EMBRYOLOGY OF THE RESPIRATORY SYSTEM

- **ESTABLISHMENT of GENERAL BODY FORM** at the beginning of the fourth week
  - **Folding** of the **flat trilaminar embryonic disk** into a **cylindrical** embryo.
    - **Longitudinal Folding in the Median Plane:**
      - Folding at the **cranial end** forms upper part of the anterior wall and incorporates a part of the Yolk sac into the embryo as the **foregut**, with the most cranial end named the **oropharyngeal membrane**.

        Before the folding occurs, the presumptive heart tissue is Cranial to the primitive mouth -- **oropharyngeal membrane**. After folding, this is reversed. The **oropharyngeal membrane** is the axis for the 180° turn of:
        - **Septum Transversum** turns 180° along the oropharyngeal axis.
        - **Pericardial Coelom** turns 180°.
        - **Cardiogenic Tissue** turns 180°.

      During Head-folding, these structures turn so that they are now caudal to the oropharyngeal membrane.

      - Folding at the **caudal end** forms lower part of the anterior wall and incorporates a part of the Yolk sac into the embryo as the **hindgut**, with the most caudal end named the **cloacal membrane**.
    - **Transverse Folding:** Right and left latero-medial folding.
      - This **lateral** folding produces the lateral and central part of the anterior abdominal wall and incorporates a part of the Yolk sac into the embryo as the **midgut.**
  - AFTER FOLDING
    - The pericardial coelom moved from dorsal to ventral, relative to the developing heart tissue.
    - Septum Transversum became caudal (rather than cranial) to the developing heart tissue.
    - Primitive Streak was cranial to the cloacal membrane. Now it is caudal.
    - The connecting stalk is pushed ventral-medially and becomes the umbilical cord.
  - SUMMARY OF FOLDING EVENTS AND CONSEQUENCES
    - Primitive Gut was formed from the dorsal regions of the yolk sac.
    - The embryo **changes in shape** from a "trilaminar disc" to a crescent C-Shape.
    - Lateral and Ventral body walls are formed.
    - Primitive body cavities are subdivided -- pericardial and peritoneal.
    - Future mouth is defined.
    - Umbilical cord is defined.
- **DEVELOPMENT OF THE FACE** **(**from forth to eighth weeks**)**
  - **DEVELOPMENT OF THE PRIMITIVE MOUTH (STOMODEUM)**
    - **1st branchial arch** develops lower elevations: **mandibular prominences** forming the caudal boundary of the **stomodeum.**
    - **1st branchial arch** develops upper elevations: **maxillary prominences** forming the lateral boundary of the **stomodeum.**
    - **The frontonasal prominence,** formed by proliferation of mesenchyme

ventral to forebrain, constitutes the cranial boundary of the **stomodeum.**

- The **primitive mouth or stomodeum** is separated from the primitive pharynx by the **buccopharyngeal (oropharyngeal) membrane**. This membrane ruptures at about day 24, bringing the primitive gut into contact with the amniotic fluid cavity.
  - **DEVELOPMENT OF THE NASAL CAVITY (**from the end of 4th week**)**
    - Formation of **Nasal placodes** on each side of **frontonasal prominence**
    - Formation of **medial and lateral nasal prominences** and **nasal pits**
    - Deepening of nasal pits and formation of **nasal sacs** and **oronasal membrane**.
    - Medial growth of maxillary prominences and formation of **nasolacrimal grove**.
    - Merging of maxillary prominences with lateral nasal prominences and **obliteration of the nasolacrimal groove**.
    - Merging of medial nasal prominences (6 - 7th week) and formation of **intermaxillary segment** and **nasal septum.**
    - Merging of maxillary prominences with the intermaxillary segment and formation of the **upper lip, superior alveolar arch and primary palate**.
    - **Rapture of oronasal membrane** and establishment of communication between primitive oral and nasal cavities (end of the 6th week).
    - Merging of the lateral palatine processes from maxillary prominences and formation of the **secondary palate** and **separation of the nasal cavity** from oral cavity.
    - Fusion of merged lateral palatine processes with nasal septum (vomer) and **separation of two halves of the nasal cavity.**
    - Development of **nasal conchae** from elevations of lateral wall.
    - Development of **paranasal air sinuses** from deverticuli of nasal walls.
- **<u>DEVELOPMENT OF THE BRANCHIAL APPARATUS</u>**
    - **Branchial arches** develop early in week 4 as neural crest cells migrate through the mesenchyme to the future head and neck region forming elevations.
      - **1st** branchial (**mandibular**) arch (develops two elevations: mandibular and maxillary prominences)
      - **2nd** branchial (**hyoid**) arch
      - **3rd** branchial arch
      - **4th** branchial arch
      - **5th** branchial arch (disappears by merging with 6th arch)
      - **6th** branchial arch
- By the end of week 4, 4 pairs of branchial arches are visible, the 5th and 6th being small. Branchial arches are separated by the **branchial grooves** and are numbered in a craniocaudal sequence.
- Branchial arches support the lateral wall of cranial part of foregut (primitive pharynx)

• FURTHER DEVELOPMENT OF THE BRANCHIAL APPARATUS AND ITS DERIVATIVES

- The **branchial apparatus** consists of:
  - Branchial or pharyngeal **arches**
  - Pharyngeal **pouches**
  - Branchial **grooves**
  - Branchial **membranes**
- Most congenital malformations of the head and neck originate during transformation of the branchial apparatus into its adult derivatives.
- Initially, **each pharyngeal arch** consists of **mesenchyme** derived from the **intraembryonic mesoderm** and is covered with **ectoderm externally** and **endoderm internally**.
- **Neural crest cells** migrate into the arches, creating the swellings of the arches and contributing to the arches, even though they are of **ectodermal** origin. Neural crest cells give rise to specific **skeletal** structures.
- **Mesenchyme** in the arches give rise to **muscles**.

• A typical branchial arch contains:

- **an aortic arch**
- **a cartilaginous rod**
- **a nerve**
- **a muscular component**

• Derivatives of the branchial arch cartilages

- **1st** branchial (**mandibular**) arch cartilage develops:
  - into **malleus** and **incus** (middle ear bones) from its dorsal portion
  - into the **anterior ligament of the malleus** and the **sphenomandibular ligament** from the perichondrium of its intermediated portion
  - into the primordium of the mandible from its ventral portion
- **2nd** branchial (**hyoid**) arch cartilage develops:
  - into the **stapes** (middle ear) and the **styloid process** from its dorsal part
  - into the **stylohyoid** ligament from the perichondrium of its intermediate part
  - into the **lesser cornu** and the **superior part of the hyoid bone** from its ventral part
- **3rd** branchial arch cartilage develops into the **greater cornu** and **inferior part of the body of the hyoid bone**.
- **4th** and **6th** branchial arch cartilages fuse to form the **laryngeal** cartilages, **except** for the **epiglottis,** which forms from the **mesenchyme in the hypobranchial eminence** (from the 3rd and 4th branchial arches).

• Derivative of the branchial arch nerves:

- **1st** branchial arch: **Trigeminal (V) nerve** (maxillary and mandibular divisions only)
- **2nd** branchial arch: **Facial (VII) nerve**
- **3rd** branchial arch: **Glossopharyngeal (IX) nerve**
- **4th** and **6th** branchial arches: **Vagus (X) nerve**

• Derivatives of the branchial arch muscles:

1st branchial arch:

- Muscles of mastication
- Mylohyoid and anterior belly of the digastric
- Tensor tympani
- Tensor veli palatini

2nd branchial arch

- Muscles of facial expression
- Stapedius
- Stylohoid
- Posterior belly of the digastric

3rd branchial arch

- Stylopharyngeus

4th and **6th** branchial arches:

- Cricothyroid
- Levator veli palatini
- Constrictors of the pharynx
- Intrinsic muscles of the larynx
- Striated muscles of the esophagus

• **PHARYNGEAL POUCHES** develop between the branchial arches (1st pouch is found between the first and second branchial arches). There are 4 pairs; the 5th is absent or very small.

• **Endoderm** of the pharyngeal pouches and **ectoderm** of the branchial grooves contact each other to form **branchial membranes** separating the pharyngeal pouches and the branchial grooves.

• Derivatives of the pharyngeal pouches:

• **1st** pharyngeal pouch expands into a **tubotympanic recess**. The expanded distal portion of the recess contacts the 1st branchial groove (only branchial membrane to persist in the adult) contributing to the formation of the **tympanic membrane** or eardrum. **Only** the 1st branchial groove persists in the adult as the **external acoustic meatus**.

