

# SH Lecture - Respiratory System Development

## Introduction

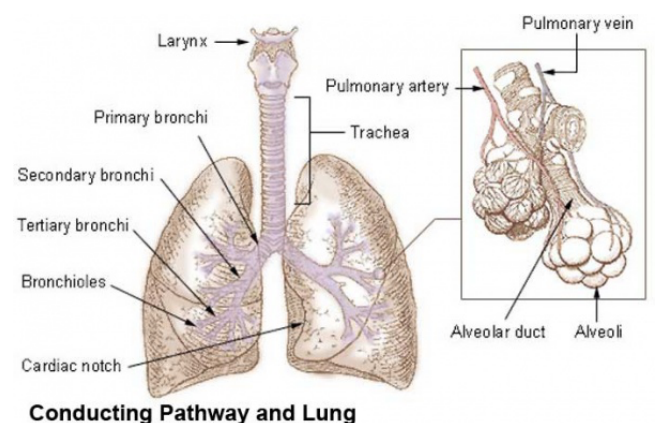
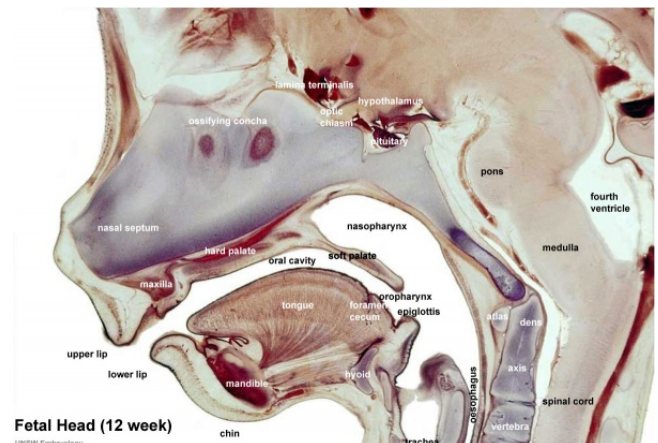
*Current research suggests that both genetic and the developmental environment (fetal and postnatal) can influence the growth, differentiation and function of the respiratory system.*

**Lecture:** [2017](#) | [2017 PDF](#) | [2016](#) | [2016 PDF](#) | [2015](#) | [2015 PDF](#) | [2014](#) | [Lecture 2014 PDF](#) | [2013 PDF](#) | [2013](#) | [2012](#) | [2012 PDF \(10 pages\)](#) | [eMed Link to Learning Activity - Respiratory System Development](#)

**SH Links:** [Lymphatic Lecture](#) | [Lymphatics Practical Support](#) | [Respiratory Lecture](#) | [Respiratory Practical Support](#) | [Medicine](#)

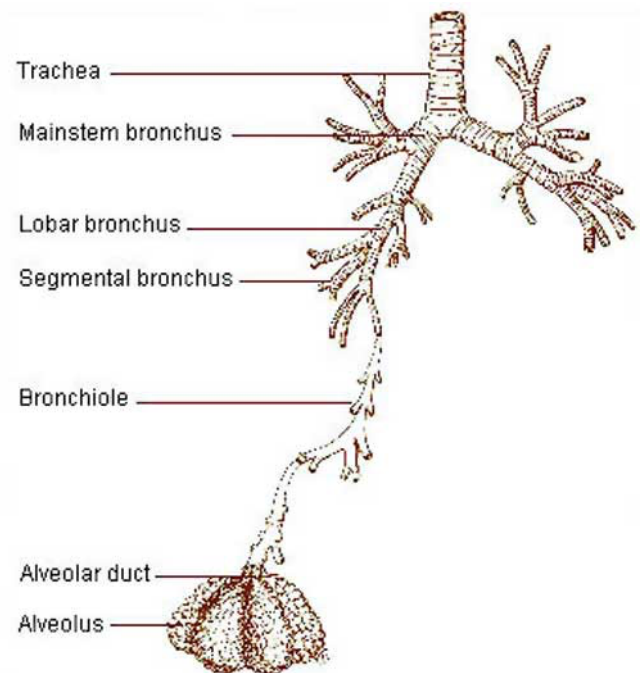
The respiratory system does not carry out its physiological function (of gas exchange) until after birth, though the respiratory tract, diaphragm and lungs do begin to form early in embryonic development and continue through fetal development, only functionally maturing just before birth. The lungs continue to grow postnatally through childhood and some research finding suggest that there remains potential for growth in the adult.

The respiratory tract is divided anatomically into 2 main parts:



1. **upper respiratory tract** - consisting of the nose, nasal cavity and the pharynx.
2. **lower respiratory tract** - consisting of the larynx, trachea, bronchi and the lungs.

The respiratory "system" usually includes descriptions of not only the functional development of the lungs, but also related musculoskeletal (diaphragm) and vascular (pulmonary) development.



## Aim

To understand the prenatal and postnatal developmental anatomy of human respiratory organs.

### Textbooks

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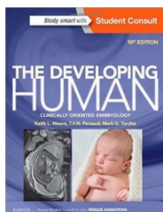


Hill, M.A. (2018). *UNSW Embryology* (18th ed.) Retrieved March 2, 2018, from <https://embryology.med.unsw.edu.au>

**Respiratory Links:** [Introduction](#) | [Science Lecture](#) | [Lecture Movie](#) | **Med Lecture** | [Stage 13](#) | [Stage 22](#) | [Upper Respiratory Tract](#) | [Diaphragm](#) | [Histology](#) | [Postnatal](#) | [Abnormalities](#) | [Respiratory Quiz](#) | [Respiratory terms](#) | [Category:Respiratory](#)

**Historic Embryology**

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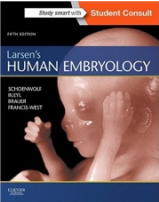


Moore, K.L., Persaud, T.V.N. & Torchia, M.G. (2015). *The developing human: clinically oriented embryology* (10th ed.). Philadelphia: Saunders.

- Chapter 10 [Respiratory System](#)
- Chapter 8 [Body Cavities and Diaphragm](#)
- Chapter 9 [Pharyngeal Apparatus, Face, and Neck](#)

## Key Concepts

1. upper and lower respiratory tract.
2. Embryonic origin of respiratory components (tract, lungs,

