CHAPTER-3

Embryonic development of the Respiratory System

Objectives

A. To understand the basic principles of embryological development of the respiratory system.

B. To know the innervation of the different parts of the respiratory tree.

C. To know the common pathologies of the respiratory system and how these affect the newborn.

Early Embryonic Development of the Respiratory System

Around the fourth week the respiratory system develops from an outgrowth of the ventral wall of the foregut. Therefore the epithelium of the internal lining of the larynx, the trachea, and bronchi as well as the lungs is entirely of endodermal origin. The cartilaginous and muscular components are derived from splanchnic mesoderm surrounding the foregut.

As discussed earlier (study guide 9) the respiratory diverticulum is in wide open communication with the oesophagus. As the respiratory diverticulum expands in a caudal direction it become separated from the foregut. The respiratory primordium, however, maintains its open communication with the pharynx through the laryngeal orifice.

Larynx

The internal lining of the larynx (voice box) is of endodermal origin. The cartilages and muscles originate from mesenchyme of the fourth and sixth branchial arches. Later on the mesenchyme of the two arches is transformed into the thyroid, cricoid and arytenoid cartilages. Since the musculature of the larynx is derived from mesenchyme of the fourth and sixth branchial arches, or laryngeal muscles are innervated by branches of the **X** (10^{th}) cranial nerve (the vagus nerve). The superior laryngeal nerve innervates derivatives of the fourth branchial arch and the recurrent laryngeal nerve derivatives of the sixth branchial arch. (Further details on the laryngeal arches/cartilages will be covered in a later study guide.)

The Trachea, Bronchi and Lungs

The two lungs are formed from two outpockets at the caudal end of the trachea known as the lung buds. The right lung bud first develops into the right primary bronchus and then into three lobar bronchi and the left principal bronchus into two lobar bronchi. The mesoderm which covers the outside of the lungs develops into the visceral pleura. The somatic mesoderm layer, covering the body wall from the inside, becomes the parietal pleura. The space between the parietal and visceral pleurae is the pleural cavity.

During development the main bronchi divide repeatedly in a dichotomous fashion and by the end of the 6th month approximately 17 generations of subdivisions have been formed. The last 6 divisions will be formed in post natal life (full maturation by the 8th year).

Maturation of the Lungs

At approximately the 7th month some of the cells of the cuboidal type lining the respiratory bronchi change into thin flat (epithelial) cells and their vascular supply increases steadily. In addition to blood vessels, lymph capillaries also invade and the surrounded spaces form terminal sacs or primitive alveoli. It is during this phase of development when sufficient capillaries are present to guarantee adequate gas exchange, that the premature infant is able to survive. At the end of the 6th month specialised cells called the alveolar epithelial cells produce a thin phospholipid layer of mucus which acts as a surfactant which lowers surface tension in the alveoli. This is essential in the early days of the infant as without it the alveoli would collapse during expiration (atelectasis).

CLINICAL NOTES

Tracheoesophageal Fistula

A tracheoesophageal fistula is an abnormal communication between the trachea and esophagus caused by a malformation of the tracheoesophageal septum. This condition results in gagging and cyanosis after feeding, abdominal distention after crying and reflux of the gastric contents into the lungs.

Respiratory Distress Syndrome

This is caused by a deficiency of surfactant. This condition is most common in premature infants, those born to diabetic mothers, and those experiencing prolonged intrauterine asphyxia. Treatment with thyroxine and cortisol can increase the production of surfactant.

Pulmonary Hypoplasia

This occurs when lung development is stunted. Congenital diaphragmatic hernia (herniation of the abdominal contents into the thorax leads to compression of the lung) and bilateral renal agenesis (oligohydramnios increases the pressure on the foetal thorax) are predisposing factors.

Congenital Cysts of the Lungs

These are formed by dilatation of the terminal or larger bronchi. If the cysts are multiple, when x-rayed they give the appearance of honeycomb. Since these cystic structures of the lungs are poorly drained they frequently cause chronic infections.

