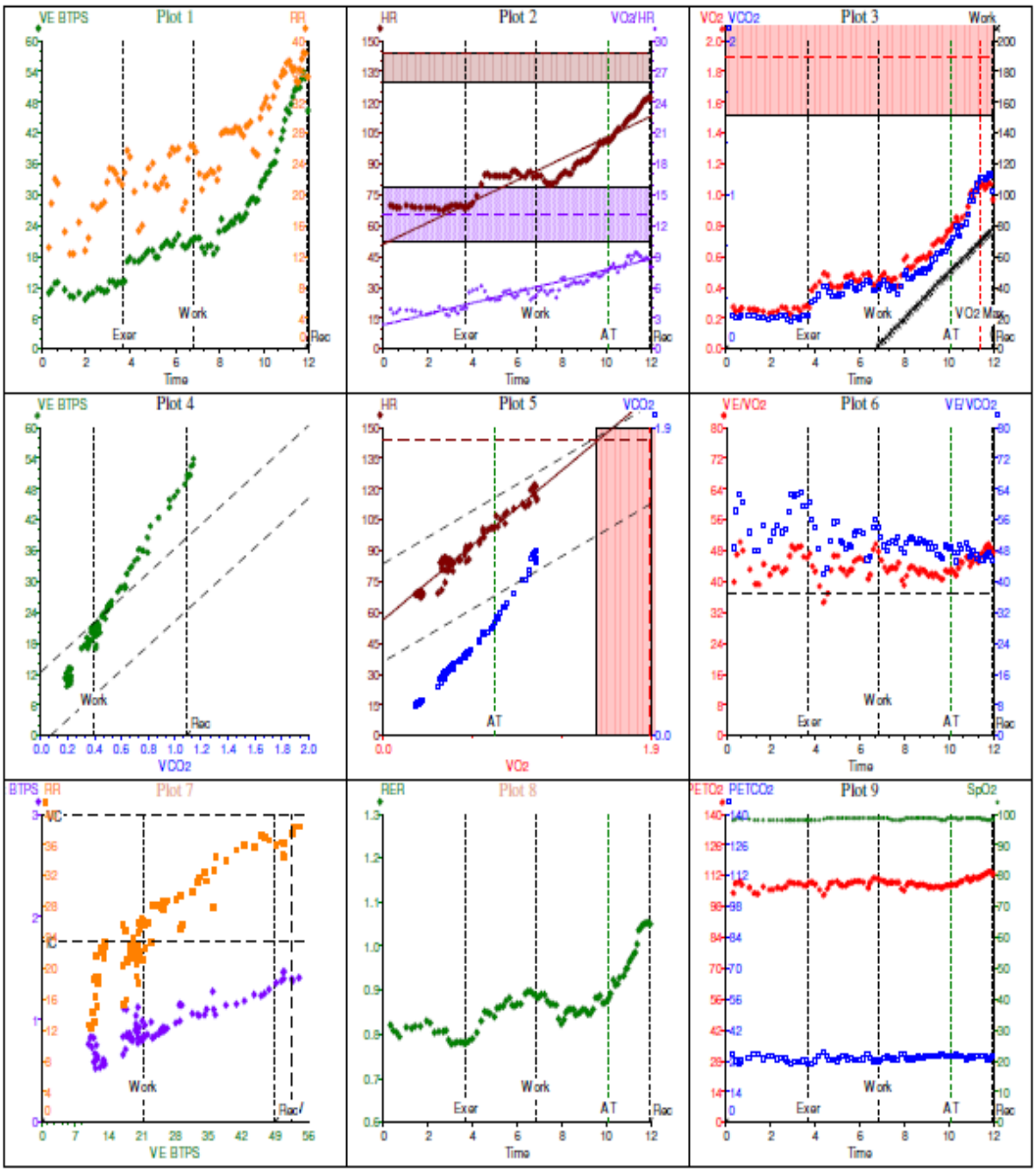
Normal cardiac limitation to exercise, normal physiological response to exercise.

Please interpret findings in light of clinical correlation.

B44 Cardiopulmonary Exercise test

76 year old male. Patient referred by the upper GI surgical team, to assess for pre-op Oesphagectomy. Medical History: Smoker (cigars). Resting ECG showed RBBB, BP 146/64, $Sp0_2$ 98%. Pre-test spirometry showed a moderate airflow obstruction – no inhalers prescribed. Patient was tested using a cycle ergometer with an incremental work rate of 15 watts per minute. Small Hans Rudolph mask, saddle height 21. Test was terminated by the patient due to leg fatigue and dyspnoea ++. The $V0_2$/work rate relationship was 10.4ml/min/watt. The ECG during exercise showed no significant changes, occasional ventricular ectopic beats and a single couplet observed during recovery.

	Rest	AT	V02 Max	Pred	VO2 Max/Pred (%)
---- WORK ----					
Work (Watts)	0	51	70	134	52
Ex Time (min)		6:24	7:41		
---- VENTILATION ----					
Vt BTPS (mL)	563	1049	1438		
RR (br/min)	23	33	35		
VE BTPS (L/min)	12.7	34.1	50.6	56.0	90
VE/MVV (%)	24	65	96		
BR (L/Min)	43.1	21.7	5.3		
---- OXYGEN CONSUMPTION ----					
VO2 (mL/kg/min)	3.9	11.9	16.5	28.5	58
VO2 (mL/min)	258	789	1092	1888	58
RER	0.78	0.88	1.02		
---- CARDIAC ----					
HR (BPM)	69	101	116	144	80
HRR (BPM)	75	43	28		
VO2/HR (mL/beat)	4	8	9	13	72
---- V/Q ----					
VE/VCO2	63	49	46	17	265
VE/VO2	49	43	46	21	223
PETCO2 (mmHg)	27	30	30		
PETO2 (mmHg)	109	108	112		
----------					
sysBP (mmHg)	146	174	190		
diaBP (mmHg)	64	69	73		
SpO2 (%)	98	99	99		
METS	1.1	3.4	4.7	8.1	58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VE BTPS
Plot 4
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VCO2
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Work
Rec
VE BTPS
RER
Plot 8
Work
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Time
PETO2 PETCO2
Plot 9
SpO2
Work
Exer
AT
Rec
Time

B44 Interpretation

Test protocol: tested using a cycle ergometer with an incremental work rate of 15 watts per minute. Small Hans Rudolph mask, saddle height 21. Test was terminated by the patient due to leg fatigue and dyspnoea ++.

Pre-test spirometry was consistent with a moderate airflow obstruction? COPD - patient not prescribed any inhaled medication. Resting ECG: RBBB, BP 146/64, $Sp0_2$ 98%. The patient exercised for 7mins and 41secs achieving a maximum workload of 70 watts (52% of predicted). RER at the height of exercise was 1.02. Sub-maximal effort test.

Aerobic capacity was moderately abnormal at 58% of predicted (normal reference >80%). $V0_2$ peak was measured at 1092ml/min or 16.5ml/kg/min when corrected for body weight. The $V0_2$/work rate response was normal at 10.4ml/min/watt (normal reference 8.3 - 12.3). The anaerobic threshold was identified confidently using the modified V-slope and confirmed using the dual criteria. 0_2 uptake measured at anaerobic threshold was recorded as 11.9ml/kg/min which is 42% of pred$V0_2$peak. This suggests a deconditioned fitness status.

Maximum heart rate at the height of exercise was 116bpm which was 80% of predicted (normal reference >90%).There was a heart rate reserve of 28bpm (normal reference <15bpm). The 0_2 pulse at peak exercise was measured as 9ml/beat which was 80% of predicted. The HR/$V0_2$ relationship was relatively normal. The ECG during exercise showed no significant changes, occasional ventricular ectopic beats and a single couplet observed during recovery. Ventilatory responses were abnormal. VE_{max} was 50.6 L/min at the height of exercise which when referenced to the MVV was 96% (normal reference <85%).There was a breathing reserve of 5.3L/min (normal reference > 11 L/min) Gas exchange responses were abnormal, The $V_E/VC0_2$ and $V_E/V0_2$ measured at anaerobic threshold were elevated at 49 (ref <34) and 43 (ref <31) respectively. Suggesting a degree of ventilatory inefficiency Sp02 trended normally throughout exercise.

Ventilatory limitation to exercise.

Please interpret findings in light of clinical correlation.

Six minute walk tests (examples B45 – B48)

The six minute walk test is sometimes referred to as a field exercise test. It is a self-paced test of walking capacity. The primary outcome of the test is the total distance walked or the 6 minute walk distance (6MWD). $Sp0_2$ is monitored throughout the test.

Typically the test is performed in a hospital corridor of 15-30m in length. The patient walks between two points at either end of the corridor and the total distance walked in 6 minutes is recorded.

For interpretation purposes the predicted walk distance can be calculated and then compared against the measured or walked distance.

The strongest indication for the 6MWT is for measuring the response to medical interventions in patients with moderate to severe heart or lung disease. The 6MWT has also been used as a one-time measure of functional status of patients, as well as a predictor of morbidity and mortality.

B45 Six minute walk Test

32 year old male complaining of increased SOBOE. Regular runner and gym attender. Has noticed racing times have been reduced over last 3/12. Intermittent cough and wheeze when breathing heavily. Worse when cold. Normal spirometry.

Patient Information

Surname			Firstname		
Hospital Number			Date of Birth		
Height	175	cm	Age	32	yrs
Weight	79	kg	Referrer		
Date of Test			Sex	M	

Pre-test

Resting BP	127/81	mmHg
Predicted Max HR	186	Bpm
HR	67	Bpm
Sp02	88	%
BORG dyspnoea	0	

Post-Test

Post ex BP	151/84	mmHg
% Predicted max HR reached	62	%
HR	112	Bpm
Sp02	97	%
BORG dyspnoea	2	

Distance

Actual walk distance (6MWD)	709	m			
Predicted walk Distance Male	717	m	Male:	*Lower limit of normal*	544 m
% Predicted walk distance Male	99	%			
Predicted walk Distance Female		m	Female:	*Lower limit of normal*	m
% Predicted walk distance Female		%			

Results

Walk time	06:00	min:sec
Pause time	00:00	min:sec
Walk distance	**709**	m
Avg Sats	**97%**	%
Min Sats	**86%**	%
Max HR	115	bpm
AVG speed	1.92	m/s

Interpretation B45

Predicted walk distance achieved (99% of predicted walk distance). No significant desaturation observed during exercise.
?appropriate test – consider CPET, full pulmonary function testing?