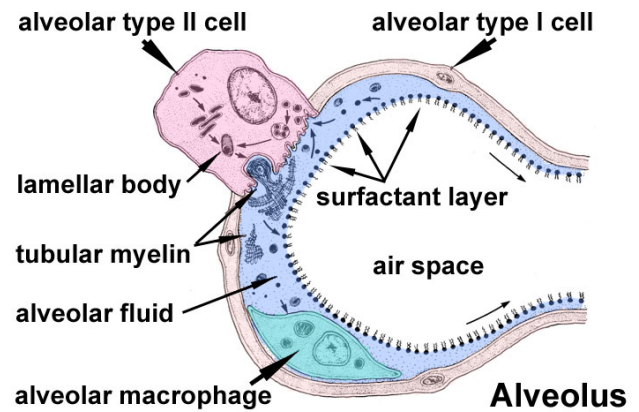
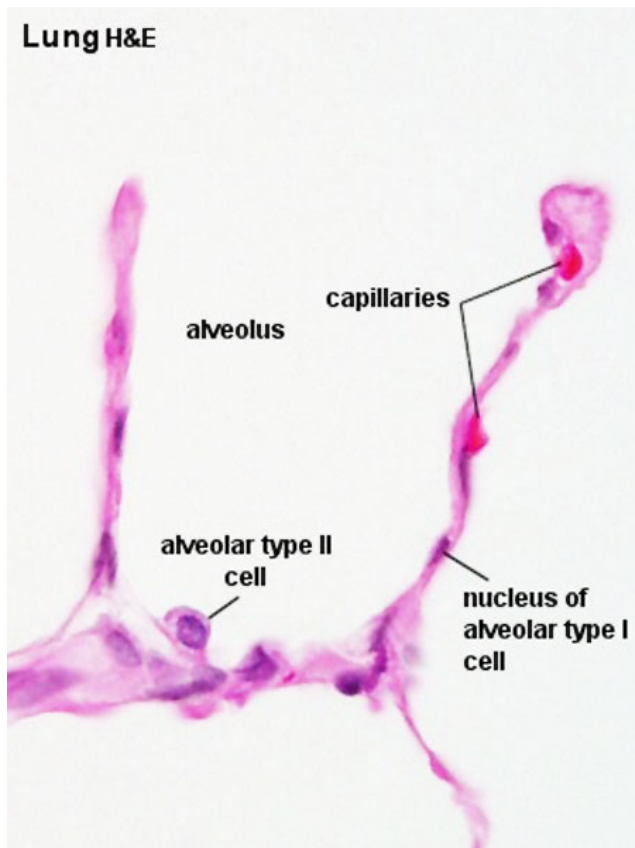
	<p>Schoenwolf, G.C., Bleyl, S.B., Brauer, P.R., Francis-West, P.H. &amp; Philippa H. (2015). <i>Larsen's human embryology</i> (5th ed.). New York; Edinburgh: Churchill Livingstone.</p> <ul style="list-style-type: none"> <li>Chapter 11 <a href="#">Development of the Respiratory System and Body Cavities</a></li> </ul>	
Additional Textbooks	<ul style="list-style-type: none"> <li>Histology and cell biology: An introduction to pathology <a href="#">Chapter 13. Respiratory System</a></li> <li>Developmental Biology 8e Online <a href="#">Lung Branching Morphogenesis</a></li> <li>Before We Are Born (5th ed.) Moore and Persaud Chapter 13 p255-287</li> <li>Essentials of Human Embryology Larson Chapter 9 p123-146</li> <li>Human Embryology Fitzgerald and Fitzgerald Chapter 19, 20 p119-123</li> </ul>	
Review article	<ul style="list-style-type: none"> <li>2017 [www.lungmap.net LungMAP]: The Molecular Atlas of Lung Development Program.<sup>[1]</sup></li> <li>2017 Development of the lung.<sup>[2]</sup></li> <li>2017 Developmental pathways in lung regeneration.<sup>[3]</sup></li> <li>2017 In utero alcohol effects on foetal, neonatal and childhood lung disease.<sup>[4]</sup></li> <li>2014 Lung development: orchestrating the generation and regeneration of a complex organ.<sup>[5]</sup></li> </ul>	<p>diaphragm, muscles).</p> <ol style="list-style-type: none"> <li>3. Key stages in respiratory development.</li> <li>4. Time course of respiratory development.</li> <li>5. Respiration at birth.</li> <li>6. Postnatal development of respiration.</li> <li>7. Developmental abnormalities.</li> </ol>

## Respiratory Functional Unit

### Alveolus

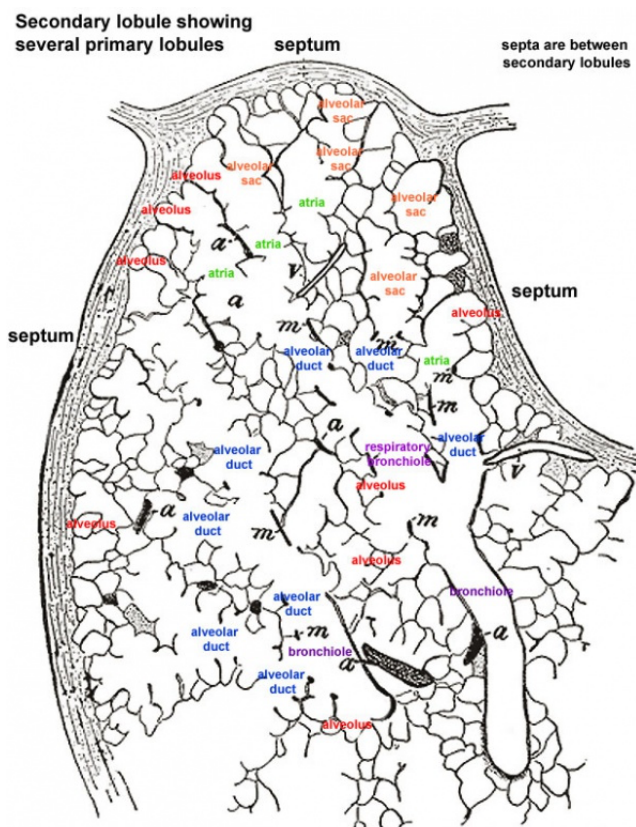
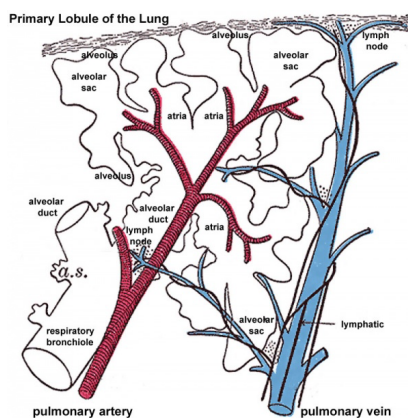
**Alveolus** (Latin *alveolus* = "little cavity", plural is alveoli)

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### Alveolus histology

### Alveolus structure



### Primary Lobule

### Secondary Lobule



- region supplied by a **respiratory bronchiole**

- region supplied by a **terminal bronchiole**
- size - up to 2.5 cm across.
- connective tissue - bounded by fibrous (interlobular) septa and containing internal (interlobular) septa.
- lobule contains a up to 12 acini and 30 - 50 primary lobules.
- blood supply - pulmonary artery branch
- blood drainage - pulmonary veins located at lobule periphery leave through the interlobular septa.
- lymphatics - arterial and interlobular septa associated (drain to subpleural plexus).

## Developmental Overview

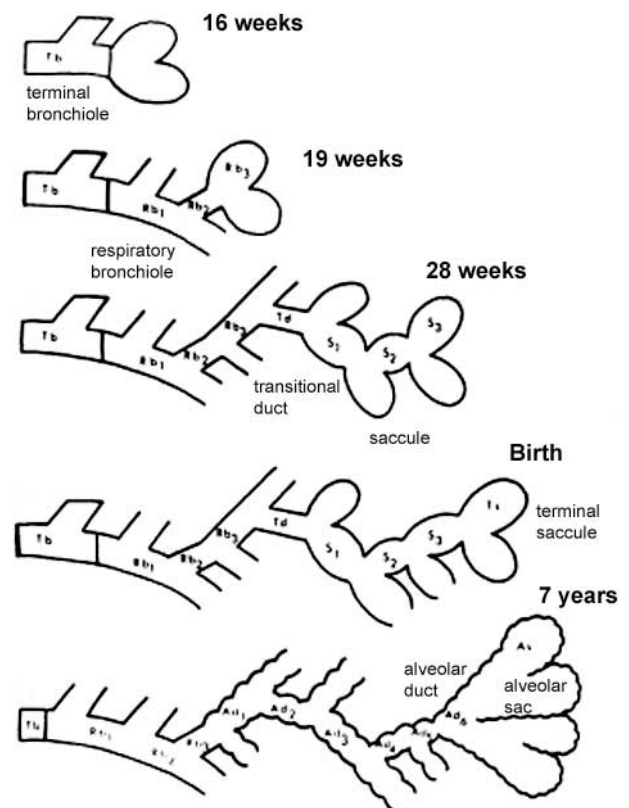
### Germ Layers

- Endoderm and splanchnic mesoderm form majority of conducting and alveoli.
- Ectoderm will contribute the neural innervation.
- Mesoderm also contributes the supporting musculoskeletal components.

