Introduction to Exercise Physiology & Sports Performance

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Lecture - 12
Respiratory System and Exercise - Part 2

Welcome back. Welcome to this NPTEL course on understanding exercise physiology and sports performance.This module on respiratory system and exercise part 2. I am Wing Commander Chandrasekara Guru. I am a sports medicine physician from the armed forces medical services.

You will be learning during this module on anatomy of respiratory system, breathing mechanics, lung volumes, pulmonary ventilation and gaseous exchange, responses of the respiratory system to exercise and its application. In this part, we will be discussing about the lung volume and the pulmonary ventilation. Let us revise what we learned in the previous session. We learned about, what is the process of respiration, anatomy of the respiratory tract and the lungs.

We saw the different zones of airway tree, the functions of the conducting zones and the respiratory zones. We studied about lungs, about the segment of the lungs, what are the functions and the various aspects about alveoli. We also dealt about the breathing mechanism, what happens during quiet breathing and during forced breathing and various respiratory muscles that take part during inspiration and expiration. Let us proceed further. So, to recapitulate as you inspire, you have a negative pleural pressure in the pleural cavity as we have studied in the last session.

In addition, there is active contraction of the respiratory muscles, the muscles of inspiration, namely the diaphragm and the external intercostal muscles.This causes further decrease in the thoracic pressure, which causes a decrease in the alveolar pressure, which becomes lesser than the atmospheric pressure. Because of this pressure gradient, there is movement of air from outside towards the alveoli. As and when the neutralization of this pressure happens, meanwhile the gaseous exchange happens between the inhaled air and the pulmonary circulation. The pressure neutralizes between the alveolar and the outside atmospheric pressure, this causes, halting of the movement of air from outside.

Because of the elastic nature of the lungs, you will have passive recoiling causing movement of the air outside during quiet breathing. As and when there is an increase in demand or there is increased resistance to the airflow, what happens? There is activation of the accessory muscles,

namely the abdominal muscles and the internal intercostal muscles. Both of these cause an increased intraabdominal pressure as well as an increased thoracic pressure, thereby pushing the air outside. So, thus the process of inspiration and expiration happens. In order to further understand the function that happens in the lungs, we need to know various lung volumes.

The lung is a hollow structure where the air is moving and moving out. The lung is for the functional purpose is divided into various volumes. But before going on, what are the factors which decide? It is very simple, you have to remember one word that is size. Whenever the size is more, the lung volume will be more. So, it is similar to a balloon size.

If the size of the balloon is more, the air that is going to go inside is going to be more. So, that determines the volume. So, with age, the size varies. With gender, the size varies. Male have a different size of thoracic cage, females have different size.

So, again that is a factor. Also, with the body size per se, someone who has a large body will have a more lung volume. So, have huge lung volumes. And another important aspect is again the stature or the height of the individual. More the height, more will be the vertical diameter. So, more will be the lung volume. So, these are the factors that you know affects the lung volume.

Further the lung volume for ease of understanding is divided into two components as static and dynamic. The static volume depicts more of a dimensional aspect and the dynamic volume depicts based on the performance capacity of the lung during the inspiration and expiration. So, let us see what are the different types of sub divisions of volumes that are there in both these groups.

The static volumes are further divided into tidal volume, inspiratory reserve volume, expiratory reserve volume and residual volume. Now, coming on to the dynamic volume, the dynamic volume is further divided into vital capacity, forced vital capacity, inspiratory capacity, functional residual capacity and the total lung capacity. So, the importance of knowing the volume is that, the static volume is genetically determined. So, your size is determined genetically. So, there is not much of a change that you can do because of the exercise training per se.

But however, dynamic volume can be trained by exercise and again is an important aspect that is used to assess the performance of the lungs. Further, we deal in detail about these volumes in the subsequent slides. So, we have the static volumes, as we said, divided into various types.

The tidal volume is the volume of air that is inspired or expired during quiet breathing. It is a volume of air that you inspire and expire during a normal breathing. It is approximately 500 ml normally.