* The tubotympanic recess gives rise to the **tympanic cavity** and the **mastoid antrum**. Connection between the tubotympanic recess and the pharynx elongates to form the **auditory tube**.

• **2nd** pharyngeal pouch contributes to the formation of the **palatine** tonsil and **the epithelial lining of the fauces**.

• **3rd** pharyngeal pouch contributes to the formation of the **inferior** parathyroid glands (week 5- bulbar portion) and the **thymus** (elongate portion). which migrate inferiorly (past the superior parathyroid glands of the 4th pouch).

• **4th** pharyngeal pouch contributes to the formation of the **superior** parathyroid gland (bulbar portion) and the **parafollicular cells or** calcitonin cells of the thyroid gland (elongate portion - **ultimobranchial body**).

• **<u>DEVELOPMENT OF THE LARYNX, TRACHEA, BRONCHIAL TREE, LUNGS AND PLEURA</u>**

• The lower respiratory system (from the pharynx down)

- develops during week 4 (26-27 days)

- starts as a **median laryngotracheal groove** in the caudoventral wall of the primitive pharynx.
- The **endoderm** lining the groove **gives rise** to the **epithelium and glands** of the larynx, trachea, bronchi and the **pulmonary epithelium**.
- **Connective tissue, cartilage and smooth muscle** of these structures develop from the **splanchnic mesenchyme** surrounding the foregut.

• The **laryngotracheal groove** deepens into a diverticulum ventrally which enlarges distally into a **lung bud**. The diverticulum becomes separated from the primitive pharynx by longitudinal **trachoesophageal folds** which fuse to form the **trachoesophageal septum**, dividing the foregut into the **ventral laryngotracheal tube** and the **dorsal esophagus**.

• A **fistula** may exist connecting trachea and esophagus and resulting in abnormal communication between the 2.
- This is usually associated with **superior esophageal atresia**. In a newborn infant, this is associated with coughing and choking upon swallowing. Gastric contents may reflux into the trachea and lungs resulting in **pneumonia** or **pneumonitis** (inflammation of the lungs).
- An excess of amniotic fluid (**polyhydramnios**) is associated with esophageal atresia and trachoesophageal fistula because amniotic fluid may not pass to the stomach and intestines for absorption and transfer via the placenta for disposal.

CONGENITAL ABNORMALITIES OF TRACHEA:

- Tracheoesophageal Fistula:
  - Communication connecting trachea & esophagus that occurs in every 2500 births
    - It has four main varieties:
      - 1. Superior portion of esophagus ends blindly (esophageal atresia), inferior portion joins trachea near its bifurcation (most common – 90%)
      - 2. Esophagus has communication with trachea near its bifurcation
      - 3. Upper end of esophagus has communication with trachea near its bifurcation, whereas the lower portion ends blindly
      - 4. Upper end of esophagus has communication with trachea, whereas the lower portion of esophagus also has communication with trachea near its bifurcation
- Tracheal Stenosis (narrowing) and Atresia (closure)
- Tracheal diverticulum

• The **lung bud** develops into 2 **endodermal bronchial buds** which grow into the pericardioperitoneal cavities, the primordia of the pleural cavities.
- Early in week 5, each bronchial bud enlarges into the primordium of a **primary bronchus**. The right one is slightly larger than the left and is oriented more vertically.
- The primary bronchi subsequently divide into **secondary bronchi** and then into the **tertiary bronchi** by week 7.
- By week 24, they divide another 14 times and the **respiratory bronchioles** have developed.
- They will divide an additional 7 more times before birth.
- As the bronchi develop, the surrounding mesenchyme synthesizes the surrounding cartilages, smooth muscle, connective tissue and capillaries.

• The **lungs** acquire **a layer of visceral pleura from the splanchnic** mesenchyme.

• The **thoracic body wall** becomes lined by **a layer of parietal pleura** derived from the somatic mesoderm.

- **LUNG DEVELOPMENT**

  - **1. Pseudoglandular period (5-17 weeks)**

    Proliferation of endodermal epithelium. By week 17 all major elements of the lungs have formed except for those involved with gas exchange. The lungs look like an endocrine organ. **No respiration is possible!**

  - **2. Canalicular period (16-25 weeks)**

    The lumen of the bronchi and terminal bronchioles become larger and the lungs become vascularized. By week 24, respiratory bronchioles have developed and respiration becomes possible, although the chances of survival are slim. Surfactant production begins by 20 weeks but it is present in only small amounts in premature infants; it does not reach adequate levels until the late fetal period.

  - **3. Terminal sac period (24 weeks to birth)**

    - More terminal sacs develop and capillaries enter into close relationship with them. They are lined with **Type 1 alveolar cells or** pneumocytes.
    - **Type II pneumocytes** secrete **surfactant** counteracting the surface tension forces and facilitating expansions of the terminal sacs.

    By 24 weeks, the terminal sacs are lined mainly by squamous epithelial cells – type I pneumocytes – across which gas exchange occurs. During terminal sac period the capillary network proliferates rapidly along with formation of rounded secretory epithelial cells – such as Clara cells and type II pneumocytes. They secrete components of pulmonary surfactant, a complex mixture of phospholipids. Surfactant forms as a monomolecular film over the internal walls of the terminal sacs, lowering surface tension at the air-alveolar interface. The maturation of surfactant producing cells and surfactant production varies widely in fetuses of different gestational ages. Surfactant counteracts surface tension forces and facilitates expansion of the terminal sacs (primitive alveoli). Consequently, fetuses born prematurely at 24 to 26 weeks after fertilization may survive if given intensive care; however, they may suffer from respiratory distress because of surfactant deficiency. The production of surfactant increases during the terminal stages of pregnancy, particularly during the last 2 weeks before birth.

    Adequate pulmonary vasculature and sufficient surfactant are critical to the survival of premature infants.

  - **4. Alveolar period (late fetal period to 8 years)**

    95% of the mature alveoli develop after birth. A newborn infant has only 1/6 to 1/8 of the adult number of alveoli and the lungs look denser in an x-ray.

CONGENITAL ABNORMALITIES OF THE LUNGS:

- Congenital Lung Cysts
- Agenesis of Lungs or one Lung
- Lung Hypoplasia
- Accessory Lung
- Lobe of Azygos Vein
- INFANT RESPIRATORY DISTRESS SYNDROME (IRDS)

INFANT RESPIRATORY DISTRESS SYNDROME (IRDS): Also called **Hyaline Membrane Disease**

- ETIOLOGY: Premature birth, or delayed or absent surfactant production.
  - 36-37 weeks (slight premature): surfactant is usually OK.
  - 28-31 weeks: You see a lot of IRDS babies.
  - Prolonged intrauterine asphyxia may also produce irreversible changes in the type II alveolar cells, making them incapable of producing surfactant.
- PATHOPHYSIOLOGY:
  - Lack of surfactant causes the lungs to **collapse** with each breath.
- SYMPTOMS: Look for the following symptoms in the baby
  - Tachypnea
  - Flaring of the nose
  - Cyanosis
  - Grunting (to create positive pressure)

  Infants with respiratory distress syndrome develop rapid, labored breathing shortly after birth. Their lungs are under inflated and alveoli contain a fluid of high protein content that resembles a glossy or hyaline membrane. In absence of surfactant, the alveoli tend to collapse during exhalation, and although the conducting passageways remain open, the newborn infant must then inhale with extra force to reopen the alveoli on the next breath. In effect, every breath must approach the power of the first, and the infant rapidly becomes exhausted. Respiratory movements become progressively weaker, eventually the alveoli fail to expand, and gas exchange ceases.
- INFANTILE CONSEQUENCES: **Cranial Hemorrhage** can occur with IRDS.
- ADULT CONSEQUENCES of IRDS: Three classic adult consequences with severe cases
  - Chronic Lung Disease
  - Neurologic Impairment

Visual Impairment / Retinal Disease

- **<u>Development of the body cavities and the diaphragm</u>**

• The **intraembryonic coelom** is the primordium of the embryonic body cavities and begins to develop near the **end of week 3**.

• By the **beginning of week 4**, it is a horseshoe-shaped cavity in the cardiogenic and lateral mesoderm. The curve of the horseshoe represents the future pericardial cavity and its lateral limbs represent the future pleural and peritoneal cavities.

• During **folding of the embryonic disc in week 4**, the lateral parts of the intraembryonic coelom are brought together on the ventral aspect of the embryo.