**Week 4** - laryngotracheal groove forms on floor foregut.

**Week 5** - left and right lung buds push into the pericardioperitoneal canals (primordia of pleural cavity)

**Week 6** - descent of heart and lungs into thorax. Pleuroperitoneal foramen closes.



Modified from Dilly SA. Thorax. 1984 Oct;39(10):733-42. PMID: 6495241

**Week 7** - enlargement of liver stops descent of heart and lungs.

**Month 3-6** - lungs appear glandular, end month 6 alveolar cells type 2 appear and begin to secrete surfactant.

**Month 7** - respiratory bronchioles proliferate and end in alveolar ducts and sacs.

## Development Stages

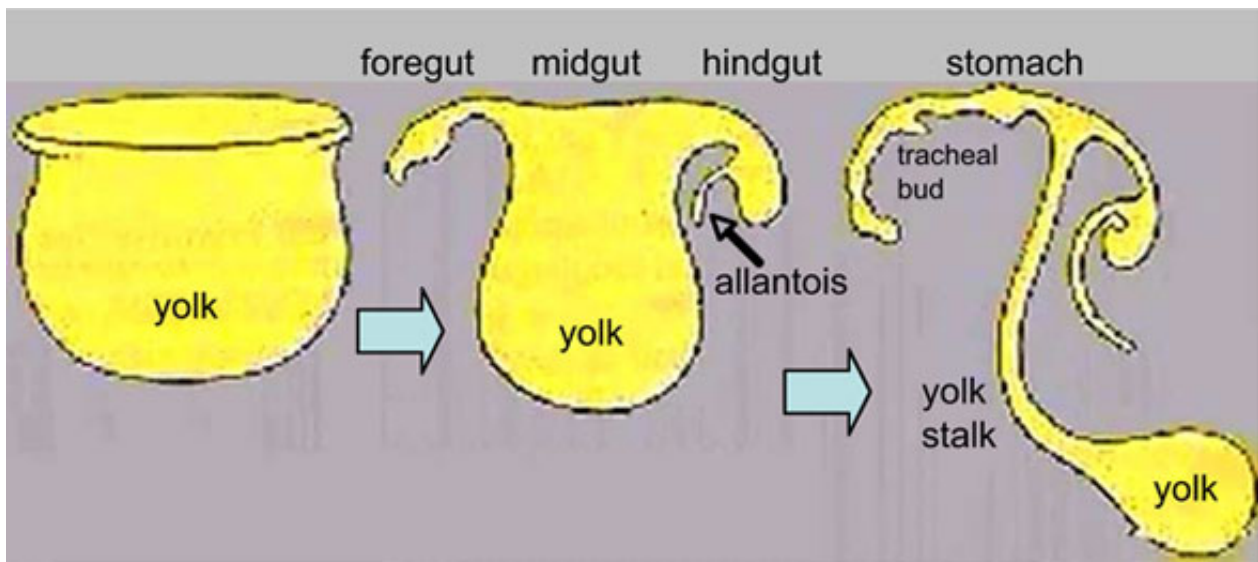
Note - the sequence is important rather than the actual timing, which is variable in the existing literature.

### Human Lung Stages

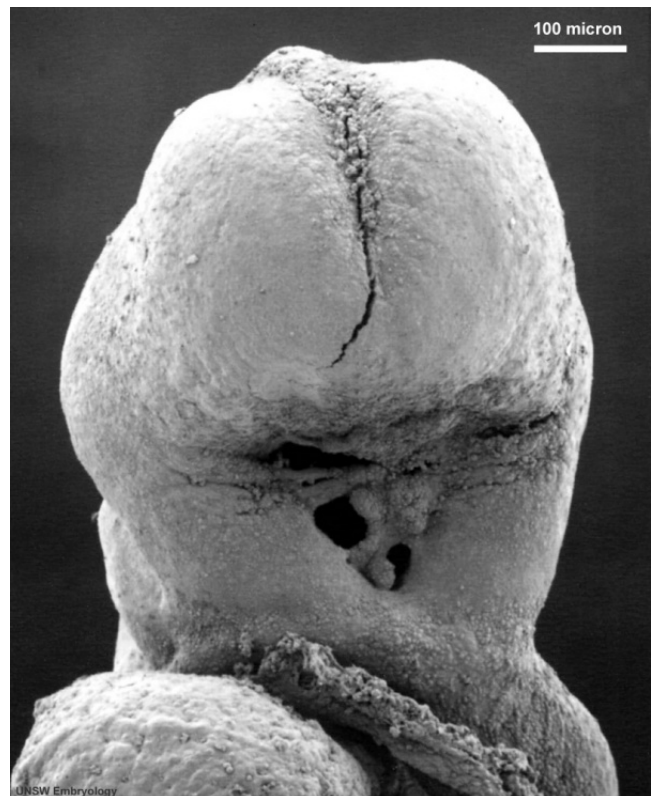
Stage	Human	Features
Embryonic	week 4 to 5	lung buds originate as an outgrowth from the ventral wall of the foregut where lobar division occurs
Pseudoglandular	week 5 to 17	conducting epithelial tubes surrounded by thick mesenchyme are formed, extensive airway branching
Canalicular	week 16 to 25	bronchioles are produced, increasing number of capillaries in close contact with cuboidal epithelium and the beginning of alveolar epithelium development
Saccular	week 24 to 40	alveolar ducts and air sacs are developed
Alveolar	late fetal to 8 years	secondary septation occurs, marked increase of the number and size of capillaries and alveoli

### Embryonic

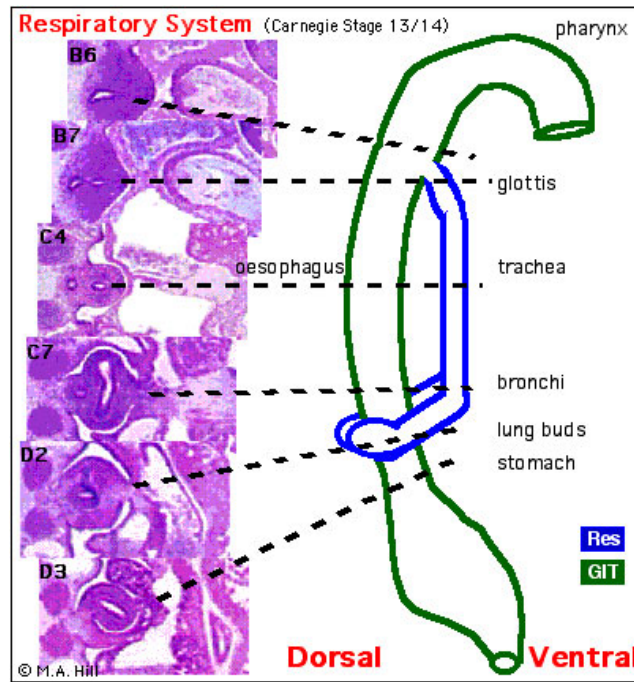
Week 4 to 5 - lung buds originate as an outgrowth from the ventral wall of the foregut where lobar division occurs.



Stomodeum (Week 4, stage 11)



Buccopharyngeal membrane (Week 4, stage 11)



(Week 5, stage 14)

- **week 4 - 5**
- Endoderm - tubular ventral growth from foregut pharynx.
- Mesoderm - mesenchyme of lung buds.
- Intraembryonic coelom - pleural cavities elongated spaces connecting pericardial and peritoneal spaces.

