



Pulmonary Anatomy and Physiology

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...Nadine Salmon, MSN, BSN, IBCLC the Clinical Content Manager for RN.com. She is a South African trained Registered Nurse, Midwife and International Board Certified Lactation Consultant. Nadine obtained an MSN at Grand Canyon University, with an emphasis on Nursing Leadership. Her clinical background is in Labor & Delivery and Postpartum nursing, and she has also worked in Medical Surgical Nursing and Home Health. Nadine has work experience in three countries, including the United States, the United Kingdom and South Africa. She worked for the international nurse division of American Mobile Healthcare, prior to joining the Education Team at RN.com. Nadine is the Lead Nurse Planner for RN.com and is responsible for all clinical aspects of course development. She updates course content to current standards, and develops new course materials for RN.com

... Karen Siroky, RN, MSN for updating the course in 2010.

... Lori Constantine MSN, RN, C-FNP, the original author of the course.

Purpose & Objectives

The focus of this pulmonary anatomy and physiology course is to provide information about the structures and functions of the respiratory system. Understanding the fundamental structures and functions of the respiratory system will assist you to provide appropriate care for all patients you encounter and intervene effectively for those with alterations in oxygenation status.

After successful completion of this course, you will be able to:

Identify the functions of anatomical structures within the pulmonary system.

Discuss the process of respiration in terms of ventilation, diffusion, and transport.

Introduction

Understanding pulmonary anatomy and physiology is important and will help you to manage your patient's oxygenation status. This course will review lower and upper pulmonary anatomy, bronchial circulation, and the physiology of gas exchange. These anatomical structures work together to achieve two main goals: delivery of oxygen to cells and removal of carbon dioxide, the waste product of respiration.

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This course will provide you the background knowledge needed to conduct a thorough pulmonary assessment in adult patients. It will provide information on how to identify normal structural and functional processes of the pulmonary system.

Glossary

Alveolar ventilation (V_a) - Is the portion of total ventilation that reaches the alveoli and takes part in gas exchange.

Alveoli - The functional gas exchanging units of the lungs.

Alveoli ducts - Microscopic bronchioles.

Bronchial Tree - Comprises the bronchus and the respective bronchioles.

Compliance - Is a measure of the elasticity of the lungs.

Dead space ventilation (V_d) - Is the volume of inspired air that does not participate in gas exchange.

Diaphragm - Is the major muscle of inspiration.

Diffusion - The actual exchange of oxygen and carbon dioxide across the respiratory membrane.

Expiratory Reserve Volume (ERV) - The volume of air that can be forcefully exhaled beyond normal tidal volume.

Functional Residual Capacity (FRC) - The amount of air remaining in the lungs at the end of quiet exhalation.

Hypoxia - Low amounts of oxygen at the cellular level.

Inspiratory Capacity (IR) - The maximum volume of air that can be inspired after the end of normal, quiet inhalation.

Inspiratory Reserve Volume (IRV) - The volume of air inhaled during maximum inspiration beyond normal tidal volume.

Larynx - Is the voice box and lies just at the upper end of the trachea and the lower end of the laryngopharynx.

Minute Ventilation (V_E) - Total expired volume of air after one minute (equals the V_T times respiratory rate).

Nasal Turbinates - A long, narrow and curled bone shelf which protrudes into the breathing passage of the nose.

Oxyhemoglobin Dissociation Curve - Represents the relationship between arterial oxygen saturation (SaO_2) and dissolved oxygen in the blood (PaO_2).

Pharynx - Starts at the internal nares and extends to the cricoid cartilage, and is subdivided into the nasopharynx, oropharynx, and laryngopharynx.

Pleura - A two-layered protective membrane which surrounds the lungs.

Residual Volume (RV) - The amount of air left in the lungs after a forced expiration.

Respiratory Membrane - The barrier between the incoming air and the blood.

Surfactant - A substance that is responsible for keeping the alveoli open during exhalation, so they do not collapse completely.

Tidal Volume (V_T) - The normal volume of air inhaled or exhaled with each breath.

Total lung ventilation - Is the sum of the alveolar and dead space ventilation.

Trachea - Also known as windpipe, and extends from the larynx to the primary bronchi.

Transport - Refers to the carrying of oxygen and carbon dioxide throughout the circulatory system.

Ventilation - The exchange of air between the atmosphere and the alveoli.

Vital Capacity (VC) - The maximum amount of air that can be exhaled after maximal inspiration.

Pulmonary Anatomy

Upper Respiratory Structures

The upper respiratory structures include the nose and pharynx. The space inside the nose known as the nasal cavity is divided into right and left sides by the nasal septum, a bony, cartilaginous nostrils (Tortora & Derrickson, 2014).

