Types of Pulmonary function tests

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Week 1
Lecture 6

In this module, we are going to see about the types of pulmonary function tests. What are pulmonary function tests? They are objective measures of lung functions. They assess the lung capacity, efficiency and the overall lung functions. What are the uses of pulmonary function tests? They serve mainly as diagnostic tools to diagnose lung disorders and to plan treatment accordingly and after the treatment is begun to follow up the patients too. So they serve as follow up tools and it is also widely used as a research tool to study the impact of environmental, occupational and drug exposures on lung. So, these are the uses of pulmonary function tests, diagnostic purpose, follow up purpose and research purpose.

So now, let us see about the different types of pulmonary function tests or the classification of pulmonary function tests. The classification is based on the aspects of lung functions measured. This is the schematic representation of the respiratory system and the goals of respiratory system are ventilation which refers to the air which moves in and out of the respiratory tract and then at the alveoli at the functional unit gas exchange happens and following that the gases are transported in the blood and they reach the tissues where again gas exchange happens and these gases are used for cellular oxidation. These are the five goals of the respiratory system and classification of pulmonary function test is also based on these goals of respiratory system.

How are they classified? They are classified based on these lung functions measured and the test of airway function which is the first and foremost important classification of lung function test and there are tests to assess the lung volumes and ventilation, tests to assess the diffusion capacity of the lung and tests to assess the gas exchange which happens at the level of the alveoli and cardiopulmonary exercise tests and metabolic measurements. So, these are all the types of lung function tests which we will be seeing now. The principles of each of these we will be doing it now. And what are the tests of airway function? Tests of airway function, they test the mechanical aspects of the lung functions and what are the tests which are commonly done. The most important one being spirometry which is the most commonly used, widely used for lot of purpose, for teaching purpose, for research purpose, for diagnostic purpose, spirometry is the most important technique which is being used and this spirometry using this spirometry lot of parameters can be measured.

It assesses lung volumes and as well as air flow. So, both the static lung volumes and dynamic lung volumes can be measured. We will see about these static lung volumes and dynamic lung volumes in the next module or in module 5. And what are the other tests of airway function? Tests to assess the respiratory muscle strength like maximal inspiratory pressure, maximal expiratory pressure and also tests to assess the airway resistance and compliance. So, all these put together they assess the mechanical aspects of the lung functions and they are all tests of airway functions.

What are the parameters measured using the spirometry technique? Lot of parameters are measured using spirometry technique. There are simple spirometry techniques to measure the static lung volumes like tidal volume, expiratory reserve volume, vital capacity, inspiratory capacity, forced vital capacity maneuver using forced vital capacity maneuver, lung volumes, dynamic lung volumes like forced vital capacity, forced expiratory volume in 1 second, forced expiratory flow can be measured. And then the other parameters which can be measured, the flow volume curves and then the maximum voluntary ventilation. All these are the parameters which can be measured using spirometry technique and this will be done for you in detail in module 5. Now let us see about the other tests of airway function.

The test of airway function to measure the respiratory muscle strength, maximum inspiratory pressures and maximal expiratory pressures. What are these? Maximal all these pressures are to assess the respiratory muscle strength. By the way we have to assess the respiratory muscle strength, they are also adjuncts to spirometry and in pulmonary as well as in non-pulmonary disorders they are used to assess the respiratory muscle strength and patient when the patient is started on rehabilitation patients with poor respiratory muscle strength when the strength training is done, rehabilitation is done to assess such patients and also in patients who need ventilatory support such pressures measurements will be very helpful and how are these pressure measurements done. Let us see about the maximum inspiratory pressure. Maximum inspiratory pressure refers to the lowest pressure which is obtained during a forceful sustained inspiration and how do we do this? Patient is asked to take a maximum expiration first after which the airway is occluded and the patient is asked to inspire maximally and maintain it for a few seconds for 1 to 2 seconds.

So, this is how you can see the patient doing this maneuver. So, you can see the patient sitting with a nose clip and breathing through the mouthpiece and this is connected to the pressure manometer to measure the inspiratory muscle strength, inspiratory muscle pressure. So, here this measures the inspiratory muscle strength and what about expiratory pressures, maximal expiratory pressure? Maximal expiratory pressure refers to the highest pressure that can be developed during a forceful sustained expiratory effort. How is this done? This is done after a maximum inspiration, the airway is occluded and then a maximum exhalation is the subject is asked to do a maximal exhalation and

maintain it for 1 to 2 seconds. And the graph what you see here is the maximal expiratory pressure graph and the maximal inspiratory pressure graph what you see here.