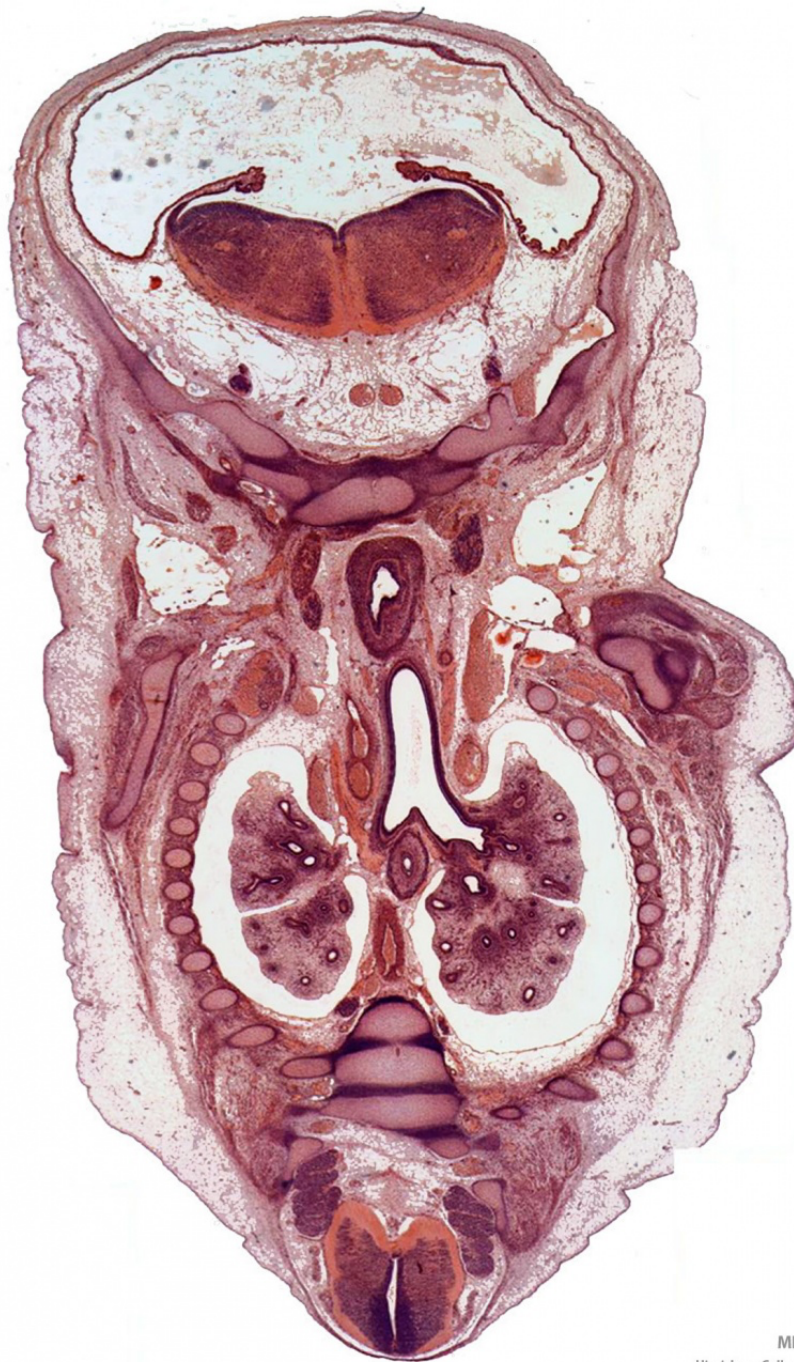
### Stage 13 - Trachea and Lung buds

### **Pseudoglandular stage**

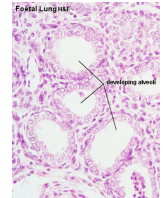
- **week 5 - 17**
- tubular branching of the human lung airways continues
- by 2 months all segmental bronchi are present.
- lungs have appearance of a glandlike structure.
- stage is critical for the formation of all conducting airways.
  - lined with **tall columnar epithelium**
  - more distal structures are lined with **cuboidal epithelium**.
- Pulmonary neuroendocrine cells (PNECs) - develop in late embryonic to early fetal period, later in mid-fetal period clusters of these cells form neuroepithelial bodies (NEBs) in airway epithelium. May stimulate mitosis to increase branching, secrete



2 peptides - gastrin-releasing peptide (GRP) and calcitonin gene related peptide (CGRP)



ME 54  
Hinrichsen Collection



Fetal  
lung  
histology

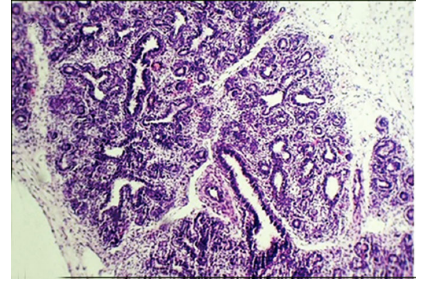
Week 8

(This is what a gland looks like.)

## Canalicular stage

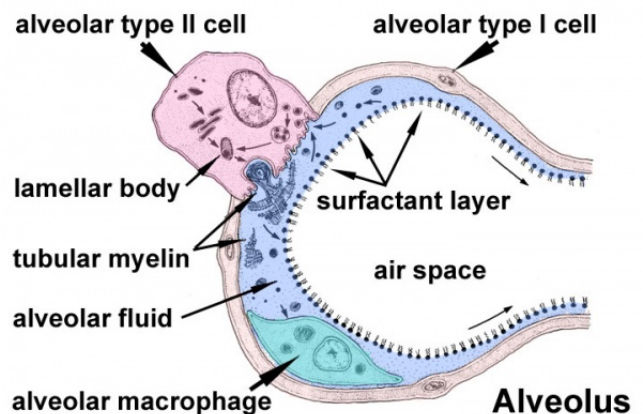
- week 16 - 24
- Lung morphology changes dramatically

- differentiation of the pulmonary epithelium results in the formation of the future air-blood tissue barrier.
- **Surfactant** synthesis and the canalization of the lung parenchyma by capillaries begin.
- future gas exchange regions can be distinguished from the future conducting airways of the lungs.



## Saccular stage

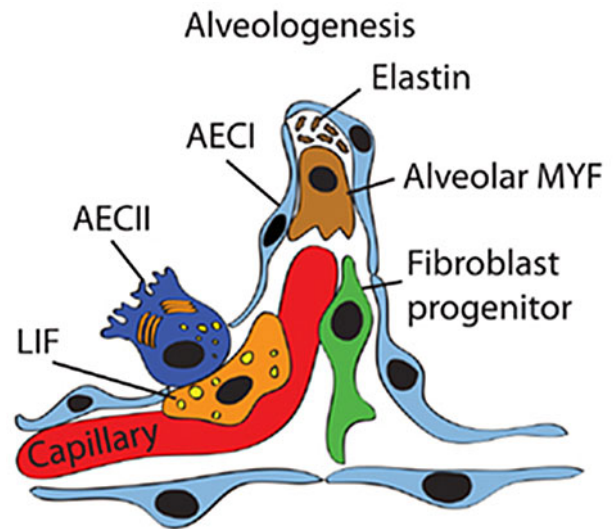
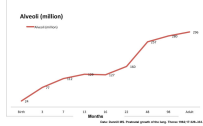
- **week 24 to near term.**
- most peripheral airways form widened "airspaces", termed **saccules**.
- saccules widen and lengthen the airspace (by the addition of new generations).
- future gas exchange region expands significantly.
- Fibroblastic cells also undergo differentiation, they produce extracellular matrix, collagen, and elastin.
  - May have a role in epithelial differentiation and control of **surfactant secretion**.
- Alveolar Cells Type II (Type II pneumocytes)
  - begin to secrete **surfactant**, levels of secretion gradually increase to term.
  - allows alveoli to remain inflated
- Vascular tree - also grows in length and diameter during this time.



## Alveolar stage

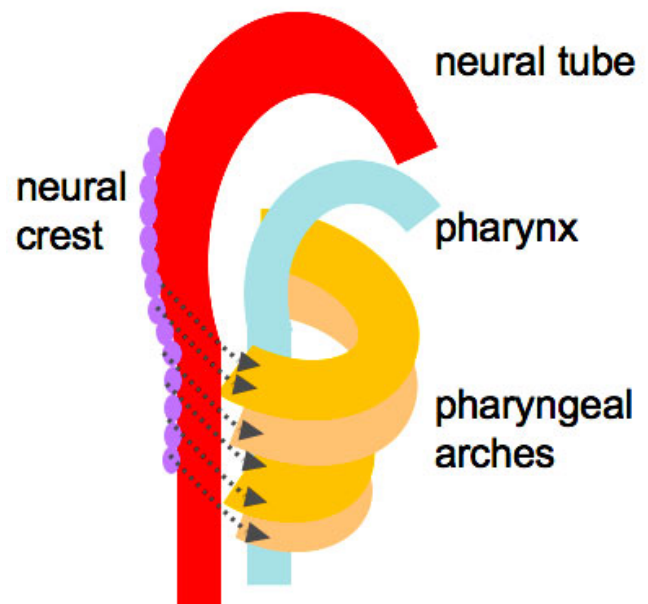
- late fetal to 8 years.
- Secondary septum

- Expansion of gas exchange alveoli, vascular beds (capillaries), lymphatics and innervation.
- Postnatal lung, with **alveoli** forming.