? EIB – exercise induced asthma?

B46 Six minute walk test

65 year old female attended joint ILD/RA clinic complaining of worsening SOB on stairs and inclines. Progressive UIP on CT with decreasing FVC and TL_{CO}. Currently taking Methotrexate. $Sp0_2$ 95% on air.

Patient Information

Surname			Firstname			
Hospital Number			Date of Birth			
Height	161	cm	Age	65	yrs	
Weight	54	kg	Referrer			
Date of Test			Sex	F		

Pre-test

Resting BP	151/89	mmHg
Predicted Max HR	163	Bpm
HR	67	Bpm
Sp02	94	%
BORG dyspnoea	2	

Post-Test

Post ex BP	175/99	mmHg
% Predicted max HR reached	98	%
HR	147	Bpm
Sp02	92	%
BORG dyspnoea	6	

Distance

Actual walk distance (6MWD)	208	m			
Predicted walk Distance Male		m	Male:	*Lower limit of normal*	m
% Predicted walk distance Male		%			
Predicted walk Distance Female	507	m	Female:	*Lower limit of normal*	368 m
% Predicted walk distance Female	41	%			

Results

Walk time	04:47	min:sec
Pause time	01:13	min:sec
Walk distance	**208**	m
Avg Sats	**91%**	%
Min Sats	**86%**	%
Max HR	115	bpm
AVG speed	0.58	m/s

Interpretation B46

Predicted walk distance not achieved (41% predicted, 208m), Significant desaturation during exercise. Minimum $Sp0_2$ 86%, Average saturation of 91%. Significant change in BORG post exercise.

?requires assessment for LTOT and ambulatory oxygen.

B47 Six Minute Walk Test

71 year old male, ex-smoker with diagnosis of COPD. Awaiting left hip replacement under GA. 6MWT requested as part of pre-op assessment.

Patient Information

Surname			Firstname		
Hospital Number			Date of Birth		
Height	188	cm	Age	71	yrs
Weight	97	kg	Referrer		
Date of Test			Sex	M	

Pre-test

Resting BP	175/101	mmHg
Predicted Max HR	158	Bpm
HR	73	Bpm
Sp02	96	%
BORG dyspnoea	0	

Post-Test

Post ex BP	177/99	mmHg
% Predicted max HR reached	87	%
HR	127	Bpm
Sp02	97	%
BORG dyspnoea	3	

Distance

Actual walk distance (6MWD)	128	m			
Predicted walk Distance Male	588	m	Male:	*Lower limit of normal*	435 m
% Predicted walk distance Male	22	%			
Predicted walk Distance Female		m	Female:	*Lower limit of normal*	m
% Predicted walk distance Female		%			

Results

Walk time	03:04	min:sec
Pause time	02:56	min:sec
Walk distance	128	m
Avg Sats	96	%
Min Sats	96	%
Max HR	117	bpm
AVG speed	0.36	m/s

Interpretation B47

Predicted walk distance not achieved (22% predicted 128m). Numerous stops during walk test. Significant change in BORG post exercise. No significant oxygen desaturation observed.

? CPET

B48 Six Minute Walk Test

31 year old female complaining of reduced exercise tolerance. Currently using NIV for OHS. Lung function shows a restrictive defect. Under investigation for pulmonary hypertension. ? Desaturation on exercise.

Patient Information

Surname			Firstname		
Hospital Number			Date of Birth		
Height	155	cm	Age	31	yrs
Weight	129	kg	Referrer		
Date of Test			Sex	F	

Pre-test

Resting BP	154/92	mmHg
Predicted Max HR	186	Bpm
HR	88	Bpm
Sp02	92	%
BORG dyspnoea	4	

Post-Test

Post ex BP	161/95	mmHg
% Predicted max HR reached	94	%
HR	175	Bpm
Sp02	95	%
BORG dyspnoea	9	

Distance

Actual walk distance (6MWD)	270	m				
Predicted walk Distance Male		m	Male:	*Lower limit of normal*		m
% Predicted walk distance Male		%				
Predicted walk Distance Female	519	m	Female:	*Lower limit of normal*	380	m
% Predicted walk distance Female	52	%				

Results

Walk time	05:35	min:sec
Pause time	00:25	min:sec
Walk distance	270	m
Avg Sats	94	%
Min Sats	92	%
Max HR	175	bpm
AVG speed	0.75	m/s

Interpretation B48

Predicted walk distance not achieved (52% predicted, 270m). No significant oxygen desaturation during exercise. Minimum $Sp0_2$ of 92%.

Bronchial Hyper-reactivity Responsiveness Tests (examples B49 – B52)

Bronchial Hyper-reactivity Responsiveness (BHR) tests assist in identifying airway hyper-responsiveness which is a major feature of asthma. It is particularly useful in patients who have normal spirometry with no bronchodilator reversibility but have symptoms typical of asthma.

There are multiple protocols for BHR tests using multiple stimuli, modes of administration and threshold doses for determining BHR.

The following examples are BHR tests using inhaled mannitol. This type of BHR test is termed an indirect challenge and act by causing the release of inflammatory mediators which act on airway smooth muscle receptors to cause bronchoconstriction. The test provides information regarding current airway inflammation. The Mannitol challenge has a low sensitivity so is not a test to be used to rule out asthma. The patient with a negative mannitol challenge test may still have asthma. The referrer needs to consider the diagnosis of asthma in light of clinical correlation (signs & symptoms) and should consider further testing i.e. reversibility, peak flow monitoring etc. or perhaps a direct bronchial hyper-reactivity test. Therefore the main usefulness of the mannitol challenge is that it allows, in patients who have current symptoms of asthma, to confirm the presence of the disease.

Other inhalation agents include hypertonic saline. Indirect physical challenges include voluntary hyperpnoea or hyper-ventilation (EVH) and exercise.

A direct challenge; typically using methacholine or histamine act on smooth muscle receptors to cause bronchoconstriction. This test is useful for any referral for BHR testing when the reason for referral is not to identify asthma. BHR is also found in a spectrum of other lung diseases from chronic obstructive pulmonary disease (COPD) to cystic fibrosis. It is often detected in atopic individuals, in patients with rhinitis but without pulmonary symptoms, in smokers and ex-smokers, after respiratory infections and following acute inhalation exposure to irritant chemicals. BHR is often regarded as a defining feature of asthma. That understanding has led to the overwhelming, but incorrect, generalisation that a positive response to BHR testing is diagnostic of asthma.

Inhalation challenges such as an inhaled mannitol challenge test are stepped cumulative dose challenges with an upper limit of stimuli delivered. That is, following a baseline spirometry, the provoking stimulus (mannitol) is delivered to the airway in steps. The FEV_1 is then measured after each step. Bronchial hyper-responsiveness to the provoking stimulus is described as the Provoking Dose (PD) or concentration required to provoke a predetermined percentage fall in FEV_1.

When interpreting a positive mannitol challenge test the following guidance should be followed:

A positive response is a ≥15% drop in FEV_1 from baseline and a PD_{15} <635mg of Mannitol or a ≥10% drop in FEV_1 between consecutive doses. A negative response is a <15% drop from baseline FEV_1 and PD_{15} >635mg of mannitol inhaled.

Severity classification (taken from the ERS Technical Standard on Bronchial Challenge Testing: Pathophysiology and Methodology of Indirect Airway Challenge Testing 2018) using the PD_{15} dose:
Mild >155mg,
Moderate >35mg ≤155mg
Severe ≤35mg

B49 Mannitol bronchial provocation Test

76 year old male attended clinic complaining of SOBOE. Non-smoker. BMI 30. Previously attended the gym 2-3 times per week. Occasional use of salbutamol when breathing very heavily to good effect. Normal spirometry. Minor variations in serial PEF. ?Asthma

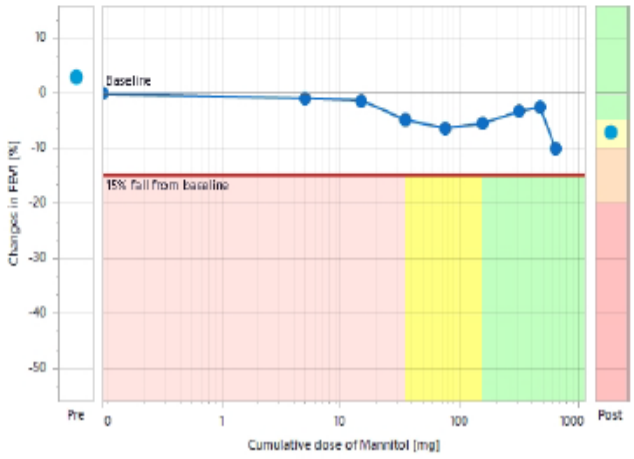
Gender	Male	Height	175 cm		Asthma	No
Ethnicity	Caucasian	Weight	91 kg	BMI 29.7	COPD	No
Smoker	No					

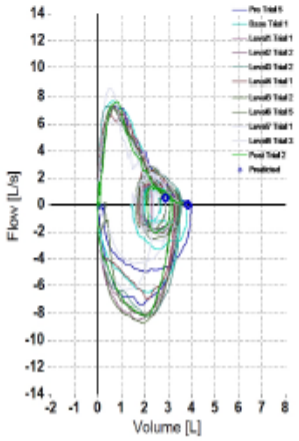
Provocation, FVL Tidal — Your FEV1 / Predicted: 108%;

Test Date	07/10/2019 14:25:13	BTPS (IN/EX)	1.11/1.02
Predicted	Quanjer (GLI), 2012		

Provocation - Mannitol — PD15: >635 mg

Dose	Total	Administer Time	FEV1	Test Time	Δ Step [%]	Δ Base [%]
Pre		14:25	3.10 L	14:31		
0 mg	0 mg	14:35	3.00 L	14:37	-3.0 %	
5 mg	5 mg	14:37	2.98 L	14:39	-0.8 %	-0.8 %
10 mg	15 mg	14:39	2.97 L	14:41	-0.4 %	-1.2 %
20 mg	35 mg	14:41	2.86 L	14:43	-3.6 %	-4.8 %
40 mg	75 mg	14:44	2.82 L	14:45	-1.5 %	-6.2 %
80 mg	155 mg	14:46	2.84 L	14:47	0.8 %	-5.4 %
160 mg	315 mg	14:50	2.91 L	14:51	2.4 %	-3.2 %
160 mg	475 mg	14:54	2.93 L	14:55	0.8 %	-2.5 %
160 mg	635 mg	14:57	2.70 L	14:59	-7.7 %	-9.9 %
Post		15:18	2.79 L	15:19		-7.0 %