When air first enters the nose, it is filtered, warmed, and humidified by the nasal turbinates in the internal nares. The turbinates are bony, curved structures located within the nose.

The pharynx starts at the internal nares and extends to the cricoid cartilage. The pharynx is usually subdivided into the nasopharynx, oropharynx, and laryngopharynx. The nasopharynx humidifies and filters the air we breathe. Additionally, it helps equalize ear pressure and maintains balance by exchanging air with our eustachian tubes. The oropharynx and laryngopharynx have both digestive and respiratory functions (Tortora & Derrickson, 2014). Our olfactory receptors are also located within the nose and are responsible for our sense of smell.

Pulmonary Anatomy

Lower Respiratory Structures

The lower respiratory structures include the larynx, trachea, bronchi, and lungs. The larynx lies just at the upper end of the trachea and the lower end of the laryngopharynx. The larynx, or voice box, is made of nine cartilages. Three of the largest cartilages of the larynx are the:

Thyroid cartilage, which laypersons may refer to as the Adam's apple

Epiglottis, which prevents food and liquid from entering the trachea

Cricoid cartilage

(Thibodeau & Patton, 2009)

The trachea, or windpipe, extends from the larynx to the primary bronchi (Thibodeau & Patton, 2009).

Pulmonary Anatomy

Lower Respiratory Structures

The trachea is the first in a series of tubes that furnish air to the lungs.

At the lower end of the trachea, there are two primary bronchi. The right is slightly larger than the left. These bronchi enter their corresponding lung, where they branch into secondary and then tertiary bronchi. The tertiary bronchi branch into even smaller airways, the bronchiole or bronchial tree because the primary bronchi and their respective branches resemble an upside down tree.

The bronchiole continue to divide into smaller and smaller tubes called the alveolar ducts and eventually become microscopic. Each duct ends at in two or three alveolar sacs, which then divide into several alveoli. It is at the alveolar level that diffusion of gases occurs (Thibodeau & Patton, 2009).

Pulmonary Anatomy

Lower Respiratory Structures

The alveoli are truly the functional gas exchanging units of the lungs. There are approximately 300 million alveoli in the lungs. This is equivalent to over 900 square feet if opened up and laid out flat (Thibodeau & Patton, 2009).

The walls of the alveoli are extremely thin and lie right next to a bed of capillaries. This barrier between the incoming air and the blood is known as the respiratory membrane. Oxygen travels across this membrane into the bloodstream and carbon dioxide travels from the bloodstream across the membrane and into the alveoli, where it is exhaled.

Within the alveoli is a substance known as surfactant. Surfactant is an important component that is responsible for keeping the alveoli open during exhalation. Surfactant reduces the surface tension of the alveoli, keeping the alveoli open on exhalation and increasing the ability of oxygen and carbon dioxide to cross the respiratory membrane (Thibodeau & Patton, 2009; Tortora and Derrickson, 2014).

The Lungs

The lungs extend from the diaphragm (base) to slightly above the clavicles (apex) and expand through the entire rib cage. The right lung has three lobes and is responsible for about 55% of lung activity. The left lung has two lobes and is responsible for about 45% of lung activity.

The lungs perform two main functions: ventilation and diffusion. Ventilation is the function of both the upper and lower airways. Diffusion is the function of the alveoli and the capillary bed surrounding them.

Test Yourself

Adam's Apple is another term used to describe:

The epiglottis

The cricoid cartilage

The thyroid cartilage – Correct!

The notch in the left lung

The Pleura

The pleura is a two-layered protective membrane which surrounds the lungs. The outer layer, the parietal pleura lines the thoracic cavity and the inner layer, the visceral pleura lines the lungs. The space in between the two pleura is known as the pleural space. This space contains a thin layer of lubricating fluid that allows the lungs to expand smoothly and fully.

The Diaphragm

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Another structure within the thoracic cage is the diaphragm. The diaphragm is a large, dome-shaped muscle located at the base of the lungs. The diaphragm will contract to force air into the lungs and then it relaxes. This is normally an involuntary action but it can also be a controlled, voluntarily action. As a major muscle for inspiration the diaphragm is responsible for about 70% of the tidal volume.

Most of the time other muscles of respiration are not used for gas exchange. When your patient needs more than normal lung volumes or has a respiratory disease process, these muscles, the external and internal intercostal muscles, abdominals, and accessory muscles in the neck, may assist in ventilation (Sherwood, 2012).