SELF ASSESSMENT QUESTIONS

1. Which components of the respiratory system are formed from mesoderm and which from endoderm.

2. Which parts of the respiratory system are supplied by the 10th cranial nerve

3. What is the purpose of the surfactant phospholipid substance secreted in the alveoli

4. What causes Respiratory Distress Syndrome in the neonate

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SECTION-B

Anatomy and physiology

of the

The Respiratory System

Overview of the Respiratory System

The cardiovascular and respiratory systems are intimately involved. Cells continually use oxygen for their metabolic purposes, in order release energy from the nutrients. These reactions result in the release of carbon dioxide, which converts to cytotoxic (cell toxic) carbonic acid. The respiratory system delivers oxygen to the red blood cells in the blood, which in turn delivers oxygen to the cells of the body. The circulatory system returns carbon dioxide to the lungs, which eliminate this gas to the atmosphere. This contributes towards the maintenance of homeostasis within the body.
The respiratory system is also involved in communication through vocalisation.

Learning Outcomes:

The student should be able to:

- Relate how the cardiovascular system is linked to the respiratory system
- Describe the process of gas exchange
- Identify the organs of respiration
- Describe the structure and function of the components of the respiratory tract
- Identify the muscles of respiration
- Identify the external landmarks of the lungs
- Describe the anatomy of the lung tissue
- Describe the blood supply to the lungs, and the relationship of the pulmonary circulation to that of the heart

The Organs of Respiration

The upper respiratory tract

- The nose
- The pharynx

The lower respiratory tract

- The larynx
- The trachea

- Two bronchi (singular bronchus to each lung)- which divide to become bronchioles, bronchioli, alveolar ducts, and alveoli within the lungs
- The muscles of respiration- the diaphragm and intercostal (inter= between, costal= ribs) muscles

The Nose and Sinuses

These structures are lined with a vascular mucous membrane of ciliated columnar epithelium.
Pairs of paranasal sinuses open into the nasal cavity and are lined with a mucous membrane continuous from the nasal cavity. The sinuses are cavities within the cranium, which function to reduce the weight of the cranium, and to add resonance to our vocal sounds. Sinusitis occurs with an allergic reaction or infection, when the mucous membrane become inflamed, and blocks the drainage to the nasal cavity. In this case, pressure builds up, resulting in 'sinus headaches'.

The sinuses are the **maxillary** sinuses, **frontal** sinuses, **sphenoidal** sinuses, **mastoid** sinuses, and **ethmoid** sinuses- named after the cranial bones surrounding them.

The nose functions to warm and moisten the atmospheric air, and filters particles through trapping within the nasal hairs or through the sticky mucous. The nose is the organ of olfaction (smell). Nerve endings in the roof of the nose lead directly to the brain where the sensation of smell is perceived. The olfactory nerve passes through the limbic system of the brain, which is associated with emotional response. This mechanism can be used therapeutically to affect the mood of patients through the use of substances such as essential oils.

The Pharynx

The pharynx is a passage, which extends from the nasal cavity to the level of the 6th cervical vertebra. At this level it becomes differentiated into the **oesophagus** (for swallowing food) and the **trachea** (the major air passage). The pharynx is lined with a mucous membrane, which differs depending on the region of the pharynx it is lining.

The pharynx is divided into three parts:
1) The uppermost region is the **nasopharynx**, housing the opening to the auditory (Eustatian) tube, and the pharyngeal tonsils. Lined with ciliated columnar epithelium.
2) The **oropharynx** lies behind the mouth, and extends to the level of the 3rd cervical vertebra. This region bears the palatine tonsil, and the uvula, which separates the oral pharynx from the nasal pharynx during swallowing. Lined with stratified columnar epithelium, which serves to protect the pharynx from the passage of rough or hot food particles.
3) The **laryngopharynx** continues from the oropharynx to become the oesophagus at the level of the 6th cervical vertebra.

The functions of the pharynx:

- Passage for food and air.
- Warms and moistens the air
- Involved in taste
- Hearing
- Protection from the lymphoid tissues in the tonsils.