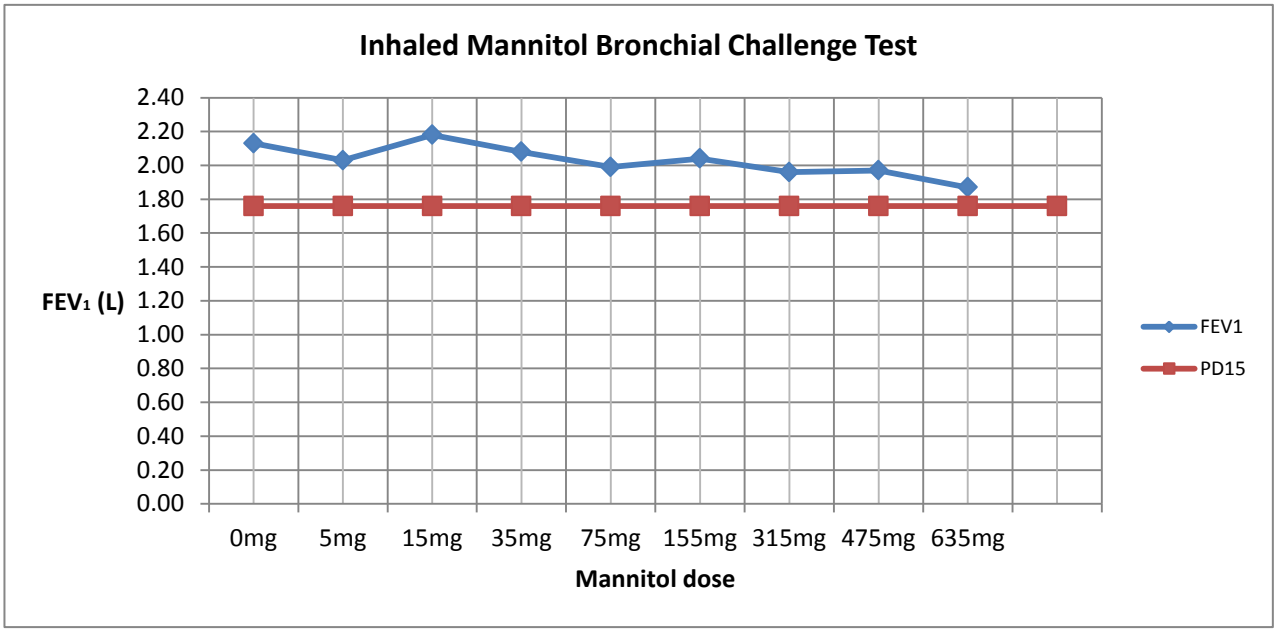
Interpretation B49

Negative test, no significant fall in FEV_1 during test. Consider FeN_O? Please note a negative test does not rule out the possibility of Asthma as a diagnosis.

B50 Mannitol bronchial provocation test

34 year old female university student. Plays hockey 3 times per week. Has noticed decreased exercise tolerance in last couple of months. Worse when playing in cold conditions. Also complaining of intermittent cough and wheeze. Normal spirometry. ? Asthma.

Stage	Cumulative dose mg	FEV_1	PD_{15}	Incremental % Change	Change from 0 mg (%)
Pre challenge spirometry		2.07	**1.76**		
Baseline (0mg)	0mg	2.13	**1.76**	3	
5mg	5mg	2.03	**1.76**	-5	-4.70
10mg	15mg	2.18	**1.76**	7	2.35
20mg	35mg	2.08	**1.76**	-5	-2.35
40mg	75mg	1.99	**1.76**	-4	-6.57
80mg (2 x 40mg)	155mg	2.04	**1.76**	3	-4.23
160mg (4 x 40mg)	315mg	1.96	**1.76**	-4	-7.98
160mg (4 x 40mg)	475mg	1.97	**1.76**	1	-7.51
160mg (4 x 40mg)	635mg	1.87	**1.76**	-5	-12.2



	FEV_1	% change
Pre challenge FEV1	2.07	
Post BD	2.03	-2
Post BD nebuliser		

Post BD FEV_1 must have returned to within >=-5% of pre challenge FEV_1.

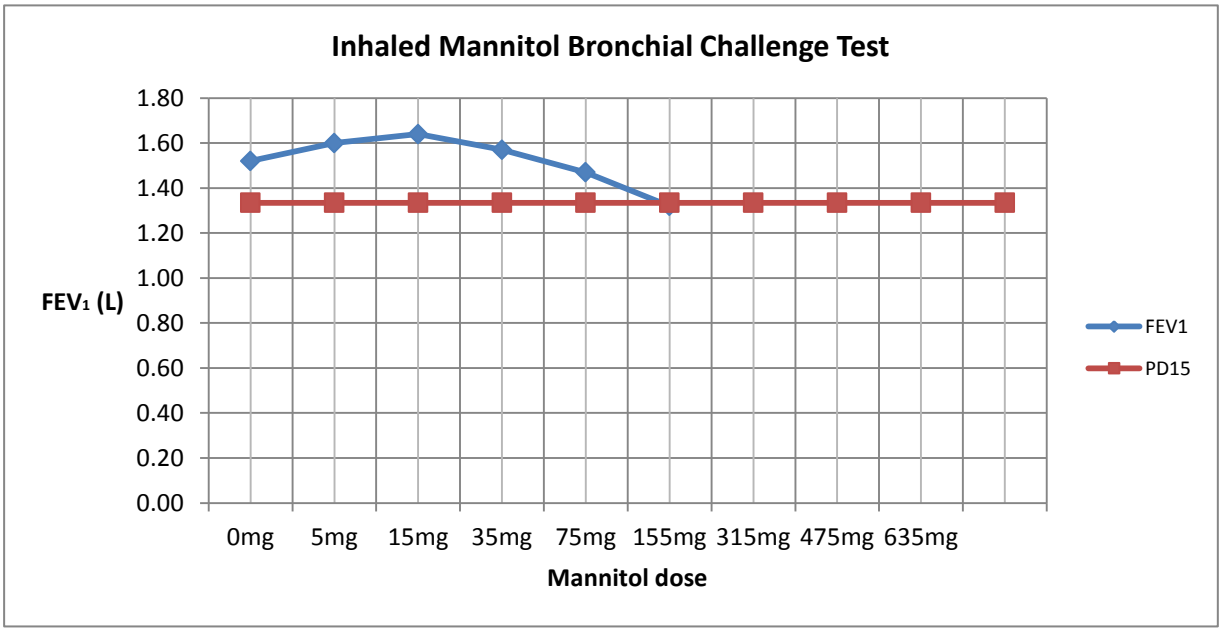
Interpretation B50

The test is complete and did not result in a ≥15% fall in FEV_1 from 0mg dose (-12.2% fall) or a ≥10% fall in FEV_1 between doses. Please note a negative test does not rule out Asthma as a possible diagnosis. Consider F_eN_O testing and serial home PEF monitoring?

B51 Mannitol bronchial provocation test

55 year old female attended clinic complaining of persistent dry cough which is worse at night, wheeze and a hoarse voice. She has never smoked. Baseline spirometry shows a borderline mild restrictive pattern. $Sp0_2$ at rest was 98%. Normal CXR.

Stage	Cumulative dose mg	FEV_1	PD_{15}	Incremental % Change	Change from 0 mg dose (%)
Pre challenge spirometry		1.57	**1.33**		
Baseline (0mg)	0mg	1.52	**1.33**	-3	
5mg	5mg	1.60	**1.33**	5	5.26
10mg	15mg	1.64	**1.33**	2	7.90
20mg	35mg	1.57	**1.33**	-4	3.29
40mg	75mg	1.47	**1.33**	-6	-3.29
80mg (2 x 40mg)	155mg	1.32	**1.33**	-11	-13.16
160mg (4 x 40mg)	315mg		**1.33**		
160mg (4 x 40mg)	475mg		**1.33**		
160mg (4 x 40mg)	635mg		**1.33**		



	FEV_1	% change
Pre challenge FEV1	1.57	
Post BD	1.74	10
Post BD nebuliser		

Post BD FEV_1 must have returned to within >=-5% of pre challenge FEV_1.

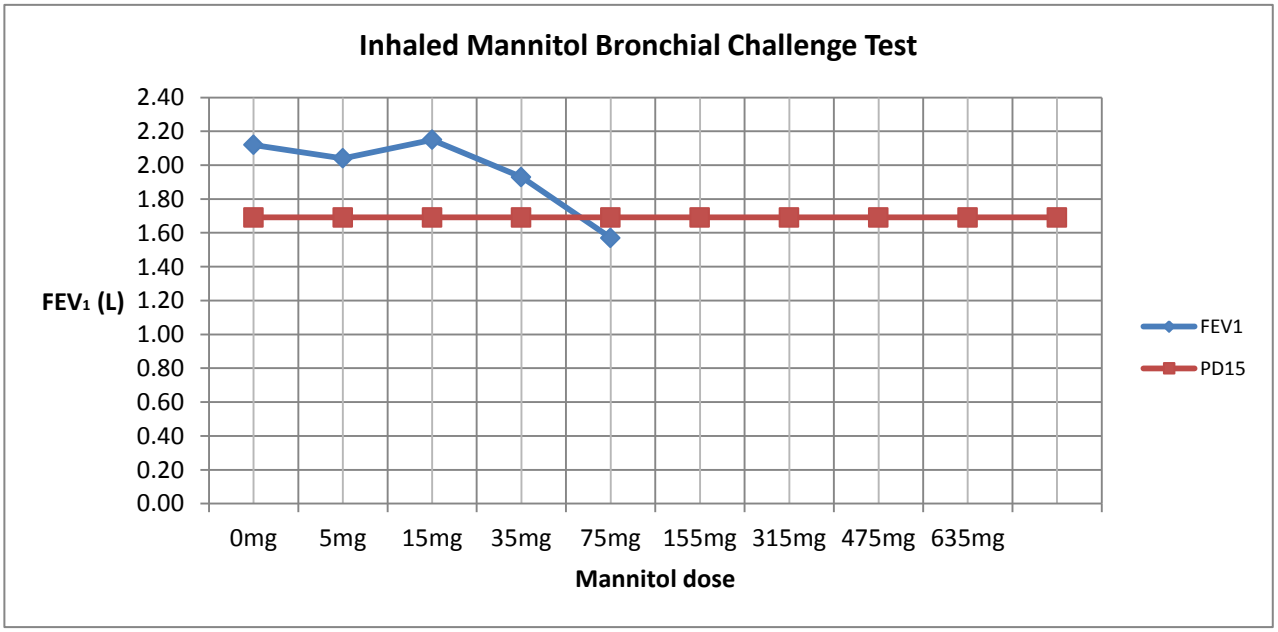
Interpretation B51

Result shows a positive test. A ≥ 10% fall in FEV_1 has occurred between doses. Total dose at positive result is 155mg. Consistent with Asthma.