• **When the caudal part of the ventral mesentery** disappears, the right and left parts of the intraembryonic coelom **merge and form the peritoneal cavity**. As the peritoneal portions of the intraembryonic coelom come together, the **splanchnic layer** of the mesoderm encloses the primitive gut and suspends it from the dorsal body wall by a double-layered peritoneal membrane known as the **dorsal mesentery**.

• **Until week 7**, the embryonic pericardial cavity communicates with the peritoneal cavity through **paired pericadioperitoneal canals**. During weeks 5 and 6, partitions form near the cranial and caudal ends of these canals:

- Fusion of the cranial **pleuropericardial membranes** with mesoderm ventral to the esophagus separates the pericardial cavity from the pleural cavities.
- Fusion of the **caudal pleuroperitoneal** membranes, during formation of the diaphragm, separates the pleural cavities from the peritoneal cavity.

- **The diaphragm forms from:**
  - 1) **septum transversum**,
  - 2) **pleuroperitoneal membranes,**
  - 3) **dorsal mesentery of the esophagus,**
  - 4) **body wall.**

Septum Transversum: The posterior border of the developing heart. It will develop into the diaphragm.

- It is the primitive **central tendon** of the adult diaphragm.
- It rotates *around* the foregut like a blanket, hence giving rise to the **esophageal hiatus**.

Pericardioperitoneal Canals: Two canals in the embryo. Between the two canals is the **foregut**.

- The Thoracic Cavity is formed as a result of forming the diaphragm.
- Each canal contains a **pleuroperitoneal membrane**.
  - An ingrowth of these membranes closes off the pericardioperitoneal canals. Muscle wall moves in with it, eventually forming the diaphragm.
- The **Central Tendon** of the diaphragm is a remnant of the septum transversum.
  - Birth Defect: The GI-Tract may expand into the Thoracic cavity if the diaphragm does not fully form. A posterolateral defect of the diaphragm results in **congenital diaphragmatic hernia** and is due to **failure of fusion between the pleuroperitoneal membranes** and **other diaphragmatic components**.

Innervation of Diaphragm

- The **Phrenic Nerve** innervates the diaphragm.
- Phrenic nerve originates at C3-C5, because the developing diaphragm is located in the neck region.
- During development the diaphragm is displaced inferiorly to the lower thoracic aperture. It drags the phrenic nerve along with it.

Referred Pain: Chest pain, lung pain, or pain in the diaphragm may be felt in the left shoulder. This is because the sensory origins of the **phrenic nerve** (C3-C5) also innervate the left shoulder region. When the pain is displaced in this manner, it is called referred pain.

FETAL CIRCULATION

- Oxygenated blood returns from the placenta by the umbilical vein.
- 1/2 blood passes through the liver whereas 1/2 bypasses the liver by the **ductus venosus**.
- Blood enters into the inferior vena cava and then the right atrium of the heart. This blood is now partially deoxygenated because it is mixed with returning blood from the lower portion of the body and the abdominal organs.
- Most of the blood in the right atrium passes through the **foramen ovale** into the left atrium and mixes with the blood returning from the lungs (deoxygenated).
- From the left atrium, blood passes into the left ventricle and the ascending aorta. Arteries to the heart, head and neck, and upper limbs receive well-oxygenated blood.

- A small amount of blood from the right atrium mixes with blood from the superior vena cava and coronary sinus. It passes into the right ventricle and leaves via the pulmonary trunk. Most of it passes into the **ductus arteriosus** into the aorta. A small amount passes into the lungs.
- 50% of the blood passes via the umbilical arteries into the placenta for reoxygenation, the rest supplies the viscera and the inferior 1/2 of the body.

• The fetal circulation is designed to carry oxygenated blood from the placenta to the fetal circulation, bypassing the lungs.

• Changes Occurring in the Respiratory System at Birth:

• Prior to delivery, pulmonary arterial resistance is high, because the pulmonary vessels are collapsed. The thoracic cage is compressed and the lungs and airway contain only fluid and no air.

• **After birth, the circulation of fetal blood through the placenta ceases** → *delivery of oxygenated blood to fetus ceases → the sphincter venosus constricts so all blood entering the liver passes through the hepatic sinusoids → fall of blood pressure in the IVC and right atrium occur → hypoxia of all tissues is increasing → respiratory centers of the brain stem are stimulated by carbon dioxide → contraction of inspiratory muscles occurs → expansion of the thorax & of the lungs and first breath takes place → inspired air enters respiratory passageways, pushes the contained fluids out of the way and inflates the bronchial and respiratory trees → fall in pulmonary vascular resistance → ductus arteriosus constricts → a marked increase in pulmonary blood flow → the pressure in the left atrium becomes higher than in right atrium → valve of the foramen ovale is pressed against the septum secondum → the foramen ovale closes thus separating the right and left atria*; the infant's lungs begin to function and newborn infant utters a loud cry.

• The three shunts: foramen ovale, ductus arteriosus, ductus venosus and umbilical vessels are no longer needed and they close and cease to function.

• The change from the fetal to the adult pattern of blood circulation through the liver, heart and lungs is not a sudden occurrence. Some changes occur with the first breath (caused by Hypoxia), and others are effected over hours and days.

• The following congenital malformations of cardiovascular system (shunts between right and left cardiac chambers), which provide conditions for mixture of oxygenated and deoxygenated blood or its insufficient oxygenation may lead to a condition known as a "blue baby":

Ventricular septal defects
Atrial septal defects (patent foramen ovale)
Transposition of great arteries and pulmonary stenosis
Tetralogy of Fallot

• Developing **lungs at birth are half filled with amniotic fluid because breathing movements occur before birth** to cause aspiration of amniotic fluid into the lungs.

• Aeration of lungs at birth is the rapid replacement of intra-alveolar fluid by air

The fluid in the lungs is cleared at birth by three routes:

- through mouth and nose by pressure on the thorax during delivery.
- into the pulmonary capillaries and via the pulmonary and bronchial veins
- into the lymphatics and via lymph vessels of visceral pleura and the lungs.

Because of aeration of lungs the pulmonary blood flow increases and this is associated with:

Dramatic fall in pulmonary vascular resistance

Progressive thinning of walls of pulmonary arteries, which results from stretching as lungs increase in size with first few breaths.

September 2007

INTRODUCTION TO THE THORAX & THORACIC CAVITY

Thoracic Walls, Apertures and their Boundaries:

- **Thoracic Walls:** Anterior, 2 Lateral and Posterior
  - Walls of thoracic cavity:
    - Anterior – sternum, costal cartilages, sternal ends of true ribs and anterior parts of their intercostal spaces.
    - Lateral (2) right & left –12 pairs of ribs and middle parts of their intercostal spaces
    - Posterior – bodies of 12 thoracic vertebrae, their intervertebral disks, vertebral ends of 12 pairs of ribs and posterior parts of their intercostal spaces.
- **Superior - thoracic inlet** (superior thoracic aperture), costopleural membrane
  - boundaries: T1 vertebral body, inner borders of 1st ribs, clavicular & jugular notches of manubrium sterni;
- **Inferior - thoracic outlet** and diaphragm
  - boundaries: T12 vertebral body, two12th ribs, costal arch & cartilages of ribs 7-12 on right & left sides and xiphoid process anteriorly.

Subdivisions

- Pleural cavities (2)
- Mediastinum

Contents

- Endothoracic fascia
  - Parietal and visceral pleurae
  - Trachea & bronchi
  - Lungs (2)
  - Heart & Pericardium
  - Thymus
  - Esophagus
  - Great vessels, nerves and lymph nodes

Respiratory movements: The thoracic cavity is enlarged by elevation of ribs and contraction of diaphragm, decreasing pressure in pleural cavities, resulting in air being sucked into the lungs. Negative pressure in pleural cavities is a very important condition for breathing.

- Expansion of rib-cage.
  - Ribs 1-7 rotate during respiration. They undergo the pail-handle effect. As they are raised, they **increase volume of the thorax** in two dimensions:
    - Anterior-posterior dimension.
    - Medial-Lateral dimension (because they are bowed)
  - Ribs 9-12 bow out laterally, increasing volume in both dimensions described above.
  - Vertical Increase (superior-inferior) is the most significant: It results from contraction of the diaphragm, displacing it inferiorly.

PLEURA : is a serous membrane, investing the lungs and lining the walls of the pleural cavities.

- **Visceral Pleura:** The inner membrane of the pleural cavity, or the membrane immediately surrounding the lung. It covers each lobe invaginating into the fissure(s) of the lung (where

there are extension(s) of the pleural cavity between lobes) and it is reflected over the root of the lung to the mediastinum, where it is continuous with the Parietal Pleura.

