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Respiratory Tract, Ventilation, and Pulmonary Functions Tests

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Abstract: Breathing is considered the common factor that links studying, sleeping, and activities. It is one of the primary indicators that is frequently considered when determining whether or not an unconscious individual is still alive. The evolution and development process of the respiratory system that occurs in a foetus is primarily from head to tail (cephalocaudal). Many changes occur throughout this period until the 28th week of pregnancy at which the foetus's respiratory system will attain adequate development for the rest of his or her life. The respiratory system comprises of the lungs and the encompassing thoracic wall, which includes the thoracic cages, midriff (diaphragm), and the abdominal wall. Spirometry is a procedure used for estimating air volumes that enter and exit the pulmonary system with the aid of a spirometer. The various pulmonary parameters that reflect pulmonary ventilation are of great significance in diagnosing respiratory diseases. The respiratory system will be discussed in more detail in this article.

Keywords: Respiratory tract; Ventilation; Pulmonary functions tests

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1. Respiratory process

The respiratory process is as follows [1,2]:

(1) ventilation; this process includes the transference of air inside and outside the lungs;
(2) external respiration; this process includes the exchange of gases between the lungs and the bloodstream;
(3) internal respiration; this process includes the exchange of oxygen (O_2) and carbon dioxide (CO_2) between the blood and body tissues.

2. Respiratory system

The pulmonary system, as shown in **Figure 1** [3], consists of the upper respiratory tract and the lower respiratory tract. The upper respiratory tract includes the nasal fossa and the pharynx (throat), whereas the lower respiratory tract includes the larynx (glottis), trachea (windpipe), bronchial tubes, and the lungs. The diaphragm and the muscles present in the chest wall are necessary for the completion of the breathing process. Air is warmed up to 37°C and dampened to a relative humidity percentage of 99%; this occurs in the nose, mouth, and pharynx. The pharynx is the principal entrance of both the gastrointestinal system and

the pulmonary system. Air that enters through the nose or mouth, as well as food or water that enters through the mouth are all received by the pharynx. The pharynx is connected to the respiratory system at the larynx and to the digestive system at the oesophagus on the lower side.

The larynx or the voice box is composed of nine cartilages, which are linked with each other by muscles in addition to two couples of ligaments. The epiglottis prevents food and liquid from entering the larynx and air from exiting the lungs.