Secondary septae

PMID: 25973420



## Upper Respiratory Tract

**Foregut Development** - from the oral cavity the next portion of the foregut is initially a single gastrointestinal (oesophagus) and respiratory (trachea) common tube, the pharynx which lies behind the heart. Note that the respiratory tract will form from a ventral bud arising at this level.

- part of **foregut** development (Oral cavity, Pharynx (esophagus, trachea), Respiratory tract, Stomach)
- anatomically the nose, nasal cavity and the pharynx
- **pharynx** forms a major arched cavity within the pharyngeal arches (**MH** - pharyngeal arches will be described in BGD head development lecture).
- **palate** - development



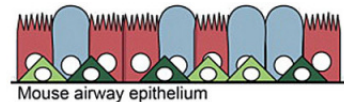


for mammals, allows breathing while feeding.

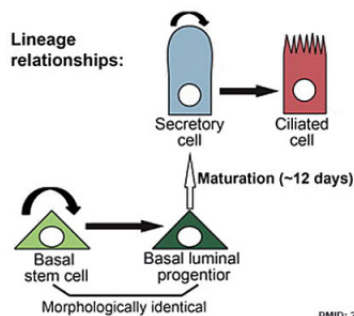
Note - Specialised **olfactory epithelium** for smell, a small region located in roof of nasal cavity.

## Respiratory epithelium

- pseudo-stratified
- ciliated cells
- goblet cells
- basal cells

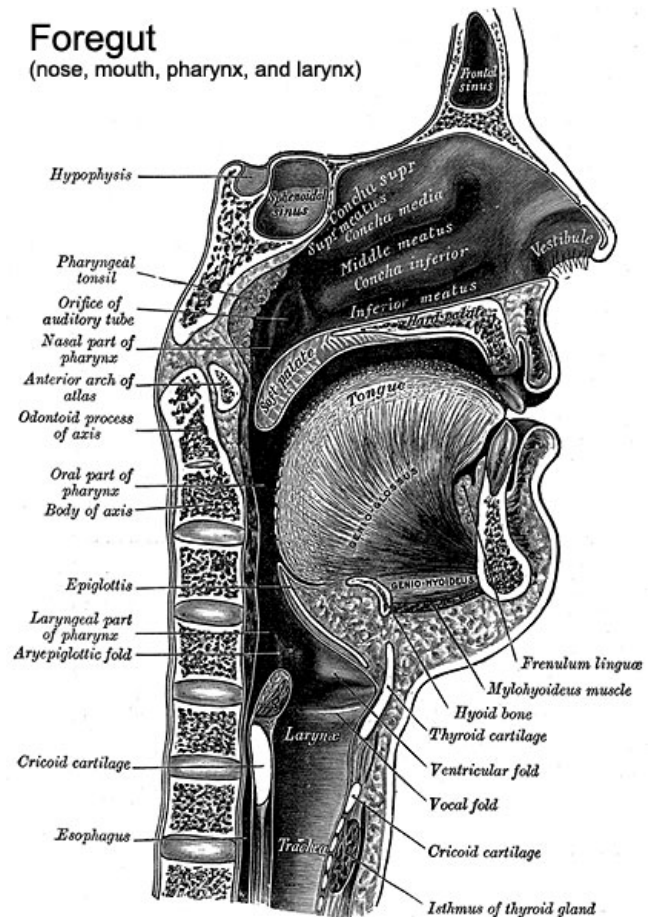


Lineage relationships:



Respiratory epithelium development

## Foregut (nose, mouth, pharynx, and larynx)



- 
- 

- Adult upper respiratory tract conducting system

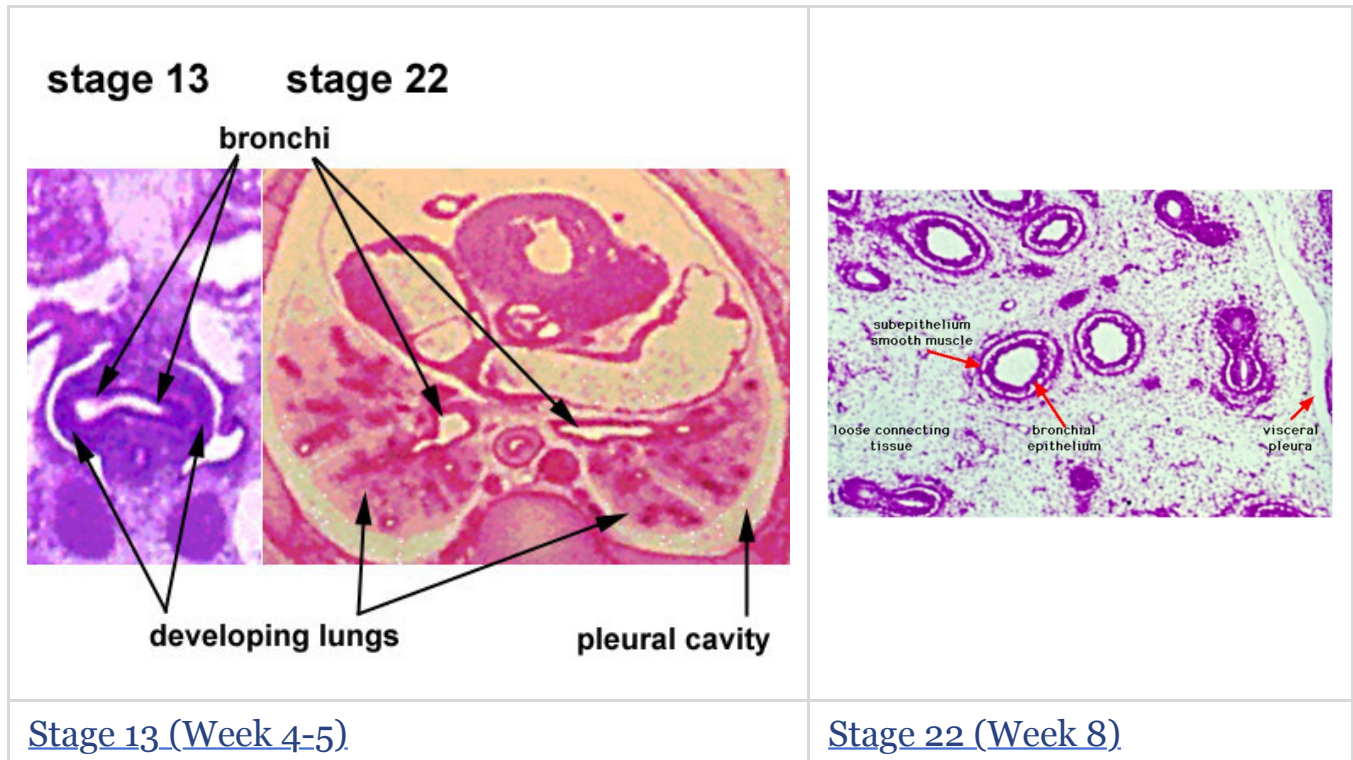
## Additional Information - Histology [Expand]