B52 Mannitol bronchial provocation test

45 year old female complaining of persistent dry cough when coming into contact with strong perfumes and smoke. Allergic to cats and suffers with hay fever when pollen count is high. Normal spirometry. ?asthma.

Stage	Cumulative dose mg	FEV_1	PD_{15}	Incremental % Change	Change from 0 mg dose (%)
Pre challenge spirometry		1.99	**1.69**		
Baseline (0mg)	0mg	2.12	**1.69**	7	
5mg	5mg	2.04	**1.69**	-4	-3.77
10mg	15mg	2.15	**1.69**	5	1.42
20mg	35mg	1.93	**1.69**	-9	-7.55
40mg	75mg	1.57	**1.69**	-20	-25.94
80mg (2 x 40mg)	155mg		**1.69**		
160mg (4 x 40mg)	315mg		**1.69**		
160mg (4 x 40mg)	475mg		**1.69**		
160mg (4 x 40mg)	635mg		**1.69**		



	FEV_1	% change
Pre challenge FEV1	1.99	
Post BD	2.19	9
Post BD nebuliser		

Post BD FEV_1 must have returned to within >=-5% of pre challenge FEV_1.

Interpretation B52

Result shows a positive test. A ≥15% fall in FEV_1 has occurred since the 0 mg dose. Dose prior to ≥15% fall in FEV_1 was 35mg. Total dose at positive result was 75mg. PD_{15} dose = 48mg. 19% fall in FEV_1 seen at a dose of 75mg, consistent with Asthma. Consider skin prick allergy testing?

PART C

Part C

This section has eight lung function case study questions each with a selection of multiple choice answers to evaluate your reporting skills. The answers are available at the end of the section to help you evaluate your knowledge.

Question 1.

A 31 year old female is sent for testing via her GP, presenting with wheeze and shortness of breath. She has not been prescribed any medication. Baseline spirometry showed the following results:

Spirometry	Actual	predicted	% predicted	z-score	Post BD	% predicted	z-score	Volume change (mls)	% change
PEF (L/min)	280			-2.20	350		-0.91		
FEV_1 (L)	1.75	2.77	63	-2.90	2.45	88	-1.05	700	40
FVC (L)	2.95	3.26	90	-1.25	3.15	97	-0.77	200	7
FEV_1/FVC%	59			-3.64	78		-1.13		

Results were reproducible and meet quality assurance standards. Post BD spirometry was measured following the administration of 400mcgs of a β_2-agonsit via a spacer device.

How would you report this spirometry?

A. There is irreversible airflow obstruction.

B. There is some reversibility, but not sufficient to fulfil the guidelines for defining reversibility.

C. The reversibility observed is consistent with that seen in patients with COPD.

D. Moderately severe airflow obstruction with significant reversibility, consistent with asthma. Prescription of a β_2-agonist would be appropriate. Inhaled corticosteroids may also be helpful.

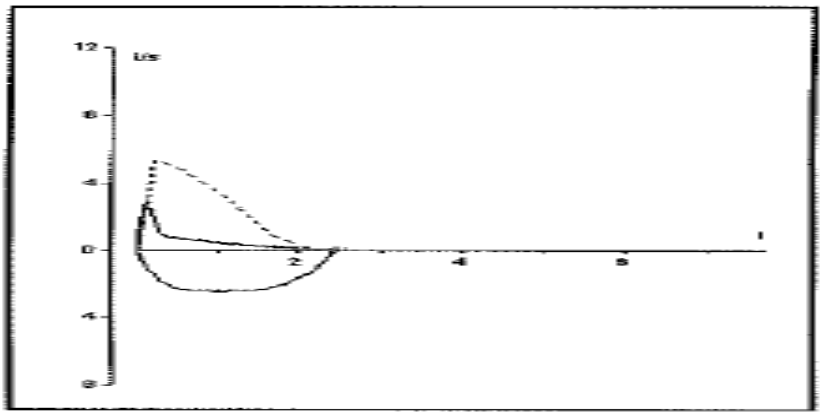
E. These results are unhelpful. Further, more in depth tests are required.

Question 2

A 74 year old female, weight 55kg, height 159cm with a normal H_b was referred for a full lung function test. The referral requested baseline lung function to investigate shortness of breath on exertion. The patient had a 10 pack year smoking history. The baseline lung function test showed the following results:

	Measured	z-score
Spirometry		
Peak Expiratory Flow (L/min)	182	-2.62
FEV_1	0.92	-2.35
FVC	2.59	0.88
SVC	2.84	1.57
FEV_1/VC%	32	-6.48
Lung Volumes (Body Plethysmography)		
TLC	5.81	1.90
TGV	4.61	3.97
RV	2.97	2.63
Gas Transfer Factor		
TL_{co}	1.34	-4.48
K_{co}	0.32*	
V_A	4.13	

**predicted K_{co} is 1.41; results were reproducible and met quality assured testing standards*



How would you report this lung function test?

A. Mixed obstructive-restrictive defect on spirometry with a significant reduction in gas transfer factor. Normal lung volumes.

B. Moderately severe airflow obstruction. Further tests are required.

C. These results are within normal limits.

D. Moderately severe airflow obstruction. These results are consistent with Asthma.

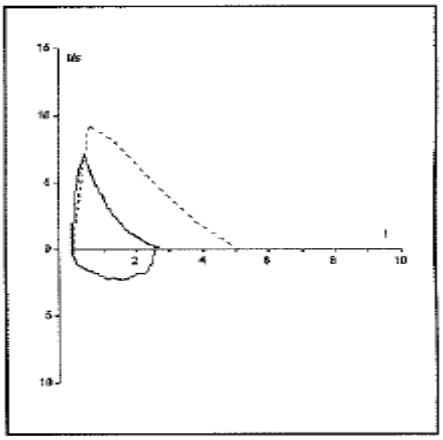
E. Moderately severe airflow obstruction on spirometry, static lung volumes are consistent with gas trapping/hyperinflation. There is a marked reduction in gas transfer factor in the presence of a relatively normal V_A and a reduced K_{co}. Suggestive of parenchymal or pulmonary vascular disease. Consider COPD/Emphysema.

Question 3

A 58 year old male, weight 138kg, height 189cm with a normal Hb was referred for a full lung function test. The clinical reason for the test was shortness of breath on exertion.

	Measured	z-score
Spirometry		
FEV_1	2.21	-3.43
FVC	2.83	-3.63
SVC	2.88	-4.23
FEV_1/VC%	78	0.18
Lung Volumes (Body Plethysmography)		
TLC	5.19	-4.04
TGV	3.28	-0.96
RV	2.31	-0.52
Gas Transfer Factor		
TL_{co}	6.79	-3.08
K_{co}	1.46*	
V_A	4.66	

*predicted K_{co} is 1.39; results were reproducible and met quality assured testing standards



How would you report this lung function test?

A. Mixed obstructive and restrictive defect with a significant reduction in gas transfer factor.

B. The results are consistent with a severe restrictive pattern possibly due to obesity (BMI = 38.6). The gas transfer factor is severely reduced in the presence of a reduced V_A and a normal K_{co}. Lung disease may be present when the K_{co} is normal in the presence of a reduced gas transfer factor and V_A. The result may be due to loss of lung units, poor gas mixing, parenchymal or pulmonary vascular dysfunction or a combination of these.

C. There is a restrictive lung pattern, cause? Abnormal gas transfer factor.

D. The results are consistent with a restrictive lung pattern, the reduced lung volumes are confirmed by a TLC that is significantly reduced. BMI = 38. The reduced gas transfer factor indicates a significant alveolar gas exchange defect.

E. Mixed obstructive and restrictive pattern with a normal gas transfer factor

Question 4

A 26 year old female has been referred with wheeze and shortness of breath. She is a non-smoker, has no sputum production and her MRC dyspnoea score is 3. The GP is unsure how to proceed and wants advice. She had not been prescribed any medication before the test. Baseline spirometry and a post 6 week trial of an inhaled corticosteroid showed the following:

	Baseline spirometry				Post 6 week steroid trial			
	Pre BD	z-score	Post BD	z-score	Pre-BD	z-score	Post BD	z-score
PEF	300	-2.42	335	-1.78	385	-0.85	445	0.26
FEV_1	1.55	-4.53	1.95	-3.47	2.30	-2.55	2.85	-1.11
FVC	3.05	-1.61	3.15	-1.37	3.10	-1.49	3.55	-0.44
FEV_1/FVC%	51	-5.10	62		74	-1.54	80	

Results were reproducible and met quality assured testing guidelines. Post BD spirometry is following the administration of 400mcgs of a β_2-agonst via a spacer device.

How would you report this spirometry result?

A. Baseline studies show a mild airflow obstruction with some reversibility. The post steroid trial suggests that inhaled corticosteroids may be useful, but this is not conclusive. Prescription of a β_2-agonist may be appropriate.

B. There is some reversibility but not sufficient to fulfil the guidelines for defining reversibility for asthma.

C. The reversibility and steroid response observed is consistent with that seen in patients with COPD. Prescription of both a β_2-agonist and a corticosteroid would be appropriate.

D. Baseline spirometry shows a severe airflow obstruction with significant reversibility. This is consistent with asthma. The post 6 week steroid trial shows further improvement in both pre and post BD spirometry. Prescription of a β_2-agonist and an inhaled corticosteroid would be appropriate. Consider FeN_O measurement.

E. The results suggest asthma it would be appropriate to undertake further testing, including a FeN_O measurement and a bronchial provocation/challenge test.

Question 5.