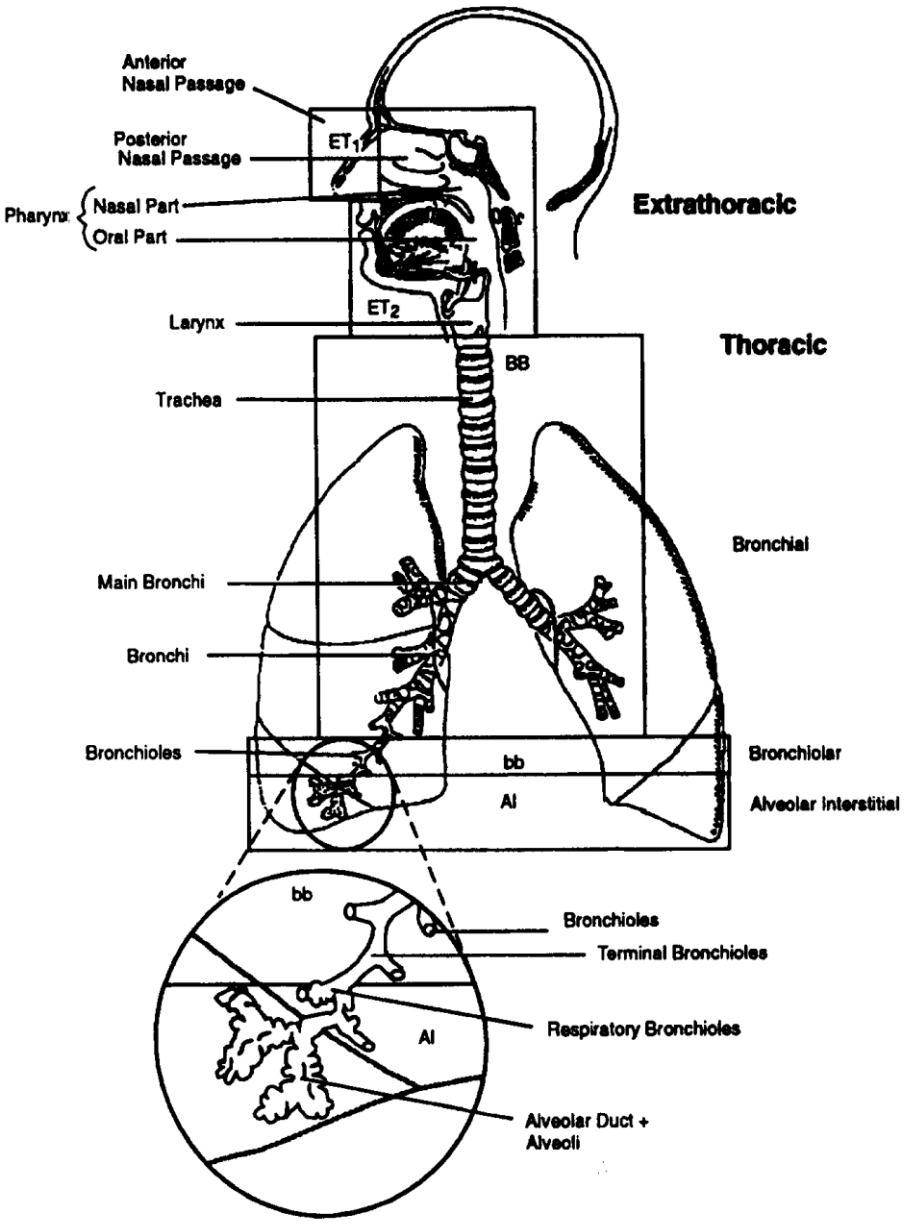

Figure 1. Components of the human respiratory system

The trachea or the windpipe can be defined as a membranous tube, structured of thick connective tissue that is supported by number of C-shaped cartilages (15 to 20). These cartilages are the cornerstone in the construction of both the frontal and side walls of the trachea (windpipe). Cartilages act as a safeguard for the trachea, and they also help in keeping the airway passage from collapsing. The posterior (back side) wall of the trachea does not have any cartilages; rather, it has a membranous sheath and several involuntary smooth muscles.

The trachea has two branches: the left bronchus and right bronchus. They are also braced by C-shaped cartilaginous rings. The remaining segments of the bronchial tree are reinforced with several small cartilaginous slices in the airway walls instead of the "C-shaped cartilaginous rings." Descending downwards, the cartilages appear to be smaller, and there are more smooth muscles.

The hilum or the root is the point at which the bronchi enter the lungs (**Figure 2**). The lungs are the main organs responsible for ventilation, and they are also considered one of the largest organs in the human body. Each lung appears to have a conical configuration, with its base leaned on the chest diaphragm, and its tip extending in the upper side. It is well understood that the lung located on the right side is larger (about 620 grams in weight) than the other lung located on the left side (560 gram in weight). The right lung consists of three lobes, whereas the left lung consists of only two lobes. There is a fissure between every two lobes. Each lobe is made up of lobules that are separated from one another by connective tissues, but neither do they have blood flow nor nerve innervation. This makes it possible to remove damaged or infected lobules from a person's lungs via surgery. The left lung consists of nine lobules, whereas the right lung consists of ten lobules.

The main structures of the trachea and bronchi resemble a tree with forked branches [4]. Each branch of this tree gives rise to a new generation (G) of respiratory tracts. The trachea (G0) branches into two basic bronchi structures (G1), which further divide into secondary bronchi structures (G2), tertiary bronchi structures (G3), bronchioles, and finally terminal bronchioles (G16) and alveoli (G17 to 23) (**Figure 2**). Moving along the pulmonary tree beginning from the trachea to the terminals, there is a decrease in tubule thickness and an increase in the number of pulmonary airways, resulting in an increase in the total surface area of the lungs.

