Introduction to Exercise Physiology & Sports Performance
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Lecture - 06
Respiratory System and Exercise - Part 1

Last week, I had an avid runner coming to me and asking me, I stay in Delhi I go for long runs outside in the morning. I used to have breathing issues during cold. Should I wear a face mark when I go for a run? This is the question asked to me. If the same question is asked to you. if you are in the fitness industry, I am sure such questions would come from your clientele. So what would be your recommendation? Welcome to this NPTEL course on Exercise Physiology and Sports Performance.

This is a module on Respiratory System and Exercise. I am Wing Commander Chandrasekara Guru. I am a sports medicine physician. I am here to give you the perspective of this respiratory system and exercise in three different parts.

In this module you will be learning about anatomy of the respiratory system, breathing mechanics that happens during inspiration and expiration, what are the various lung volumes, and how the pulmonary ventilation and gas exchange happens; and how you can use this for your practice. Why do we need a respiratory system? As you know, in the cardiovascular system we have seen that the right side of the heart pumps the oxygenated blood to the lungs. When the deoxygenated blood reaches the lungs, the gaseous exchange happens here. Wherein, you have inhalation of the air, from which oxygen is taken inside the blood. Thereafter, the carbon dioxide which is in the deoxygenated blood is exchanged and breathed out.

So the main function is to exchange the oxygen and carbon dioxide. In addition to that, the important aspect of the respiratory system is acid-base balance buffering; that is mainly achieved by exhalation of carbon dioxide. So, respiration is a process by which oxygen from the atmosphere is taken inside into the tissues; and thereafter the carbon dioxide which is produced as a byproduct is eliminated outside. This generally happens in four stages. They are: ventilation stage, transport stage, exchange stage and finally the tissue stage.

So, let us see in the ventilation stage the gaseous exchange happens at the level of lungs. It is generally called as pulmonary ventilation. Thereafter, the gas that is exchanged is transported into the blood. In the exchange stage, the gas which is there in the blood is exchanged into the tissue. Thereafter, in the tissue the delivered gas is utilized for further metabolism.

Thus, the entire process of inhaling, or rather you know inspiring the hair and then the process till which the gas is being transported and utilized is basically the complete process of respiration. Moving on to the anatomy, what are the components of the respiratory system? The picture clearly shows that the air enters through the nose. Thereafter, it enters into the nasal cavity. Basically the air which is breathed in is humidified, warmed up and purified at this level. Further after which it enters into the larynx which again enters into the trachea.

From trachea downwards, this particular airway is further divided and it ends up in alveoli. So, the system until the larynx is called the upper respiratory tract; and the system beyond the trachea till the alveoli is termed as the lower respiratory tract. Let us focus on the airway tree or the tracheobronchial tree. The airway tree as I mentioned branches starting from the trachea and ends up into the final branches or the respiratory mechanism called as the alveoli. The diameter as you see, it is like a network which becomes smaller in size with every branching.

The entire airway tree is lined by ciliated cells. If you see the figure, the cells are lined along the border of the respiratory layer and you have at the end of the cells brush like border, which is like a brush which only moves along one particular direction. So in the respiratory bronchial tree, what happens is, this air like cilia, they move towards the nose. So, whenever there is a foreign body which gets inside the trachea or the bronchial tree, the foreign body is tried to pushed outside by the movement of these ciliated cells. In addition, the respiratory epithelium also has secretory glands along the trachea and the bronchi, they secrete certain mucus like substance.

This secretion helps in processing or moving forward the foreign body outside towards the nasal cavity, and then it is finally coughed out or sneezed out. However, in the respiratory tree if you see, the glands are absent in the bronchioles and the alveoli. Further, the airway is divided into various zones as and when the trachea bifurcates into the right and the left bronchus, it further divides and branches out 23 times, and they called as generations. So there are 23 generations of airway branching. The branching generation until 16 are called as conducting airway zones; wherein the air which is inhaled through the nose. Until the 16th generation it is there only for conducting or passing of this air from the nose nasal cavity till the 16th branching airway zone.

These zones are named as conducting zones, and their main function is only to warm up the inhaled air, humidify them and thereafter distribute it to the further generation of this bronchial tree. Hence, they do not involve in any kind of gaseous exchange; they are generally considered as the anatomical dead space where no exchange of gases happens. They are purely acting as conducting zones. Whereas, the generations beyond 16; that is from 17 till the 23rd until the opening up of alveoli the respiration or what you term as gaseous exchange happens, and these generation of airway tree are termed as respiratory airway zone wherein actual gaseous

exchange happens. It is important that the entire airway tree is patent, so that patency is maintained by what you call as bronchial tone.

It is purely formed of smooth muscle the bronchial smooth muscles and they are innervated. So, it is mainly controlled by the nervous system. We have seen about the autonomic nervous system, namely the sympathetic and the parasympathetic during our discussion in the cardiovascular system. So, the sympathetic nervous system causes bronchodilation in case of airway tree whereas the parasympathetic system causes what you call as bronchoconstriction wherein the airway reduces in size the diameter reduces in size. Also certain chemical mediators affect the bronchial tone, they are the histamine and the cytokines.

