What lung function data are relevant concerning the assessment of COPD patients for out patient rehabilitation?

An information package on lung function tests and interpretation of test data in identifying limitations in COPD out patients.

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Preface

We wish to acknowledge and thank all those who helped and gave us support and advice throughout this project.

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Summary

Chronic Obstructive Pulmonary Disease is a growing worldwide problem. It has been proved that participating in a rehabilitation programme improves the patient’s quality of life and exercise capacity. Physiotherapists are key figures in planning and implementing patients rehabilitation programmes.

It is recommended in the KGNF guidelines that physiotherapists should have the relevant expertise and the diagnostic and therapeutic skills necessary to treat these patients and that they should be familiar with the measuring instruments used in pulmonary assessment and be familiar with the interpretation of incremental exercise test results.

Pulmonary function testing includes amongst others, spirometry, plethysmography and cardio pulmonary exercise testing (CPET). The data obtained from spirometry and plethysmography is useful for diagnosing, measuring the severity of and evaluating the effects of treatment of COPD. The data from the CPET is indispensable for identifying exercise limitations such as cardiovascular and ventilatory restrictions.

The ability to interpret the data provides the physiotherapist with an invaluable tool to assist with the planning, implementation and evaluation of the individual’s treatment plan.
Introduction

The topic we chose for our assignment is the interpretation of pulmonary function test data, focusing on the limitations affecting COPD patients when planning outpatient rehabilitation programmes.

Chronic Obstructive Pulmonary Disease is a major cause of morbidity and mortality throughout the world. Its prevalence is increasing and it is the only major leading cause of death that is increasing. Pulmonary rehabilitation programmes are firmly established as a successful method to treat the patient.

The physiotherapist is a key figure in the rehabilitation programme and responsible for planning and implementing the exercise component of the programme. In order to be able to competently structure an individual’s treatment, it is essential that the therapist is able to recognise the limitations to exercise that the COPD patient can present with. The patient’s programme can then be adapted to minimise the effect of the particular limitation.

Pulmonary function testing is frequently part of routine pre rehabilitation programme assessment. The data obtained are used to diagnose, plan treatment, monitor and evaluate effects of treatment. They are used to identify the limitations to exercise. The results provide the physiotherapist with an important tool for planning the patients’ rehabilitation programme because they provide a means of identification of the limiting factors that will affect the patient’s progress or ability to participate or benefit from the programme.

According to the guidelines produced by the KNGF, physiotherapists working in the area of pulmonary rehabilitation should have the relevant expertise and the diagnostic and therapeutic skills needed to treat these patients. (KNGF 2003, pp. 12) It is also recommended that the therapist should be familiar with the measuring instruments used in pulmonary assessment and be familiar with the interpretation of incremental exercise test results.

The focus of our project is the interpretation and analysis of the data from lung function tests for junior physiotherapists or student physiotherapists and the application of the data to the physiotherapy treatment of COPD out patients.

Chapter 1 provides the reader with a general introduction to COPD; outpatient’s rehabilitation programmes and briefly describes the limitations that can influence the structure and planning of the patient’s individual programme.

Chapter 2 provides the reader with a description of the individual tests and how they are performed.

Chapter 3 describes the interpretation of the tests, focusing on COPD out patient rehabilitation. The interpretation is based on the particular tests that are performed at the St. Lucas Andreas hospital.
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Chapter one

The first chapter will provide the reader with general information on COPD and some statistics and epidemiology. COPD outpatient rehabilitation programmes are described and information on possible exercise limitations in COPD patients is provided.

COPD

Chronic obstructive pulmonary disease COPD is a condition of chronic diffuse irreversible airway obstruction. It is defined by progressive, irreversible airflow limitation and an inflammatory response of the lungs, usually to cigarette smoke (Lapperre et al. 2004, pp. 499). COPD is a disease mainly of adults over 45 years old who usually have a history of risk factors such as cigarette smoking or exposure to airborne pollution. It is a slowly progressive disease of the airways characterized by gradual loss of lung function. COPD has been recognized as a disorder with components of chronic bronchitis, small airways disease, emphysema, and, in some patients perhaps, features of asthma (Mannino 2002, pp.122).

Emphysema

Emphysema is characterized by the destruction of the alveolar walls, as well as atrophy and collapse of the lower airways - those from the terminal bronchioles on down. The lungs actually undergo self destruction by proteolytic enzymes secreted by leucocytes in the lungs in response to a variety of factors. Cigarette smoking is by far the most important of these factors; it exerts its action by stimulating the release of the proteolytic enzymes and by destroying the other enzymes that normally protect the lung against the proteolytic enzymes. As a result of alveolar-wall loss, adjacent alveoli fuse to form fewer but larger alveoli, and there is a loss of the pulmonary capillaries that were originally in the walls. The merging of alveoli, often into huge balloon-like structures, reduces the total surface area available for diffusion, and this impairs gas exchange. Moreover, even more important, because the destructive changes are not uniform throughout the lungs, some areas may receive large amounts of air and little blood, while others have just the opposite pattern; the result is marked ventilation-perfusion inequality. In addition to problems in gas exchange, emphysema is associated with a marked increase in airway resistance, which greatly increases the work of breathing and, if severe enough, may cause hypoventilation. The airway obstruction in emphysema is due to the collapse of the lower airways due to the destruction of the elastic tissues in the lung. (Vander 2004, pp.477).

It (emphysema) is defined pathologically as the presence of permanent enlargement of the airspaces distal to the terminal bronchioles, accompanied by destruction of their walls and without obvious fibrosis (Snider et all. 1986, pp.182).

Chronic bronchitis

Chronic bronchitis is characterized by excessive mucus production in the bronchi and chronic inflammatory changes in the small airways. The cause of obstruction
is an accumulation of mucus in the airways and thickening of the inflamed airways (Vander 2004, pp 480).

In patients with COPD either of those conditions may be present. However, the relative contribution of each to the disease process is often difficult to determine as the conditions can and frequently do coexist.

COPD is not only a disorder of the lungs but also has serious implications for the patient's systemic health. The negative impact of airflow obstruction begins in the early natural history of COPD. Mild airflow limitation early in the disease can result in reduced activities of daily living and a gradual and possibly imperceptible reduction in activity level. A cycle of reduced activity and reduced aerobic endurance is introduced and contributes to a state of premature morbidity well before advanced states of airflow obstruction and COPD occur. The psychological effects of COPD which include 'anxiety, depression and somatic preoccupation' (Petty 1994, pp.1637) will increase the negative impact. Food intake may be decreased because of smoking, dyspnoea or excessive sputum production with resulting deficits in caloric intake, protein intake and a lack of antioxidant vitamins. This will result in multiorgan effects including immune system deficiency and increased susceptibility to infection with resulting metabolic and nutritional stresses on the patient. Progressive functional decline is inevitable.

The cost of COPD is high. It has effects on morbidity, mortality and economics. It is estimated that the condition affects 600 million people worldwide and its incidence is increasing (WHO 1998). COPD was the cause of 2.74 million deaths in 2000 (WHO 2001). According to the American Lung Association, COPD is an increasing problem and is an area of growing demand on health services worldwide. It is the fourth leading cause of death in the U.S. (ALA 2005). Respiratory disease is the third most common cause of death in the E.U. (Siafakes et al. 1995, pp.1416).

The national heart, lung and blood institute in the United States has estimated COPD to have cost the health system there $37.2 billion in 2004. It is the reason for 16 million doctor visits and 500,000 hospital admissions annually. Lost productivity due to COPD has a particularly high impact on the economy, accounting for 67% of overall costs in France, 50% in the Netherlands and 41% in the UK (Wouters 2003, pp.12) In the Netherlands, 46% of COPD patients are unable to hold down a full time job due to symptoms. The average sick leave for a working person in the Netherlands is 22 days. This is much increased in COPD patients with figures of 77 days annually for chronic bronchitis patients and 167 days annually off sick for emphysema patients.