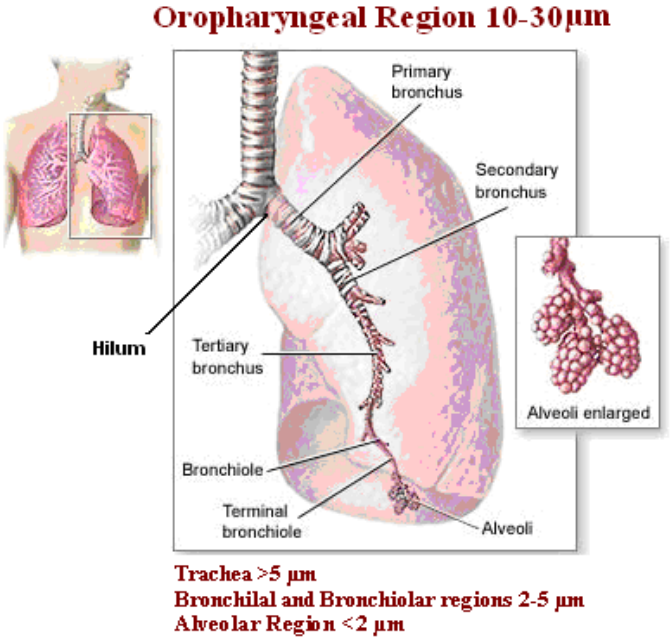

Figure 2. Branching of pulmonary airways in human lungs

The alveolar sac consists of two or more alveoli with a single common orifice. The lungs consist of approximately three hundred million alveoli. Each alveolus has an extremely thin wall, with a mean thickness of nearly 0.25 mm. These alveoli are enclosed by a crossed mesh of blood capillaries, as shown in **Figure 3**. In a normal healthy adult, the overall estimated surface area of the pulmonary membrane is approximately 70 m^2, which represents about half of the area of a tennis court [2].

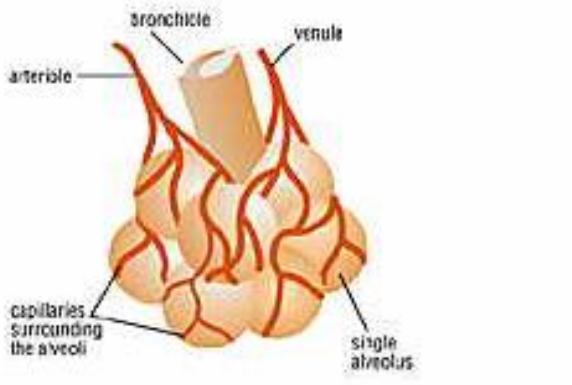

Figure 3. Blood supply to the alveoli

The alveolar region is lined with simple squamous epithelial tissue rather than mucoid tissue. There are two types of alveolar cells: type I pneumocytes, which are thin cells responsible for the scattering of gas and drug particles, and type II pneumocytes, which are cuboidal-shaped cells that are responsible for the storage, excretion, and reutilizing of pulmonary surfactant. The role of pulmonary surfactant is to reduce the pulmonary surface tension, and in return, this will help maintain the alveoli's essential structural and functional properties required for performing ventilation. The lack of surfactant in newborns usually causes a disease known as respiratory distress syndrome (RDS); in adults, this disease is known as acute respiratory distress syndrome (ARDS). RDS can be treated with β_2-adrenergic agonists by stimulating the secretion of surfactant from type II pneumocytes [5-7].

3. Role of lungs in ventilation

Lungs are characterized by their extreme flexibility. It gives them the capacity to expel air and return to their normal pre-inflated state. However, when lungs return to their normal pre-inflated state, they still hold some air inside them to maintain their sponge-like structure. The lungs are located inside the thoracic cavity. Each lung is enclosed with an independent pleural cavity made up of pleural serous membranes.

The respiratory system is composed of the lungs encased within the chest wall. The components of the chest wall include the ribs, diaphragm, and abdominal wall (**Figure 4** [8]).

