

Course Name: Pulmonary Function Test -Interpretation and Application in clinical practice

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W1_L2_Mechanics of Respiration

In this section, the mechanics of respiration is discussed under the headings of the muscles involved in breathing and the movements brought about by the muscles, predominantly the bucket handle movement and the pump handle movement, the pressure changes that are happening during inspiration and expiration, compliance and elastance of the lungs, the role of alveolar surface tension and the surfactant and the work of breathing.

Muscles of Respiration

Respiration includes inspiration as well as expiration. Inspiration is an active process. The diaphragm brings about almost 80 % of the inspiration which when contracts, pulls down the thoracic cavity so that the vertical diameter increases. The other important muscle that helps in inspiration is the external intercostal muscles which when contract increases the anteroposterior diameter as well as the lateral diameter of the thoracic cavity. These two muscles are normally involved during resting conditions but when sometimes there is a need to breathe heavily like in exercise, the accessory muscles like Sternocleidomastoid, serratus anterior and scaleni also will come into play.

On the contrary, the expiration is a passive process, chiefly brought about by the elastic recoil of all the structures that have been expanded during inspiration. In addition to that, if needed, the internal intercostal muscle will also come into play. But whenever there is a need for more expiration, these accessory expiratory muscles – the abdominal muscles, which includes external oblique, internal oblique, rectus abdominus and transverse abdominus will come for action.

During inspiration there is increase in the size of the thoracic cavity, which is brought about chiefly by the diaphragm and the external intercostal muscles. Because of these muscles there is increase in the vertical diameter, anteroposterior diameter, and the lateral diameter. Increase in the thoracic cavity size causes a drop in the intra thoracic pressure so that the air rushes from the atmosphere into the lungs.

During Expiration, there is decrease in the size of the thoracic cavity with all its diameters gets decreasing and there will be increase in the pressure in the lungs so which pushes the air outside to the atmosphere.

Movements of Respiration

Thus, the chief movements of the respiration include the vertical movement of the diaphragm which increases the vertical diameter, the pump handle movement, and the bucket handle movement.

In pump handle movement, the thoracic cavity and its structures are compared with that of a water pump. The sternum is viewed similar to the tip of the water pump, the ribs compared with that of the handle of the water pump and the base of the water pump is the vertebra. When the external intercostal muscles of the upper ribs contract, the sternum is pushed outwards and away from the thoracic cavity, causing an increase in the antero-posterior diameter.

In the bucket handle movement, the ribs are viewed like the handle of the bucket. When the handle of the bucket filled with water is lifted, the bucket increases in its lateral diameter. Similarly, when the external intercostal muscles of the lower ribs contracts, the ribs are pulled outwards and there occurs increase in the lateral diameter or transverse diameter of the thoracic cavity. This is called as bucket handle movement which results in increase in the transverse diameter.

Pressures of the thoracic system

Structures in the thoracic cavity: The outermost layer is the chest wall which is made up of the muscles the external and the intercostal muscles and the ribs in between. The lungs they are freely floating in the thoracic cavity except at one place at the hilum where it is attached. The lungs are covered by a layer called as pleura which has got two layers. The layer which is present next to the lung surface is the visceral pleura. And the one which is lying near the thoracic wall is the parietal pleura. There is a potential space between the two pleural layers and this is called as pleural cavity which is filled with the negligible quantity of fluid called pleural fluid. It is the presence of this pleural fluid that the lungs are not just rubbing each other causing friction and inflammation. Instead, it is freely sliding over each other. This is similar to the situation when two glass slides separated by a drop of water in between slides very smoothly when rubbed over each other.

Pressures: There are three pressures acting in the respiratory system. The **pressure A**, is the pressure that is seen inside the alveoli or we can simply say as that which is present in the lungs parenchyma. A, is nothing but intrapulmonary pressure, intrapulmonary pressure, or intra-alveolar pressure. It is also referred as P_{pul} . So, this intrapulmonary pressure is found to be 760 mm of Hg.

Pressure B present in the pleural cavity is called intra-pleural pressure. It is also referred as P_{IP} . P_{IP} is little lesser than the intrapulmonary pressure. It is around 756 mm of Hg. There is another pressure which is acting on the chest wall that is **Pressure C**, which is the barometric pressure or atmospheric pressure. It is referred as $P_{Atmosphere}$ which is 760 mm of Hg.

These pressures can also be mentioned with respect to the atmospheric pressure. Intrapulmonary pressure can be written as Pressure A – Pressure C which is $760 - 760 = 0$ **mm of Hg**.