## Lower Respiratory Tract

- week 4 early respiratory endodermal bud
- week 4 later ventral endoderm growth



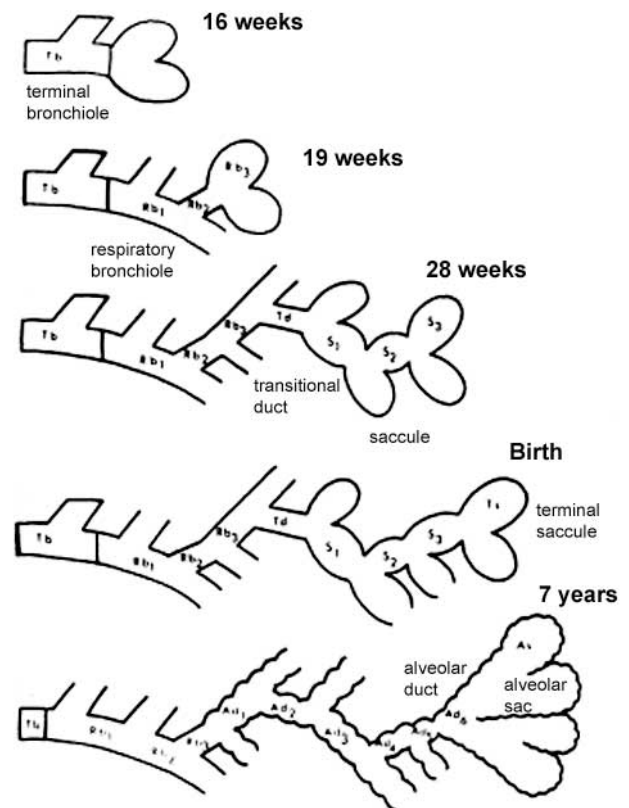
- lower respiratory tract
- conducting system bronchi to lungs



- lung buds ( endoderm epithelial tubes) grow/push into mesenchyme covered with pleural cells (lung border)
- generates a tree-like network by repeated:

1. elongation
2. terminal bifurcation
3. lateral budding

Growth initially of branched "conducting" system of bronchial tree, followed by later development of the "functional units" of the alveoli.



Modified from Dilly SA. Thorax. 1984 Oct;39(10):733-42. PMID: 6495241

Lung alveoli development cartoon

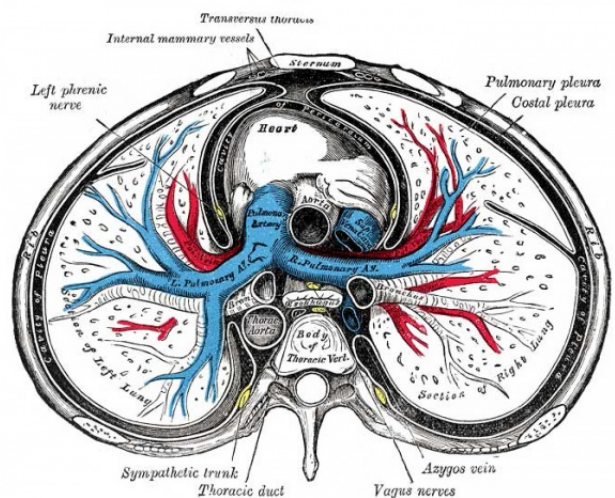
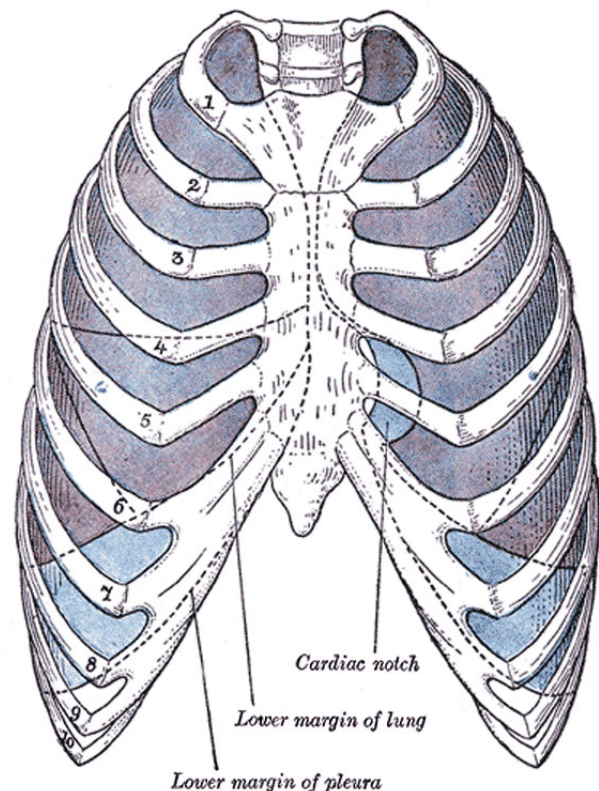
## Additional Information - Histology [Expand]

### Fetal Lung Volume

Each human lung volume as determined by ultrasound and matched to gestational age<sup>[6]</sup>

### Pleural Cavity

- anatomical body cavity in which the lungs develop and lie.
- pleural cavity forms in the **lateral plate mesoderm** as part of the early single **intraembryonic coelom**.
- This cavity is initially continuous with pericardial and peritoneal cavities and form initially as two narrow canals.
  - later becomes separated by folding (pleuropericardial fold, pleuroperitoneal membrane) and the later formation of the diaphragm.
- **pleuropericardial fold -** (pleuropericardial membrane)  
An early embryonic fold which restricts the communication between pleural cavity and pericardiac cavity, contains both the cardinal vein and phrenic nerve.





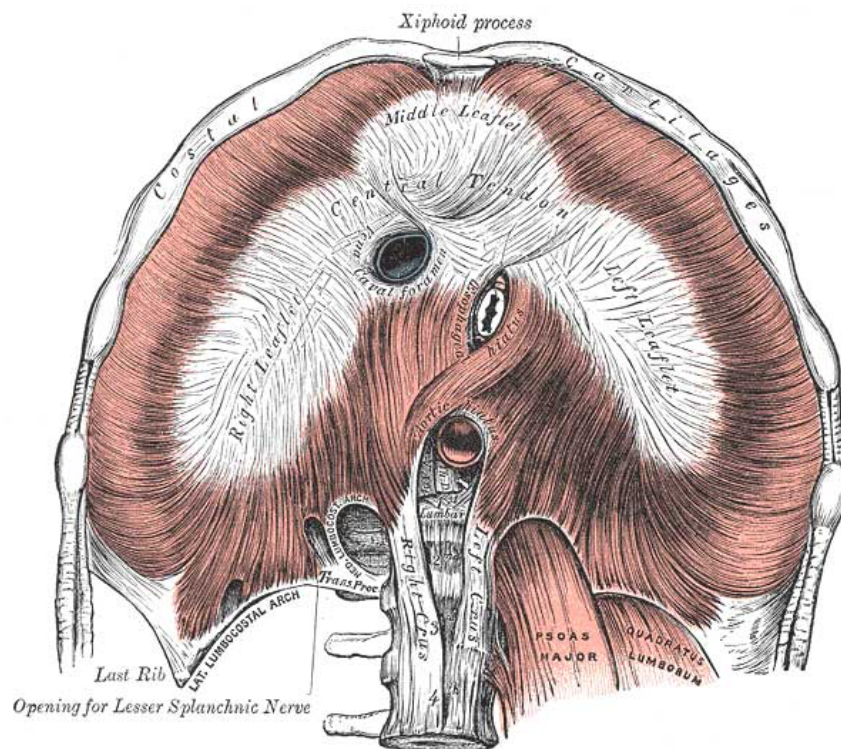
- **pleuroperitoneal membrane** - An early embryonic membrane that forms inferiorly at the septum transversum to separate peritoneal cavity from pleural cavity.

## Pleura

- **serous membrane** covers the surface of the lung and the spaces between the lobes.
- arranged as a closed invaginated sac.
- two layers (**pulmonary, parietal**) continuous with each other, the potential space between them is the **pleural cavity**.