- **Parietal Pleura:** The outer membrane, lining the walls of the pleural cavity. It is subdivided into four parts:
  - The **Costal Pleura**: That portion of the parietal pleura bordering the rib-cage.
  - The **Mediastinal Pleura:** That portion of the parietal pleura bordering the mediastinum.
  - The **Diaphragmatic Pleura:** That portion of the parietal pleura bordering the diaphragm.
  - The **Cervical Pleura :** That portion of the parietal pleura above the level of the superior thoracic aperture, projecting to the root of the neck.

PLEURAL CAVITY: is a slit-like cavity (containing a capillary film of serous fluid) between the visceral and parietal pleurae (with a negative pressure).

- There are two separate pleural cavities (right and left) in which the lungs are contained. All surfaces of the lung, covered by the visceral pleura, are surrounded by the pleural cavity.
- The right pleural cavity is separated by the mediastinum from the left pleural cavity.
- The **mediastinum** is a complex of organs located between the right and left mediastinal pleurae behind the sternum and in the front of the vertebral column thus forming a partition or septum separating two pleural cavities.
- At the site, where one wall of the pleural cavity is continuous with another the **parietal pleura** is reflected from one wall to another to limit a part of the pleural cavity, named a **Pleural Recess** (or Sinus).
- The **Pleural Recess** is limited by two adjacent parts of the parietal pleura and a lung can enter it only during a deep inspiration. There are three main pleural recesses on each side of the thorax:
  - **Costodiaphragmatic Recess:** The recess created by the junctions (**reflections**) between the costal pleura and diaphragmatic pleura The inferior part of the pleural cavity below the inferior border of the lung between the thoracic wall and the diaphragm.
  - Whenever fluid accumulates in the pleural cavity (pleuritis), this is a good place to put a drain tube.
  - **Costomediastinal Recess:** The recess created by the junctions (**reflections**) between the mediastinal pleura and costal pleura on the anterosuperior portion of both lungs.
  - The **left** costomediastinal recess is larger than the right, due to the **cardiac notch** -- the impression left on the left lung from the heart.
  - **Mediastinodiaphragmatic Recess:** The recess created by the junctions (**reflections**) between the mediastinal pleura and diaphragmatic pleura.

THORACIC BONES:

- **12 thoracic vertebrae**
- **12 pairs of ribs**
  - ribs 1st, 2nd, 10th, 11th, 12th "atypical" ribs
  - ribs 3-9 "typical" ribs
  - ribs 1–7 "true" ribs (direct attachment to sternum)
  - ribs 8-10 "false" ribs; (attachment to sternum via cartilage of 7th rib)
    They form costal arch (cartilages of 7 to 10 ribs)
  - rib 11-12 "floating" ribs (no attachment to sternum or costal arch)
- **Sternum**

The First Rib

Most acutely curved and usually shortest, it is broad and flat, its surfaces superior and inferior, its borders internal and external. It slopes obliquely down and forwards to its sternal end. The head is small, round and bears an almost circular facet, articulating with the first thoracic vertebral body. The neck is rounded and ascends posterolaterally. The tubercle, wide and prominent, is directed up and backwards; medially an oval facet articulates with the first thoracic transverse process. At the tubercle the rib is bent, its head turned slightly down; angle and tubercle therefore coincide. The superior surface of the flattened shaft is crossed obliquely by two shallow grooves, separated by a slight ridge which ends at the internal border as a usually small, pointed projection, the scalene tubercle. The inferior surface is smooth and ungrooved. The external border is convex, the internal border is concave with a scalene tubercle near its midpoint. The anterior end is larger than in any other rib.

The Second Rib

It is twice the length of the first, with a similar curvature. The non-articular area of the tubercle is small. The angle is slight and near the tubercle. The shaft is not twisted, but at the tubercle is convex upwards, as in the first rib but less so. It has a short costal groove.

The Tenth Rib

This has a single facet on its head.

The Eleventh and Twelfth Ribs

Each has one large, articular facet on the head, but no neck or tubercle; their pointed anterior ends are tipped with cartilage. The eleventh has a slight angle and shallow costal groove. The twelfth has neither, being much shorter and sloping cranially at its vertebral end.

Gross Anatomy of the typical rib (rib 3 to 9):

- **Posterior (vertebral) end**
  - **Wedge-shaped head** located on vertebral end of rib
    - **Two articular facets** for articulation with two vertebrae
    - **Crest of head** separating two articular facets
  - **Neck,** stout part, located between head and tubercle, anterior to transverse process of vertebra
    - **Crest of neck** (superior border)
  - **Tubercle,** located on posterior surface at junction of neck and shaft
    - **Smooth convex articular facet** for articulation with transverse process of vertebra
    - **Rough non articular part** for attachment of lateral costotransverse ligament
- **Shaft** (body), rest of rib in front of its tubercle, thin, flat and curved
  - **External and internal** surfaces
  - Thick, rounded **superior border**
  - Thin, sharp **inferior border**
    - **Costal groove** (sulcus) on its internal surface for intercostal nerve and vessels
    - **Flange** – extension of external part of inferior border (to protect nerve and vessels in costal groove)
    - **Angle**, point of greatest change in curvature
- **Anterior (sternal) end**

Joints of the typical rib:

- **Two Costovertebral joints (synovial)**
  - **Joint of the head of rib**
    - **Inferior articular semifacet** of head of rib articulate with
    - **superior costal demifacet** on the body of the corresponding vertebra

Superior articular semifacet of head of rib articulate with **inferior costal demifacet** on the body of the vertebra superior to it

Crest of head is attached to intervertebral disk by **intraarticular ligament**. It divides joint into **two synovial** cavities (superior & inferior)

Articular capsule connects head of rib to circumference of joint cavity. It is reinforced anteriorly by **radiate ligament.**

Costotransverse joint

Articular facet of tubercle of rib articulate with articular facet on tip of transverse process of corresponding vertebra

Articular capsule is attached to edges of articular facets

Costotransverse Ligaments:

Lateral costotransverse

Superior costotransverse

Costal cartilage (Hyaline) connect rib to sternum

Costochondral joint

Cup-shaped depression in anterior end of rib is firmly bound to its costal hyaline cartilage by continuity of periosteum with perichondrium

Sternocostal joint (synovial)

Sternal end of costal cartilage articulates with articular surface of **costal notch** on **lateral border of sternum**

Articular capsule is reinforced by anterior and posterior radiate sternocostal ligaments

Movements of rib during inhalation and exhalation:

Movements at costovertebral joints

Up and Down gliding movements of costal head and tubercle, which permit rotation of costal neck around its long axis

Upward rotation brings about elevation of shaft and sternal end of rib during inspiration (**tubercle glides Down**)

Downward rotation brings about depression of shaft and sternal end of rib during expiration (**tubercle glides Up**)

Bucket-handle inspiratory movement, when pail handle is raised, its convexity moves laterally, increasing transverse diameter of thorax. It occurs during elevation of shafts of ribs. Depression of shafts causes expiration.

Pump-handle inspiratory movement, when rib is elevated, sternal end moves anteriorly like a pump handle, increasing anteroposterior diameter of thorax. Depression of sternal end causes expiration.

- **Sternum has the following structures:**
  - manubrium
  - jugular (suprasternal) notch
  - clavicular notch
  - sternal angle
  - body
  - costal notch
  - xiphoid process
- **Thoracic vertebra has the following structures:**
  - body
  - arch

- pedicles
- processes (articular, transverse, spinous)
- notches (superior & inferior)
- articular facets/semifasets (for heads of ribs on vertebral bodies and for costal tubercles on transverse processes)
- vertebral foramen

MUSCULATURE OF THE THORAX

Muscles Associated with Movement of Arm and Neck: These muscles are relevant to movement of upper limbs. They are also involved in respiration.

- **Pectoralis Major**: Most anterior portion.
- **Pectoralis Minor:** Deep to pectoralis major.
- **Scaleni Muscles** (anterior, medius, posterior)
- **Serratus Anterior**

Muscles of the Thorax Proper: All of these muscles are associated with respiration.