And what is the significance of these measurements? The decreased MIP and MEP are seen in neuromuscular disorders and also in muscular disorders involving respiratory muscles. What are the tests of airway resistance and compliance? Airway resistance and compliance are also test of airway functions and these are forces which govern maximal airflow. So, how do we measure resistance? Resistance is measured using the Ohm's law analogy which says E = IR and E/I = R and using the same analogy airway resistance is also measured. So, here to measure airway resistance we need pressure gradient and the airflow and this is measured using body plethysmography technique which will be done, the principle of this will be done in a couple of slides. The other technique impulse oscillometry technique, a very important technique, a very unique technique to assess the airway function.

So, here this is also used to measure the airway resistance but in spontaneously breathing subjects and in pediatric age group individuals. So, the principle here is this is measured using high frequency sound waves. A loudspeaker is placed proximal to the device's flow sensor and this causes forced oscillations of flow and the pressure oscillations are used to measure the airway resistance using this technique and the advantage of this technique is it can be done in pediatric age group individuals who are unable to perform the forced maneuvers using the spirometry. This requires only a normal breathing, normal tidal breathing is required and here in this picture you can see the child holding on to the cheeks and with the nose clip on child is breathing normally spontaneously or a normal breathing through the mouthpiece and he is holding on to the cheeks to make a tight seal at the lips. So, this is the technique used to measure airway resistance and this technique is called impulse oscillometry or forced oscillation technique.

And what are the other tests of airway functions, test to measure the lung compliance. What is compliance? You have already studied about compliance in unit change in volume by unit change in pressure. This is a measure of the elastic property of the lung and how do we measure compliance? By passing a balloon into the oesophagus which is connected to the pressure transducer and a spirometer changes in volume and the pressure can be obtained from which complaints can be calculated. So, the other tests, the other pulmonary function tests, we have seen about the test of airway function of which spirometry will be done for you in module 5. We have seen about how to measure the inspiratory and expiratory muscle pressures and then the test of airway resistance and compliance put together all these constitute test of airway functions.

The second classification of the pulmonary function test, measurement of lung volumes and ventilation. So, what are these tests and how is it being done? So, there are techniques to measure the amount of gas which remains in the lungs after a complete

exhalation. You will be seeing in module 5 that the lot of lung volumes can be measured using spirometry technique but certain lung volumes like the amount of air which remains in the lungs at the end of a normal exhalation cannot be measured using that technique. You need special techniques to measure those. The measurement is called the functional residual capacity and this is measured using nitrogen washout method, helium dilution method and body plethysmography technique.

Let us see in detail about the principle of the helium dilution method and the body plethysmography technique now. And then the other lung volumes and ventilation, the measures of lung volumes and ventilation are minute ventilation, alveolar ventilation and dead space measurement. So, you have seen about this in detail in the previous lecture. What is minute ventilation? Minute ventilation = Tidal volume × Respiratory rate, it is the amount of air which moves in and out of the respiratory tract per minute and this minute ventilation includes dead space volume into account.

What is dead space volume? Dead space volume is the volume which remains and which does not take part in the gas exchange. So, if you subtract dead space volume from tidal volume and then multiply this by the respiratory rate you get alveolar ventilation. Hence alveolar ventilation can be measured after measurement of dead space. There are techniques to measure the dead space volume like Fowler's method, Christian Bohr method, using this dead space volume can be calculated and hence alveolar ventilation can be calculated too.

And the distribution of ventilation, how uniform is the ventilation? There are some techniques to measure to assess the distribution of ventilation like single breath nitrogen technique, multiple breath nitrogen technique and helium equilibration techniques of which the single breath nitrogen technique is commonly used to assess the distribution of ventilation. So, these are all the tests to assess the lung volumes and ventilation. What is the principle of this helium dilution technique? This is a schematic representation of a person sitting and breathing through the mouthpiece. So, you can see the person is asked to breathe a known volume and a concentration of helium. When should you start this breathing through this, re-breathe through this mouthpiece following a normal tidal expiration? The amount of air which remains in the lungs at the end of normal tidal expiration has to be calculated.