Prevalence figures for COPD are believed to be underestimated. It has been estimated that 75% of COPD cases in the general population remain undiagnosed. (Siafakes et al, 1995, pp. 1400) It is difficult to accurately estimate the prevalence of COPD in the general population because it is often undiagnosed for several reasons. Reference criteria and diagnostic criteria differ amongst countries. The disease is often asymptomatic in its early stages and the symptoms have an insidious pattern so the patient in the early or moderate stage of the disease is unaware of its presence. Symptoms are often not evident until
the patient is middle aged or elderly and can be attributed to increasing age. Sufferers tend not to seek medical advice until the disease has progressed and the condition is severe and by the time the disease is diagnosed, often < 50% of lung function has already been lost and the need for healthcare is high. (Engstrom et al. 2001, pp. 74). According to National Heart, Lung and Blood Institute (1998), COPD is the only major leading cause of death that is increasing. Coronary heart disease, stroke and other CVDs all show consistent and substantial reduction.

The cost to the quality of life of the patient is also high. The symptoms of the disease contribute to functional deficits with up to almost three out of four patients with COPD report difficulty in the simplest of everyday activities, being out of breath after simply walking upstairs (Vermeire 2002, pp.s7). Significant exercise limitation is present in patients with only modest degrees of airflow obstruction (Carter et al. 1993, pp. 746). Participation in everyday activities and restrictions regarding work and social activities lead to a reduction in quality of life, with 80% of patients hospitalized following an exacerbation reporting a health status rated or quoted by a physician as being ‘worse than death’ (O Reilly et al 2003).

Social isolation and resulting depression is common amongst patients and also their carers are affected with one study on a small population of patients with COPD in Australia demonstrating that levels of loneliness, social isolation and depression are similar among carers and their patients.

**Rehabilitation Programmes for COPD Out-Patients**

Out-patients rehabilitation programs have been proven to be effective. It has been shown that patients who take part in a rehabilitation program show significant improvement in the 6 minutes walking test in comparison to a control group (Finnerty et al. 2001, pp.1708, Salman et al. 2003, pp.215). Furthermore significant improvement in quality of life in patients with COPD has been shown in comparison to control groups of COPD patients (Finnerty et al. 2001, pp.1707). It also has been proved that exercise increases the bronchial mucus transport (Oldenburg et al. 1979, pp. 744). Furthermore it has been shown that exercise programs as a part of the rehabilitation program has a positive effect on the maximal and sub maximal exercise capacity of COPD patients (Pies et al. 1995, pp. 830).

In general an improvement in exercise capacity, reduction in exertional dyspnoea and an improvement in health status can be observed after rehabilitation programs (American Thoracic Society & European Respiratory Society. 2004, pp.100). However, it should be noted that there is nearly no improvement of the actual lung function data (American Thoracic Society & European Respiratory Society.2004, pp.100). Also it has been shown that patients with mild or moderate COPD can benefit from long and short term rehabilitation programs while patients with severe COPD need a rehabilitation program for at least 6 months before they benefit from it (Salman et al.2003, pp.219-220).

The main goals of rehabilitation programs for COPD patients are reduction of the patient’s disability and to promote a general improvement of quality of life.
The minimum of an outpatients rehabilitation programme should be 6 weeks with 2 supervised sessions per week and additional instruction to train at home on a daily basis (British Thoracic Society. 2001, pp. 829). A regular rehabilitation programme contains physical exercise, disease education as well as nutritional, psychological, social and behavioural interventions (British Thoracic Society. 2001, pp.829). According to the KNGF guidelines (2003, pp.9, 26) a rehabilitation program should include physical exercises, educational intervention and support for the patient.

The physical exercises include aerobic training, peripheral muscle strengthening as well as inspiratory muscle training. It is important that rehabilitation programs involve a multidisciplinary team and the patient’s family; however it is also important to look at the individuals needs.

**Exercise limitations**

In order to plan the patient’s rehabilitation program it is essential to know which factor is limiting the patients exercise capacity. The KNGF guidelines from 2003 mention five different exercise capacity limitations, which are cardio circulatory limitation, ventilatory limitation, oxygen transport limitation, peripheral muscle weakness and other factors such as psychosocial limitation.

A cardio circulatory limitation implicates that there is a problem with the cardiovascular system. The cardiovascular system consists of the heart and the two networks of blood vessels – the systemic circulation and the pulmonary circulation. Failure of the cardiovascular system has effects on the circulation of the blood around the body and therefore it also has effects on oxygen transport to the tissue and the removal of waste products from the tissue.

In the case of a ventilatory limitation, the ventilatory requirement can not be met because it is normally increased in COPD patients while the ventilatory capacity tends to be decreased. In the case of emphysema the ventilatory capacity is reduced due to an increased airflow obstruction in combination with reduced lung elastic recoil while in the case of chronic bronchitis and asthma the reduced ventilatory capacity is caused by an increased airflow resistance. In COPD patients the increased ventilatory requirement is mainly caused by inefficient ventilation of the lung as a consequence of mismatching of ventilation to perfusion.

Limitation of oxygen transport can be caused by different factors such as diffusion problems which are commonly seen in COPD patients. These problems occur due to alveolar wall breakdown which results amongst other things in decreased surface area for gas exchange and loss of pulmonary capillaries affecting perfusion and the diffusion of gases.

Peripheral muscle weakness can become an exercise limitation and is not uncommon in COPD patients. It can be caused by different factors such as metabolic changes, or immobility.

The KNGF guidelines also identify other factors that can act as exercise limitations such as psychosocial issues and exercise fear. It is always important to have this in the back of your mind and it can be taken into account by giving the patient education during the rehabilitation program.
Chapter two

In this chapter a brief history of pulmonary lung function testing will be given. The different pulmonary function tests, which are performed at the St Lucas Andreas Hospital, will be described. Each pulmonary function test is described in its own section and the description is done in the same order as the tests are performed at the St Lucas Andreas Hospital.

Brief history

Pulmonary function test has long history. In 129-200 A.D. Galen discovered that inspiration-expiration (tidal volumes) volumes do not change over a period of time. The first measurement of inspiration was done by Borelli in 1681. R. Menzies was the first person who used the method of body plethysmography in 1796. In this cylinder the subject was placed and the changes of water level were measured during inspiration and expiration. In 1844 Hutchinson who was working with spirometers showed that there is a linear relationship between vital capacity and height but that there is no relationship between vital capacity and the body weight.

Reference Criteria

Reference values are a set of laboratory test values obtained from an individual or from a group in a defined state of health. Many pulmonary function test data are expressed as a percentage of a predetermined normal value. The information for these normal values is derived from the reference criteria.

Reference values are taken from studies of healthy individuals of same sex, similar stature, age, and other characteristics such as ethnic origin with no known previous or present conditions that adversely affect their ventilatory function. The characteristics of the healthy reference population should match the study group as much as is possible. The equipment, techniques, and measurement conditions used in the health studies to determine reference criteria should be similar to those used in actual patient testing in order to provide accurate and reliable data. (In fact, the best reference value is the value observed in the subject during a period when the disease is stable and minimal for that person.)

At the St Lucas hospital, the reference values are already programmed on the lung function equipment by the manufacturing company and are based on age, body size and gender. However, race is not taken into account so the person interpreting the data has to take into account that there can be a discrepancy in the results that is affected by the subject’s race. The person interpreting the test results in any department should be aware of which reference values are used to predict the normal preset values that the patients’ results are compared to.

There are no specific recommended reference criteria in Europe. Therefore there is an urgent need to standardize techniques, equipment and methods of analysis,
so that individual data from different laboratories can be collated in the future ( Stocks and Quanjer 1995).

**Spirometry**

The objective of Spirometry is to assess ventilatory function. Spirometry is used to test pulmonary volumes, measuring volume and air flow times. It is used to diagnose, measure the severity of and evaluate the progress of obstructive lung disease. Spirometry is best performed with the patient seated and in an upright position.