Pulmonary & Bronchial Circulation

The lungs receive their blood supply via the pulmonary arteries from the heart and the bronchial arteries that are direct branches off of the aorta (Tortora, 2012; Tortora & Derrickson, 2014). The pulmonary artery brings deoxygenated blood to the lungs. This blood contains high amounts of carbon dioxide. The blood flows into the capillary system that is adjacent to the alveoli. Diffusion causes oxygen (O₂) to move from the lungs into the blood, and carbon dioxide (Co₂) to move from the blood to the lungs for elimination. The oxygenated blood exits the lungs via the pulmonary veins that terminate in the left atrium. The oxygenated blood moves to the left atrium and into the general circulation of the body, for use by tissues around the body.

Pulmonary & Bronchial Circulation

The bronchial arteries supply oxygenated blood to the lung tissue itself, similar to any other arterial system in the body. They supply this oxygenated blood to the bronchi, connective tissue of the lungs, and the lungs themselves. Interestingly, deoxygenated blood is removed via either the bronchial veins or the pulmonary veins.

As mentioned previously, the pulmonary veins generally bring oxygenated blood to the rest of the circulation. But this is mixed with some deoxygenated blood from the bronchial circulation.

The pulmonary circulation is unique in that “oxygenated” blood is carried by veins, as opposed to arteries!

Test Yourself

The pulmonary arteries carry oxygenated blood.

True

False – Correct!

Pulmonary Physiology

A thorough understanding of the anatomy of the pulmonary system is necessary to understand the role and function of the respiratory system, which is the ventilation, diffusion, and transport of gases – primarily oxygen (O₂) and carbon dioxide (Co₂).

Pulmonary Physiology

Ventilation: The actual exchange of air between the atmosphere and the alveoli. Literally, ventilation is the process of breathing oxygenated air into your lungs and exhaling carbon dioxide.

Diffusion: The actual exchange of oxygen and carbon dioxide across the respiratory membrane. Diffusion occurs when the oxygen molecules move from the alveoli into the blood stream and the carbon dioxide molecules move from the blood stream into the alveoli.

Transport: Often forgotten, transport refers to the carrying of oxygen and carbon dioxide throughout the circulatory system. This requires the heart to pump the oxygenated blood out via the aorta, arteries and arterioles. The deoxygenated blood is then returned to the heart via the venules, veins, and the superior and inferior vena cava.

Ventilation: Abbreviations

O₂ – Oxygen

PO₂ - Partial pressure of oxygen

PaO₂ - Partial pressure of arterial oxygen

CO₂ - Carbon Dioxide

PaCO₂ - Partial pressure of arterial carbon dioxide

SaO₂ - Oxygen saturation of arterial blood

pH - Measure of acidity or alkalinity

VA - Alveolar ventilation

VD - Dead space

SpO₂ - Pulse oximetry oxygenation

Breath Sounds

Breath sounds are produced by turbulent air flow. In general, the larger the airway, the louder and more high-pitched the breath sound will be.

Normal breath sounds include:

- Vesicular breath sounds: Low pitched, soft sounds usually heard over most lung fields. Sounds like the rustling of wind in trees.
- Bronchial (tracheal) breath sounds: High pitched, harsh and loud sounds heard over the trachea and larynx. Sounds hollow and tubular.
- Bronchovesicular breath sounds: Moderate, mixed quality sounds heard over the major bronchi where fewer alveoli are located.

Abnormal breath sounds are extra sounds that are referred to as adventitious breath sounds.

(Jarvis, 2012)

Ventilation – Normal Lung Mechanics

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Normally, when the diaphragm contracts, it moves downward, increasing the diameter of the chest and elevating the lower ribs. This action decreases the amount of negative pressure within the pleural space and decreases the amount of negative pressure within the alveoli. This change in pressure results in air being pulled into the lungs. When the lungs are filled with air, the pressures within the lungs are greater than the pressure in the atmosphere, and air is exhaled (Sherwood, 2012). Any condition that alters normal lung mechanics will alter the ventilation capability of the lungs.

Examples include:

- COPD
- Emphysema
- Pneumonia
- Flail chest
- Hemo- or pneumothorax
- Guillian Barre syndrome
- Spinal cord injury

Major Functions of the Respiratory System

There are four main functions of the respiratory system:

1. Supplying oxygen to the body.
2. Removing waste (carbon dioxide) from body tissues
3. Maintaining hemostasis (acid-base balance) of arterial blood
4. Maintaining heat exchange

(Jarvis 2012)

By supplying oxygen to the body and eliminating carbon dioxide from the body, respiration maintains the acid-base balance of the body. When this balance moves out of an acceptable pH range, the lungs can compensate to try to restore the pH balance. Hypoventilation (slow, shallow breathing) can increase carbon dioxide levels in the blood by removing less carbon dioxide than usual. Conversely, hyperventilation (rapid, deep breathing) can cause a shift in blood pH levels by causing more carbon dioxide to be eliminated (Jarvis, 2012).