So, for that ask the subject to do a normal breathing, normal expiration and following that subject has to re-breathe this known volume and concentration of helium has to be, he has to re-breathe through this mixture for a few minutes that is for around 5 minutes for equilibration to happen. So, before equilibration, concentration is known, volume is known. And now this is the volume which is there in the lungs at the end of tidal expiration. So, now what happens to this helium? Whatever helium is there gets now redistributed in the volume which is there in the lungs too. So, after equilibration you can

measure a concentration, the new concentration which can be measured and this helium is now distributed in these two volumes V1 and V2. So, it gets distributed. We all know that mass is constant, law of conservation of mass. So, $C1 \times V1 = C2 \times (V1 + V2)$. So, here what are the known parameters? We already know C1 and V1 and C2 can be measured, the final concentration which can be measured and from this you can calculate V1 + V2 and after that V2 which is the unknown volume can be finally calculated. So, this is the principle of helium dilution technique which is used to measure the volume which remains in the lungs at the end of normal tidal expiration which is called functional residual capacity. There is another technique to measure this functional residual capacity which is called the body plethysmography technique.

What is the principle of this? So, here this is also the schematic representation where the subject is made to sit in an airtight box and the volume and the pressure of this is already known and the subject breathes through the mouthpiece and this is connected. There are two pressure transducers you can see, pressure transducer to measure the mouth pressure and pressure transducer to measure the box pressure. Subject sits in this airtight box and subject is asked to make initially at the end of normal tidal expiration, subject has to make panting respiratory efforts against a closed mouthpiece. So, now when there are volume and pressure changes in the lungs, accordingly the volume and pressure in the box also changes based on the lung volume changes. And according to Boyle's law, based on Boyle's law pressure and volume are inversely related $P1 \times V1 = P2 \times V2$ where P1 and V2 are already known from that P2 can be measured.

So, this is the principle of body plethysmography technique which is also used to measure the volume which remains in the lungs at the end of a normal tidal expiration called functional residual capacity. So, these two techniques, helium dilution technique and body plethysmography technique help in measurement of FRC or functional residual capacity. Now we have seen about two tests of lung functions. The third one is the test to assess the diffusion capacity of the lung, what is it? So, diffusion capacity is a measurement of rate of gas transfer happening at the level of the alveoli.

So, this is a schematic representation of the alveolar capillary membrane where the gas exchange happens and this gas exchange which happens in the alveoli or the rate of transfer of the gas that is proportional to the pressure difference across this alveolar capillary membrane and also it is dependent on other factors like area, thickness of the membrane surface area, thickness of the membrane and the diffusion constant.

Put together you can call this diffusion capacity of the lung. So, when you simplify this equation, so diffusion capacity of the lung is given by rate of transfer of the gas by the pressure gradient or the pressure difference. So, if these two parameters can be measured, diffusion capacity of the lung can be measured. It is based on this principle that diffusion capacity of the lung is measured and diffusion capacity of the lung is measured using

carbon monoxide and this is also called diffusion capacity or transfer lung capacity and how is this measured? Using a single breath technique, using small concentrations of carbon monoxide. So, what you see here, this will be done for you in detail in module 5 and this is the diffusion lung capacity apparatus where small concentrations of carbon monoxide along with tracer or quantities of helium and then the inspiratory composition of oxygen and nitrogen.

So, in this, this is the mixture which the subject has to breathe and this is the DLCO apparatus and then after that at the end of the subject has to breathe this mixture and then hold this mixture for a few seconds for 10 seconds or so and at the end of it the subject has to do an expiration and the expiratory gas is collected and it is analyzed. So, using the carbon monoxide analyzes. So, this is the principle to measure the diffusion lung capacity using carbon monoxide. But why? Why is carbon monoxide chosen to measure the diffusion capacity? Because its uptake is limited by diffusion not by blood flow and the initial to calculate the diffusion lung capacity you need the initial alveolar capillary difference to for oxygen this cannot be measured, but for carbon monoxide there is essentially no carbon monoxide in the venous blood initially and then also the affinity of carbon monoxide for hemoglobin is very high it is around 210 times greater than that of oxygen. Hence the partial pressure of carbon monoxide is almost 0 and the pulmonary capillaries which makes carbon monoxide suitable to measure the diffusion capacity of the lung.