The patient is required to inhale fully and form a seal around the mouthpiece with their lips. The patient is then required to exhale fully to RV. (Residual Volume). The exhalation must continue until no more air can be exhaled and must last at least 6 seconds. (It may take up to 15 seconds). It is essential that the patient co operates fully.

Spirometry results will only be of value if the expirations are performed satisfactorily and consistently. The test results are expressed in 2 graphs on the computer (appendix 3) - a flow volume loop and a time volume curve (Figure 1).

The test should be repeated in the same fashion 3 times. Both FVC (Forced Vital Capacity) and FEV1 (Forced Expiratory Volume in 1 second) should be the largest value obtained from any of 3 technically satisfactory curves and the FVC and FEV1 values in these three curves should vary by no more than 5% or 100 ml, whichever is greater. The FEV1/FVC is calculated using the maximum FEV1 and FVC from technically acceptable (not necessarily the same) curves.

Figure 1. Spirometry results depicted in graph form during lung function testing.
Plethysmography

Plethysmography is used to measure changes in volume within the body or part of the body from fluctuations in the amount of air or blood it contains. It works by detecting changes in pressure. It is used to measure absolute lung volumes i.e. residual volume, functional residual capacity and total lung capacity. (Spirometry is the standard method for measuring most relative lung volumes; however, it is incapable of providing information about absolute volumes of air in the lung.)

Plethysmography is performed with the patient sitting in an upright position inside an airtight box (Figure 2). The patient breathes through a tube with a valve. Initially the patient continues with his/her normal breathing cycle. During the breathing cycle and on instruction from the tester the patient inhales or exhales to a particular volume (usually FRC) and the tester closes a shutter in the valve of the breathing tube for a few seconds.

The patient is required to make respiratory efforts against the closed shutter. This feels and looks like panting although no actual breathing takes place as the valve is closed. Each time the patient tries to pant out, the air in the lungs is decompressed slightly and the gas in the box surrounding the patient is compressed slightly. When the patient tries to breathe in, the opposite occurs i.e. the volume of air in the chest decreases and the volume in the box increases. The pressure changes are measured and the amount of gas in the patient’s lungs can be calculated.

Figure 2. Body Plethysmography is performed in an airtight box.

Single Breath Diffusing Capacity

The single breath diffusing capacity, or DLCO, is a measure of the ability of the lungs to diffuse oxygen into, and carbon dioxide from, the bloodstream. The test is performed at the same time as plethysmography with the patient sitting in an upright position. The patient expired to RV and then inhales fully to TLC, breathing from a supply of test gas containing a preset amount of carbon monoxide. (Figure 3). The breath is held by the patient for ten seconds and then
expired forcefully. The concentration of carbon monoxide present in the test gas is measured prior to the test. The initial portion of the final expire is discarded, and a portion of the remainder is analyzed. Generally, the difference between the concentrations present before the breathhold and after the breathhold indicates the amount of gas that diffuses through the lungs and into the bloodstream.

Figure 3. Diffusion capacity equipment and gas.

Maximal Inspiratory Pressure (MIP or PI max) and the Maximal Expiratory Pressure (MEP or PEmax) Test

The maximal inspiratory pressure (MIP or PI max) and the maximal expiratory pressure (MEP or PEmax) tests are performed as a part of the body plethysmography. For these tests it is necessary that the patient wears a nose clip to avoid breathing through the nose. It is also important that the breathing tube is totally enclosed by the subject’s lips. An upright sitting position is essential to ensure the optimal respiratory muscle function. Furthermore it is important that the manoeuvre is performed several of times to reach consistency, two measurements should be within 10% of the highest measured pressure. An adequate period of rest in-between the different manoeuvres is needed. The test obtains two time-pressure graphs one for the inspiration manoeuvre and one for the expiration manoeuvre. Each graph consists of several curves one curve for each manoeuvre.

The maximal inspiratory pressure (MIP or PI max) is the greatest sub atmospheric pressure that can be developed during inspiration against an occluded airway. It is normally measured at the residual volume (RV) (Bañez 2000). This measurement is used to assess the strength of inspiration muscles. There are two way to measure the MIP. The maximum static manoeuvre (no flow; PI, max) and the sniff manoeuvre (with flow through a well defined leak; Psniff, max). At
the St Lucas Andreas Hospital the maximum static manoeuvre is performed and therefore will only be described.

The subject is asked to maximally exhale through a breathing tube until, only the residual volume (RV) is left in the lungs. Then a shutter closes the breathing tube and the subject has to inhale as forcefully as possible and hold this for 1-2 seconds. The shutter is then opened and the patient breathes normally. This test results are expressed in a time-pressure graphs and the most accurate graphs will be used for the interpretation (appendix 3).

MEP is usually measured at total lung capacity (TLC). This is an estimation of expiratory muscle strength. To measure the maximal expiratory pressure (MEP or PEmax) the subject is ask to inhale up to the total lung capacity (TLC). At the maximal inspiration a shutter closes the breathing tube and the subject has to exhale as forcefully as possible against the shutter. The patient is again asked to hold this position for 1 – 2 seconds and then continue to breathe normally. It is advisable that the patient holds his hands against his/her cheeks to reduce the chance of a leak between the lips and the tube. This test results are also expressed in a time-pressure graphs and the most accurate graphs will be used for the interpretation.

**Cardiopulmonary Exercise Test (CEPT)/ Maximal Aerobic Capacity Test**

The cardiopulmonary exercise test (CPET) is used for diagnostic and prognostic purposes and also as an assessment tool to assess the response of the patient to treatment.

In regards to the COPD patient the cardiopulmonary test is used to detect exercise limitations and to identify potential contributing factors such as heart diseases (e.g. to detect ischemic changes that occur during exercise). It is also used to detect the degree of hypoxemia that occurs during exercise and therefore can be a useful guide to determining if a patient needs supplementary O2 during exercise or rehabilitation.

At the St Lucas Andreas Hospital the maximal cardiopulmonary test is performed on a static cycle (figure 4). Before the actual bike test is performed the predicted values are calculated according to Wasserman et al (1999). The predicted values are based on factors such as the patient’s weight, height, ethnicity and the level of activity in daily life. The patient’s predicted maximal load indicates which protocol is used. The predicted maximal load has to be reached within 10 minutes and the increments in load are dictated by the individual’s protocol. For example if the patients predicted maximal load is 100W the 10W/min protocol is used while if the patient’s predicted maximal load is 150W the protocol for an increase of 15W/min is used. At the St Lucas Andreas Hospital the following protocols are used:

- 10 W/min: every 6 sec 1 W increase warm-up 15 W
- 15 W/min: every 4 sec 1 W increase warm-up 15 W
- 20 W/min: every 3 sec 1 W increase warm-up 20 W
- 25 W/min: every 5 sec 2 W increase warm-up 25 W
• 30 W/min: every 6 sec 3 W increase warm-up 30 W
• 40 W/min: every 3 sec 2 W increase warm-up 40 W

After calculating the predicted values the patient is positioned on the ergometer and the machine is set up for the maximal exercise test. The patient’s condition is monitored throughout the test, a physician is always present and ECG is constantly monitored and the blood pressure is measured. There are certain criteria to stop the exercise test immediately such as chest pain and some ECG or blood pressure irregularities.

The subject wears a face masked in order to measure ventilatory values. The O2 saturation is measured by pulse oximetry. Arterial blood is taken by the physician at the beginning of the test and again when the patient reaches his anaerobic threshold (or if not, at the end of the test) to monitor blood gas levels.

The procedure is explained to the patient and he is asked to keep a constant repetition per minute (rpm) between 60-65 rpm throughout the whole test. The subject then starts the test with an unloaded cycling phase for two minutes and from then on, the load is increased steadily according to the individual’s protocol.