Similarly, intrapleural pressure can be referred with respect to the atmospheric pressure as Pressure B – Pressure C which is $756 - 760 = -4$ **mm of Hg**. The intrapleural pressure is negative normally. This is because of certain forces that are acting on this pleural cavity.

The visceral pleura is clinging to the surface of the lungs. The lungs always tend to collapse. So the elastic recoil tendency of the lungs is to collapse. When the lungs collapse it also pulls the visceral pleura along with it. The parietal pleura is adhered to the chest wall and the tendency of the chest wall is always to pop outwards. Hence, when the chest wall is recoiling it recoils outwards and the parietal pleura is pushed outwards. Thus, the visceral pleura is pushed inwards whereas the parietal pleura is pushed outwards.

This creates an increase in this cavity space (Volume) and the pressure automatically drops. By Boyle's law, when the pressure increases the volume decreases and vice versa. Thus, the intrapleural pressure decreases and it becomes negative.

There are the two important gradients of the pressure. One is this difference between the intra-pulmonary and the intra-pleural pressure which is nothing but Pressure A minus Pressure B. This is called as trans-pulmonary pressure (T_p). T_p which comes around $760 - 756$ mm of Hg = 4 millimeters mercury. This trans-pulmonary pressure is the elastic recoil of the lungs. Another gradient is the difference between the intra-pleural pressure and the atmospheric pressure which is Pressure B – C = $756 - 760$ mm of Hg = -4 mm of Hg. This is called trans-thoracic pressure acting across the chest wall and is equivalent to intra-pleural pressure. Trans-thoracic pressure will be the same anywhere in the thoracic cavity may it be the esophagus or the mediastinum or the intra-pleural cavity. But the trans-thoracic pressure is not the same everywhere within the lungs. This is because of the effect of gravity. The pleural cavity space in the base of the lungs is decreased because of the pull of the gravity. This visceral pleura comes close to the parietal pleura. The decrease in the cavity space is less so the pressure becomes less negative. Whereas in the apex, especially when a person is standing, the parietal pleura and the visceral pleura are farther apart because by the effect of gravity the visceral pleura is pulled downwards and the pleural space is increased. The cavity size increases and hence the pressure becomes more negative.

Pressure changes during respiration

The pressure inside the pleural cavity which is called as intra-thoracic pressure or intra-pleural pressure is always **sub-atmospheric** in nature. At the beginning of inspiration with the pleural pressure which is usually it is negative, -2.5 mm of Hg (-5 cms of H₂O). At the end of inspiration, it becomes more negative, i.e. -6 mm of Hg (-7.5 cms of H₂O).

With this increasing negativity of the pleural pressure the lung volume increases to around

0.5 liters that means with each breath taken in, the pressure goes more negative and there is an increase or rushing of air of about 0.5 liters. This is called the tidal volume.

In standing posture because of the effect of the gravity the apex is having more negative intra-pleural pressure when compared to the base of the lungs. Whenever there is an accumulation of the air or water as in the case of pneumothorax or hydro-pneumothorax, there occurs collapse of the lung that breaches the negative pressure inside the pleural cavity which pushes the lungs to collapse.

The intra-alveolar pressure or intra-pulmonary pressure or simply alveolar pressure which is present inside the alveoli. Normally it is 0 mm of Hg with respect to the barometric pressure. During Inspiration, it decreases to - 1 mm of Hg and during expiration it goes to +1 mm of Hg. This trans-pulmonary pressure is the difference between the alveolar pressure and pleural pressure. This is the measure of the elastic recoil tendency of the lungs and is also called as recoil pressure.

Summary of respiratory movements

The respiratory centers actually initiate the stimuli for inspiration and these impulses are carried via the nerves; phrenic nerve carries the impulses to the diaphragm; intercostal nerves carry the impulses to the external intercostal muscles. This causes the muscles - diaphragm and the external intercostal muscles to contract and that causes increase in the cavity size of the thorax. Because of that the intra pleural pressure become negative the intra alveolar pressure also becomes sub-atmospheric so the air from the atmosphere rushes in into the lungs.

On the contrary during expiration opposite thing happens. Here the respiratory centers stop sending the impulses so the muscles undergo relaxation, the thoracic cavity size becomes decreased, and these causes decrease in the intra pleural pressure and the intra alveolar pressure which become less negative, so, the alveoli undergo elastic recoiling and air from the lungs rush out of the lungs into the atmosphere. This causes deflation of the lungs.