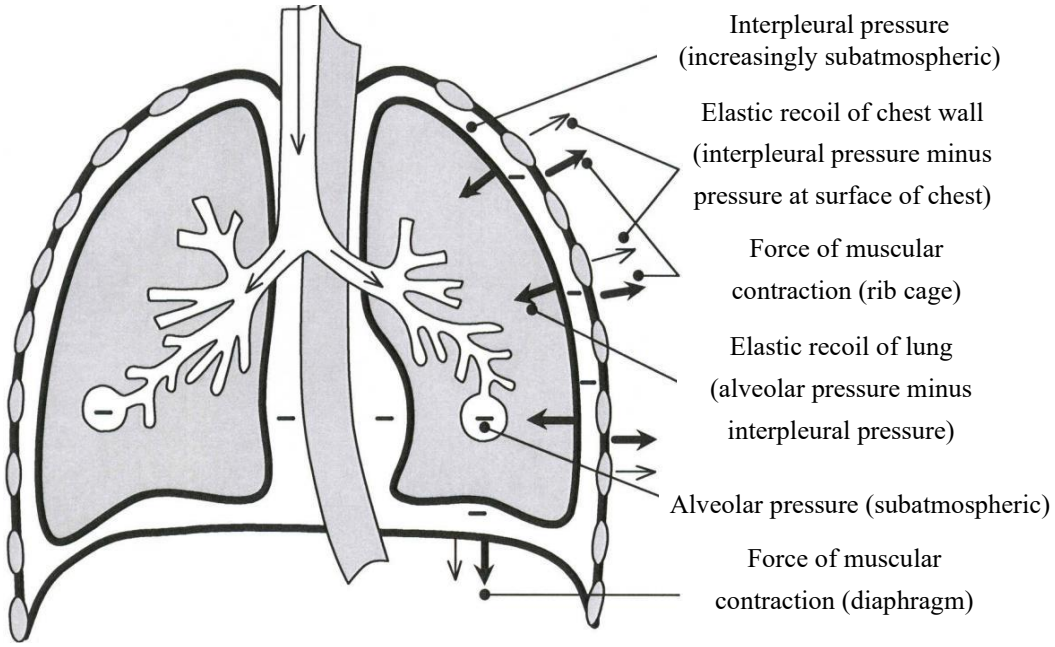

Figure 4. Forces and pressures during inspiration

There are two types of muscle groups: inspiratory muscles and expiratory muscles. The inspiratory muscles include the diaphragm and muscles that lift the ribs upwards, whereas expiratory muscles are those that are involved in moving the ribs downwards as well as the sternum. Each muscle contraction leads to sequential inhalation (inspiration) and exhalation (expiration).

The transportation of air inside and outside the lungs is controlled by the imbalance of pressure across individual lungs. At the end of exhalation, the atmospheric pressure and alveolar pressure become equal; hence, no transportation of air inside or outside the lungs occurs at this point. The contraction of inspiratory muscles (diaphragm and intercostal muscles) causes the thoracic cavity and the lung surface to expand throughout the application of pressure (force) to the lungs. The expansion of the lung surface area takes place as the lungs are acquiescent and liable to be distended. When lungs expand, a negative pressure (approximately -1 cmH_2O) is produced inside the lungs, particularly in the respiratory airways and alveoli. This results in the movement of air from a higher pressure to a lower pressure, which is in accordance with the direction of the pulmonary alveoli. When inhalation ends, neither the chest, lungs, or pulmonary alveoli will enlarge. At the end of inhalation, the atmospheric pressure and alveolar pressure become equivalent, and no transportation of air occurs inside or outside the lungs. However, the lung volume increases at the end of inhalation more than that at the end of exhalation. The chest volume falls during exhalation because the diaphragm relaxes and both the thorax and lungs blench. The decrease in thoracic volume leads to a decrease in pulmonary alveolar volume. This causes the pulmonary alveolar pressure to become higher than the atmospheric pressure by nearly 1 cmH_2O. In that case, the air moves out from the lungs. At the end of expiration, the decrease in thoracic volume maintains, as do the pulmonary alveoli's size changes, and another cycle begins from inhalation.

A reduction in airflow occurs when the resistance to airflow increases under the effect of certain conditions that decrease the radius of pulmonary airways. The resistance to airflow is proportional to the radius (r) of the tube raised to the power of four (r^4) [9]. Hence, any change in the radius (even if small) will lead to a large difference in resistance. This, in turn, eliminates the flow of air.

4. Pulmonary volumes, capacities, and indices

Spirometry is a procedure for estimating the air volume that enters and exits an individual's pulmonary system. A spirometer is a device that measures lung functions. **Figure 5** shows the parameters that reflect pulmonary functions.

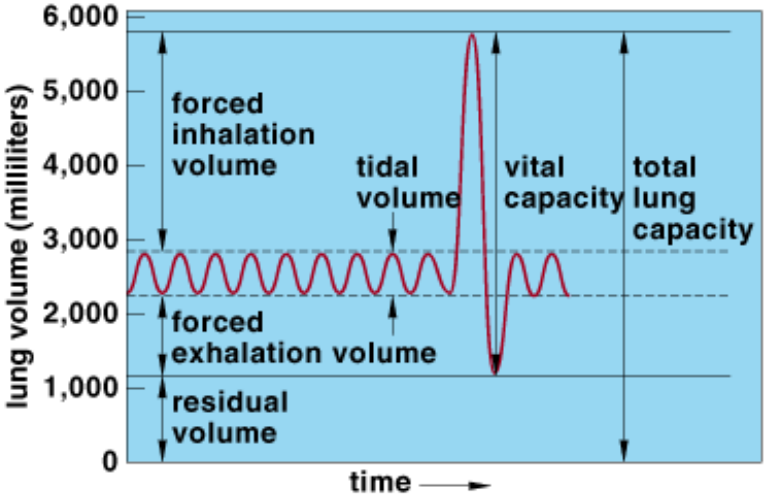

Figure 5. A spirometer trace demonstrating different measures for lung volumes and capacities

There are four standard lung volumes.