At the completion of the cardiopulmonary exercise test the patient is asked to fill out the Borg-scale (see appendix 3) which provides a subjective estimation of dyspnoea and muscle fatigue. At the St Lucas Andreas Hospital the patient also fills out 3 different “Chronic Respiratory Questionnaires (CRQ) (Self reported)”.

Figure 4. Maximal bike test in progress.
Chapter three

Chapter three provides the reader with information on interpretation of the different pulmonary function tests and enables the reader to identify the patient’s specific limitation.

Spirometry (the measuring of breath)

Spirometry is the most common pulmonary function test. The objective of spirometry is to assess ventilatory function by means of measuring lung volumes and the flow or speed that air can be inhaled or exhaled. Spirometry is used for diagnosing, measuring the severity and evaluating the effects of treatment of lung conditions such as COPD and asthma.

Spirometry provides measurement of:

- FVC – forced vital capacity
- FEV1 – forced expiratory volume in the first second
- FEV1 / FVC - This is the ratio of FEV1 and FVC, which showing the amount of the FVC that can be expelled in one second.
- FEF25-75% - Forced Expiratory Flow 25-75% or 25-50% - This is the average flow (or speed) of air coming out of the lung during the middle portion of the expiration (also sometimes referred to as the MMEF, for maximal mid-expiratory flow).
- MVV maximum voluntary ventilation – maximal volume of air that can be breathed per minute
- Peak Expiratory Flow (PEF) - This is the speed of the air moving out of the lungs at the beginning of the expiration, measured in liters per second,
- FET Forced Expiratory Time - This measures the length of the expiration in seconds.

(Spirometry also provides information about inspiratory parameters but for this project these will not be discussed.)

Spirometry primarily detects airways obstruction. In healthy individuals, approximately 80% of forced vital capacity (FVC) is expelled in the first second. (FEV1) This is not the case in people with obstructive lung disease. In obstructive lung diseases such as emphysema or chronic bronchitis, the FEV1 is reduced disproportionately more than the FVC resulting in an FEV1/FVC ratio less than 70 - 80%. This reduced ratio is the primary criteria for diagnosing obstructive lung disease by spirometry. Asthma can be differentiated from COPD using spirometry because in asthmatic patients the obstruction is reversible. This is demonstrated by administering prescribed bronchodilators and observing improved test results subsequently.

The severity of the disease can also be measured using this method. A reduction in the ratio of FEV1/FVC indicates the severity.
FEV1  |  > 80% predicted |  normal  
|      |  65 - 80%        |  mild      
|      |  50 - 65%        |  moderate  
|      |  < 50%           |  severe    

Depending on the severity of the obstruction, the FVC may be reduced as well as the FEV1. However there should continue to be a disproportionate reduction in FEV1 as evidenced by the FEV1/FVC ratio.

Spirometry results are commonly expressed diagrammatically and as raw data. The diagrams consist of a time volume curve (Figures 5 & 6) showing volume in liters along the Y-Axis and time (seconds) along the X-Axis and a flow volume loop (Figure 7) which graphically depicts the flow of air compared to the total volume inspired or expired.

Forced Expired Volume in 1 Second (FEV1) and Forced Vital Capacity (FVC)

![Diagram of Time Volume Curve](Gross 2005)

Figure 5. Time Volume Curve (Gross 2005)

Effect of Airways Obstruction

![Diagram of Effect of Airways Obstruction](Gross 2005)

Figure 6. Obstructive disease is suggested on the time volume curve by a slower progression to maximum volume than that of a healthy individual. Also, the curve ascends more gradually than that of a healthy individual suggesting a longer expiratory time is needed due to the impairment. (Gross 2005)
The presence of COPD changes the shape of the flow volume loop (Figure 7). There may be a reduction in the size of the initial peak on the graph (PEF). The curve descends quickly and takes on a concave shape (Figure 8). This indicates a reduction in the FEF25-75 (the volume of air in the mid portion of the exhalation) which occurs when there is collapse of small airways. (This result when expressed in the presence of other normal values can indicate early obstructive disease). This pattern becomes more exaggerated with increasing severity of COPD.
The raw data are expressed as a percent of predicted values for patients of similar physical characteristics (e.g. height, weight, age, sex and race) (Figure 9).

<table>
<thead>
<tr>
<th>SPIROMETRY</th>
<th>Predicted Value</th>
<th>Observed Pre</th>
<th>%Pred</th>
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<td>FVC</td>
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</tr>
<tr>
<td>FET Sec</td>
<td></td>
<td>3.72</td>
<td>3.07</td>
</tr>
<tr>
<td>FIVC L</td>
<td></td>
<td>3.82</td>
<td>4.61</td>
</tr>
<tr>
<td>PIFR L/S</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9. Spirometry data of a healthy individual.

Generally speaking, results nearest to 100% predicted are the most normal, and generally results over 80% are often considered normal.

The results of the test (appendix 3) will only be accurate if the test is performed correctly. The patient must exhale until RV. This must last for at least 6 seconds. Therefore the patient must be able to co operate with the technician. FVC and FEV1 should be the greatest values taken from a selection of 3 technically correct graphs and the FVC and FEV1 values in these three curves should vary by no more than 5% or 100 ml, whichever is greater. The FEV1/FVC is calculated using the maximum FEV1 and FVC from technically acceptable curves. The data can be taken from different curves so the best reading should be used.

Those with chest pain or frequent cough may be unable to perform a satisfactory test and this should be noted. There is a normal age-related decline in the FEV1/FVC ratio, so normal elderly patients without airway obstruction will have a ratio below 70-80% (Dykstra et al 1999, pp. 69).

The mid-range flows (FEF25-75) are always reduced in obstructive airways disease. However, some patients have normal spirometry with the exception of a reduced FEF25-75. It is then important to look at the predicted value and the level that the patient reached. A mid-range flow less than 50% is likely to be abnormal and is suggestive of possible small airways dysfunction and potentially early obstruction, but it should not be interpreted as meeting obstructive criteria. In this case the patient may need further investigation to exclude asthma or the results may be interpreted (with history and symptoms) as a possible early indicator of smoking related lung disease.
Plethysmography

Although spirometry is the standard method of measuring lung volumes, it is not possible to measure absolute lung volumes through this means. Therefore an alternate method has to be used. There are two commonly used methods used to measure absolute lung volumes. These are gas dilution tests and body plethysmography. Gas dilution tests involve inhaling a preset amount of helium. The patient is requested to breathe the helium diluted air several times until the helium gas has equilibrated between the bag and the patient's lungs. The new mixed concentration of helium is then recorded. This method is only used at St Lucas Andreas hospital when the patient is unable to tolerate plethysmography. This method is unable to detect air pockets in the lungs of an emphysema patient so is therefore not as accurate as body plethysmography and also takes longer. Body plethysmography provides a means to measure thoracic gas volume (VTG). Thoracic gas volumes can be used to determine static lung volumes including the total lung capacity (TLC), the residual volume (RV), and the functional residual capacity (FRC).

Measurement of lung volumes and capacities (a lung capacity is a combination of 2 or more standard lung volumes) is the second most common pulmonary function test performed. (Other tests that can be administered in the body plethysmograph include airways resistance (Raw), Spirometry, bronchial challenge, diffusing capacity (D_{CO}), single-breath nitrogen (N_2), multiple-breath N_2 washout, pulmonary compliance, and occlusion pressure. (These will not be discussed as part of this project).

A pressure plethysmograph is usually measured at the end-expiratory level in order to measure the amount of air remaining in the lungs after a maximal expiration. (RV) (Figure 10). The mouth pressure and box pressure changes that are measured during tidal breathing and panting maneuvers which are performed during the test by the patient at the end of expiration are sent to a microprocessor unit that calculates thoracic gas volume. Airway resistance (Raw) can also be measured using this method. According to Allen (1997, pp. 70) this measurement may be useful in detecting asthma which is associated with increased airway tone and although this measurement may have some advantages over FEV1 the clinical indications for measuring airway resistance remains uncertain.