For a review of respiratory versus metabolic acidosis / alkalosis please review RN.com's course: Interpreting ABGs: The Basics.

Physiology of Ventilation

Any disease process or injury that impacts the lungs could impact one of the above elements of ventilation. The physiology for the lungs is such that compensatory mechanisms (e.g. breathing more rapidly or more deeply) may occur spontaneously or deliberately.

As mentioned previously, much of ventilation occurs spontaneously, through chemoreceptors and stretch receptors that send and receive information from the brain.

Respiratory Receptors

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Chemoreceptors react to the pH of the cerebral spinal fluid (which is impacted by the pH of the blood) and acts upon the respiratory center in the brain to correct the imbalance. If the pH is low (acidosis), the chemoreceptors stimulate the respiratory center to increase the respiratory rate, in an effort to normalize the blood pH. Conversely, if the pH is high (alkalosis), the chemoreceptors will stimulate the respiratory center to decrease the respiratory rate.

Peripheral receptors in the aorta and carotid bodies also respond to changes in pH of the blood, and stimulate the respiratory center.

The stretch receptors of the bronchi and bronchioles react to the physical stretching of the lungs and tell the brain when inflation of the lungs should be stopped. This information is conducted to the pneumotoxic part of the pons. This stimulation of the pons inhibits the respiratory center and prevents the lungs from overinflating and begins the process of exhalation.

Lung Volume Terminology

The following terms summarizes lung volumes and capacities. Deviations from these normal values usually result in a deviation in the lungs ability to ventilate (Sherwood, 2012).

Tidal Volume (VT) - The normal volume of air inhaled or exhaled with each breath. About 500 ml is the normal value in a healthy young male. Comparative value = about 2 cups.

Inspiratory Reserve Volume (IRV) - The volume of air inhaled during maximum inspiration beyond normal tidal volume. About 3,000 ml is the normal value in a healthy young male. Comparative value = 1 and ½ 2 liter bottles of soda.

Inspiratory Capacity (IR) - The maximum volume of air that can be inspired after the end of normal quiet inhalation. About 3,500 ml is the normal value in a healthy young male. Comparative value = Just under 1 gallon.

Expiratory Reserve Volume (ERV) - The volume of air that can be forcefully exhaled beyond normal tidal volume. About 1,000 ml is the normal value in a healthy young male. Comparative value = Approximately 1 quart.

Residual Volume (RV) - The amount of air left in the lungs after a forced exhalation. About 1,200 ml is the normal value in a healthy young male

Functional Residual Capacity (FRC) - The amount of air remaining in the lungs at the end of quiet exhalation. About 2,200 ml is the normal value in a healthy young male. Comparative value = A bit more than a 2 Liter bottle of soda.

Total Lung Capacity (TLC) - The total volume of air in the upper and lower conducting airways and alveoli at the end of maximum inspiration. About 5,700 ml is the normal value in a healthy young male.

The maximum amount of air that can be exhaled after maximal inspiration. About 4,500 ml is the normal value in a healthy young male. Comparative value = About the same as 6 bottles of wine.

Minute Ventilation (VE) - Total expired volume of air after one minute (This equals the VT times respiratory rate). About 6,000 ml is the normal value in a healthy young male.

Diffusion

Diffusion is the second step in the process of respiration. Diffusion refers to the exchange of carbon dioxide and oxygen across the respiratory membrane. Diffusion occurs down a concentration gradient from an area of higher to an area of lower concentration.

During inspiration, the oxygen in the lungs is at high concentration. It moves across the respiratory membrane in the pulmonary arterioles where the oxygen concentration is rather low. At the same time the high concentration of carbon dioxide moves out of the blood and into the lungs.

The newly oxygenated blood is pumped to the left side of the heart and into the general circulation. The air in the lungs, now filled with carbon dioxide, is exhaled, and the process begins again.

Test Yourself:

Diffusion is the movement of molecules from a high to a low concentration.

True – Correct!