- **Serratus Posterior** (Outer Muscles): Originate from the vertebrae and insert on the ribs on the posterior thoracic wall.
  - **Serratus Posterior Superior:** Insert on superior ribs posteriorly. When they contract, they raise the ribs.
  - **Serratus Posterior Inferior**: Insert on inferior ribs posteriorly. When they contract, they lower the ribs.
- **Levatores Costarum** (Outer Muscles): Small muscles that pass all along the vertebral column. Raise the ribs upon contraction.
- **Intercostal Muscles:** Inner Muscles that pass between the ribs.
- **External Intercostals:**
  - Occupy intercostals spaces between tubercles and costochondral junctions
  - Superior attachment – **external aspect of inferior border of rib above**
  - Inferior attachment – **external aspect of superior border of rib below**
    - They run from rib above superoinferiorly & posteroanteriorly to rib below
    - Originate at vertebrae and travel along intercostal spaces to sternum.
    - Stop before they get to the sternum.
    - **External Intercostal Membrane:** Connects muscle to sternum on anterior side.
- **Internal Intercostals:**
  - Occupy intercostals spaces between sternum and angles of ribs
  - They run deep to and at right angles to external intercostals
  - Superior attachment–**floor of costal groove of rib above and costal cartilage**
  - Inferior attachment – **internal aspect of superior border of rib below**
    - Run from rib below inferosuperiorly and anteroposteriorly to rib above, crossing the external intercostals.
    - Start at the sternum, pass laterally and posteriorly, and stop before they get the vertebral column.
    - The **Internal Intercostal Membrane** connects the muscles to the vertebrae at that point.

Actions:

External intercostals: **Elevate ribs in Inspiration**

Internal intercostals: **Depress ribs in Expiration**

External and Internal intercostals: **Act together to stiffen chest wall during descent of diaphragm in Inspiration**

- **Innermost Intercostals:** Start at the angle of the ribs, and move anteriorly and stop before the sternum.
    - They are the deepest, have the same directions as internal intercostals and only cover the lateral region of the thoracic cavity.
- **Transversus Thoracis:** Can be seen from innermost aspect of thorax. Connected to innermost intercostals through a membrane.
- **Subcostals:** Located on the posterior aspect, internally. Have the same direction as the innermost intercostals. Slips of muscle that pass between the posterior ribs over one rib.

DIAPHRAGM

Diaphragm is a dome-shaped musculotendinous partition between thoracic and abdominal cavities, it is a principal muscle of respiration.

Parts:

Central aponeurotic part (central sheet like tendon). It is fused with fibrous pericardium.
It is incompletely divided into three leaves, like a clover leaf.
It has no bony attachments.
It gives attachment to muscular fibres of diaphragm.

Muscular part is formed by skeletal muscle fibres, which converge to central tendon.
It is divided into three parts because of distinct origin of muscle fibres.

Sternal part consists of two slips that are attached to posterior aspect of xiphoid process of sternum, they converge radially to central tendon.

Costal part consists of wide muscular slips that arise from inferior six ribs and their costal cartilages on each side. They form right and left hemidiaphragms or domes.

Lumbar part arises from anterolateral surface of upper two (left) or three (right) lumbar vertebrae by two musculotendinous crura, which blend with anterior longitudinal ligament of vertebral column.

Right crus is broader and longer than **left crus**.
Crura are united opposite disc between T12 and L1 vertebrae by a tendinous band, called **median arcuate ligament**.
It passes over anterior surface of aorta and provides attachment for some fibres of right crus of diaphragm.

Lumbar part has **two arcuate ligaments** beside each crus:

Medial arcuate ligament (medial lumbocostal arch) – thickening of anterior layer of thoracolumbar fascia over psoas major muscle. It runs from crus of diaphragm anterior to psoas to transverse process ot L1 vertebra.

Lateral arcuate ligament (lateral lumbocostal arch) – thickening of anterior layer of thoracolumbar fascia over quadratus lumborum muscle. It runs from transverse process ot L1 vertebra to 12^{th} rib.

Triangles:

Sternocostal hiatus (of Morgagni) – between sternal and costal parts.
It contains superior epigastric vessels and limph vessels from liver.

Lumbocostal (vertebrocostal) – between lumbar and costal parts, just above lateral arcuate ligament (closed by fibrous membrane on left side).
This membrane separates left kidney from parietal pleura.

Triangles are potential places for internal herniations.

Diaphragmatic apertures:

Foramen for inferior vena cava

It is located at level of **intervertebral disc between T8 and T9** vertebrae, 2 to 3 cm to the right of median plane at posterior junction of right and anterior leaves of central tendon. Inferior vena cava is adherent to margin of vena caval foramen and when diaphragm contracts during inspiration, it widens foramen and stretches and dilates inferior vena cava, thus facilitating blood flow through it. Some branches of right phrenic nerve and lymph vessels also pass through this foramen.

Esophageal hiatus

It is located in muscular part in right crus of diaphragm, 2 to 3 cm to the left of median plane at level of **T10 vertebra.**

It transmits esophagus, anterior and posterior vagal trunks and esophageal branches of left gastric vessels.

Fleshy fibres of right crus form esophageal sphincter, which prevents reflux of gastric contents into esophagus during inspiration.

Aortic hiatus

It is located between **T12 vertebra** posteriorly and median arcuate ligament anteriorly to the left of median plane. Aorta passes posterior to median arcuate ligament and it does not pierce diaphragm, so it is unaffected by contraction of diaphragm.

Arterial supply

Superior & inferior phrenic arteries
Musculophrenic arteries
Pericardiacophrenic arteries

Venous drainage

Through veins, which accompany arteries

Lymphatic drainage

Lymph vessels run to the following lymph nodes: phrenic and from them to parasternal and posterior mediastinal or to superior lumbar (lateral aortic).

Innervation

Motor innervation – phrenic nerves (C3,4,5)

Sensory innervation – phrenic nerves, lower 6 intercostal nerves and subcostal nerves.

Role in pulmonary ventilation

When diaphragm contracts, its right and left domes move inferiorly so that it convexity is flattened. This descent of diaphragm increases vertical diameter of thoracic cavity in inspiration. It works almost solely during quite respiration. During forced inspiration its muscular portion contracts to maximal extent, drawing its central tendon inferiorly about 4-5 cm that increases volume of thoracic cavity and decreases intrathoracic pressure, resulting in air being taken into lungs. Elastic recoil of abdominal organs and abdominal muscles push it back causing expiration.

NERVE AND BLOOD SUPPLY TO THE INTERCOSTALS

V.A.N: Going from superior to inferior, the order of each intercostal space is vein, artery, nerve.
Origin of Intercostal Nerves:

- **Mixed Nerve:** Sensory Nerve Fibres come from the Dorsal Root of the spinal nerve. Motor Nerve Fibres come from the ventral root of the spinal nerve. These two merge together to become one spinal nerve.
- The mixed **Spinal nerve** divides into the dorsal ramus and ventral ramus. Ventral rami of thoracic spinal nerves are called **Intercostal nerves.**
- **Dorsal Ramus:** Innervates the back muscles.
- **Ventral Ramus:** Innervates the intercostal muscles
- The intercostal nerve also receives postganglionic fibers from the Sympathetic Chain Ganglia, the sympathetic part of the ANS.

Arterial Blood Supply to the intercostal muscles: **Intercostal Arteries (Anterior and Posterior)**. Anterior and posterior intercostals arteries anastomose at the intercostals space. The vasculature branches as follows:

- Subclavian Artery ------> Internal Thoracic Artery ------> Anterior Intercostal Arteriy (11 spaces anteriorly).
- Subclavian Artery ------> Costocervical Trunk ------> Supreme/highest Intercostal Artery ------> Posterior Intercostal Arteries (upper 2 spaces posteriorly).
- Descending Thoracic Aorta ------> Posterior Intercostal Arteries (from 3rd to 11th spaces posteriorly).
    - **Internal Thoracic Artery:** Travels from subclavian artery inferiorly, lateral to the sternum (12 mm laterally to sternal margin), deep to the costal cartilages.
    - **Costal Groove: Posterior and Anterior Intercostal** arteries, veins, and Intercostal nerves run along this path, on the inferior aspect of the ribs.

Clinical Application: To place a needle through the thoracic wall, it should be placed in the center of the intercostal space between adjacent ribs, because the vessels and nerves (VAN) run along each inferior border of the rib on the costal groove.