Figure 10. Measurement of lung volumes (Wales 2003).
Measurements of lung volumes and TLC is more useful for diagnosing restrictive lung disease rather than obstructive. The measurement is expressed as a percentage of a predicted norm and the lower the ratio of TLC to the predicted norm, the greater the restriction.

Measurement of lung volumes can however indicate some obstructive factors e.g. a greater than predicted RV suggests air trapping suggesting obstructive disease and an increase in FRC suggests hyperinflation which is a recognized clinical feature of COPD. Lesser degrees of hyperinflation exist in the progression of COPD due to changes in the elastic and recoil properties of the lungs. This can be determined on the plethysmograph by the ratio of residual volume (RV) to total lung capacity (TLC). Dykstra et al (1999) reported measurements of lung volumes in 4774 patients with airflow obstruction (FEV₁: FVC < 70%) and noted that hyperinflation, as determined by the ratio of residual volume (RV) to TLC was strongly correlated with the degree of airflow obstruction.

![Plethysmography Diagram](image)

Figure 11. Plethysmograph showing increased RV and TLC (Gross 2005).

Test results should be obtained from a minimum of 3 to 5 separate clinically acceptable panting maneuvers (appendix 3). The results should indicate whether the volume was measured at FRC or RV. If gas dilution tests are performed, results should be compared. The plethysmograph involves spending a short period of time in an enclosed box. This can cause feelings of claustrophobia in some patients and is therefore unsuitable. Prolonged confinement in the plethysmograph chamber could result in hypercapnia or hypoxia; however, because of the limited length of the test, this is an uncommon occurrence. Transmission of infection is possible via improperly cleaned equipment (i.e. mouthpieces) or as a consequence of the inadvertent spread of droplet nuclei or body fluids.

**Diffusing Capacity (Pulmonary gas transfer index)**

‘Pulmonary gas transfer index is a measure of the rate of uptake of a particular gas across the alveolar-capillary bed for a specified driving pressure for that gas’. (Wasserman et al. 1999, pp. 526).
Diffusing capacity provides an estimate of how well a gas is able to move from the alveoli into the blood. The test is used to estimate the gas exchanging capability of the lungs so provides an estimate of the transfer of oxygen from alveoli to capillary and the transfer of carbon dioxide from capillary to alveoli. The total process is a measure of the interaction of:

- Alveolar surface area
- Alveolar capillary perfusion
- The physical properties of the alveolar capillary interface
- Capillary volume
- Haemoglobin concentration
- The reaction rate of CO and haemoglobin

The measurement is obtained by measuring the diffusion of a preset amount of Carbon Monoxide from the alveoli to the pulmonary capillary. Generally, the difference between the concentrations present before the breathhold and after the breathhold indicates the amount of gas that diffuses through the lungs and into the bloodstream.

Carbon monoxide is most commonly used in this test as the tracer gas for measurement because of its high affinity for binding to the haemoglobin molecule. This property allows a better measurement of pure diffusion, because the movement of the CO is mainly dependent on the properties of the diffusion barrier and the amount of haemoglobin. CO transfer is not affected by perfusion rate. The transfer of CO into the capillary is diffusion limited as opposed to perfusion limited. This test is usually performed during pulmonary function testing when the patient is having plethysmography and Spirometry.

Diffusion capacity is affected by surface area, partial pressure difference, gas solubility and the thickness of the tissue of the alveolar-capillary barrier. The test is pertinent for patients with COPD because in patients with emphysema, the surface area of the lung is usually reduced due to destruction of alveolar tissue leading to loss of functioning alveolar-capillary bed. The diffusion capacity in COPD patients can also be reduced because of failure of inspired air to reach the alveoli during exacerbations of the condition or due to poor ventilation-perfusion ratio. It is also useful for differentiating among chronic bronchitis, emphysema, and asthma in patients with obstructive patterns and it is useful to predict arterial desaturation during exercise in these patients.

The patients HB level will also affect the result so all data is adjusted according to the individuals HB during the test. (American Association of Respiratory Care, 2001)

Interpretation should not be done in isolation but in conjunction with spirometric and lung volume assessment.

The results are based on a ratio between the uptake of CO in mL per minute divided by the average alveolar pressure of CO. Overall TLCO is expressed as the uptake of CO in mmol of gas per minute and per kPa driving pressure of CO - mmol/min/kPa and is expressed as a percentage of a predicted normal value.
Results of the following parameters are expressed on the data (see also appendix 3)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN</td>
<td>Inspiratory volume</td>
</tr>
<tr>
<td>TLC – He</td>
<td>Total lung capacity</td>
</tr>
<tr>
<td>RV – He</td>
<td>Residual Volume</td>
</tr>
<tr>
<td>RV%TLC-He</td>
<td>RV expressed as a % of the TLC</td>
</tr>
<tr>
<td>VA</td>
<td>Alveolar Volume</td>
</tr>
<tr>
<td>TLCO SB</td>
<td>Transfer factor of CO for a single breath</td>
</tr>
<tr>
<td>TLCO/VA</td>
<td>Transfer factor of CO as a % of Alveolar volume</td>
</tr>
<tr>
<td>HB</td>
<td>Haemoglobin</td>
</tr>
<tr>
<td>TLCOc SB</td>
<td>LCO SB adjusted as per patients HB</td>
</tr>
<tr>
<td>TLCOc/VA</td>
<td>TLCO as % VA adjusted as per patients HB</td>
</tr>
</tbody>
</table>

The most important result for the therapist is the HB adjusted transfer factor of CO expressed as a % of VA. This figure can be used to estimate the degree of severity of diffusion limitations and can be interpreted as follows:

**Degree of severity of decrease in diffusing capacity for carbon monoxide**

<table>
<thead>
<tr>
<th>Degree</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&gt;60% and &lt;LLN</td>
</tr>
<tr>
<td>Moderate</td>
<td>40-60%</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;40%</td>
</tr>
</tbody>
</table>

The TLco results will be abnormal in patients with lung disease due to effects on the distribution of diffusion properties and alterations in alveolar volume and capillary blood flow.

Reduced diffusion capacity will be found in patients with decreased alveolar surface area and diminished capillary bed/blood volume. This is typical of emphysema patients. In emphysema, where there is hyperinflation and destruction of the alveolar architecture, the lung volumes are increased and DL-CO/VA is decreased. Poor diffusion would be expected in patients with decreased pulmonary tissue, increased diffusion distance, or those with anaemia. The patients with simple chronic bronchitis do not usually have hyperinflation; therefore, their lung volumes are normal. Because their lung architecture is normal, the diffusion capacity is not affected.

Although gas dilution techniques are based on a simple principle, are widely used, and provide a good measurement of all air in the lungs that communicates with the airways, a limitation of this technique is that it does not measure air in noncommunicating bullae and, therefore, may underestimate TLC, especially in patients with severe emphysema.

The patient is required to be able to cooperate with the technician performing the test and be able to follow instructions. Patients should be alert, oriented, able
to exhale completely and inhale to total lung capacity, able to maintain an airtight seal on a mouthpiece, and able to hold a large breath for 10 seconds. The patient should refrain from smoking for several hours before the test and also to refrain from alcohol for the previous 8 hours as alcohol vapours can affect the accuracy of CO analyzers.

Maximal Inspiratory Pressure and Maximal Expiratory Pressure

As mentioned earlier the maximal inspiratory pressure (MIP or PImax) and the maximal expiratory pressure (MEP or PEmax) are used to assess the respiratory muscle strength. However it should be noted that this is only estimation due to the fact that respiratory muscle force is indirectly measured through the pressure generated during inspiration or expiration.