A 56 year old male is referred with shortness of breath ?asthma ?COPD ?cause. He is an ex-smoker, has minimal sputum production and an MRC dyspnoea score of 3. He has not been prescribed any inhalers. He is a retired foundry worker and has had significant secondary smoke exposure. Baseline spirometry and a post 6 week trial of an inhaled corticosteroid showed the following:

	Baseline spirometry				Post 6 week steroid trial			
	Pre BD	z-score	Post BD	z-score	Pre-BD	z-score	Post BD	z-score
PEF	300	-2.73	335	-2.25	310	-2.59	3.15	-2.52
FEV_1	1.55	-3.39	1.70	-3.10	1.65	-3.19	1.80	-2.90
FVC	3.05	-1.74	3.10	-1.66	3.10	-1.66	3.25	-1.41
FEV_1/FVC%	51	-3.64	55		53	-3.33	55	

Results were reproducible and met quality assured testing guidelines. Post BD spirometry via 400mcgs of a β_2-agonist via a spacer device

How would you report this spirometry result?

A. Baseline studies show a mild obstruction with no significant reversibility. These results do not exclude asthma or COPD. The post 6 week steroid trial shows no improvement. Prescription of a β_2-agonist and an inhaled corticosteroid would be appropriate.

B. Baseline studies show a mild airflow obstruction with some reversibility. Results are not consistent with COPD. The post 6 week steroid trial shows no improvement. Prescription of a β_2-agonist and an inhaled corticosteroid would be appropriate.

C. Baseline spirometry shows a severe airflow obstruction with no significant reversibility. Results are consistent with asthma. The post 6-week steroid trial shows no improvement. Prescription of a β_2-agonist and an inhaled corticosteroid would be appropriate.

D. Baseline spirometry shows a severe airflow obstruction with no significant reversibility. These results do not exclude asthma or COPD. The post 6-week steroid trial shows no improvement in post BD spirometry when compared to the baseline post BD spirometry six weeks earlier. These results more likely reflect COPD.

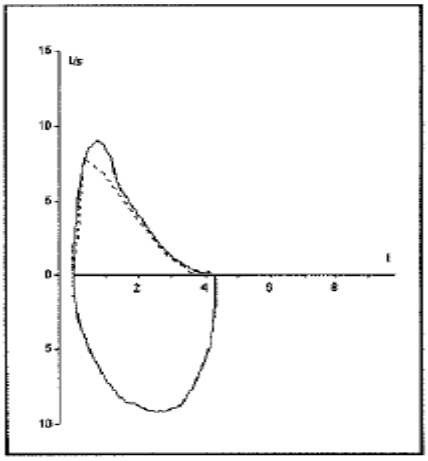
E. Baseline spirometry shows a severe airflow obstruction with significant reversibility, consistent with asthma. The post 6-week steroid trial confirms the baseline results. Prescription of a β_2-agonist and an inhaled corticosteroid would be appropriate. When making a diagnosis of asthma, this should be based on the clinical examination, history, together with the results of diagnostic tests.

Question 6

A 57 year old male, weight 57kg, height 165cm with a normal H_b and no cardiac history was referred for a full lung function test. The referral indicated that the patient was complaining of shortness of breath on exertion. His MRC dyspnoea score was 3.

	Measured	z-score
Spirometry		
FEV_1	3.12	0.66
FVC	4.26	0.93
SVC	4.42	1.05
FEV_1/VC%	77	0.06
Lung Volumes (Body Plethysmography)		
TLC	5.98	-0.20
TGV	2.91	-0.62
RV	1.56	-1.53
Gas Transfer Factor		
TL_{co}	7.64	-0.66
K_{co}	1.30*	
V_A	5.89	

**predicted K_{co} is 1.40; results were reproducible and met quality assurance guidelines.*



How would you report this lung function result?

A. Spirometry is consistent with a mild restrictive lung pattern. This is confirmed by a reduced RV. There is a mild gas transfer factor defect.

B. These results are within normal limits. Patient to be discharged from clinic.

C. Spirometry and lung volumes are within normal limits. As the patient has an elevated BMI, then this may explain his shortness of breath on exertion – suggest lifestyle changes (weight loss).

D. These results are within normal limits. The reduced gas transfer factor indicates a gas exchange defect.

E. The lung function tests are within normal limits for this patient. The shortness of breath on exertion requires further investigation. Consider a Cardiopulmonary Exercise Test (CPET).

Question 7.

A 42 year old male, weight 63kg, height 172cm and with a normal Hb was referred from a neurologist for baseline lung function testing. The patient was complaining of shortness of breath. No diagnosis was given by the neurology team. During testing the physiologist recorded the patients symptom history and noted that the patient became more short of breath lying flat and currently sleeps in a semi-recumbent position with 4 pillows. Also noted was that the patient suffered with frequent morning headaches. On the basis of this history the respiratory physiologist undertook further tests which may aid in the diagnostic process:

Spirometry	seated	z-score	supine	z-score
PEF	438	-1.32	295	-3.29
FEV_1	2.85	-1.63	2.25	-3.66
FVC	3.50	-1.61	2.66	-2.98
FEV_1/VC%	81	0.25	84	
Lung Volumes (Body Plethysmography)				
TLC	5.55	-1.59		
TGV	2.78	-0.88		
RV	2.05	0.24		
Gas Transfer Factor				
TL_{co}	8.44	-1.33		
K_{co}	1.62*			
V_A	5.21			
Simple respiratory Muscle assessment				
	measured	LLN		
MIP	59	82		
MEP	62	56		
SNIP	65	70		
Cough PEF	452	270		

**Predicted K_{co} is 1.58; results were reproducible and meet quality assurance guidelines*

How would you report these lung function results?

A. Test is within normal limits. The decrease in FVC (supine) is within expected volume decrease compared to when seated.

B. Mild restrictive pattern on spirometry and lung volumes. Normal gas transfer factor. The FVC falls by >20% which confirms the presence of significant diaphragmatic weakness/dysfunction. Referral to a sleep and ventilation clinic is suggested to undertake overnight sleep studies, blood gases. Consider NIV?

C. Seated spirometry, lung volumes and gas transfer factor are all within normal limits. However when in the supine position the FVC falls by -24% and is suggestive of diaphragmatic weakness/dysfunction. This is confirmed by a reduced MIP and SNIP – a low MIP suggests isolated diaphragmatic weakness. Normal cough PEF. Refer to a sleep and ventilation clinic for consideration of overnight sleep studies, morning blood gases. Consider NIV?

D. Mild restrictive pattern on spirometry and lung volumes. The reduced MIP and MEP suggest a degree of respiratory muscle weakness, further confirmed by a fall in FEV_1 when in supine.

E. The results are within normal limits and no further investigation is required.

Question 8

A 52 year old male, weight 85kg, height 178cm was referred by their GP for baseline lung function tests to investigate breathing difficulties on exertion. A history was taken during testing and this indicated that the patient was complaining of chest tightness and wheeze in the morning, occasionally during the night and following exercise.

	Measured	z-score
Spirometry		
PEF	602	1.02
FEV_1	3.97	0.66
FVC	5.08	0.90
SVC	4.93	0.37
FEV_1/VC%	78	0.05
Lung Volumes (Body Plethysmography)		
TLC	7.17	0.10
TGV	3.19	-0.57
RV	2.10	-0.35
Gas Transfer Factor		
TL_{co}	8.47	-1.27
K_{co}	1.30*	
V_A	6.49	
Resting Sp02		
Sp02 on air	97%	

**predicted K_{co} is 1.35; results were reproducible and met quality assurance guidelines.*

How would you report these results?

A. Lung function is within normal limits. Patient to be discharged from clinic.

B. Gas transfer factor is reduced. This would explain the shortness of breath on exertion.

C. Lung function is within normal limits. Results do not explain breathing difficulties.

D. The results are within normal limits. A normal test does not rule out asthma. When making a diagnosis of asthma, this should be based on the clinical examination, history, together with the results of diagnostic tests. The history suggests an asthmatic component, especially during exercise. Consider further testing. Serial home PEF monitoring to assess for diurnal variation plus a FeN_O measurement also consider an assessment for exercise induced bronchoconstriction (exercise spirometry).

E. The results are within normal limits. The history is consistent with asthma. Prescribe standard asthma therapy medication as appropriate.

Section C Answers

1.	D
2.	E
3.	B
4.	D
5.	D
6.	E
7.	C
8.	D

The Importance of Test Quality Assurance

Lung Function tests require in most cases a significant amount of patient co-operation and understanding. Some also require maximal effort to ensure test accuracy. Regularly patients will have difficulty performing or completing measurements so not all lung function reports will be from quality assured tests. Patients may be short of breath, apprehensive or unwell. The diagnostic test data may therefore need assessing for accuracy and usefulness.

Generally it is important not to just simply disregard the report but perhaps use elements of it to assist with your clinical judgement and decision making. It is however important to review the data with caution as accuracy cannot be guaranteed.

Quality assurance is essential for interpretation. Good quality tests provide a good representation of the patients lung function, poor quality or suboptimal tests may not.

Not reporting results may be better than providing suboptimal test results which ultimately may lead to misclassification or misdiagnosis. However, elements of a suboptimal test report may provide some useful information.

The physiologist/clinical scientist will always provide cautionary statements on the report to enable clinical judgement to be applied as to the reports usefulness.

A prime example may be that only one acceptable good effort blow/manoeuvre was obtained and that the patient was unable to meet reproducibility criteria, that single good effort could be used, with caution, and not disregarded.

It is therefore imperative that the technical comments are assessed prior to any interpretation takes place.

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If you have any suggestions or comments regarding the content of the portfolio then please forward these onto peter.moxon@nhs.net.

Thank you.

