Lung Anatomy & Function

- Prime role of lung = gas exchange
- Other roles of lung:
  - Metabolizes compounds
  - Filter of FB
  - Acts as reservoir for blood

Equations

Partial Pressure of Gas

- Partial pressure of gas = concentration x total pressure
  - Eg dry air had 21% O2
    - @ sea level pressure = 760mmHg. Po2 @ sea level = 20.93/100 x 760 = 159mmHg
- When air inhaled it is warmed & humidified
- This causes a drop in PO2 because water vapour dilutes it
  - Water vapour pressure (P_{H2O}) = 49mmHg ⇒ total dry gas pressure = 760 - 49 = 711
  - Po2 inspired air = 21/100 x 711 = 149mmHg
  - this is Daltons Gas low of partial pressures in action

Alveolar Gas Equation

- Allows calculation of:
  - relationship PAO2 and PACO2
  - calculation of ideal A-a PO2 difference [D(A-a)O2]
    - = index of
      - V/Q mismatch ±
      - shunt ±
      - diffusion abnormalities
  - alveolar PAO2 = balance between:
    - delivery O2 to alveoli (in inspired gas)
    - O2 uptake into pulmonary capillaries
    - actual alveolar gas cannot be sampled directly because end expired gas contains alveolar dead space gas
- Premise for equation is that effect of shunt & V/Q mismatch do NOT ⇒ impt differences between PaCO2 and PACO2
  - ie PaCO2 ~ PACO2 (see shunt/VQ mismatch section)
- R = ratio of CO2 production (VCO2) and O2 consumption (VO2)
  - = ~0.8 (V/Q value for whole lung is also 0.8)
  - determined by dietary substances used for metabolism ie carbohydrates, proteins, fats
    - all have own individual RQ's
- F = small correction factor:
  - Due to an additional effect of the RQ ie the expired gas volume differs from inspired volume
  - ~2mmHg on RA
  - can be higher if on 100% O2
  - usually ignored

- \( \frac{P_AO2}{R} = \frac{P_fO2 - PACO2}{R} + F \)
  - F= small correction factor (~2mmHg)
  - R = respiratory quotient (~0.8)
    - determined by CO2 production/O2 consumption
    - ie metabolism of tissues in steady state
  - \( P_fO2 = \) composition of inspired gas (0.21x (760-49))

- \( \therefore \) PAO2 using norm values = 100mHg
  - 02% in alveolar gas ~ 14% [(100/150) x 21% = 14%]
Other Forms of Equation

\[ P_A O_2 = F_i O_2 (P_B - P_H_2O) - \frac{P_A CO_2}{R} + F \]

Or.....

\[ P_A O_2 = P_i O_2 - P_a CO_2 (P_i O_2 - P_E O_2) \]

\[ P_E CO_2 \]

\[ \text{does not require RQ} \]

Boyles Law

- \( PV = K \)
- Pressure x volume is constant (at a constant temp)

Blood Gas Interface

- \( O_2 \) & \( Co_2 \) move by simple diffusion along gradient of partial pressure
- Ficks Law: - see later
- Blood-gas barrier very thin and very large surface area – 50 to 100 \( m^2 \)
- 500 million alveoli

Airways & Airflow

- conduction zone:
  - trachea \( \Rightarrow \) main bronchi \( \Rightarrow \) lobar bronchi \( \Rightarrow \) segmental bronchi \( \Rightarrow \) terminal bronchioles \( \Rightarrow \)
- respiratory zone:
  - \( \Rightarrow \) resp bronchioles \( \Rightarrow \) alveolar ducts \( \Rightarrow \) alveoli
    - lined continuously with alveoli
    - have occasional alveoli off
- anatomic dead space = conduction zone
  - \( \sim \) 150mls

- respiratory zone = alveolated region
  - \( \sim 2.5-3 \) litres
- acinus = portion of lung distal to terminal bronchiole
- inspiration by down diaphragm & up ribs \( \Rightarrow \) cross sectional area of lungs \( \Rightarrow \) volume of lungs \( \Rightarrow \) bulk flow of air down to terminal bronchioles
- @terminal bronchioles little further forward velocity of air
  - \( \Rightarrow \) in resp zone diffusion is mechanism of ventilation
- speed of diffusion of gas molecules \( <1 \)sec