And if you remember, we discussed about the anatomical dead space in part 1, wherein the conductive passage up to a generation of 16 are conductive zone, and here there is no exchange

of gas happens and hence they are anatomically dead space for the actual gaseous exchange and that constitutes about 150 ml.
What is inspiratory reserve volume? The air which is inspired with maximal inspiratory effort in addition to the tidal volume, constitutes the inspiratory reserve volume. It depends on the different gender. So, in male it is about 3.3 litres and in females it is about close to 2 litres.
What is the expiratory reserve volume? It is the air that is expired with maximal expiration effort in addition to your tidal volume. So, normally it is about 1.2 litres in male and about 0.7 litres or 700 ml in females.

What is residual volume? So, the volume of air remaining in the lungs after maximal expiration, so that is going to be left over in the lungs even after maximal expiratory residual volume, it is about 1.2 litres in males and 1.1 litres in females. So, during exercise the normal breathing, that is the tidal volume has to increase because of the increase in demand. So, this tidal volume encroaches on to either the inspiratory reserve volume or the expiratory reserve volume to cater for the oxygen need during exercise.

So, let us see about the dynamic volumes, it is also called as capacity, because it is in relation to the time effort. So, the vital capacity is the maximum volume of air expired after maximum inspiratory effort. So, normally it is about 4 litres in males and 3 litres in females.
How is it different from forced vital capacity? So forced vital capacity denotes the volume of air that is exhaled with greatest force rapidly in the shortest time after maximal inspiration. So, here the time component is important. So, that is called as the forced vital capacity. And normally this almost equal to ideal capacity, but then in case of diseases, this particular forced vital capacity component may reduce. And an important thing to know here is out of the 100%, 80% of this forced vital capacity happens in the first 1 second, and hence it is very important and it is termed as forced expiration capacity in first second that is FEV1, which is important diagnostic tool, which is used for assessing the functional capacity of the lung.
What is inspiratory capacity? Inspiratory capacity is again the maximum volume of air inspired after tidal expiration. So, it is tidal volume plus inspiratory reserve volume. Normally it is about 3.5 litres. Functional residual capacity is the volume of hair remaining in the lungs at the end of each tidal expiration, it is not forced expiration, it is tidal expiration, quiet expiration, it constitutes about 2 to 2.5 litres. Why it is important because during expiration, even though expiration causes movement of air outside, certain amount of air is required for the gaseous tension to be maintained so that the exchange happens. So, that is why it is very important.

This particular functional residual capacity may increase in certain conditions where the lung is kind of hyper inflated. Say in examples of obstructive lung disease, you may have inflated lungs where the functional residual capacity may increase. So, combining all these capacities, the total lung capacity and the volume of hair in the lungs at the end of maximal inspiration. So, normally it is about 6 litres in males and 4.2 litres in females.

So, let us see what are the factors that these dynamic volumes are dependent on. The main factor is the maximum force vital capacity because that becomes your denominator, maximum it is the dynamic volumes are dependent on that. The speed at which it moves because as I mentioned earlier, it is the time component. So, that is again the important determinant factor. The other important factor is also the airway resistance, the resistance that is offered to the movement of the air by the airway.

So, we discussed in the previous session about various factors with maintaining the bronchial tone, the diameter of the bronchial airways. So, these are the factors which may increase or decrease the resistance of the airflow. The other aspect is the respiratory compliance that is offered by the thoracic cage per se as well as the lungs. So, they also may affect the dynamic volume and also an important aspect is the exercise which I had mentioned earlier, exercise training can improve the dynamic volume of the lung.

So, let us see this in a simple graph. This you might find in most of the standard, you know, textbook of physiology. So, I have tried to, you know, try to explain it in an easier way for you say, the tidal volume which we had discussed during which happens during the quiet breathing. So, it is about, you know, which happens during the quiet breathing times and that is denoted here by the tidal volume. So, whenever there is a requirement of demand, so it encroaches into the inspiratory reserve volume. So, that is giving the maximum inspiration in addition to the TV that you, what is highlighted here as the IRV, that is inspiratory reserve volume.

The volume that is after a forced expiration in addition to the TV would be your expiratory reserve volume and that is denoted here. And further the remaining volume of air that does not involve after expiration, maximum expiration, the remaining volume of air in the lungs are called as the residual volume. So, with respect to the dynamic, the tidal volume plus IRV constitutes the inspiratory reserve capacity, the functional residual capacity is the expiratory reserve volume with the residual volume together. The vital capacity is during a forced inspiration followed by a forced expiration. So, that constitutes your vital capacity, and together it is the total lung capacity which constitutes about 6 liters.