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Appendices

1. Lung Function Acceptability and Reproducibility criteria

Relaxed Vital Capacity measurement

Acceptability	Reproducibility
Efforts/trials must be free from artefact	2 largest VC need to be within 100ml of each other.
No cough	A minimum of 3 efforts/trials
No leak or hesitation at the mouthpiece	A maximum of 5 efforts/trials
No obstruction of the mouthpiece with the tongue	
Plateau reached	

Dynamic Spirometry

Acceptability	Reproducibility
Efforts/trials must be free from artefact	A minimum of 3 efforts/trials
No cough within the first second	A maximum of 8 efforts/trials. After 8 attempts the probability of getting a better result is significantly reduced. Do not reject results, comment on repeatability and report best efforts.
Rapid rise to PEF (FVL). The highest reading of at least 3 technically acceptable blows should be recorded.	The two largest values of FVC must not differ by more than 0.15L (150ml) of each other The two largest values of FEV_1 must not differ by 0.15L (150ml) of each other
No early termination of expiratory effort, plateau reached (the volume–time curve shows no change in volume (<0.025 L) for last 1 second of the test). Note that if plateau has <u>not</u> been achieved the FEV_1 may still be of some use. Early termination is not a reason to eliminate all data obtained as indices such as FEV_1 may not be affected and will still be valid.	For those with an FVC of ≤1.0 L, the two largest FVC and FEV_1 must be within 0.1L (100ml) of each other.
Forced Expiratory Time (FET) ≥3 s in children aged >6 and <10 years and for ≥6 s in subjects aged >10 years. Consideration must be given to restrictive subjects (FET can be < 6seconds). Pre-school children can reach a volume plateau in <1 s. Do not report FEV_1 if FET <1 s. Instead consider using $FEV_{0.75}$/FVC%.	FVL reproducible in shape. This is particularly important when there is a suggestion of upper airway obstruction.

No poorly co-ordinated start or slow start (back extrapolated volume must be <5% of the FVC or 0.1 L if the FVC is < 2.0L. In subjects <6yrs back extrapolated volume <75ml or 10% of the FVC is acceptable).	PEF-approximately 90% of subjects can achieve three PEF measures within 30 L/min (0.5L/s), 95% of subjects are within 40 L/min. Maximum number of 5 attempts for PEF.
No obstruction of the mouthpiece with the tongue, distortion of mouthpiece due to excessive biting or obstruction by the teeth.	The chosen results should be the greatest values from three technically acceptable tests. FEV_1 and FVC may be taken from different manoeuvres.
Test performed with an open glottis	
No leak at the mouth (consideration must be given to neuromuscular weakness patients and those with facial palsy)	
No extra breath taken during effort	
Maximal inspiration to TLC prior to forced expiratory effort.	

Static Lung Volumes (Helium dilution and Nitrogen washout)

Acceptability	Reproducibility
No excessive switch in error. Small differences in switch in volume (~50ml) can be discounted as being of little clinical significance. Larger differences of >500ml should result in test being abandoned and then restarted. For differences between 50ml – 500ml the subject should be maintained at the switch in volume and the difference subtracted (or added) to the measured FRC.	Obtain one technically acceptable result*. FRC_{He} inter-test variability is so small [17] that only one test needs to be performed, more attempts will improve accuracy. If a second FRC_{He} is made, there should be an interval equivalent to test duration of first test or 10 minutes if equilibrium not reached.
Time for equilibrium does not exceed 10 minutes. If equilibrium does exceed 10 mins then a comment highlighting this should be included.	If a second FRC_{N2} is made then there should be a rest interval equivalent twice the time taken to complete the first measurement.
Equilibrium reached (He ± 0.02% or FRC ± ±0.025L over a 30 second period).	Ideally the reported FRC_{He} should be the mean value from two measurements, assuming there is no significant differences i.e. <200ml. Repeatability between technically acceptable FRC_{N2} should be within 10% and the average value is to be reported.
No equipment leaks. Volume of added 0_2 exceeds 200ml – 250ml/min or 0.04L/kg/min.	The highest ERV and IC should be reported.
Stable baseline tidal volume achieved.	

No patient leaks (mouthpiece/nose/eardrum). During nitrogen washout the exhaled nitrogen profile will instantly display a "spike" should any leak occur. Test should be discontinued and not repeated until twice the duration of the failed test has passed.	

*There is no evidence to suggest this as best practice. A duplicate measurement should ideally be performed.

Static Lung Volumes (Body Plethysmography)

Acceptability	Reproducibility
No excessive force when panting leading to hysteresis,	At least 3 technically acceptable TGV_{pleth} which agree within 5%, the mean value is reported (the difference between the highest and lowest values divided by the mean is ≤ 5%).Additional TGV_{pleth} should be obtained until three values agree with 5% of their mean.
Incorrect panting frequency (should be ~ 1 breath/second), panting frequency > 0.5Hz < 1.5Hz	
No excessive panting manoeuvre producing large, variable, invalid recordings	
No leak in box seal.	
No thermal drift	

Gas Transfer Test

Acceptability	Reproducibility
Rapid inhalation achieved within 1.5 – 2.0 seconds (normal and restrictive subjects) and ≤4.0 seconds in obstructive (FEV_1/FVC % < 50%)	A minimum of 2 and a maximum of 5 technically acceptable tests. 5 gas transfer factor tests will increase COH_b by ~3.5% which will ultimately lower measured transfer factor by 3.5%.
A V_{in} ≥ 90% of the subjects VC or a V_{in} ≥ 85% of the subjects VC with a V_A within 200mls or 5% (whichever is greater).	2017 ERS/ATS standards for single breath gas transfer -criteria for reproducibility are at least two acceptable TL_{co} measurements. TL_{co} within 0.67 mmol/min/kPa. K_{co} within 1.0 mmol/min/kPa/L Alveolar Volume (V_A) within 5%.
Breath hold time should be 10 seconds ± 2 seconds with no valsalva or mueller manoeuvres.	The mean of two technically acceptable manoeuvres should be reported
Modern rapid gas analysis systems allow the operator to inspect the continuous exhaled gas concentration curves and accurately identify deadspace washout, this	

is vital in these systems.	
Time between manoeuvres of at least 4 minutes. Patients with severe airflow obstruction may require longer.	
Expiratory time <4seconds and to sample collection < 3 seconds	
No step wise inhalation or exhalation	
Exhaled volumes that do not exceed inhaled volumes	
No Inspiratory or expiratory gas leak	

2. Z-score severity classification .

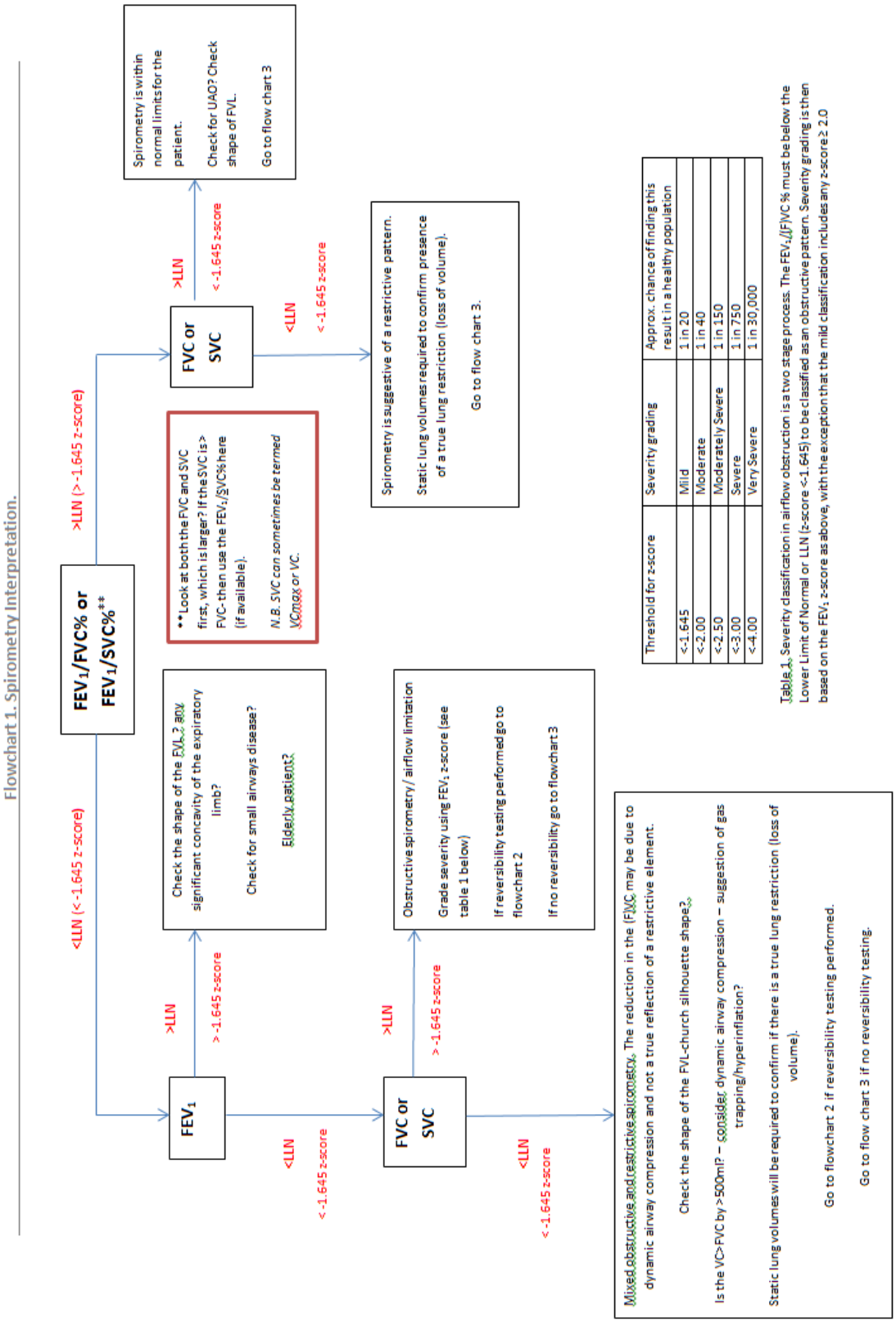
Threshold for Z-score	Severity Grading	Approximate chance of finding this result in a healthy population
< - 1.645	MILD	1 in 20
< - 2.00	MODERATE	1 in 40
< - 2.50	MODERATELY SEVERE	1 in 150
< - 3.00	SEVERE	1 in 750
< - 4.00	VERY SEVERE	1 in 30,000

Severity classification in airflow obstruction is a two stage process. The FEV_1/FVC must be below the Lower Limit of Normal or LLN (Z-score < -1.645) to be classified as an obstructive pattern. Severity grading is then based on the FEV_1 Z-score as above, with the exception that the mild classification includes any FEV_1 Z-score ≥2.0