The Larynx

This is the voice box or 'Adam's apple' of the throat. It is made up of several cartilage structures, ligaments and the hyoid bone. Within the larynx are the vocal cords, which are made up of mucous membrane.

The Trachea

The trachea is the major airway passage, and extends from the larynx to the level of the 5th thoracic vertebra, where it bifurcates into the right and left **bronchi**. The trachea lies anterior to the oesophagus, and posterior to the thymus gland. It is composed of 16 to 20 C-shaped hyaline cartilage rings, which hold the airway open. These rings are joined by connective tissue and smooth muscle in three layers.

1) **The inner layer** is made up of ciliated columnar epithelium, containing mucous secreting goblet cells. The cilia form the muco-ciliary escalator, beating upwards and aiding the expectoration or swallowing of mucous, thus keeping the lungs clear.
2) **The middle layer** is made up of the cartilage rings and bands of smooth muscle. There are also some blood and lymph vessels, autonomic nerves and areolar connective tissue.
3) **The outer layer** is made up of fibrous and elastic tissue, enclosing the cartilage, which function to prevent collapse and subsequent obstruction to the air-passage.

The Bronchi

The bronchial tree is the colloquial term referring to the divisions of the respiratory tract from the largest structure, the trachea, down to the smallest structures, the alveoli (sing. alveolus).
The bronchi continue to divide into smaller passages known as bronchioles. At the level of the bronchioles, the cartilage rings are absent, but the walls become thicker and responsive to autonomic nervous impulses. The ciliated mucous membrane changes to become cuboidal epithelium. The right lung has three branches as it is made up of 3 lobes. The left lung has only two branches, as there are 2 lobes allowing for the space occupied by the heart in the thoracic cavity.
The bronchioles divide into terminal bronchioles, respiratory bronchioles, alveolar ducts and alveoli. The alveoli walls are composed of simple squamous epithelium, with some elastic and reticular fibres. They are richly surrounded by capillaries, which are fused to the walls of the alveoli. Oxygen and carbon dioxide rapidly diffuse through these walls.

The Lungs

The lungs lie protected by the ribs, within the thoracic cavity, on either side of the **mediastinum**. Their superior border (the **apex**) is slightly superior to the clavicle, and their inferior border (at the **base** of the lung) lies on the diaphragm. The inferior borders of the lungs lie at the level of the 6th costal cartilage anteriorly, and the 10th thoracic cartilage posteriorly. The medial borders, which 'face' the heart, have a depression known as the **hilum**, through which the bronchi, blood and lymphatic vessels, and nerves enter and leave the lungs. Attached to the ribs are the internal and external intercostal muscles, which contribute to the mechanism of breathing.

Pleura

Surrounding the lungs are the pleura. The pleura, is a closed sac of serous membrane, and is made up of two layers.

1. The visceral pleura, adheres closely to the body of the lung.
2. The parietal pleura, adheres to the inside of the thoracic cavity and the diaphragm.

These two layers are not separated, but are the result of an invagination of one layer. Between these layers is a potential space, referred to as the pleural cavity. Within the pleural cavity is a film of serous fluid (pleural fluid), which functions to allow the surfaces to glide over each other, and at the same time to remain closely adherent to each other, similar to the way two plates of glass with a film of water between them would behave. The pleural fluid acts as lubrication allowing the two surfaces slide to over each other during inhalation and exhalation.

Lobes

The right lung is divided by the horizontal and oblique fissure into three lobes, whilst the left lobe is only divided into two lobes by the oblique fissure (Bear in mind the space occupied by the heart on the left side). The lobes are supplied by a secondary or lobar bronchus.

Each lobe is further divided into ten bronchopulmonary segments, which are supplied by the tertiary or segmental bronchi and a segmental artery, and is drained by segmental veins and lymphatics.

The bronchopulmonary segment is made up of many smaller areas known as lobules. Each lobule contains a lymphatic vessel, arteriole and venule, plus a branch of a terminal bronchiole. The terminal bronchiole has no cartilage, but is supported by smooth muscle.