The pressures which are used to estimate the muscle strength reflect pressure changes against atmospheric pressure. Therefore it is not possible to assess strength of an individual muscle involved in respiration, the strength of all the muscles involved in inspiration or expiration is measured together. Furthermore the pressure measured during maximal inspiration or expiration is influenced by the elastic recoil of the lungs and chest wall. Because maximal expiratory pressure is measured at the TLC, the recorded pressures are the combination of the effort of the expiratory muscles and the elastic lung recoil at TLC. The maximal inspiratory pressure is measured at RV and is therefore a combination of the action of the inspiratory muscles, and the pressure generated by the tendency of the chest wall to expand at RV. To avoid these two aspects it would be necessary to measure the maximal pressures at the functional residual volume because the elastic recoil of the lungs and the chest wall generate equal pressures. Therefore any additional pressure measured during inspiration or expiration is exclusively caused by the strength of respiratory muscles at this particular lung volume. However, it is easier for the patient to perform the test at the RV or TLC instead of the functional residual volume and therefore these two lung volumes are used as a starting position of the tests.

There are some contraindications for these tests, which are pathological conditions where relatively large pressure changes in the thorax or abdomen should be avoided (e.g. aneurism, uncontrolled hypertension, and urinary incontinence).

During the test the peak pressure should be reached directly at the beginning of the maneuver. The pressure which is maintained for at least 1 s is generally called the MIP or MEP (plateau pressure). This can be also found in the obtained graphs (figure 13). Healthy subjects can reach pressures bigger than 30 kPa during the tests (Troosters et al. 2005, pp.60).

Normally the absolute number of MEP is approximately twice the absolute number of MIP (Troosters et al 2005, pp.62). In some diseases (e.g. spinal cord injury, below C3-5, multiple sclerosis) the reduction of MEP is higher than the reduction of MIP.
If the values for MIP are 70% or less of the predicted values it indicates that the respiratory muscles are weak and respiratory muscle strength training should be applied (KNGF 2003, pp.34-35) (see figure 12). However, it has to be noted that these tests do not state anything about the endurance of the respiratory muscles. Greatly reduced expiratory muscle strength can cause problems with expectoration. However, this is normally not problem of COPD patients which are participating in out-patients rehabilitation programs.

Figure 12. Flowchart for interpreting the MIP test values.

Maximal inspiratory pressure (MIP/Ptmax)

≥ 70% of predicted value

No indication for respiratory muscle strength training

≤ 70% of predicted value

Respiratory muscle strength training should be applied

Figure 13. The obtained data from MEP and MIP test in the St Lucas Andreas Hospital.
Maximal Bike Test (Cardiopulmonary Exercise Test)

The cardiopulmonary test is an important assessment tool to analyse the exercise limitation in a patient. By knowing the exercise limitation it is already possible to make a prognosis for the degree of benefit of a pulmonary rehabilitation program. For example according to Planke et al (2005, pp.113-115) patients with cardiopulmonary limitation have a better prognosis to show an improvement in their VO2 peak then patients with a ventilatory limitation. Furthermore the cardiopulmonary test is especially useful to determine deficits in the function of the cardiovascular and ventilatory systems, because the defects are amplified during exercise.

It is important to know that in Cardiopulmonary testing there are certain criteria which lead to an immediate stop of the exercise test. The symptoms and/or finding according to ATS/ACCP (2001, pp. 227) are the following one:

- Chest pain suggestive of ischemia
- Ischemic ECG changes
- Complex ectopy
- Second or third degree heart block
- Fall in systolic pressure > 20 mm Hg from the highest value during the test
- Hypertension (> 250 mm Hg systolic; >120 mm Hg diastolic)
- Severe desaturation: SaO2 ≤ 80% when accompanied by symptoms and signs of severe hypoxemia
- Sudden pallor
- Loss of coordination
- Mental confusion
- Dizziness or faintness
- Signs of respiratory failure

In the case of a completed maximal bike test the test is stopped because the subject’s RER > 1.2, which is an indication that the subject has reached his/her anaerobic threshold. However, in the case of COPD patients it is not uncommon that the cardiopulmonary test is stopped before the patient reaches his/her anaerobic threshold due to dyspnea, muscle pain/fatigue or other symptoms. By interpreting the maximal bike test you can identify 4 different limitations and get links to 2 others. The four limitations are ventilatory, cardiovascular, peripheral muscle and psychological. Furthermore the bike test can be an indication for diffusion problems and abnormal O2 content. In this section we will concentrate on the 4 limitation which were just mentioned. A flowchart for identifying these limitations can be found in appendix 1.

The following points can indicate a ventilatory limitation.

**Ventilatory limitation:**

- Max. VE during exercise exceeds the value of 70% of MVV this means that a ventilation limitation can be suspected (Cesar et al 2003, pp.527). This particular value is not calculated or measured during the maximal
bike test at the St Lucas Andreas Hospital. However this value equals a breathing reserve (BR %) of \( \leq 30\% \) \((BR=1-(\text{VE max}/\text{MVV}) \) (Wasserman et al 1999, pp.535)), which is mentioned in the obtained data.

- The Breathing reserve (BR) is low at the point when the exercise test is stopped (ATS/ACCP 2001 pp.248,252), this indicates a ventilation limitation because the breathing reserve reflects the relationship of ventilatory demand to ventilatory capacity.
- The absence of an anaerobic threshold during exercise (Babb 1991 pp.18). This can be found if the exercise test was stopped before the subject reached his/her anaerobic threshold for example due to dyspnea.
- Max \( \text{VO}_2\ ) and anaerobic threshold are not reached (Weber et al 1988 pp.845). An individual is considered to reach \( \text{VO}_2\text{max} \) when, during maximal exercise, the progressive increase in the loads does not increase \( \text{VO}_2 \) by more than 150 mL/min, and a plateau is graphically obtained (Taylor et al 1995 pp.877). When this plateau is not reached, the highest \( \text{VO}_2 \) is called peak oxygen consumption (\( \text{VO}_2\text{ peak} \) ) (Wasserman et al 1999 pp.528).
- An increased for the ratio of \( \text{VE/VCO}_2 \) and an abnormal \( \text{VD}/\text{VT} \) response (ATS/ACCP 2001 pp. 248).
- Determination of the flow-volume loop during exercise as compared with the flow-volume loop at rest may indicate a limitation in the expiratory flow.

In this paragraph the abnormalities of values which could indicate a cardiovascular limitation are outlined.

**Cardiovascular limitation:**

- Reduction of age related maximum heart rate (HR) (KNGF 2003, pp.16)
- The Test was stopped at a \( \text{VO}_2\text{ peak} < \text{VO}_2\text{ max} \) but normal predicted HR. In this case there are different possibilities. Initially, exercise could be limited by cardiovascular function and/or it could be limited by O2 content factor and/or limited by skeletal muscle dysfunction (ATS/ACCP 2001 pp.252). The case of an O2 content factor limitation is discussed in more details under blood gasses. The case of a skeletal muscle dysfunction is not in detail discussed in this information pack because it a huge subject on his own.
- Abnormal value for the ratio of \( \text{VE/VCO}_2 \) and \( \text{VD}/\text{VT} \) responses without O2 desaturation. This indicates a moderate to severe heart failure (ATS/ACCP 2001 pp.252).
- Max. \( \text{VE} \) during exercise does not exceed the value of 50% of \( \text{MVV} \) (Cesar et al 2003, pp.527). As already mentioned earlier this particular value is not calculated or measured during the maximal bike test at the St Lucas Andreas Hospital. However, these value equals a breathing reserve (BR%) of \( \geq 50\% \) \((BR=1-(\text{VE max}/\text{MVV}) \) (Wasserman et al 1999 pp.535)), which is mentioned in the obtained data.
- If the breathing reserve (BR) is high when the exercise test is stopped it is more likely to be a cardiovascular limited test. (ATS/ACCP 2001 pp.248, 252).
- If the heart rate reserve (HRR) is low when the exercise test is stopped it is more likely to be a cardiovascular limited test (ATS/ACCP 2001 pp. 252).
- No increase of blood pressure during exercise testing could indicate cardiac limitations or abnormality of sympathetic control of blood pressure can be strongly suggested (ATS/ACCP 2001 pp.233).