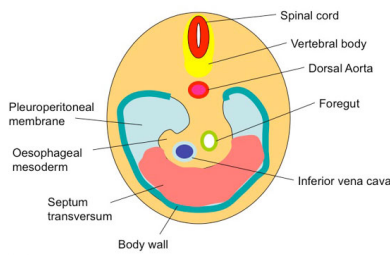
## Diaphragm

### Adult Diaphragm.



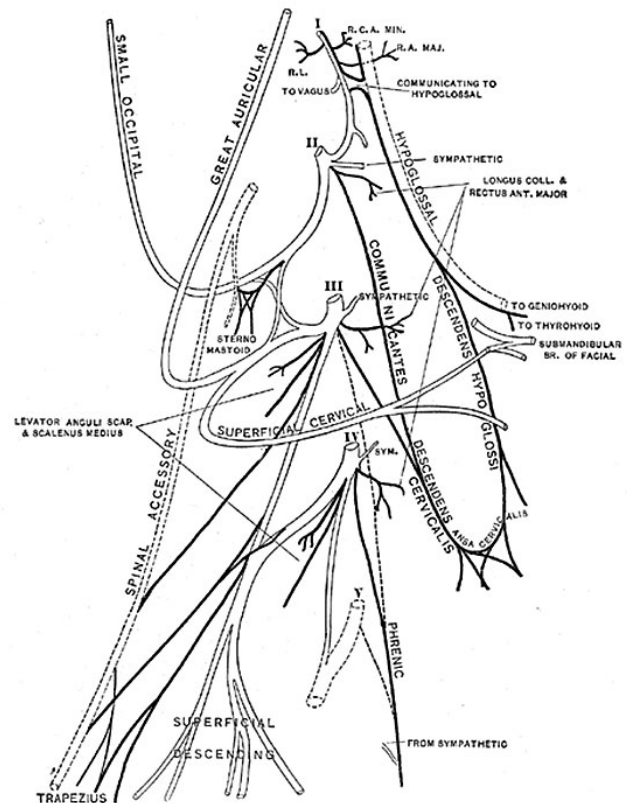
- Not respiratory tract but musculoskeletal development, there are **5 embryonic elements** that contribute to the diaphragm.
- Innervation of the human diaphragm is by the **phrenic nerves**

## Developing Diaphragm



1. septum transversum- central tendon
2. 3rd to 5th somite- musculature of diaphragm
3. ventral pleural sac- connective tissue
4. mesentery of oesophagus- connective tissue around oesophagus and IVC
5. pleuroperitoneal membranes- connective tissue around central tendon

- Phrenic Nerves - arising from the same segmental levels as the diaphragm skeletal muscles, segmental levels C3 to C5.
- The paired phrenic nerves are **mixed nerves**
  - motor neurons for the diaphragm
  - sensory nerves for other abdominal structures (mediastinum, pleura, liver, gall bladder).



Adult Cervical Plexus (phrenic nerve shown lower right)

**Bochdalek hernia** - most common on the posterior left side (85%). Failure of the pleuroperitoneal foramen (foramen of Bochdalek) to close allows viscera into thorax. Intestine, stomach or spleen can enter the pleural cavity, compressing the lung.

## Pulmonary Circulation

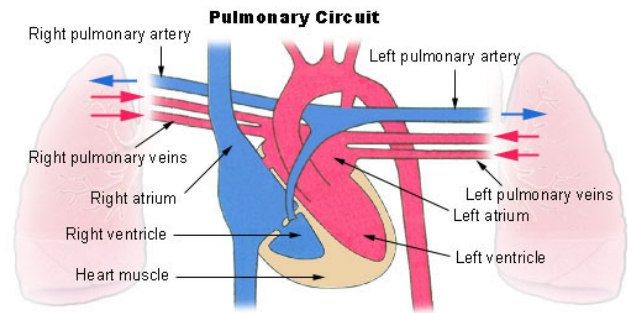
- the pulmonary system not "functional" until after birth
- pulmonary arteries - 6th aortic arch arteries
- pulmonary veins - are incorporated into the left atrium wall
- bronchial arteries - branches from dorsal aorta



# Fetal

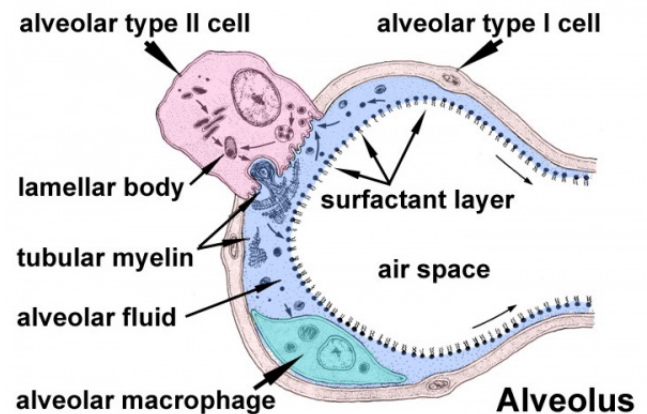
## Fetal Respiratory Movements

- Fetal respiratory movements (FRM) or Fetal breathing movements (FBM) are regular muscular contractions occurring in the third trimester.
- preparing the respiratory muscular system for neonatal function.
- may also have a role in late lung development.



## The First Breath

- The respiratory system does not carry out its physiological function (gas exchange) prenatally and remain entirely fluid-filled until birth.
- At birth, fluid in the upper respiratory tract is expired and fluid in the lung aveoli is rapidly absorbed this event has also been called "dewatering of the lung".
  - The lung epithelia has to now rapidly change from its prenatal secretory function to that of fluid absorption.



The exchange of lung fluid for air leads to:

- fall in pulmonary vascular resistance
- increase in pulmonary blood flow
- thinning of pulmonary arteries (stretching as lungs increase in size)
- blood fills the alveolar capillaries

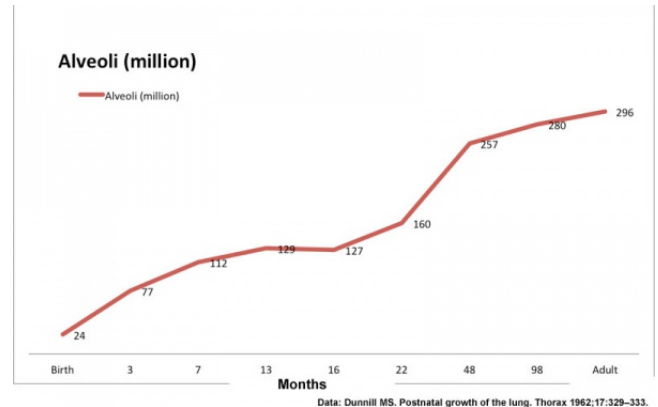
In the heart - pressure in the right side of the heart decreases and pressure

in the left side of the heart increases (more blood returning from pulmonary).

## Postnatal

### Alveoli

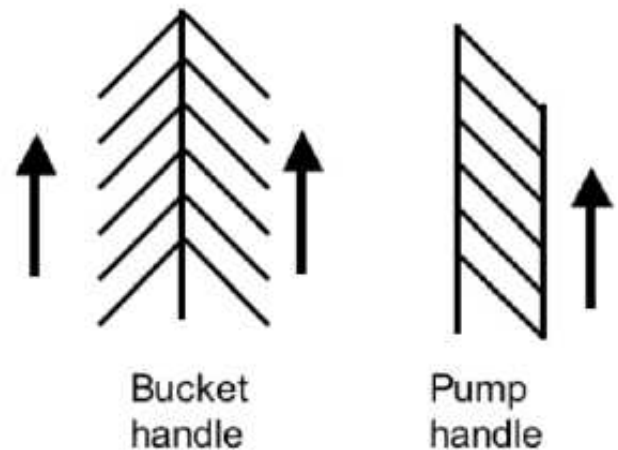
- At birth about 15% of adult alveoli number have formed
  - 20 - 50 million to in the adult about 300 million.
- remaining subdivisions develop in the first few postnatal years



### Alveoli Number

### Respiratory Rate

- neonatal rate is higher (30-60 breaths/minute) than adult (12-20 breaths/minute).
  - tachypnea - (Greek, rapid breathing) an increased respiratory rate of greater than 60 breaths/minute in a quiet resting baby



Age	Rate (breaths/minute)
Infant (birth - 1 year)	30 - 60
Toddler (1 - 3 years)	24 - 40
Preschool (3 - 6 years)	22 - 34
School age (6 - 12 years)	18 - 30
Adolescent (12 - 18 years)	12 - 16