Overall the thoracic wall is supplied by the following arteries:

- **Anterior intercostal arteries to anterior half of upper six intercostal spaces (from Internal thoracic artery)**
- **Anterior intercostal arteries to anterior half of 7 – 9 intercostal spaces (from Musculophrenic artery)**
- **The first & second posterior intercostal arteries to posterior half of upper two intercostal spaces (from Superior intercostal artery)**
- **3rd to 11th Posterior intercostal arteries to posterior half of lower nine intercostal spaces (from Descending part of thoracic Aorta)**
- **Subcostal arteries – last paired branches of thoracic aorta below the twelfth ribs**
- **Dorsal scapular artery along medial border of scapula (from Subclavian artery) anastomoses with posterior intercostal arteries**
- **Superior thoracic artery descend along medial border of pectoralis minor muscle (from first part of Axillary artery)**
- **Thoracoacromial artery to pectoral region (from second part of Axillary artery)**
- **Lateral thoracic artery descend along lateral border of pectoralis minor muscle to serratus anterior and pectoral muscles (from second part of Axillary artery)**
- **Subscapular artery (from third part of Axillary artery) anastomoses with posterior intercostal arteries**

RESPIRATORY MUSCLES

• **Muscles involved in Inspiration:**	**Their nerve supply:**
Quiet and Forceful Inspiration	
• External intercostal	Intercostal nerves
• Diaphragm	Phrenic nerves
Forceful Inspiration	
• Scaleni (anterior, medius, posterior)	Ventral rami of cervical spinal nerves
• Sternocleidomastoid	Accessory nerve
• Serratus anterior	Long thoracic nerve
• Serratus posterior superior	Intercostal nerves
• Pectoralis major	Lateral & medial pectoral nerves
• Pectoralis minor	Medial & lateral pectoral nerves
• Levatores Costarum	Dorsal rami of thoracic spinal nerves
• Quadratus Lumborum	Ventral rami of spinal nerves T12 and L1-4

• **Muscles involved in Expiration:**	**Their nerve supply:**
Quiet and Forceful Expiration	
• Internal & innermost intercostals	Intercostal nerves
• Subcostals	Intercostal nerves
Forceful Expiration	
• Transversus thoracis	Intercostal nerves
• Rectus abdominis	Lower six intercostal and subcostal n-s
• Obliquus externus abdominis	Lower five intercostal & subcostal n-s
• Obliquus internus abdominis	Lower five intercostals & subcostal n-s and first lumbar spinal nerves
• Transversus abdominis	Lower five intercostal, subcostal n-s and first lumbar spinal nerves
• Latissimus dorsi	Thoracodorsal nerve
• Serratus posterior inferior	Lower three intercostal & subcostal n.

Table 1. Muscles of the pectoral region

Muscle	Origin	Insertion	Innervation	Function
Pectoralis major	Medial half of clavicle and anterior surface of sternum, first seven costal cartilages, aponeurosis of external oblique	Proximal part of humerus (lateral lip of intertubercular groove – Crest of greater tubercle)	Medial and lateral pectoral nerves	Adduction, medial rotation, and flexion of the humerus at the shoulder joint
Subclavius	Rib I at junction between rib and costal cartilage	Groove on inferior surface of middle third of clavicle	Nerve to sub-clavius	Pulls clavicle medially to stabilize sternoclavicular joint
Pectoralis minor	Anterior surfaces of the third, fourth and fifth ribs, and deep fascia overlying the related intercostal spaces	Coracoid process of scapula	Medial pectoral nerves	Depresses tip of shoulder; protracts scapula

Table 2. Muscles of the thoracic wall

Muscle	Superior attachment	Inferior attachment	Innervation	Function
External intercostal	Inferior margin of rib above	Superior surface of rib below	Intercostal nerves; T1-T11	Most active during inspiration; supports intercostal space; moves ribs superiorly
Internal intercostal	Lateral edge of costal groove of rib above	Superior surface of rib below deep to the attachment of the related external intercostals	Intercostal nerves; T1-T11	Most active during expiration; supports intercostal space; moves ribs inferiorly
Innermost intercostal	Medial edge of costal groove of rib above	Internal aspect of superior surface of rib below	Intercostal nerves; T1-T11	Acts with internal intercostal muscles
Subcostales	Internal surface (near angle) of lower ribs	Internal surface of next second or third rib below	Related inter-costal nerves	May depress ribs
Transversus thoracis	Lower margins and internal surfaces of cocostal cartilages of second to sixth ribs	Inferior aspect of deep surface of body of sternum, xiphoid process and costal cartilages ribs IV-VII	Related inter-costal nerves	Depresses costal cartilages

The Pleurae

Each lung is invested by an exceedingly delicate serous membrane, the **pleura,** which is arranged [1] in the form of a closed invaginated sac. A portion of the serous membrane covers the surface of the lung and dips into the fissures between its lobes; it is called the **pulmonary pleura.** The rest of the membrane lines the inner surface of the chest wall, covers the diaphragm, and is reflected over the structures occupying the middle of the thorax; this portion is termed the **parietal pleura.** The two layers are continuous with one another around and below the root of the lung; in health they are in actual contact with one another, but the potential space between them is known as the **pleural cavity.** When the lung collapses or when air or fluid collects between the two layers the cavity becomes apparent. The right and left pleural sacs are entirely separate from one another; between them are all the thoracic viscera except the lungs, and they only touch each other for a short distance in front; opposite the second and third pieces of the sternum the interval between the two sacs is termed the mediastinum.

Different portions of the parietal pleura have received special names which indicate their position: [2] thus, that portion which lines the inner surfaces of the ribs and Intercostales is the **costal pleura;** that clothing the convex surface of the diaphragm is the **diaphragmatic pleura;** that which rises into the neck, over the summit of the lung, is the **cupula of the pleura** (*cervical pleura*); and that which is applied to the other thoracic viscera is the **mediastinal pleura.**

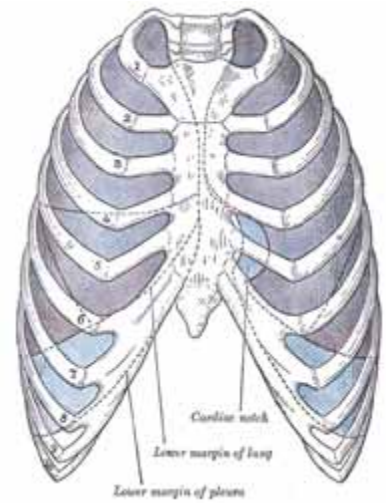

FIG. 965– Front view of thorax, showing the relations of the pleuræ and lungs to the chest wall. Pleura in blue; lungs in purple. (See enlarged image)

Reflections of the Pleura (Figs. 965, 966).—Commencing at the sternum, the pleura passes [3] lateralward, lines the inner surfaces of the costal cartilages, ribs, and Intercostales, and at the back part of the thorax passes over the sympathetic trunk and its branches, and is reflected upon the sides of the bodies of the vertebræ, where it is separated by a narrow interval, the **posterior mediastinum,** from the opposite pleura. From the vertebral column the pleura passes to the side of the pericardium, which it covers to a slight extent; it then covers the back part of the root of the lung, from the lower border of which a triangular sheet descends vertically toward the diaphragm. This sheet is the posterior layer of a wide fold, known as the **pulmonary ligament.** From the back

of the lung root, the pleura may be traced over the costal surface of the lung, the apex and base, and also over the sides of the fissures between the lobes, on to its mediastinal surface and the front part of its root. It is continued from the lower margin of the root as the anterior layer of the pulmonary ligament, and from this it is reflected on to the pericardium (**pericardial pleura**), and from it to the back of the sternum. Above the level of the root of the lung, however, the mediastinal pleura passes uninterruptedly from the vertebral column to the sternum over the structures in the superior mediastinum. *Below,* it covers the upper surface of the diaphragm and extends, in front, as low as the costal cartilage of the seventh rib; at the side of the chest, to the lower border of the tenth rib on the left side and to the upper border of the same rib on the right side; and *behind,* it reaches as low as the twelfth rib, and sometimes even to the transverse process of the first lumbar vertebra. *Above,* its cupula projects through the superior opening of the thorax into the neck, extending from 2.5 to 5 cm. above the sternal end of the first rib; this portion of the sac is strengthened by a dome-like expansion of fascia (**Sibson's fascia**), attached in front to the inner border of the first rib, and behind to the anterior border of the transverse process of the seventh cervical vertebra. This is covered and strengthened by a few spreading muscular fibers derived from the Scaleni.