So, here we have taken an example of 6 liters and then try to analyze them into different static and dynamic volumes. So, the measurement of these volumes is done by something called as pulmonary function test using a spirometer, it is called as the process of spirometry. The application is: during lung infections, you will have damage to the lungs. So, obviously the lung becomes less inflated and parenchyma is also lost, that causes a restrictive lung disease, the static volume decreases. Whereas, in case of inflammation of the airway, so you will have obstruction of the airway, increased resistance may be increasing the inflation of the you know lungs parenchyma and the alveoli, so that results in increased resistance as well during expiration.

So, that decreases the dynamic volume. So, what happens in exercise? In exercise, as I mentioned there is an increase in the need, so there is increase in the ventilation which causes an increase in the alveolar surface. The alveolar surface is normally used for the gaseous in increases that causes an increase in the dynamic volume. So, the dynamic volume parameters increases because of increased alveolar surface available as well as the alveoli also has certain surfactants which are helpful in better gaseous exchange, and they keep the you know alveoli compliant, and that is the increase in the surface area causes an increase in the surfactant as well and that causes an increased lung distensibility, which again helps in better increased lung volume.

So, we need to know also about the airway resistance as we have mentioned as one of the important factor. The airway is dependent on the diameter of the airway which is the most important factor. Whenever the diameter decreases the resistance will increase. So, bronchoconstriction or the agents that cause bronchoconstriction will increase the resistance. So, there will be forceful expiration, there is additional need for your expiration, and if the diameter is more bronchodilation there will be better you know ventilation, the effort will be lower. So, that is an important aspect, and how you know people use certain drugs also for this change in the diameter and improve their performance. So, hence certain drugs which cause bronchodilation are banned according to the world anti doping agency.

And another important aspect is the lung volume. Lung volume again decreases the resistance during inspiration and increases during expiration, because of the elastic nature there is increase in the resistance whenever there is a requirement and more demand. Then you have the accessory muscles supplementing or complementing the expiration. Bronchial tone is also by you know directly can be controlling the diameter by the nervous system as well the sympathetic and the parasympathetic. You have various drugs as I mentioned, the drug classes of the beta agonist which can you know increase the diameter of the bronchial airway.

Then also you have the environmental factors like certain dust in the pollen grains, and some allergens can influence the bronchial or bronchial diameter thereby also can affect the airway resistance as well. So, what is the application of this you know, I had mentioned about the FEV1 which is an important diagnostic tool. So, the FEV1 as a fraction of the force vital capacity is an important tool to diagnose certain diseases, most commonly to differentiate between an obstructive and a restrictive disease. So, the normal ratio is about 85 percent, and if it is less than 0.7 it is about you know airway obstruction and if it is further reduced about 0.4 it means that there is severe airway obstruction. In cases of bronchial asthma it is important for diagnosis as well as with treatment you can assess the prognosis of the condition as well. In case of certain specific conditions called as exercise induced bronchoconstriction; because of the exercise there is exercise can also cause, can induce reduction in the bronchial airways diameters that is called

as exercise induced bronchoconstriction. In such cases the classification is mainly based on this particular assessment. So, you need a pulmonary function test to further classify them as well, and also the gold standard for diagnosing these people with exercise induced bronchoconstriction is by doing a bronchial challenge test where again the dynamic lung volumes are used as important parameters.

Further, when you ask the individual to breathe to the maximum capacity so that something is called as maximum breathing capacity, or the maximum voluntary ventilation. So, individual is ventilating voluntary to his fullest potential. So, generally we ask the individual to do it voluntarily for a period of 15 seconds only, as it is very tiresome. So,15 seconds you do it and thereafter it is multiplied by 4 to one full minute. So, in case of athletes elite athletes it can reach up to level of 180 to 200 liters per minute.