In addition, there is change in the bronchial tone with day time of the day, what you called as the biological clock or the circadian rhythm. Say at 6 am in the morning the airway is generally constricted. So, that is why you will find people with bronchial asthma or any kind of allergic related issues they generally have increased symptoms and frequency in the early morning hours. It is because of the natural physiological constriction that happens during the morning time, whereas if you see at the evening time at around 6 pm there is bronchodilation. So, that is a variation with respect to the time of the day.

As I also mentioned, allergens or the foreign substances also have an effect on the bronchial tone. In addition, cold air also can cause bronchoconstriction by stimulating the smooth muscle. So, what is the reason that the airway does not collapse? You know, in the respiratory passage up to 10th generation you have in addition to smooth muscle you also have something called as the cartilage. Cartilage is a bony, you know immature bone you could say and this particular immature bone helps in maintaining the patency of the airway, thereby it prevents collapse of the airway. If you can palpate along your neck you will find ring like structures which are arranged horizontally, and these are called as the cartilage.

So, these cartilage are responsible for maintaining the patency of the airway. So, as I mentioned, cartilage is present in the trachea, bronchi and the bronchioles till 10th generation. What prevents collapse beyond that? Yes, the bronchial airway beyond the 10th generation are embedded in the lung parenchyma. Lung parenchyma you can imagine is like a balloon, it is an elastic tissue. Since they are embedded within the parenchyma so they have that elastic nature.

The elastic nature per se does not allow the respiratory tree to collapse. However, you know it is something like a balloon. Imagine that you have blown up air and then you have closed the mouth of the balloon. So, that is why you have the air filled inside the balloon. The moment you leave it, automatically the air escapes out and then it collapses. The same thing happens in the lungs.

So, when you are breathing quietly the expiration happens automatically because of the elastic nature. So, the chances of collapse are there in certain conditions during expiration. So, what is the function of the secretions which I had mentioned earlier? So, there are certain glands which secrete fluid along the layer of the respiratory tree. These are nothing but the mucus like secretions which is along the layer of the respiratory tract. And this helps it form a carpet and helps in removing the foreign body outwards towards the nasal cavity along with the action of the cilia.

So, that is the function of cilia wherein along with the mucus helps in clearing of the foreign body or any of the you know allergens that get filtered along with the inspired air outside. Let us move on to the main respiratory system, the organ namely the lungs. So, we have two lungs. The lungs are enclosed within the rib cage, and you also have the heart which gives the blood supply to the lungs. So, there are two lungs: right and the left, the right lung has further three lobes and the left lung has two lobes.

The lungs are covered in total by a layer called as pleura. There are two layers of pleura one layer closely along the lungs, is called the visceral pleura, and then there is the outer layer which lays along the thoracic cage that is called as the parietal pleura, parietal is outside. So, it is the outer layer in between these two layers of pleura you have a cavity which is called as the pleural cavity and it maintains certain pressure inside and within this cavity you have this pleural cells which secrete fluids and there is filling up of this cavity by pleural fluid. About 10 to 20 ml of pleural fluid is there which prevents friction between these two layers. Basically, it separates these two layers and helps in expansion by creating a negative pressure. Sometimes, during disease condition there may be accumulation of pleural fluid in excess and that is called as pleural effusion.

Further, the lungs have the airway tree embedded within you have the vascular tree and further they are subdivided into lung segments and you finally have the alveoli where the respiratory gaseous exchange happens. The airway tree is embedded in the elastic connective tissue of the lung parenchyma, which I had mentioned earlier. The vascular tree contains the arteries, veins and the capillaries. The conducting zone which we discussed earlier is supplied by the bronchial circulation. However, the respiratory zone is supplied by the pulmonary circulation.

So, what is pulmonary circulation? The blood that is pumped from the right ventricle through the pulmonary artery into the lungs for oxygenation, that is the pulmonary circulation. So, they finally branch out and form capillaries in close proximity to the alveoli, and that is where the gaseous exchange happens. Further, the lobes are subdivided into segments, and these segments are called as bronchopulmonary segments, and they are considered as the individual unit of the lung. Further the right side has 10 segments, and left side has 9 segments. The alveoli is the functional unit where the gaseous exchange happens, and there are about 300 million alveoli in

both the lungs and if you open them, the surface area when you place along it matches as huge as a tennis court. So, that is the number of alveoli that we have in our body.

Let us move on to the breathing mechanics. During quiet breathing when you normally breathe you have the inspiration and expiration. During inspiration, you breathe-in the air. It is an active process wherein you are breathing inside by the action or the contraction of the inspiratory muscles. Whereas as I had mentioned earlier, lung is an elastic tissue like a balloon.

So, once the inspiration ends, the expiration or breathing out of the air happens automatically on its own. It is a passive process. What are the breathing muscles that are involved in respiration? So, in inspiration you have the breathing muscles involved or the diaphragm. Let me explain this. So, you have the diaphragm here and the diaphragm is along the lowermost part of the rib cage like a dome and it covers the entire region and divides the thorax into the thorax and the abdomen.