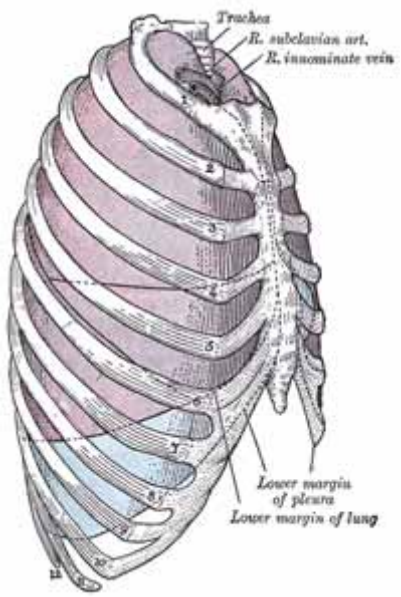

FIG. 966– Lateral view of thorax, showing the relations of the pleuræ and lungs to the chest wall. Pleura in blue; lungs in purple. (See enlarged image)

In the front of the chest, where the parietal pleura is reflected backward to the pericardium, the [4] two pleural sacs are in contact for a short distance. At the upper part of the chest, behind the manubrium, they are separated by an angular interval; the line of reflection being represented by a line drawn from the sternoclavicular articulation to the mid-point of the junction of the manubrium with the body of the sternum. From this point the two pleuræ descend in close contact to the level of the fourth costal cartilages, and the line of reflection on the right side is continued downward in nearly a straight line to the xiphoid process, and then turns lateralward, while on the left side the line of reflection diverges lateralward and is continued downward, close to the left border of the sternum, as far as the sixth costal cartilage. The inferior limit of the pleura is on a considerably

lower level than the corresponding limit of the lung, but does not extend to the attachment of the diaphragm, so that below the line of reflection of the pleura from the chest wall on to the diaphragm the latter is in direct contact with the rib cartilages and the Intercostales interni. Moreover, in ordinary inspiration the thin inferior margin of the lung does not extend as low as the line of the pleural reflection, with the result that the costal and diaphragmatic pleuræ are here in contact, the intervening narrow slit being termed the **phrenicocostal/costodiaphragmatic sinus.** A similar condition exists between the mediastinum and diaphragm – **mediastinodiaphragmatic sinus** and behind the sternum and rib cartilages, where the anterior thin margin of the lung falls short of the line of pleural reflection, and where the slit-like cavity between the two layers of pleura forms what is called the **costomediastinal sinus.**

5 The line along which the right pleura is reflected from the chest-wall to the diaphragm starts in front, immediately below the seventh sternocostal joint, and runs downward and backward behind the seventh costal cartilage so as to cross the tenth rib in the mid-axillary line, from which it is prolonged to the spinous process of the twelfth thoracic vertebra. The reflection of the left pleura follows at first the ascending part of the sixth costal cartilage, and in the rest of its course is slightly lower than that of the right side.

6 The free surface of the pleura is smooth, polished, and moistened by a serous fluid; its attached surface is intimately adherent to the lung, and to the pulmonary vessels as they emerge from the pericardium; it is also adherent to the upper surface of the diaphragm: throughout the rest of its extent it is easily separable from the adjacent parts.

7 The right pleural sac is shorter, wider, and reaches higher in the neck than the left.

8 **Pulmonary Ligament (*ligamentum pulmonale; ligamentum latum pulmonis*).**—From the above description it will be seen that the root of the lung is covered in front, above, and behind by pleura, and that at its lower border the investing layers come into contact. Here they form a sort of mesenteric fold, the pulmonary ligament, which extends between the lower part of the mediastinal surface of the lung and the pericardium. Just above the diaphragm the ligament ends in a free falciform border. It serves to retain the lower part of the lung in position.

9 **Structure of Pleura.**—Like other serous membranes, the pleura is covered by a single layer of flattened, nucleated mesothelial cells, united at their edges by cement substance. These cells are modified squamous epithelial, and rest on a basement membrane. Beneath the basement membrane there are net-works of yellow elastic and white fibers, imbedded in ground substance which also contains connective-tissue cells. Bloodvessels, lymphatics, and nerves are distributed in the substance of the pleura.

10 **Vessels and Nerves.**—The **arteries of the pleura** are derived from the intercostal, internal mammary, musculophrenic, thymic, pericardiac, and bronchial vessels. The **veins** correspond to the arteries. The **lymphatics** are described on page 719. The **nerves** are derived from the phrenic and intercostal nerves for the parietal pleura and parasympathetic (vagal) and sympathetic nerves for the visceral pleura. (Luschka). Kölliker states that sympathetic nerves accompany the ramifications of the bronchial arteries in the pulmonary pleura..

ANATOMY TABLES

THORAX, MUSCLES OF RESPIRATION, PLEURA AND PLEURAL CAVITIES

Osteology		
Bone	**Structure**	**Description**
rib 3-9 (typical ribs)	head	posteromedial end; articulates with semi facets of adjacent vertebral bodies
	neck	constriction lateral to head
	tubercle	posteroinferior projection lateral to neck; articulates with transverse process of vertebra
	body	shaft is twisted
	angle	marked angulation of body lateral to tubercle
	costal groove (sulcus)	on inner surface of inferior border of body; accommodates intercostal neurovascular bundle
rib 1	scalene tubercle	superior surface, between grooves for subclavian vein & artery; attachment of scalenus anterior
rib 2	articulates via costal cartilage with sternum at sternal angle	attachment of scalenus posterior, shaft is not twisted
rib 8-10	belong to "false" ribs; (8 – 12) articulate via costal cartilages with costal cartilage of rib 7	
rib 11-12	"floating" ribs; anterior ends do not articulate with sternum, indirectly or directly	
sternum	manubrium	superior part
	jugular (suprasternal) notch	superior border of manubrium, between clavicular notches
	sternal angle	junction of manubrium & body; located at the level of the T4/T5 intervertebral disk
	body	articulates with manubrium & xiphoid process
	xiphoid process	variable in size, shape & ossification; articulates with body at the level T9

Muscles					
Muscle	**Origin**	**Insertion**	**Action**	**Innervation**	**Notes**
external intercostal	lower border of rib above	upper border of rib below, coursing, down & medially in front	elevates rib, keeps intercostal space from blowing out or sucking in during respiration	intercostal nerves (T1-T11)	continuous with the external intercostal membrane anteriorly at the costochondral junction
innermost intercostal	upper borders	fibers course up and medially to	depresses rib, keeps intercostal	intercostal nerves (T1-	innermost intercostal, subcostalis, and transversus

	of ribs below at mid-portion	insert on the inferior margin of the rib above	space from blowing out or sucking in during respiration	T11)	thoracis mm. lie deep to the intercostal neurovascular bundle
Muscle	**Origin**	**Insertion**	**Action**	**Innervation**	**Notes**
internal intercostal	upper border of rib below	lower border of rib above, coursing up and medially in front	depresses rib, keeps intercostal space from blowing out or sucking in during respiration	intercostal nerves (T1-T11)	continuous posteriorly with the internal intercostal membrane at rib angles
subcostalis	angle of ribs below	angle of 2-3 ribs above origin	depresses ribs, compresses intercostal spaces	intercostal nerves	subcostalis, transversus thoracis & innermost intercostal mm. make up the innermost intercostal muscle layer
transversus thoracis	posterior aspect of sternum	costal cartilages of 2-6 ribs	depresses ribs, compresses thorax for forced expiration	intercostal nerves 2-6	transversus thoracis, subcostalis & innermost intercostal mm. make up the innermost intercostal muscle layer

Nerves					
Nerve	**Source**	**Branches**	**Motor**	**Sensory**	**Notes**
intercostal	ventral primary rami of T1-T11	lateral & anterior cutaneous brs.	intercostal muscles; abdominal wall muscles (via T7-T11); muscles of forearm & hand (via T1)	skin of chest & abdomen anterolaterally; skin of medial side of upper limb (via T1-T2)	travels below posterior intercostal a. in the intercostal space
subcostal	ventral primary rami of T12	lateral & anterior cutaneous brs.	muscles of abdominal wall	skin of the anterolateral abdominal wall	
phrenic	brs. of C3-C5 ventral primary rami	pericardial brs.	diaphragm	pericardium & mediastinal, diaphragmatic & costal pleurae	crosses the anterior surface of the anterior scalene m.
vagus	medulla: dorsal motor nucleus (preganglionic parasympathetic) and nucleus	auricular br., pharyngeal br., superior laryngeal, superior & inferior cervical cardiac brs., recurrent laryngeal, thoracic cardiac brs., anterior and	intrinsic muscles of larynx, pharynx (except stylopharyngeus), & palate (except tensor veli palatini); preganglionic processes synapse in small ganglia within or	skin of external auditory meatus; viscera of head, neck, thorax & abdomen proximal to splenic flexure; taste to epiglottis	also known as: CN X, 10th cranial nerve; passes through jugular foramen; vagus means "wanderer" in reference to its

	ambiguus; superior and inferior ganglia	posterior brs. to pulmonary plexus, esophageal plexus, anterior & posterior vagal trunks	near viscera of thorax and abdomen; postganglionic processes from these ganglia supply smooth muscles of respiratory tree & gut (proximal to splenic flexure), heart or are secretomotor to mucous glands of larynx, bronchial tree, pharynx & gut, digestive glands		extensive distribution to the body cavities