**Peripheral muscle limitation:**
The cardiopulmonary exercise test can also be limited by peripheral muscle dysfunction. This limitation can be indicated by a max test which is stopped due to muscle fatigue or pain. In this case it is also important to take the Borg scale into account; a high number for muscle fatigue on the Borg scale supports the possibility of a muscle limitation (KNGF 2003, pp.17). As mentioned earlier the skeletal muscle dysfunction is not discussed in more detail in this information pack due to the fact that it is quite a big subject on its own.

**Psychosocial limitation or poor effort:**
In patients it is relatively common that a cardiopulmonary exercise test is stopped before it is actually completed due to symptoms but there is also a chance that it is limited due to psychological reasons. A psychological limitation or a poor effort can be suspected in the case of a decreased VO2 peak, a high Breathing Reserve (BR) as well as a high Heart Rate Reserve (HRR) and a low RER without apparent peripheral problems (e.g. lung transplantation) (ATS/ACCP 2001 pp.253).

Finally it should be noted that in most of the COPD patients it is not possible to identify only one limitation due to the fact that in most cases there is a combination of limitations present.

**Arterial Blood Gases (ABG)**
Arterial blood pH and arterial partial pressure of oxygen have to be maintained within a narrow range for the various systems in the body to function optimally. Arterial blood gas samples provide information about these factors and can also provide essential information on cardio respiratory conditions. The blood is taken from the radial, brachial or femoral artery.

ABG analysis shows oxygenation and carbon dioxide levels within the body and also provides information about acid-base disturbances. It provides information on ventilation by measuring pH and the partial pressure of oxygen (PaO2) and carbon dioxide (PaCO2) indicating the amount of oxygen delivered to the blood from the lungs and the lungs capacity to eliminate CO2.

ABG analysis is used in acute cardio respiratory conditions such as exacerbation of COPD and severe asthma but is also used to assess and monitor the patient’s response to exercise during cardiopulmonary exercise testing.

Assessment of PaO2 will inform the tester about the levels of blood oxygenation. This is particularly relevant during CPET in order to detect O2 transport limitations. There is a chemical relationship between arterial blood pH, HCO3-
and PaCO2. If one of these parameters changes, the others will also have to undergo change. Therefore an increase in PCO2 will have the effect altering blood ph and the base excess HCO3- levels will also alter as the body compensates in order to maintain ph within the optimal range.

**Normal values**

<table>
<thead>
<tr>
<th>Normal Values</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>7.36 to 7.44</td>
<td>7.4</td>
</tr>
<tr>
<td>PaCO2</td>
<td>35 to 45</td>
<td>40 mmHg</td>
</tr>
<tr>
<td>HCO3</td>
<td>23 to 27</td>
<td>25 mEq/L</td>
</tr>
<tr>
<td>PaO2</td>
<td>80 to 100 mmHg</td>
<td>Lower when older</td>
</tr>
<tr>
<td>Base Excess</td>
<td>-4 to +4</td>
<td>0</td>
</tr>
</tbody>
</table>

Reid & Chung (2004)

When examining ABG results it is essential to note that older adults have progressively lower PaO2 (Lundbäck et al 2003, pp. 7). A healthy young adult has a PaO2 of 100 mmHg whereas a health 70 to 80 year old has a PaO2 of approximately 75 to 80 mmHg)
Conclusion

According to the KNGF guidelines, it is recommended for physiotherapists to have knowledge of and to be educated about COPD, out-patients rehabilitation programs and to be able to use the provided data to identify possible exercise limitations in COPD patients. This knowledge and education is essential for the physiotherapist caring for COPD outpatients in order to provide individual care and therapy.

It is also helpful if the therapist is knowledgeable about the actual pulmonary function testing as it can provide information about the patients exercise capabilities and also about the limitations that can occur during the actual testing.

It is very important for Physiotherapists to be able to interpret the data which is obtained by pulmonary function tests. The interpretation of the pulmonary function test data is an essential part of planning a patient's rehabilitation program. Depending on the exercise limitation the rehabilitation program has to be adjusted and has to focus on different aspects. Cardiovascular limited patients should perform an endurance training to improve their exercise capacity (KNGF 2003, pp. 16). While a rehabilitation program for ventilatory limited patients should focus more on respiratory muscle training to improve their strength and endurance and consequently improve their ventilatory capacity (KNGF 2003, pp. 17). In the case of an oxygen transport limitation it is essential that patients “learn to use their bodies more efficiently” (KNGF 2003, pp.17). Also the training of specific breathing exercise can help to reduce the dead space. However, supplementary oxygen might be necessary (KNGF 2003, pp.17).

In patients with psychosocial limitation physical exercise is a useful tool to reduce exercise limiting factors (KNGF 2003, pp.17). For patients with a peripheral muscle limitation the physiotherapist should consider peripheral muscle strength training as an important part of patient’s specific rehabilitation program.

The content of this information package is aimed at junior physiotherapists and senior student. Although respiratory physiotherapy is covered in the Dutch education system, it is not covered in a separate respiratory module. This area is an area of growing demand because of the increasing incidence of the condition.

However, it is important to notice that the interpretation of pulmonary function test is a huge and complicated subject and therefore it is not possible to discuss all aspects of the subject in detail in the professional assignment project.

This professional assignment is supposed to give the physiotherapist a short explanation of topics such as COPD, out-patients rehabilitation program and possible exercise limitations. It also provides the reader with an explanation of the different pulmonary function tests and the interpretation of the obtained data. Although the data provided by pulmonary function testing is a valuable diagnostic tool, it is not supposed to give a total and detailed interpretation of the patient’s condition. That can only be achieved when the patients is assessed in a holistic manner and his diagnosis is made from a combination of information obtained from patient history, symptoms and the results of the investigations.
References:


O’REILLY, J., WILLIAMS, A.E., LEDGER, G. & RICE, L. 2003. Health utility burden for exacerbation of COPD requiring admission into hospital as measured by the EQ-5D. Blackpool Victoria Hospital NHS Trust, Blackpool, UK


Further readings:


Appendix 1 (Cardiopulmonary exercise test flowchart)
In this appendix you can find a flowchart (next page) which can help you to identify the patient’s exercise limitation. This flowchart should be used as a tool for interpretation of exercise limitations in conjunction with the obtained CPET data. The flow chart is used by initially identifying the reason the patient stopped the test (the first row of the chart) and by systematically following the relevant branch the following limitations can be identified.

- Cardiovascular limitations
- Diffusion limitations
- Skeletal muscle limitations
- Psychosocial limitations
- Ventilatory limitations
- Gas transfer limitations
Appendix 2 (Glossary) (Wasserman et al 1999, ATS/ACCP et al 2001)

**AT (anaerobic threshold):** Exercise \( \dot{V}O_2 \) that marks the transition between no change or little change in arterial lactate concentration and the sustained increase in concentration of lactate (also known as the lactate threshold). Postulated by some authors to be the \( \dot{V}O_2 \) above which anaerobic energy production substantially supplements aerobic energy production.

**FEV1 (forced expiratory volume in 1 second):** Volume of exhale from the lungs during the first second of a forced expiratory manoeuvre (FVC), expressed in litres (btps).

**HR (heart rate):** Number of heart beats per.

**HRR (heart rate reserve):** Difference between the highest heart rate attained during a maximal exercise test and the maximal value predicted for that subject. Expressed in units of beats per minute.

**MVV (maximal voluntary ventilation):** Maximal volume of air that can be breathed per minute by a subject. This is conventionally measured from a maximal volitional breathing effort for a short period of time (e.g., 12 seconds) over which the exhaled volume is summed and expressed in units of liters per minute (BTPS).