So, that is the kind of maximum voluntary ventilation an individual is capable of reaching, it means it can go up to 120 liters per minute. The importance is that in bronchial challenge test this is an important criteria, wherein we will have to reach at least the basic of that much level. This can easily be calculated using the FEV1 which I had mentioned earlier, 35 times of that generally gives a rough estimate of once maximum breathing capacity, which you can easily use in your day to day practice. Also it is found that if you have it is less than 40 percent of a predictor.mSo, this is something you know obstruction is going on. So, it is an important factor or you can see an additional factor diagnose obstructive disease and you can relate it with their exercise training.
And with exercise training over a period of time if you assess this you can use it as a monitoring tool as well wherein the MVV increases with period of time based on the exercise that has been given. The pulmonary ventilation is the other aspect wherein actually the ventilation happens is studied in two different aspects as minute ventilation and alveolar ventilation. So, ventilation is the dynamic process that moves air in and out of the lungs. So, this can be studied as either minute ventilation and alveolar ventilation.

So, let us see what is minute ventilation ? It is a ventilation that happens per minute is called as minute ventilation the word simply the word itself explains that,it is a product of the number of times the individual breathes into the tidal volume. Tidal volume is the volume of air that you normally breathe in and out. So, the factors that controls are as we discussed earlier mainly the age, the gender, the body size and the metabolic state the requirement say for example, exercise you know fever these are metabolic high metabolic state which may increase the minute ventilation. So, let us know about the normal respiratory rate. The normal range is between 10 to 20 that happens in 1 minute. So, the increase in rate of breathing and increase in the depth of breathing that is the TV, is equal to the increase in the pulmonary ventilation. It is a simple mathematical explanation.

Let us see an example here we have a 38 year old lady Mrs. Sharma, she is your gym clientele and respiratory rate when, you assess her for one full minute, you found that it was about 12 breaths per minute which is normal, and she is just sitting there calmly, not doing anything at rest. The tidal volume during quite breathing is around 500 ml. So, what would be the minute ventilation is a simple product of the these two variables yeah right. So, let us see what is the minute ventilation is minute ventilation is respiratory rate into tidal volume right. So, here it is 12 per minute into the tidal volume is about 500 ml at rest. So, it gives you about 6 liters in this individual.

Minute Ventilation = Respiratory Rate x Tidal Volume

So, the other question here is what happens to the respiratory rate during exercise. So, in order to increase the demand. So, exercise causes a demand in the muscle. So, there is increase need of energy, because of which there is an increased need of oxygen. Oxygen is supplied by increase in the cardiac output, oxygen exchange happens in the lungs. So, we need more oxygen. So, we need more air to move in. So, there is increase in the respiratory rate as well. So, there is increase in the respiratory rate.

So, alveolar ventilation. So, alveolar ventilation is the volume of air that actually reaches the alveoli for gaseous exchange per minute. So, this is very important because not the entire air that you take into minute ventilation is involved in gaseous exchange. As I said earlier, there is some amount of anatomical dead space.

So, that is given by tidal volume minus the anatomical dead space into the respiratory rate that gives you the alveolar ventilation. So, it depends on the anatomical dead space. So, if the breathing is very rapid, and it is not so deep very shallow superficial rapid breathing, they may be increasing the minute ventilation, However, it will only increase the anatomical dead space. So, actually there is no gaseous exchange and the alveolar ventilation may or may not increase further.

Alveolar ventilation = (TV - Anatomical dead space) x Respiratory Rate

However, if you breathe slow and deep. So, there is an increase in the intake of minute ventilation, and minute ventilation increases predominantly because of increase in the alveolar ventilation. The anatomical space may remain the same. So, why is this important because, in order to improve the alveolar ventilation where the actual respiratory exchange happens, it is important that the depth should be increased rather than the respiratory rate. So, it is important that we teach or train the individual on this particular aspect. So, increasing the depth will increase the gaseous exchange which is required during activity or exercise.

Let us do an exercise with this knowledge. So, what is anatomical dead space? How much is it? So, I think you must already have the answer ready made with you. The air in the conducting zone does not take part in gaseous exchange right, and unlike the air that is in the respiratory zone of the airway tree, and this is called the anatomical dead space and this is about 150 ml. So, if the tidal volume is 500 ml and the respiratory rate is 12 minutes the same individual which we discussed earlier in exercise 1, what will be the percent of minute volume that does not participate in gas exchange. So, the tidal volume 500 ml respiratory rate is about 12 per minute.