Arteries				
Artery	**Source**	**Branches**	**Supply**	**Notes**
intercostal, posterior	supreme/highest intercostals-branch of subclavian: (upper 2 spaces), descending thoracic aorta (3rd-11th spaces)	posterior br., spinal br., anterior br., collateral br., lateral cutaneous br.	intercostal muscles posteriorly & laterally & overlying muscles, spinal cord & vertebral column & back muscles, skin & superficial fascia posteriorly & laterally	
internal thoracic	subclavian (1st part)	pericardiophrenic, perforating brs., anterior intercostal aa., mediastinal brs., thymic brs., musculophrenic a., superior epigastric a.	mediastinum, anterior thoracic & abdominal walls, respiratory muscles, diahragm	is continuous as superior epigastric artery
superior epigastric	internal thoracic		upper rectus abdominis, upper abdominal wall	direct continuation of the internal thoracic a.; anastomoses with inferior epigastric within rectus abdominis m.
Musculophrenic	internal thoracic	anterior intercostal (spaces 7-10 or 11)	anterior diaphragm, intercostal spaces 7-10 or 11 anteriorly	
intercostal, anterior	internal thoracic (upper 6 spaces), musculophrenic (7-10th spaces)		intercostal muscles anteriorly, overlying muscles skin	2 anterior intercostals per side per space, running above & below the ribs
bronchial,	descending	right bronchial	lower trachea, bronchial	usually 2 in number

left	thoracic aorta	(occasionally)	tree	
bronchial, right	third right posterior intercoctal		lower trachea, bronchial tree	usually 1 in number
pulmonary trunk	right ventricle	right & left pulmonary	lungs	

Veins				
Vein	**Tributaries**	**Drains Into**	**Region Drained**	**Notes**
intercostal, posterior	lateral cutaneous v.	1st: brachiocephalic; 2nd-4th: superior intercostal; right 5th-11th: azygos; left 5th-7th or 8th: accessory hemiazygos; left 9th-11th: hemiazygos	intercostal space including skin, muscles & adjacent ribs; spinal cord segment & corresponding vertebra	
intercostal, superior	2nd-4th posterior intercostal vv.	right: arch of azygos; left: left brachiocephalic	intercostal spaces 2-4	
pulmonary	lobar vv.	left atrium	lungs	usually two pulmonary vv. per side, superior & inferior; empty into left atrium
azygos	right 5th-11th posterior intercostals, accessory hemiazygos, hemiazygos	superior vena cava	posterior wall of thorax and abdomen, bronchi, eosophagus	

Topographic Anatomy		
Structure/Space	**Boundaries/Description**	**Significance**
parasternal line	location: vertical line passing beside sternum	
midclavicular line	location: vertical line passing through midshaft of clavicle	inferior border of lung with visceral pleura crosses it at level of 6 rib; inferior border of parietal pleura crosses it at level of 7 rib
anterior axillary line	location: vertical line passing through anterior border of axilla	inferior border of lung with visceral pleura crosses it at level of 7 rib; inferior border of parietal pleura crosses it at level of 8 rib

midaxillary line	location: vertical line passing through middle of axilla	inferior border of lung with visceral pleura crosses it at level of 8 rib; inferior border of parietal pleura crosses it at level of 9 rib
posterior axillary line	location: vertical line passing through posterior border of axilla	inferior border of lung with visceral pleura crosses it at level of 9 rib; inferior border of parietal pleura crosses it at level of 10 rib
scapular line	location: vertical line passing through inferior scapular angle	inferior border of lung with visceral pleura crosses it at level of 10 rib; inferior border of parietal pleura crosses it at level of 11 rib
Structure/Space	**Boundaries/Description**	**Significance**
paravertebral line	location: vertical line passing beside vertebral column	inferior border of lung with visceral pleura crosses it at level of 11 rib; inferior border of parietal pleura crosses it at level of 12 rib
nipple	location: 4th intercostal space in male and prepuberal female	may be used to help locate apex of heart, approx. 4 finger breadths from midline in left 5th intercostal space, or middle lobe of right lung
sternal angle	location: junction of manubrium & body of sternum (manubriosternal symphysis), where costal cartilage of 2nd rib attaches to sternum	horizontal plane through sternal angle passes through T4/5 intervertebral disc, marking inferior boundary of superior mediastinum
suprasternal (jugular) notch	location: superior border of manubrium between sternoclavicular joints	jugular venous arch located above it
thoracic inlet	boundaries:T1 vertebral body; clavicular & jugular notches of manubrium; inner borders of 1st ribs	marks boundary between neck and superior mediastinum
thoracic outlet	boundaries: 12th ribs, costal cartilages of ribs 7-12, xiphisternal joint, T12 vertebral body	closed by thoraco-abdominal diaphragm

Lymphatics					
Structure	**Location**	**Afferents from**	**Efferents to**	**Regions drained**	**Notes**
bronchomediastinal trunk	along brachiocephalic v.	union of efferents from paratracheal nodes, parasternal nodes, anterior mediastinal nodes	left: thoracic duct; right: right lymphatic duct	thoracic wall & viscera, medial part of breast	right bronchomediastinal trunk receives lymph from lower lobe of left lung; bronchomediastinal trunk may drain to venous system separately on either side

bronchopulmonary nodes	hilum of lung	pulmonary nodes	tracheobronchial nodes	lung	also known as: hilar nodes
hilar nodes	at hilum of lung	pulmonary nodes	tracheobronchial nodes	lung	also known as: bronchopulmonary nodes
mediastinal nodes, anterior	posterior aspect of sternum		broncho-mediastinal trunk	thymus, anterior diaphragm & pericardium, some areas of heart	
mediastinal nodes, posterior	along azygos system of veins & esophagus		thoracic duct & inferior & superior tracheobronchial nodes	posterior mediastinum, posterior aspect of heart & pericardium, posterior diaphragm	
Structure	**Location**	**Afferents from**	**Efferents to**	**Regions drained**	**Notes**
paratracheal nodes	lateral to trachea & esophagus	superior tracheobronchial nodes	bronchomediastinal trunk	lungs, trachea, upper esophagus, larynx below vocal folds	
pulmonary nodes	within the lung parenchyma		Bronchopulmonary/hilar nodes	lung parenchyma, bronchial tree within lungs	
tracheobronchial nodes, inferior	inferior to tracheal bifurcation	bronchopulmonary nodes	right superior tracheobronchial nodes	lower lobes of lungs, middle & post. mediastinum	
tracheobronchial nodes, superior	superolateral to tracheal bifurcation	bronchopulmonary nodes, inferior tracheobronchial nodes (to right)	paratracheal nodes	lungs, middle & post. mediastinum	inferior tracheobronchial nodes drain lymph from lower lobe of left lung to right superior tracheobronchial nodes

Viscera/Fascia		
Organ	**Location/Description**	**Notes**
fascia, endothoracic	connective tissue between inner aspect of chest wall & costal parietal pleura	equivalent to transversalis fascia layer of the abdomen
pleura	serous lining of pleural cavity; visceral pleura covers lungs; parietal pleura lines the walls of pleural cavity	parietal pleura is sensitive to pain but visceral pleura is not
pleura, cervical parietal	serous lining of pleural cavity extending above level of 1st rib; continuous inferiorly with costal & mediastinal pleura; reinforced by scalene fascia	also known as: cupula or cervical dome
pleura, costal parietal	serous lining of pleural cavity on the ribs, costal cartilages, & intercostal mm.; continuous anteriorly with	

	mediastinal parietal pleura at costomediastinal reflection; continuous posteriorly with mediastinal pleural at vertebral bodies; continuous inferiorly with diaphragmatic pleura at costodiaphragmatic reflection; continuous superiorly with cervical pleura above 1st rib	
pleura, diaphragmatic parietal	serous lining of pleural cavity on superior surface of diaphragm; continuous superiorly with costal pleura at costodiaphragmatic reflection; continuous superomedially with mediastinal pleura at mediastinodiaphragmatic reflection	
pleura, mediastinal parietal	serous lining of pleural cavity lying on lateral surface of mediastinum; continuous anteriorly with costal pleura at costomediastinal reflection; continuous inferiorly with diaphragmatic pleura; continuous posteriorly with costal pleura lateral to vertebral bodies; continuous superiorly with cervical pleura above level of 1st rib	