False

Transportation

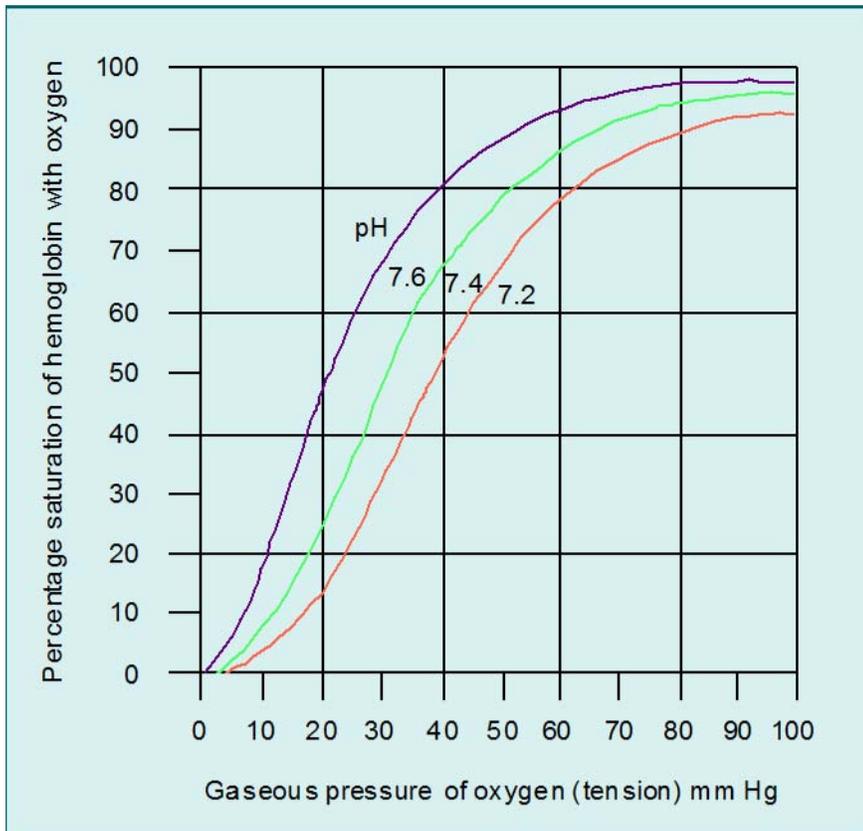
The transport of oxygen and carbon dioxide to the cells is the final step in respiration. Oxygen is transported in the blood in two ways: bound to hemoglobin on the red blood cell and dissolved in the plasma. Hemoglobin binds to dissolved oxygen in the blood, until the molecule is fully saturated, and can be measured by pulse oximetry as the SpO₂.

The remaining oxygen is dissolved in the plasma and can be measured by arterial blood gas sampling (PaO₂). The normal SpO₂ is above 95%. A normal PaO₂ (partial pressure of arterial oxygen) is 80-100mm Hg (mercury).

Oxyhemoglobin Dissociation Curve

The oxyhemoglobin dissociation curve is a fundamental concept in understanding how oxygenation occurs. As the amount of oxygen in the atmosphere (or to the patient through supplying external oxygen) increases the PaO₂ will increase- but only up to a certain point. Generally at about 60% oxygen, the curve flattens out and there is relatively little change in the oxygen saturation.

Also, the predictability of the curve relies on the patient being normothermic, and the pH being within the normal range. When either of these factors is impacted, the oxyhemoglobin dissociation curve is impacted and an increase in oxygen will not affect the oxygenation of the blood in the same fashion.



Elimination of Carbon Dioxide

The second key part of transport is the elimination of carbon dioxide, the product of cellular waste. It is transported in the blood in three ways:

- It can be dissolved in the plasma and is reflected in the arterial blood gas as the PaCO_2 (normal values are 35-45 mm Hg).
- It can be combined with the hemoglobin molecule.
- It is carried in the form of bicarbonate. In normal respiration CO_2 eventually reaches the alveolar-capillary bed where it is released from the hemoglobin molecule, diffused across the respiratory membrane into the alveoli, and finally exhaled.

Elimination of Carbon Dioxide

Although we normally think of the lungs as being critical in oxygenating the cells of the body, the elimination of carbon dioxide is critical to the pH, a measure of how acid or how alkaline the blood is.

The normal pH of the blood is 7.35-7.45. When the pH is normal, along with normal oxygen levels, the respiratory system is functioning at its normal, base capacity, keeping our tissues well oxygenated and removing the waste products of the cells adequately.

Conclusion

A thorough knowledge of pulmonary anatomy and physiology is essential to healthcare providers to effectively evaluate and care for patients.

Although the pulmonary system and its physiological processes can be complex, they clearly impact other parts of the body, and are critical to the function of all body parts.

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Note: All dosages given are for adults unless otherwise stated. The information on medications contained in this course is not meant to be prescriptive or all-encompassing. You are encouraged to consult with physicians and pharmacists about all medication issues for your patients.

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