Terminal bronchioles divide into respiratory bronchioles, made up of smooth muscle and simple squamous epithelium. These passages house the occasional alveolar sac on their walls. Alveolar sacs become more numerous as the respiratory bronchioles subdivide further into alveolar ducts. The **alveolar duct** supports numerous **alveoli** within the **alveolar sacs**.

Alveoli

Alveoli walls are made up of two types of alveolar epithelial cells:

1) Type I alveolar cells – simple squamous epithelial cells
2) Type II alveolar cells (septal cells) – made up of cuboidal epithelial cells with microvilli, which secrete alveolar fluid. (surfactant).

The many divisions of the lung tissue allow an enormous amount of space to be contained within the relatively limited area of the thoracic cavity. This large surface area is necessary for the diffusion and exchange of gasses in and out of the blood. The alveolar sacs are richly supplied with blood capillaries for this reason. The respiratory membrane separating the blood capillaries and the air in the alveolar sac is very thin to allow for the rapid diffusion of gasses across.
The respiratory membrane between capillary and alveolus is the site where the diffusion of gasses occurs. It is made up of:

a) The alveolar wall (with alveolar macrophages)
b) An epithelial basement membrane beneath the alveolar wall.
c) A capillary basement membrane
d) The endothelial cells of the capillary.

The process of gas exchange is composed of three basic steps:

1) **Pulmonary ventilation** – the mechanical flow of air into (inspiration) and out of (expiration) the lungs.
2) **External respiration** – the exchange of gases between the air spaces of the lungs (the alveoli) and blood in the pulmonary capillaries.
3) **Internal respiration** – the exchange of gasses between blood in systemic capillaries and tissue cells. The blood loses oxygen, and gains carbon dioxide.
   Cellular respiration is the metabolic process producing ATP through the consumption of oxygen and the release of carbon dioxide.

Respiration (Breathing)

Inspiration occurs as a result of the change in air pressure when the intercostal and diaphragmatic muscles contract and expand the thoracic cavity. This pulls on the parietal pleura, which is attached to the thoracic wall. The fluid between the parietal and visceral pleura, allows the two membranes to slide over each other, but maintains their proximity to each other. Thus, the visceral pleura and the lungs are expanded with the thoracic walls. The drop in alveolar pressure below that of atmospheric pressure enables air to rush into the lungs. This process is active.
Expiration is passive, and occurs as a result of elastic recoil. The muscles relax, and recoil takes place as the result of the elastic fibres within the muscles to recoil, as well as the effect of the surface tension of the alveolar fluid. There are muscles of expiration, and these are used for example, during sneezing or exercise. These muscles include the abdominal muscles and the internal intercostals.

Blood supply to the lungs

Two sets of blood vessels:

1) **The Pulmonary arteries**: Deoxygenated blood from the pulmonary trunk divides into the left and right pulmonary artery to feed into the lungs, where the exchange of gasses occurs. Oxygenated blood is returned to the left atrium of the heart via the pulmonary veins.

2) **The Bronchial arteries**: Exit from the aorta to the lungs. These arterioles supply oxygenated blood to the walls of the bronchi and bronchioles. Most of the blood returns to the heart via the pulmonary veins, however, some blood drain into the bronchial veins, and from there into the azygos system, which returns to the heart via the superior vena cava.

The respiratory system

SELF ASSESSMENT QUESTIONS

Question 1:
Describe the structure and function of the different parts of the respiratory tract starting from the nose and mouth and finish at the alveoli.

Question 12:
Please differentiate between the structural lining of Type I and type II alveolar cells.

Question 3:
a) Where is surfacent derived from?
b) What is the function of surfacent?

Question 4:
Describe the divisions of the lungs, and name the airways (from the trachea) passages feeding into these divisions.

Question 5:
Describe the mechanisms involved in inspiration?

Question 6:
Write short notes on the mechanism of breathing involving the intercostal muscles and the diaphragm.

Question 7:
Describe the mucociliary escalator.

Question 8:
Draw a diagram to illustrate the bronchial tree.

Question 9:
Name the bones of the skull which contain the air sinus cavities.

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