So, the trunk is divided into thorax and abdomen by the diaphragm, and it makes them into two different compartments. So, whenever the inspiration happens the diaphragm contracts and it comes down as a flat structure. So, because of this, you have an increase in the volume of the thorax. This volume increases. Further, you also have a group of muscles in between the ribs.

These are the ribs that are there in the rib cage, and you have muscles which are connecting both the ribs. These are called as the intercostal muscles. The external intercostal group of muscle is the inspiratory muscle. In addition to these main primary muscles of inspiration, we also have certain muscles which are connecting the thorax to the head along the neck. So, the neck muscles and certain back muscles help in inspiration.

Further, I had earlier mentioned during expiration it is a passive process where the automatic recoiling of the lung tissue the expiration happens. But what happens during post expiration? Post expiration requires contribution from the muscles, and these muscles are the abdominal muscles and the internal intercostal muscles. Let us see how it happens. So, during respiration as I said the diaphragm contracts goes downwards and forms a flat structure, and the internal or the external intercostal muscle contracts bringing the ribs outward and downward. So, this is equated to an action that happens when you lift the handle of the bucket.

It is called as a bucket handle effect. If you just lift the handle of the bucket, you will find that the space has increased in the transverse diameter. In addition, imagine a pump, all of us would have used a hand pump to pump water. So, when you press the handle from down to an upward posture what happens? There is an increase in the diameter. So, same thing happens with the sternum and the upper ribs. So, this causes the sternum to move forward and the ribs to rotate.

So, this causes an increase in the AP and the vertical diameter. This is the reason why you have increase in the thoracic volume. Further during expiration, now the diaphragm which was flat after expiration relaxes. So, again the diaphragm has to go and form a dome shaped organ, and this is further exaggerated by the action of the abdominal muscles. Abdominal muscles forcefully push the diaphragm towards the top.

So, this causes an increase in the thoracic volume and expulsion of the inspired air after the gaseous exchange outside. So, that along with the internal intercostal muscle causes a forced expiration. So, this entire process causes an increase in the venous return also at the level of the heart, wherein there is increased venous return in the right side of the heart. From the lower body you have more blood coming on to the right side of the heart.

So, thereby increasing the cardiac output. So, hence it is also termed as a respiratory pump. So, we have three pumps; the main pump is the heart, the peripheral pump is the calf muscle which we discussed in the cardiovascular module and here we have the respiratory pump. So, what is the significance? So, exercise training of these respiratory muscles will help in further enhancing their respiratory capability; especially in terms of runners and swimmers. Let us see what happens during the process of respiration. So, during inspiration as we saw there is a negative pressure which is created naturally between the pleural layers.

So, there is a negative pleural pressure and because of the active movement of the respiratory muscle there is increase in the thoracic volume as we have seen because of the bucket handle and the pump handle effect which causes a further reduction in the thoracic volume causing a negative pressure. So, there is a decrease in the alveolar pressure. Whenever the pressure decreases, there is you know movement of the air or the molecules to neutralize this pressure. So, what happens is to neutralize this the alveolar pressure is now lesser than the atmospheric pressure. So, there is movement of air from outside into the lungs that is how you have movement of air inside.

As the air enters from the external environment to the lungs, there is gaseous exchange which happens. Gradually the pressure between the atmospheric pressure and the airway pressure normalizes. As and when this happens the movement of the air entering stops and this causes a passive recoiling. So, now the expanded lung as there is no pressure effect which is coming from outside. So, there is no further movement of the air, because of which it now tries to recoil backwards to original position because of the elastic nature, and this causes the air to move outside. So, during this process of neutralization of pressure the entire gaseous exchange happens because of the pressure gradient.

So, what happens if there is an increased resistance because of wearing a mask or because of some obstruction or because of increased demand in terms of exercise. So, there you have a

forced expiration which is required. So, the activation of the muscles happen because of which you have an increase in the intra abdominal pressure which further increases the intrathoracic pressure which causes the flushing out of air outside, thereby causing an expiration. So, that is the process how the respiration happens. To summarize, at the end of part 1 we dealt about definition of respiration, what are the stages of respiration.

We saw about the anatomy the anatomy of the lungs anatomy of the airway tree and the bronchial tone the factors that control the bronchial tone. The different zones we saw the conducting zone as well as the respiratory zone and their function we also saw in detail about the different parts of the lungs the segment also about the alveoli how the breathing happens. The inspiration and the respiration and how it differs with respect to quiet breathing and forced breathing. We also saw about the various respiratory muscles that help in inspiration and expiration. Those of you who are interested in further in-depth learning can consult these standard textbooks on exercise physiology and further enhance your knowledge. Thank you for being here.

References:

Physiology of Sports & Exercise - Wilmore & Costill
Essentials of Exercise Physiology - Katch & Katch
Essentials of Strength Training & Conditioning - NSCA
Textbook of Medical Physiology - GK Pal