3. Methods of expressing bronchodilator responsiveness

ATS (1991)	≥12% and >200ml increase (FEV_1 or FVC)
Quanjer et al (1993)	Change in FEV_1 > 9% predicted value
BTS/ARTP (1994)	160ml increase in FEV_1; 330ml increase in VC
Siafakas et al (1995)	Change in FEV_1 >10% predicted value
BTS/SIGN (2003)	≥200ml + ≥15% increase in FEV_1 from baseline
NICE (2004)	Change in FEV_1 > 400ml
ATS/ERS (2005)	**>12% + >200ml increase in FEV_1 and or FVC**
GOLD (2007)	>200ml + >12% increase in FEV_1 from baseline
BTS/SIGN (2012)	Change in FEV_1 >400ml
Ward et al (2015)	**>8% change in FEV_1 % predicted**
Quanjer (2017)	**>8% change in FEV_1 % predicted** **> +0.78 in z-score in FEV_1 from baseline** **> +0.64 in z-score in FVC from baseline**
ATS/ERS (2019)	The % change and absolute change in FEV_1 and FVC compared with pre-bronchodilator values are reported. The change in FEV_1 as a %predicted FEV_1 or as a z-score avoids sex and height bias.
Aggarwal et al (2019)	≥12% and ≥ 200ml increase (FEV_1 or FVC)

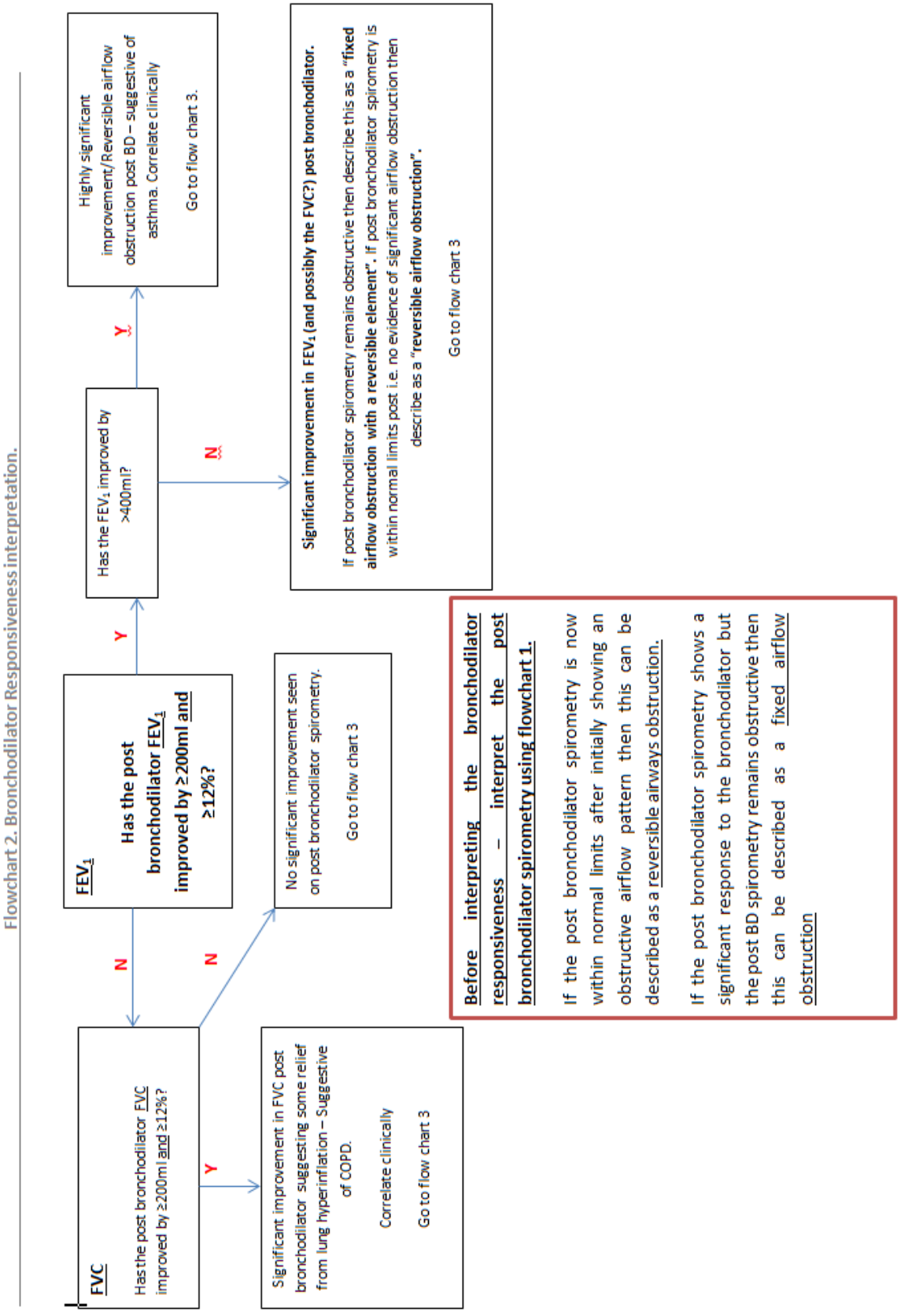
4. Flowchart – Basic Spirometry Interpretation



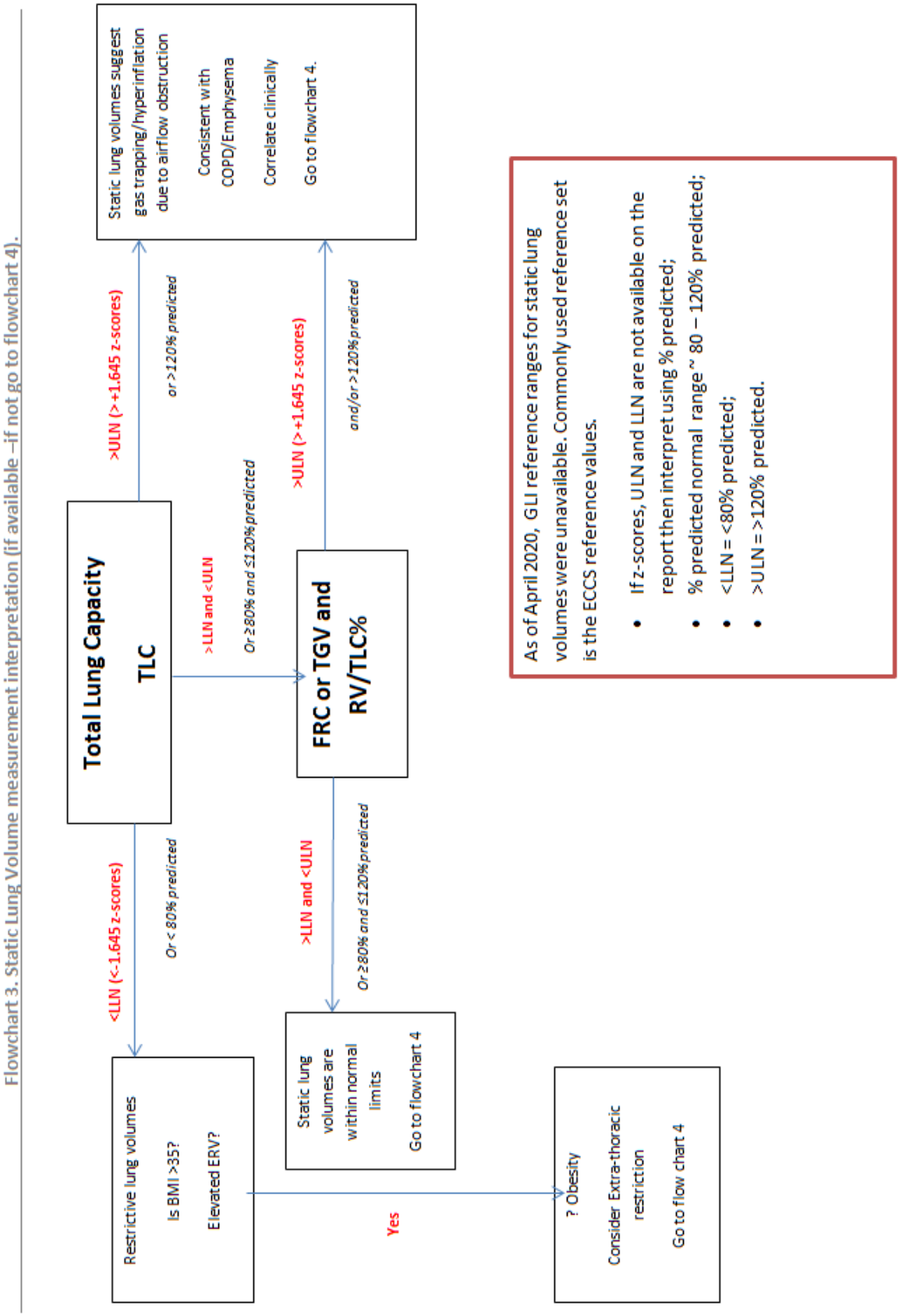
Threshold for z-score	Severity grading	Approx. chance of finding this result in a healthy population
<-1.645	Mild	1 in 20
<-2.00	Moderate	1 in 40
<-2.50	Moderately Severe	1 in 150
<-3.00	Severe	1 in 750
<-4.00	Very Severe	1 in 30,000

Table 1. Severity classification in airflow obstruction is a two stage process. The FEV_1/(F)VC % must be below the Lower Limit of Normal or LLN (z-score <-1.645) to be classified as an obstructive pattern. Severity grading is then based on the FEV_1 z-score as above, with the exception that the mild classification includes any z-score ≥ 2.0