So, we calculated the minute ventilation was 6 liters, right. So, the anatomical dead space here is 150 ml. So, let us subtract this 150 ml from the tidal volume which gives 350 ml. So, the actual alveolar ventilation is only 4200 ml per minute and out of the 6000 ml per minute. So, that would be about 70 percent which actually take part in gaseous exchange. So, the question here is what was the percentage of minute ventilation that did not take part in gas exchange.

So, that is about 100 minus 70 that gives you about 30 percent. So, 30 percent of the volume of air which was inhaled did not take part in actual gaseous exchange. So, 150 ml of anatomical dead space has kind of converted into 30 percent of unusable inspired air for you know gaseous exchange.

So, during alveolar ventilation what happens, because of the increased gaseous exchange there is more you know expiring or removing of the carbon dioxide. So, thereafter because of which there is decrease in the carbon dioxide pressure and so there is an inverse relation. So, whenever there is an increase in the carbon dioxide in the blood the alveolar ventilation is increased to remove the excess.

So, the increase in the carbon dioxide in the blood stimulates the ventilation, which causes hyperventilation. So, you start breathing faster which is an increase in the expiration of carbon dioxide and decrease in the partial pressure of carbon dioxide in the blood. So, thus there is increase in the alveolar ventilation causes and decreasing in the partial pressure of carbon dioxide, the inverse relation happens. So, that is how the lungs buffers the acid base balance also in the body. So, gaseous exchange occurs at the level of alveoli and beyond the 17th generation of the airway tree, and that entire membrane is the alveolar capillary membrane wherein the exchange of gas happens by simple diffusion.

So, this particular movement or gaseous exchange by diffusion depends on the pressure gradient. The entire expression process depends on the pressure gradient from the atmosphere to the level of alveoli. This pressure gradient is important, and also the pressure gradient at the level of blood and the tissues. So, it is the cascade that happens right from the atmosphere till the level of tissue.

So, the gradient is gradually lowered. So, there is a smooth movement of diffusion of the gases. The other important factor is simple: the other important factor is the blood flow. So, the gaseous exchange happens between the air which is in it and the pulmonary circulation, right. So, if the blood flow is hampered or it is increased.

So, the diffusion rate also varies. So, that is an important aspect. In case of any disease affecting these particular processes, say affecting the respiratory membrane or any disease affects the blood flow in cases of heart failure or right heart failure, or in cases of heart diseases; and if there is a reduced pressure gradient because of going to a high altitude region. So, these all interfere with the gas exchange in an abnormal way.

So, we discussed about the breathing mechanics, we discussed about various volumes, we discussed about various the minute ventilation and the alveolar ventilation how the gas suppression happens, but then these are all controlled by certain factors. So, what controls the breathing? The breathing is controlled mainly by the three different domains: the neural domain the neural control, the chemical control by the partial pressure of the carbon dioxide, partial pressure of the oxygen and as well as the H+ ion which is you know as a by product and you also have non chemical control by means of reflexes from the exercising muscles, the lungs and the chest wall. So, the neural control happens either voluntarily, and that is through the regions in the cerebral cortex. Automatically when you are breathing during sleep and a normal routine activity is by the control of the brain stem.

The chemical factors, as I mentioned, the receptors are present both at the central level, that is in the brain stem as well as in the peripheral level. The central receptors are more sensitive to the H plus ions and the partial pressure of carbon dioxide, whereas the peripheral receptors which are located in the carotid and the aortic bodies, where the bifurcation of the carotid artery happens. So, these receptors are more sensitive to the partial pressure of the oxygen and they control through the chemical receptors; and you have the feedback mechanism that is given through the mechanoreceptors which are present in the lungs and the chest wall and the exercising muscles. So, that gives an input about the demand that is placed on the respiratory system. So, though we have differentiated into three domains they all are integrated and they function smoothly hand in hand.

So, to summarize: we have two different lung volumes: static and dynamic. Various lung capacities, and we saw different applications of them in disease condition, in obstructive disease, in restrictive disease, lung disease as well as in case of exercise induced bronchial constriction. We also saw about the application of these capacities in terms of exercise as well the factors affecting the airway resistance, what are the different types of pulmonary ventilation the importance of alveolar ventilation. We saw two exercises on these. We also studied about the

basics of gas exchange that happens, and how the control of the entire breathing is maintained in the body. So, for those of you who are interested in further in depth learning, I would suggest the following standard text books for additional reading. Thank you.