In case that MVV was not measured it can be calculated \( MVV = FEV1 * 35 - 40 \) (ATS/ACCP 2001), MVVs estimated by this method were not discernibly different from MVVs directly measured in COPD patients (Dillard et al 1985, Hansen et al 1984).

**O2 pulse (oxygen pulse):** The oxygen uptake (\( VO_2 \)) divided by the heart rate (HR). Hence, it represents the amount of oxygen extracted by the tissues of the body from the \( O_2 \) carried in each stroke volume.

**RER or R (respiratory exchange ratio):** Ratio of \( CO_2 \) output to \( O_2 \) uptake per unit of time (measured at the mouth). This ratio reflects not only tissue metabolic exchange of the gases, but also that resulting from transient changes in the body's gas stores. For example, the gas exchange ratio exceeds the respiratory quotient as additional \( CO_2 \) is evolved from the body stores during hyperventilation; similarly, the gas exchange ratio is less than the respiratory quotient when \( CO_2 \) is being retained during hypoventilation

**SaO2 (arterial oxygen saturation):** Actual amount of \( O_2 \) bound to hemoglobin in a given volume of arterial blood and expressed as a percentage of the total capacity for \( O_2 \) binding of the hemoglobin in that blood volume.

**VD (physiologic dead space):** Notional volume of inspired gas that does not reach a gas-exchanging unit. The physiologic dead space is therefore the sum of the anatomic dead space (see below) and the alveolar dead space (the volume of alveoli that are ventilated but unperfused and a component of those that are underperfused). It is expressed in units of millilitres or litres (BTPS)
**\( \frac{V_D}{V_T} \) (ratio of physiologic dead space to tidal volume):** Proportion of tidal volume that is made up of the physiologic dead space. It is a dimensionless quantity, conventionally expressed as a fraction. Used as an index of ventilation-perfusion mismatching.

**\( \dot{V}E \) (minute ventilation):** Volume of expired air exhaled from the lungs in 1 minute. This is conventionally expressed in units of litres per minute (BTPS)

**\( \dot{V}E_{\text{max}} \) (maximal exercise ventilation):** Highest minute ventilation achieved during a maximal exercise test. This is usually determined by tests that tax large muscle masses, such as cycle ergometry or treadmill. It is conventionally expressed in litres per minute (BTPS)

**\( \frac{\dot{V}E}{MVV} = BR \) (Breathing reserve):** Expresses the relationship of ventilatory demand as reflected by peak \( \dot{V}E \) to ventilatory capacity. MVV is conventionally used as an index of ventilatory capacity. This ratio is expressed as \( (\dot{V}E_{\text{max}}/MVV) \times 100 \). The term is synonymous with ventilatory reserve.

**\( \frac{\dot{V}E}{\dot{V}CO_2} \) (ventilatory equivalent for carbon dioxide):** Ratio of the subject’s minute ventilation (BTPS) to CO\(_2\) output (STPD). It is a dimensionless quantity. This ratio indicates how many litres of air are being breathed to eliminate 1 litre of CO\(_2\). It is used as a noninvasive estimator of appropriateness of ventilation

**\( \frac{\dot{V}E}{\dot{V}O_2} \) (ventilatory equivalent for oxygen):** Ratio of the subject’s minute ventilation (BTPS) to O\(_2\) uptake (STPD). It is a dimensionless quantity. This ratio indicates how many litres of air are being breathed for each litre of O\(_2\) uptake

**\( \dot{V}O_2 \) (oxygen uptake):** Volume of O\(_2\) extracted from inspired air in a given period of time, expressed in millilitres per minute or litres per minute (STPD). This can differ from O\(_2\) consumption under conditions in which O\(_2\) is flowing into or being utilized from the body’s stores. O\(_2\) consumption is the amount of O\(_2\) utilized by the body’s metabolic processes in a given time, expressed in units of litres per minute (STPD). In the steady state, O\(_2\) uptake equals O\(_2\) consumption

**\( \dot{V}O_2_{\text{max}} \) (maximal oxygen uptake):** Traditionally the highest attainable O\(_2\) uptake for a given subject. It is determined during dynamic exercise from a "plateauing" of \( \dot{V}O_2 \) despite work rate continuing to increase. In the absence of a discernible plateau, the highest \( \dot{V}O_2 \) actually attained on the test is more properly termed \( \dot{V}O_2_{\text{peak}} \). Both \( \dot{V}O_2_{\text{max}} \) and \( \dot{V}O_2_{\text{peak}} \) are conventionally expressed in units of millilitres per minute or litres per minute (STPD) or, corrected for body weight, as millilitres per minute per kilogram

**\( \dot{V}O_2_{\text{peak}} \) (oxygen uptake at peak exercise):** Highest \( \dot{V}O_2 \) achieved on a test performed to the limit of tolerance. No additional criteria are needed for its determination, such as evidence of plateauing, to justify a \( \dot{V}O_2_{\text{max}} \). It is conventionally expressed in units of litres per minute or millilitres per minute (STPD)
\[ \Delta \dot{V}_{O_2} / \Delta \text{WR} \] Increase in \( O_2 \) uptake in response to a simultaneous increase in work rate (see below). Under appropriate conditions, this may be used to estimate the efficiency of muscular work. It is usually expressed in units of millilitres of \( O_2 \) per minute (STPD) per watt.

\( V_T \) (tidal volume): Volume of air inhaled or exhaled with each breath. Could be the volume of a particular breath or the average breath volume over a specified period of time—usually 1 minute. It is conventionally expressed in units of millilitres or litres (BTPS).

\( \text{WR} \) (work rate or power): Reflects the rate at which work is performed (i.e., work performed per unit of time). Work rate is usually measured in watts.

**Appendix 3 (Lung function test data)**

In this appendix you can find an example of the lung function test data that the physiotherapist receives from the lung function department of the St Lucas Andreas Hospital. (Next page) In general it is not essential to be able to read the different ECGs as a physiotherapist and therefore it is not necessary to look at them.
Aanmeldingsformulier longrevalidatie

Datum aanmelding :
Aanvragend specialist :

Rel. voorgeschiedenis :

Uitslag longfunctie :

Uitslag ergometrie :

Overige evtl. beperkende factoren (bijv. cardiovasculaire-, musculogene- of psychogene problematiek):

Bijzonderheden/advies:
Minimale O2-saturatie bij training?
Mag er zodanig O2 gegeven worden, zo ja hoeveel?

HANDTEKENING ARTS:
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<th>(B/P)</th>
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Datum: 09-08-0
Tijd: 15:06:15
Lab no.: 1
St. Lucas Andreas Ziekenhuis
Afdeling Longfunctie

FIA-nummer:
Naam:
Voornaam: B.J.
Geboortedatum:
Sex: male
Afdeling: --

Leeftijd: 37 Years
Lengte: 176,0 cm
Gewicht: 65,0 kg
B&B: 1,86 m²
Laborant(e): Mariët/Wies
Arts: Smitt

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Lab no.
# ERGOMETRIE

**Datum:** 13-09 09:58

**FN-nummer:**

**Naam:**

**Voornaam:**

**Geboorte datum:**

**Geslacht:**

**Bijh.**

**Laborant:**

---

### Pulmonary Profile

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<th>HR (bpm)</th>
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<th>Vtin (L)</th>
<th>VCO2 (ml/min)</th>
<th>VCO2/kg</th>
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### References

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   - **01:10**
   - **01:20**
   - **01:30**
   - **01:40**
   - **01:50**
   - **02:00**
   - **02:10**
   - **02:20**
   - **02:30**
   - **02:40**

---

**Lengte:** 178.0 cm

**Gewicht:** 69.0 kg

**BVA:**

**Laborant:** Mariet/misc

---

1-09-2009 9:1
## Exercise Summary Results

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### Blood gases

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Reden stoppen: gevoel van stikken.
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### Hoe vermoeid waren uw spieren/benen:

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