We have seen about three tests. Now let us see about the test of gas exchange. What are the tests which are used to assess the gas exchange which happens at the level of the alveoli? Intensive gas analysis, this is a very commonly widely used test especially in the intensive gas setting. So, what are the parameters measured? pH, PO2, partial pressure of oxygen, partial pressure of carbon dioxide, three important parameters are measured using these gas exchange tests, but this is an invasive procedure. Blood has to be withdrawn from the artery and without any exposure the above parameters you know had to be measured. So, it is a cumbersome procedure to but this is an ideal measure of pulmonary function because this assesses the two important functions of the lung being oxygenation and carbon dioxide removal.

Are there any non-invasive tests to measure the gas exchange? Yes, there are some non-invasive tests like pulse oximetry to measure the arterial oxygen saturation and capnography to measure the exhaled carbon dioxide and because we have done the measurement of exhaled carbon dioxide let me also you know talk about another test pulmonary function test called the exhaled nitrogen nitric oxide test and this is strictly not a test of gas exchange, but this is an inflammatory parameter. Trace amounts of nitric oxide which is seen in the exhaled air that indicates inflammatory conditions like COPD and asthma. So, hence this is also an important pulmonary function test which is being done. What are the other pulmonary function tests? Cardiopulmonary exercise tests. We

have seen about the different pulmonary function test, the four different pulmonary function tests which are very widely used clinically to in case in for diagnostic purpose that is test of airway functions, test to assess the lung volumes and ventilation, diffusion capacity which is also widely used and then the let us see the cardiopulmonary exercise test.

So, exercise testing allows simultaneous evaluation of the cellular metabolism, cardiovascular and the ventilatory system. Exercise test they assess lung functions oxygen usage during physical exertion. Any potential lung abnormalities become apparent during the physical activity. So, the subject is asked to exercise using a treadmill or a cycle ergometer. An external workload is imposed on the cardiovascular system, musculoskeletal system and then the parameters are measured.

There are different types of exercise tests like simple non-invasive test to measure the heart rate, blood pressure, respiratory rate and the ECG and then test to combined with the exhaled gas analysis to measure the oxygen consumption which is called the vivo2 max and the carbon dioxide production and test with the blood gas analysis. So, these are the different types of exercise tests. COPD, interstitial lung diseases, pulmonary vascular disease and exercise induced bronchospasm or respiratory disorders that require exercise evaluation. And why do we have to do these tests? Any exercise evaluation will help us in distinguishing it between a cardiac or a pulmonary cause of the patient's inability to exercise and hence therapy can also be started accordingly. Either a cardiac rehabilitation or a pulmonary rehabilitation can be started accordingly.

So, these are the uses of these exercise, cardiopulmonary exercise tests. And there are some other miscellaneous tests like metabolic measurements which are not used very widely but used in certain conditions, certain situations. So, these are means of assessing the nutritional status of the patient to provide the nutritional support to the patient. They help in evaluating the patients who do not respond to the normal nutritional needs. And how is it done? It is done using the indirect calorimetry technique.

And these are the, what is the significance of doing these metabolic measurements in pulmonary diseases? So, carbohydrates have to be you know substituted by lipids in case of when there is an already a ventilatory load on the respiratory system, when there is a decreased respiratory function to meet the caloric requirements, carbohydrates have to be substituted by lipids to decrease the carbon dioxide production. And not only that, in certain cases to provide a positive nitrogen balance has to be maintained in people who have respiratory failure, atrophy of the respiratory muscle, a substrate analysis can be done and a positive nitrogen balance can be provided. So, these are the uses or the applications of these metabolic measurements. So, we have seen about the different types of lung function tests in this module, the classification, the most important one being the test of airway function of which spirometry is a very important technique which will be

done for you in detail in module 5, the parameters measured using the spirometry technique. We saw about the other test too, like helium dilution, body plethysmography technique to measure the functional residual capacity, the diffusion capacity of the lung using carbon monoxide technique and then there are tests to measure the gas exchange and then cardiopulmonary exercise tests and then the metabolic measurements.

So, these are all the different types of lung function tests. These are my references, wish you all a very happy learning. Thank you.