(1) Tidal volume (TV) is the volume of air inhaled or exhaled during ordinary breathing.
(2) Inspiratory reserve volume (IRV) is the volume of air that can be inspired during a forceful inhalation after the inhalation of a normal air volume.
(3) Expiratory reserve volume (ERV) is the amount of air that can be expired during a forceful exhalation after the exhalation of a normal air volume.
(4) Reserve volume (RV) is also known as residual volume, which can be defined as the volume of air that continues to exist in the pulmonary airways and in the lungs after maximum exhalation.

Pulmonary capacities can be measured from the sum of two or more respiratory volumes.

(1) Inspiratory capacity (IC) is the sum of TV and IRV, which is the maximum amount of air that an individual can inhale after performing a normal exhalation.
(2) Functional residual capacity (FRC) is the sum of ERV and RV, which is the amount of air that is in the lungs at the end of a normal exhalation.
(3) Vital capacity (VC) is the sum of IRV, TV, and ERV, and it is the largest air volume that an individual can exhale out from his or her lungs after maximum inhalation.
(4) Total lung capacity (TLC) is the sum of IRV, TV, ERV, and RV.

In addition, measuring vital capacity upon applying maximum possible inhalation and exhalation may provide beneficial information. These measurements include forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF), and forced vital capacity (FVC).

(1) Forced expiratory volume in one second (FEV_1) is the volume of air exhaled in the first second upon forced expiratory manoeuvre after maximum inhalation. FEV_1 is considered the most commonly used index for evaluating the state of respiratory airways, including pulmonary obstruction, bronchial constriction, or bronchial dilatation. FEV_1 can be revealed as percentage of forced vital capacity (FVC) and of predicted (% of predicted). It is an ideal approach that can be used for evaluating and determining the degree of airflow limitation. In adults, FEV_1% declines with age, however that does not occur in children or adolescents.
(2) Peak expiratory flow (PEF) is the maximal flow produced during a forceful exhalation, beginning from full lung inflation.
(3) Forced vital capacity (FVC) is the change in lung volumes between a full inhalation to TLC and a maximal exhalation to RV. An estimated FVC is determined during forceful expiration. This test is carried out while measuring FEV_1 and PEF.

5. Minute respiratory volume and alveolar ventilation rate

Minute respiratory volume is defined as the overall amount of air that is transferred inside and outside the pulmonary system per minute. It is a product of multiplying TV with respiratory rate. A resting TV is about 500 ml, while a resting respiratory rate is about 12 breaths per minute. Therefore, the average minute respiratory volume is approximately 6 L/min. Minute respiratory volume does not include the estimation of air volume available for performing gas exchanges occurring in the alveoli, alveolar duct, and bronchioles.

Alveolar ventilation rate (AVR) can be defined as the volume of air ready to be used for gas exchange. It can be measured by using the following equation:

$$AVR = RR\ (TV - DAS)$$

AVR refers to alveolar ventilation rate (ml/min); RR refers to respiratory rate (respiration/min); TV refers to tidal volume (ml/respiration); DAS refers to dead air space (ml/respiration).

Dead air space is approximately 150 ml, thereby the alveolar ventilation rate (AVR) equals to 4.2 L/min.

6. Conclusion

The respiratory system is mainly divided into the upper respiratory tract and lower respiratory tract. Each division has several essential parts, and every part has a distinct role in the respiratory process. The lungs are the cornerstone of the respiratory process owing to their elastic nature, enabling them to freely expand and shrink during inhalation and exhalation with the aid of inspiratory and expiratory muscles. The pressure imbalance essentially controls the regular movement of air inside (inhalation) and outside (exhalation) the lungs. Pulmonary functions can be evaluated using spirometry (spirometer). Spirometry-measured parameters (such as PEF, FEV1, and FVC), in addition to the calculated values of several pulmonary volumes and capacities, are useful tools for determining the lung state and the diagnosis of obstructive pulmonary diseases, including asthma and chronic obstructive pulmonary disease (COPD).

Disclosure statement

The authors declare no conflict of interest.

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