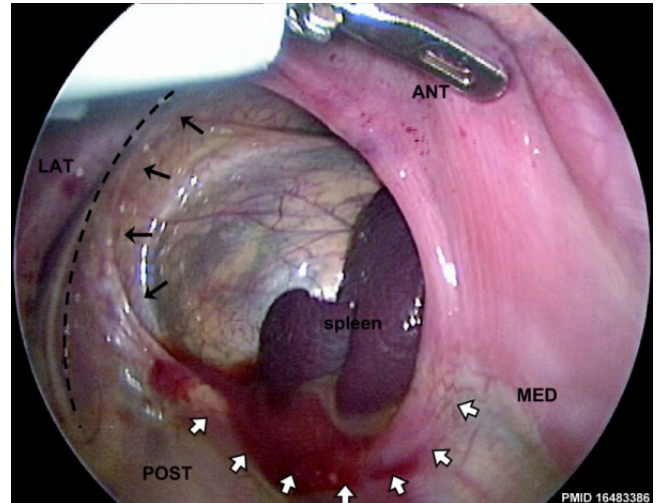
### Rib Orientation

- Infant rib - is virtually **horizontal**, allowing diaphragmatic breathing only.
- Adult rib - is **oblique** (both anterior and lateral views), allows for pump-handle and bucket handle types of inspiration.

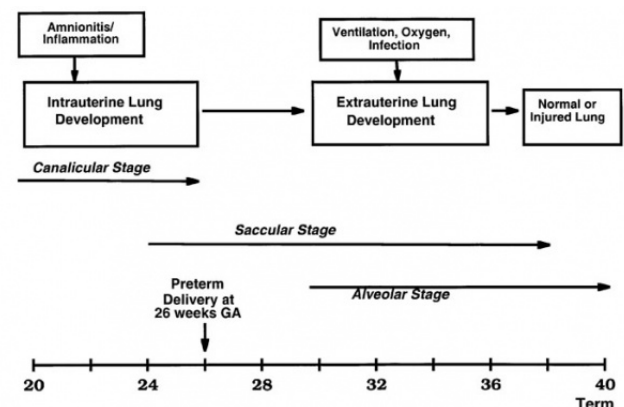
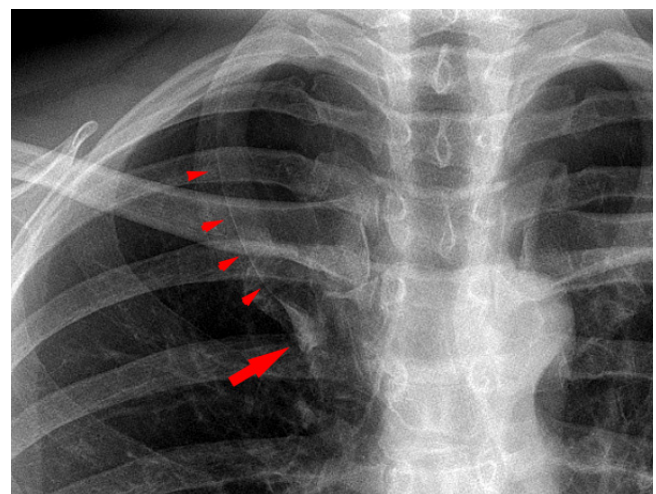
## Respiratory Tract Abnormalities

### Respiratory System - Abnormalities

- **Meconium Aspiration Syndrome** - (MAS) Meconium is the gastrointestinal contents that accumulate in the intestines during the fetal period. Fetal stress in the third trimester, prior to/at/ or during parturition can lead to premature meconium discharge into the amniotic fluid and subsequent ingestion by the fetus and damage to respiratory function. Damage to placental vessels meconium myonecrosis may also occur.
- **Newborn Respiratory Distress Syndrome** - (Hyaline Membrane Disease) membrane-like substance from damaged pulmonary cells, absence of surfactant, if prolonged can be irreversible, intrauterine asphyxia, prematurity and maternal



Congenital diaphragmatic hernia





diabetes [medline plus](#) | [eMedicine](#)

- **Tracheoesophageal Fistula** - Tracheo-Oesophageal Fistula, Oesophageal Atresia - Oesophageal Atresia with or without tracheo-oesophageal [fistula](#) **Fistula** - an abnormal communication between 2 structures (organs, vessels, cavities) that do not normally connect.
- **Lobar Emphysema** (Overinflated Lung) - There is an overinflated left upper lobe There is a collapsed lower lobe The left lung is herniating across the mediastinum
- **Congenital Diaphragmatic Hernia** - (1 in 3,000 live births) Failure of the pleuroperitoneal foramen (foramen of Bochdalek) to close (left side), allows viscera into thorax -iIntestine, stomach or spleen can enter the pleural cavity, compressing the lung. rare (Morgagni hernia) -an opening in the front of the diaphragm. [Congenital Diaphragmatic Hernia](#) | [GeneReviews](#)
- **Azygos Lobe** - Common condition (0.5% of population). The right lung upper lobe expands either side of the posterior cardinal. There is also some course variability of the phrenic nerve in the presence of an azygos lobe.
- **Congenital Laryngeal Webs** - Laryngeal abnormality due to embryonic (week 10) incomplete recanalization of the laryngotracheal tube during the fetal period. Rare abnormality occurring mainly at the level of the vocal folds (glottis).
- **Hyaline Membrane Disease** - (Newborn Respiratory Distress Syndrome) a membrane-like substance from damaged pulmonary cells.
- **Bronchopulmonary Dysplasia** - A chronic lung disease which can occur following premature birth and related lung injury. Most infants

who develop BPD are born more than 10 weeks before their due dates, weigh less than 1,000 grams (about 2 pounds) at birth, and have breathing problems.

- **Asthma** - Flow limitation during tidal expiration in early life significantly associated with the development of physician-diagnosed asthma by the age of 2 years. Infants with abnormal lung function soon after birth may have a genetic predisposition to asthma or other airway abnormalities that predict the risk of subsequent lower respiratory tract illness. PMID 8176553
- **Cystic Fibrosis** - Inherited disease of the mucus and sweat glands, causes mucus to be thick and sticky. Clogging the lungs, causing breathing problems and encouraging bacterial growth. (Covered elsewhere in the course)

## Environmental Factors

The lung is most sensitive to environmental effects given the long timecourse of development, including postnatal, multi-system origins, immune interactions, and our growing understanding of the effects of the prenatal environment on adult health ([DOHAD](#)). Below are some recent reviews of related topics. (not part of today's lecture presentation)

- [Maternal alcohol](#)<sup>[4]</sup>
- Maternal obesity<sup>[7]</sup>
- Maternal diabetes<sup>[8]</sup>
- Maternal smoking<sup>[9]</sup>
- Chronic hypoxaemia<sup>[10]</sup>
- Environmental chemicals<sup>[11]</sup>

## Additional Information

[Respiratory Quiz](#)

## Grays - Respiratory Images

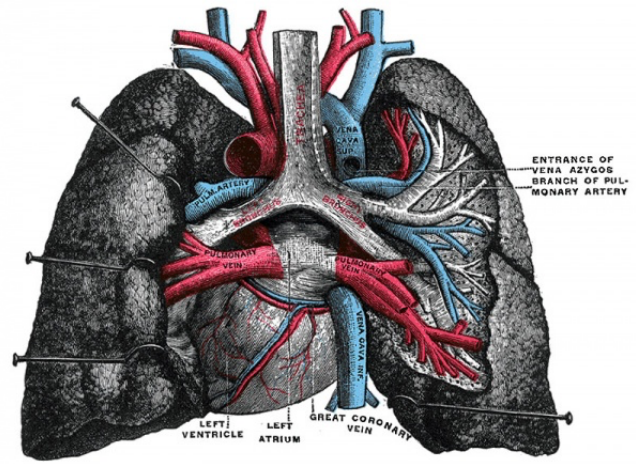
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### Respiratory Histology

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## References

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