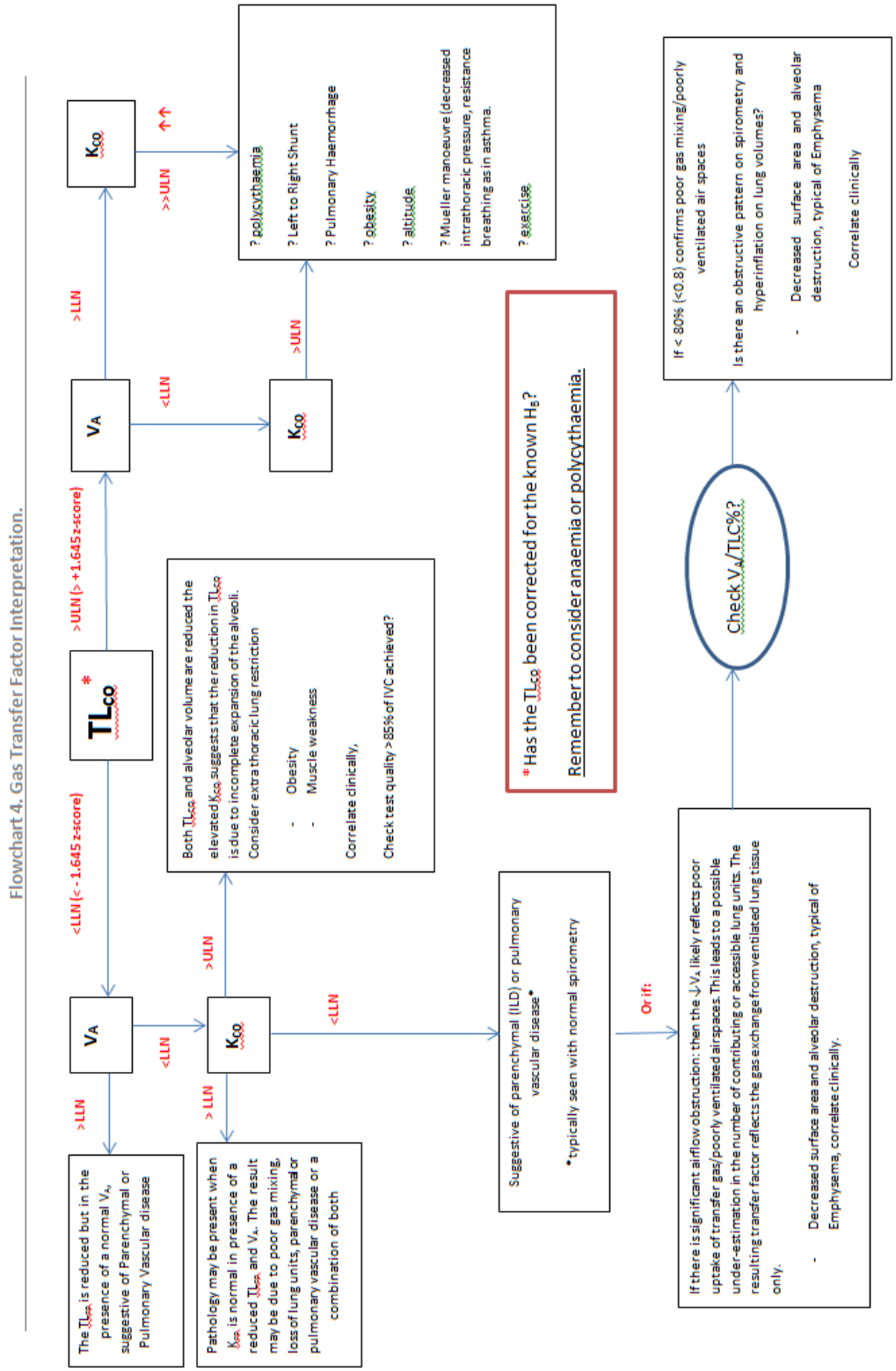
5. Flowchart – Bronchodilator Responsiveness Interpretation



6. Flowchart – Static Lung Volumes Interpretation



7. Flowchart – Gas Transfer Factor Interpretation



8. Example of a Basic Respiratory Sleep Study reporting template

The sleep study was initially autoscored and then in line with local protocol manually scored by *([staff initials and job title]).*

Overall the study is of an [*acceptable/good/poor*] quality for interpretation with a recording time of [ ] hrs and [ ] minutes. The supine time was [ ] % of the total recording time (normal reference >30%), if <30% consider repeating the study. [*There are periods of flow signal artefact*]. Flow signal quality is [ ] % and oximetry quality is [ ] %. [*Nasal flow signal artefact may lead to a possible underestimation of the severity - please interpret with caution].*

[The sleep study shows no significant evidence of sleep disordered breathing]. The AHI is <5.0.

The results indicate [*mild/moderate/severe*] sleep apnoea with an AHI of [ ] and an ODI of [ ]. [*The slightly higher ODI is a result of the loss of the flow signal during the recording]*. [*The higher AHI when compared to the ODI might suggest a higher significance of apnoea's without an associated desaturation].* The AHI in supine position is [*slightly lower/higher*] at [ ].

The patient had a snore index of [ ]% The snore index is classed as the % of the study spent in snore train - a snore train is defined as a period of 3 or more snores in a continuous row. The flow limitation index was [ ] % (normal reference <30%). Excessive flow limitation alone can lead to excessive daytime tiredness. The majority of the events were [ ] ([*enter number/count]*), there was [ ] obstructive apnoea's, [] central apnoea's and [ ] mixed apnoea. The average Sp02 was [ ] %, the minimum Sp02 was [ ] %. % of time spent <90% Sp02 was [ ] %. [*Low baseline saturation throughout recording*].

Please interpret findings in light of clinical correlation, [*due to signal artefact, please use clinical judgement when considering the report, interpret with caution*].

9. CPET Normal Variables and clinical significance

CPET Normal variable and Clinical significance

Variable	Normal	Clinical Significance
VO_{2max}	➢ 80%	Decreased in heart failure, COPD, ILD, obesity, PVD and deconditioning.
AT	➢ 40% VO_2Peak	Decreased in heart failure, COPD, ILD, PVD and deconditioning. Normal in obesity.
Heart rate HRR	➢ 90% of predicted <15bpm	Decreased in COPD, obesity, PVD and deconditioning. Normal in heart failure.
O_2 pulse	➢ 80%	Decreased in heart failure, COPD, ILD, PVD and deconditioning. Normal in obesity.
VE_{max}	<85% of MVV	Increased or normal in heart failure, COPD, ILD, obesity, PVD and deconditioning.
Respiratory Rate	Rest – 8-12min Peak exercise < 50 breaths/min	Increased or normal in heart failure, COPD, ILD, obesity, PVD and deconditioning. Elevated in athletically trained.
Breathing Reserve	>11 L/min	Increased or normal in heart failure, COPD, ILD, obesity, PVD and deconditioning.
SpO_2	➢ =95% =< 4% dip	Decreased in ILD and PVD Normal in Heart Failure, obesity and deconditioning.
V_E/VCO_2 (@ AT) V_E/VCO_2 slope	< 34 ~28	Increased in heart failure, COPD, ILD and PVD Normal in obesity and deconditioned
WR/VO_2 relationship	8.3 – 12.3 ml/min/watt	Reduced with poor O2 delivery to working muscle Increased with faster cadence or 'rise from saddle'
Chronotropic index or HR/VO_2 response	0.8- 1.30 $CI = \left[\left(\frac{Peak\ HR - baseline\ HR}{predicted\ HR - baseline\ HR}\right) \Big/ \left(\frac{Peak\ VO2 - baseline\ VO2}{predicted\ VO2 - baseline\ VO2}\right)\right]$ *Pred HR = 220-age*	Decreased (shallow) in submaximal exercise, chronotropic incompetence, training status -a low CI can be seen in exceptionally fit individuals (elevated $VO2_{max}$, elevated VO_2 @ AT) <0.8 blunted HR response ?chronotropic incompetence can indicate cardiac dysfunction also caused by medication such as Beta blockers Increased (steeper) in heart failure, myocardial dysfunction, coronary artery disease, valvular heart disease >1.30 steep HR response suggests increased dependence on HR to increase cardiac output secondary to a low stroke volume
RER	Rest – 0.7-0.95 AT point - <1.0 Peak Exercise – 1.1-1.5	Increased at rest with recent carb load or hyperventilation. Reduced at peak exercise may indicate submaximal effort

10. Example of a CPET reporting template

Cardiopulmonary Exercise Test Summary Report

Hospital Name:	Department:
Patient's Surname:	Test Date:
Patient's Name:	Type of ergometer and metabolic cart:
DOB:	Reason for referral:
Consultant:	Clinical Diagnosis:
Indication(s) for conducting the test	

TECHNICAL

Protocol:
Describe exercise protocol employed, work increment as a function of time and total incremental exercise duration.

Technical Comments:
Review criteria outlined on Figure 3 to establish whether the test has led to the limit of tolerance. Report the source of equation used to express physiological variables as a fraction of predicted normal values.

Reason for termination of test:
Report the reason(s) indicated by the patient for terminating the test (breathlessness, leg discomfort or both). Indicate whether the patient complied well with the incremental effort or claimed discomfort with the exercise or breathing apparatus as a contributing factor to exercise limitation.

EXERCISE RESPONSE

Aerobic Capacity/Anaerobic Threshold*:
A peak VO_2 of …. $mL.min^{-1}.kg^{-1}$ (…% predicted normal) was achieved along with a peak workload of …. Watts (…% predicted normal) *or peak speed of … $km.h^{-1}$*. Anaerobic threshold (AT) occurred at …. $mL.min^{-1}.kg^{-1}$ (…% predicted VO_2 max. Corresponding values were …. METs at AT and …. METs at the limit of tolerance. Indicate whether VO_2/work rate slope (…. $mL.min^{-1}.Watt^{-1}$) was within the normal range.

Cardiovascular response:
Peak HR was …. $beats.min^{-1}$ (% predicted normal). Indicate any abnormalities detected by the ECG recordings and report systolic and diastolic BP at the limit of tolerance. Conclude if cardiovascular response was normal.

Ventilatory response:
Peak VE was …. $L.min^{-1}$ (…% MVV)**. Report the change from baseline in inspiratory capacity (delta IC = …. mL). Report shortness of breath score ……. Conclude whether exercise limitation was of ventilatory origin.

Gas exchange:
Report ventilatory equivalents for VO_2 and VCO_2 at AT and at peak exercise. Report resting and peak SpO_2. Report the VE/VCO_2 slope values. Conclude whether gas exchange response to exercise was normal.

Metabolic:
RER values were …. at rest, …. at AT and …. at the limit of tolerance.

SUMMARY

Conclusion: Comment on patient's effort and exercise capacity taking into consideration peak values for work rate, *speed*, VO_2 and AT. Comment on potential ventilatory, cardiovascular or peripheral muscle limitation or simply poor effort.

Compare the results with previous tests on the same patient and indicate when the test should be repeated.

The above template is found as an inline supplement in the following guidance paper:

Radke. T, Crook. S, Kaltsakas. G *et al*. **ERS statement on standardisation of Cardiopulmonary exercise testing in chronic lung diseases**. Eur Respir Rev 2019; 28: 180101.