Course Name: Pulmonary Function Test -Interpretation and Application in clinical practice
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W1_L1_Functional Anatomy of the Respiratory Tract

Greetings to one and all on this forum. As we begin our journey in trying to understand the interpretation and the applied significance of pulmonary function tests, I would like to give you an overview of the functional anatomy of the respiratory tract. My session objectives for today are as follows. First, I will add a note on the organization of the respiratory tract from a functional point of view, which will be followed by the functional significance of the respiratory tract as a whole. Then I will talk to you about an important index, namely the death space and its influence on tidal volume. There are three types of death spaces, namely the anatomical, alveolar and physiological death space and I will add a note on these three types of death spaces.

Finally, a new concept in physiology has been introduced, it is known as the oxygen cascade, and this describes the inspiratory phase of the respiratory cycle. I will add a brief note on the oxygen cascade. And then I will also add a note on the respiratory system environment interface, namely the alveolist, following which I will conclude the presentation by talking about the non-respiratory functions of the respiratory tract and also giving you an overview on the regulation of respiration. With regards to the organization of the respiratory tract from a functional point of view, we shall try to divide the respiratory tract and compare it as an anatomical respiratory tract, a physiological respiratory tract and a clinical respiratory tract.

As all of you know the primary organs of respiration are the paired lungs which occupy the thoracic cavity laterally. The right lung as you know has three lobes and the left lung has two lobes. Around each lung is a flattened sac called the pleura. The outer layer of this pleura is the parietal pleura and the inner layer which rests directly on the lungs is the visceral pleura. There is a potential space between the parietal and visceral pleura and this space is known as the pleural cavity.

Now this diagram gives us an idea about the anatomical organization of the respiratory tract. However, I would like to describe the respiratory tract from three points of view, namely an anatomical respiratory tract, a physiological respiratory tract and a clinical respiratory tract. So, anatomically the respiratory tract comprises of the nose, pharynx, larynx, trachea, bronchi, terminal bronchioles, respiratory bronchioles, alveolar ducts and the alveoli. From a functional point of view or a physiological point of view, you have a conducting zone and a respiratory zone. The first 16 generations of the airways comprise the conducting zone and the remaining seven generations of the airways make up the respiratory zone.

Clinicians however like to describe the respiratory tract as an upper respiratory tract which extends from the nose up to the larynx or a lower respiratory tract which extends from the trachea up to the alveoli. Now this diagram is a diagrammatic representation of Wibbel's functional zones of the lungs. This was described in 1963 and as you can see in this diagram, there is a conducting zone where there is a branching up to the first 16 generations of the airways and then there is a respiratory zone where there is a branching in the last seven generations of the airways. Now coming to the muscles of respiration, it is important to recap that each respiratory cycle consists of an inspiration followed by an expression. It has 14 to 18 such cycles in one minute.

Now inspiration is an active phenomenon which requires muscular effort and the principal muscle of inspiration is the diaphragm and there are also other accessory muscles which facilitate the diaphragm during the process of inspiration. So these are all the inspiratory muscles on this side of the tabular column namely the diaphragm with the external intercostals and then the accessory muscles of inspiration which include the scalini, the sternocleidomastoid and the serratus anterior. Expiration on the other hand is a passive phenomenon and it normally depends on the elastic recoil of the lungs but however during states of stress such as exercise, expiration does require muscular effort. So, you have these muscles contributing the expression during stress namely the rectus abdominus, the internal oblique, the external oblique, the transversus abdominus and the internal intercostals. Five different types of cells have been differentiated in the respiratory tract namely the goblet cells, the type 1 alveolar epithelial cells, the type 2 alveolar epithelial cells, the clara cells and the pulmonary alveolar macrophages.

The goblet cells function to primarily secrete mucus and this is very essential for the functioning of the mucociliary escalator which helps in the clearing of foreign bodies. The type 1 alveolar epithelial cells constitute the epithelium of the respiratory tract. These are flattened cells which facilitate in keeping the epithelium thin to allow gas exchange to occur. There is an important group of cells known as the type 2 alveolar epithelial cells. These are situated in the alveolar of the lung and they secrete an important substance known as surfactant which reduces the surface tension of alveolar fluid thus preventing their collapse.

There is another group of cells known as the clara cells present in the bronchioles and these cells play a role in bronchial repair following injury. The pulmonary alveolar macrophages are situated in the alveoli and these are the principal phagocytes of the respiratory tract. The respiratory tract is predominantly lined by pseudo stratified ciliated columnar epithelium. Now let us take a look at an overview of the functional significance of the respiratory tract. The primary function of the respiratory tract is exchange of gases namely oxygen and carbon dioxide between the environment and the body.

Many physiologists have actually described the respiratory tract as a servant to the rest of the body in this regard. Now let us look at the goals of respiration. In order to provide oxygen to tissues and remove carbon dioxide from them, there are four important steps that need to be addressed. The first one is pulmonary ventilation which refers to the

movement of air between the atmosphere and the lung alveoli. Then we have alveolar ventilation which refers to oxygen and carbon dioxide diffusion between the alveoli and blood and then there is gas transport which refers to oxygen and CO2 transport within the circulation to and fro from the tissues and all these are regulated and that comprises the regulation of respiration.

Now this slide compares the anatomical unit of the lung and the functional unit of the lung. The bronchus pulmonary segment is a region of the lung supplied by a segmental bronchus. This constitutes the anatomical unit of the lung and this can be surgically removed when irreversibly diseased. The physiological unit of the lung is the respiratory zone that we previously saw and that comprises of the respiratory bronchioles, the alveolar ducts and the alveoli. This slide is a diagrammatic representation of the anatomical unit of the lung and the functional unit of the lung.

On this side of the slide, we have an anterior view and a posterior view of the lungs and you can see that each lung is divided into different segments depending on their supply by the segmental bronchus. These are the bronchopulmonary segments and they constitute the anatomical unit of the lung. On this side of the slide we can see the respiratory bronchioles continuing as the alveolar duct and finally terminating as the alveoli. This comprises the respiratory zone of the respiratory tract and this is the physiological unit of the lung. This is a clearer view of the bronchopulmonary segments and as you can see on this side of the slide, they are represented by numbers 1 to 10 which correspond to the apical, posterior, anterior, lateral, medial, medial basal, anterior basal, lateral basal and posterior basal bronchopulmonary segments.

Now we will come to a very important index of pulmonary function namely the dead space and its influence on tidal volume. The tidal volume is the amount of air that is either inspired or expired in the resting state. The tidal volume in a physiological individual is approximately 500 ml. However it must be remembered that all of this 500 ml dead ml does not get absorbed into the pulmonary circulation because exchange of gases does not take place in the conducting zone of the respiratory tract which has a volume of 150 ml and this is known as the anatomical dead space. That is the anatomical dead space refers to the conducting zone of the respiratory tract which has a volume of 150 ml.

It must also be appreciated that the volume of inspired air that is involved in gas exchange is actually the tidal volume minus the dead space volume which is about 500 minus 150 that is 350 ml. This slide shows that there are three types of dead spaces namely the anatomical, alveolar and physiological dead spaces. We just saw that the anatomical dead space is the volume of air present in the conducting zone of the lungs and this is normally 150 ml. There is another dead space known as the alveolar dead space which refers to the volume of inspired air that is directed towards the collapsed alveoli. In health all the alveoli are presumed to be functional and thus the alveolar dead space is equal to zero.

The total of physiological dead space is the sum of the anatomical and alveolar dead space and in health the physiological dead space equals the anatomical dead space because the alveolar dead space is zero. However, in respiratory disease associated with collapsed alveoli the physiological dead space is greater than the anatomical dead space. This slide is a summary of what I just spoke and you can see that the respiratory dead spaces are three in number namely the anatomical dead space, alveolar dead space and the physiological dead space. You can also see that the anatomical dead space plus the alveolar dead space is equal to the physiological dead space. Now we shall see a recently described concept in respiratory physiology namely the oxygen cascade which describes the inspiratory phase of the respiratory cycle.

This slide gives a representation of the oxygen cascade and you can see that from the atmosphere oxygen is translocated to the alveoli and then onto the pulmonary circulation and then to the systemic circulation and then to the tissues. This is mediated by a pressure gradient from a region of high pressure to a region of low pressure. This slide is a diagrammatic representation of the oxygen cascade and you can see that oxygen from the external environment diffuses into the pulmonary circulation carried to the heart and then onto the systemic circulation and then into the tissues from where carbon dioxide is similarly removed in a similar fashion till it is expired out of the body. It is important to note that the oxygen cascade is mediated by the pressure gradient of oxygen. This slide shows the partial pressure of the respiratory gases at different levels of their transport.

Let us take a look at this row of the tabular column which describes the oxygen cascade. You can see that the partial pressure of oxygen in dry ambient air is about 159 mmHg and this begins to drop and by the time oxygen reaches the tissues the partial pressure drops to about 100 mmHg and drops even further once it reaches the venous blood. So, it is important to remember that it is the pressure gradient which is responsible for the oxygen cascade. I will add a note on the respiratory system environment interface which is the functional zone of the respiratory tract. The respiratory system environment interface or the blood gas barrier is depicted diagrammatically here.

Here you can see the respiratory bronchiole continuing as the alveolar duct and terminating as the alveoli which is the functional unit of the lung. The lungs of a human contain about 3 million alveoli which have a total surface area of 50 to 100 m2 or about the area of a tennis court. Now having given you an overview of the primary functions of the lung namely oxygen and carbon dioxide transport, let us take a look at some of the non-respiratory functions of the respiratory tract. So this classification shows that the non-respiratory functions of the respiratory tract can be grouped as three functions namely the pulmonary defense mechanisms, non-respiratory functions of the pulmonary circulation and also the metabolic functions of the lungs. Let us take a look at the pulmonary defense mechanism.

It is interesting to note that the 24 hour inspiratory air load to the respiratory tract is about 10,000 liters and this in turn contains dust and related particles, products of combustion, microorganisms and toxic gases which are detrimental to the respiratory tract. There are defense mechanisms which serve to minimize this. Three of them are

shown in this slide. Firstly the air conditioning function, this occurs in the nasal cavity in which inspired air is heated to body temperature and also humidified in the process. There is also olfaction which serves to identify potentially hazardous gases and toxic material in inspired air.

There is filtration of inspired air. The nasal cavity has hairs or vibrissae that filter particles greater than 10 micrometer square. This slide shows the remaining two pulmonary defense mechanisms namely immunity and the airway reflexes. It is interesting to note that all the three types of immunity are present in the respiratory tract namely innate immunity, cell mediated immunity and humoral immunity. The tonsils and adenoids are rich collections of lymphocytes and cell mediated immunity is conferred by these lymphocytes.

The innate immunity is conferred by the alveolar macrophages present in the alveoli which are active phagocytes. The bronchial secretion also contains IgA which plays a role in humoral immunity and the synthesis of antibodies. The respiratory epithelium also contains nitrous oxide which is bacteriostatic. There are two important airway reflexes namely the sneeze reflex and the cough reflex. The cough reflex is a very important reflex that along with the mucociliary escalator gets rid of substances which are foreign and toxic to the respiratory tract.

Another non respiratory function of the respiratory tract is vocalization which consists of three phases namely phonation followed by articulation and resonance and all the structures of the respiratory tract play an important role in vocalization. This slide shows the non respiratory functions of the pulmonary circulation and there are three non-respiratory functions of the pulmonary circulation namely the pulmonary circulation is the reservoir for the left ventricle. It has a filtering function and it also participates in fluid exchange and drug absorption. So with regards to being a reservoir the pulmonary blood volume is about 500 ml and this can be translocated to the systemic circulation whenever the cardiac output is low. With regards to the filtering function the narrow pulmonary vessels they tend to filter unwanted substances blood clots, flat cells and gas bubbles to name a few and if this does not happen this can go and occlude the systemic circulation.

With regards to fluid exchange since the pulmonary capillary colloid osmotic pressure is lower than that of plasma alveolar fluid is filtered from into the pulmonary circulation thereby keeping the alveolar dry. And as most of you must be knowing most of the anesthetic drugs are usually absorbed into the pulmonary circulation from where they pass into the systemic circulation. This slide shows biologically active substances metabolized by the lungs. This is grouped as follows. We have substances which are synthesized and used in lungs.

Surfactants comes in this group and surfactant as I have told you reduces the surface tension of the alveolar fluid. There are substances which are synthesized or stored and released into the blood prostaglandins, histamine and calcarine come in this group. There are certain substances which are partially removed from the blood prostaglandins,

bradykinin, adenine nucleotides, serotonin, norepinephrine and acetylcholine fall in this group. And there are substances which are activated in the lung's angiotensin 1 to angiotensin 2 which is concerned with the regulation of systemic arterial blood pressure. And as we conclude this presentation let us have an overview on the regulation of respiration.

So the 24 hour respiration in the body is regulated by two means namely a neural mechanism and a chemical mechanism. And regulation of respiration serves to maintain a 24 hour normal partial pressure of oxygen, partial pressure of carbon dioxide and hydrogen ion concentration in the circulation. The neural regulation of respiration is brought about by the respiratory center. This is located bilaterally in the medulla and the pons of the brain stem and consists of the dorsal respiratory center, the ventral respiratory center and the pneumotaxic center. The spontaneous rhythm of respiratory center is mediated by the pre-Boschinger complex of neurons that lies on either side of the medulla oblangata.

Now with regards to the dorsal respiratory group of neurons it is located in the dorsal portion of the medulla and on stimulation it principally causes inspiration. The ventral respiratory group of neurons is located in the ventral side of the medulla and it is normally dormant in the respiratory state and it causes inspiration and expiration during periods of respiratory stress. The pneumotaxic center is located in the pons and on stimulation it controls the rate and depth of respiration. With regards to chemical regulation of respiration whenever there is excess CO2 and hydrogen ion or a fall in oxygen the respiratory center gets stimulated. An excess CO2 and hydrogen ion in the circulation stimulates the respiratory center to increase the rate and depth of respiration thereby causing CO2 to be expired.

A fall in O2 acts on peripheral chemoreceptors situated in the carotid neotic bodies. This in turn relates to the respiratory center to increase the respiratory rate. So having given you an overview of the functional anatomy of the lungs I would like to wish all of you a happy learning over the next subsequent sessions that will follow in which you will enhance your understanding on the application and interpretation of pulmonary function tests. I would also like to thank one and all who have helped me to participate in this forum and address all of you. Thank you.