Pressures

- elastic, passive return to preinsp volume
- lungs operate in low pressure system:
  - 500ml breath requires distending pressure \( <3 \)cm water
  - air flow 1litre/sec in inspiration requires pressure drop \( <2 \)cm water

Layers O2 must Cross

- surfactant \( \Rightarrow \) epithelial cell \( \Rightarrow \) interstitium \( \Rightarrow \) endothelial cell \( \Rightarrow \) plasma \( \Rightarrow \) red cell membrane

Blood Vessel & Flow

- Diameter of pulmon capillary 7-10um – just large enough for rbc
• Dense network around alveoli = sheet of blood in alveolar wall
• Extreme thinness of blood-gas barrier (<0.3um) means susceptible to pressure damage or volume
  \(\Rightarrow\) may leak plasma or rbc into alveolar space
• Pulmon artery ~15mmHg \(\Rightarrow\) flow ~6litres/min
  \(\Rightarrow\) very low pressure system allowing high flow
• Each rbc:
  o spends \(\approx 0.75\)second in capillary network
  \(\Rightarrow\) enough time for complete equilibrium in O2 & CO2
  \(\Rightarrow\) down to 0.3 sec in high exercise
  o traverses 2-3 alveoli
• bronchial circulation – supplies blood to conducting airways
  \(\Rightarrow\) can actually function well without it eg in lung transplant
• volume of adult pulm capillary bed ~ 80 – 100ml

**Stability of Alveoli**
• lung = 500million bubbles each 0.3mm diameter
• surfactant secreted to \(\downarrow\) surface tension otherwise inevitable collapse
• layers \(\sigma\)2

**Removal of inhaled Particles**
• endothelium surface area up to 120\(m^2\) \(\Rightarrow\) large target for pathogens/FBs
• mechanisms of defence:
  o nose – filters large particles
  o mucus in conducting airways – proximal escalator of mucus via cilia removes smaller particles
  o MPs & leukocytes – remove particles in
  o alveoli
By Adam Hollingworth

**Lecture 22**

**MUSCLES & MECHANICS OF RESPIRATION**

able to:

1. Analyse mm work in
   - Inspiration
   - Expiration
   - Forced expiration

2. Describe movements of
   - Diaphragm
   - Ribs - bucket + pump handle
   - Joint of thorax
   - Changes in thoracic dimension

**Diaphragm**

- Large dome-shaped sheet of mm
- Separates thorax from abdomen
- Great dome is quite high T6-T7 level
- mm is lower post. than anteriorly
  - S also beneath heart + lung
  - Above viscera

made of 3 areas of fibres:

- **Sternal fibres** - from sternum
- **Costal fibres** - from ribs...
- **Crural fibres** - from vertebrae (via lig known as "crus")

All fibres converge onto the **central tendon**

- **Sternal fibres**
  - 2 slips from post. of body of sternum & xiphoid process
  - Posteriorly
  - Central tendon
2. **COSTAL FIBRES**

- strongest & best-developed
- have most influence on thoracic dimension
- make up majority of mm
- inner surfaces lower 6 ribs
  (interdigitating with transversus abdominis)
- each up over abdominal contents
- central tendon

are 2 domes called *cupilla* - right
  left

the right is better developed as is over liver = a solid organ
left (*cupilla* over stomach = a hollow organ

& left *cupilla* aid it easier to overcome abdominal pressure

3. **CRURAL FIBRES**

named as arise from right & left crus

right crus: from bodies of L1, 2, 3
  + intervening discs
left crus: from bodies of L1, 2
  + intervening disc

superior ends are connected by *median arcuate ligament*

- create aortic opening for passage of
  aorta thru to abdomen

**Comments**

- *median arcuate lig*
- *median arcuate lig → O: L2*
  I: transverse processes L1
- *lat arcuate lig → O: transverse processes L1*
  I: Ri2 (rib)

arcuate lig, formed by thickenings in deep thoraco-lumbar fascia

arcuate lig forms space for psoas major to pass thru

but allows quadratus lumborum thru
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**OPENINGS IN CAPUT ARAEUM**

- 3 openings between thoracic + abdominl cavities
  - aorta
  - vena cava
  - oesophagus

**AORTA** (+ cavae + thoracic duct)

- at level T12
- formed by median arcuate ligament between diaphragm

**OESOPHAGUS**

- 2.5 cm to left side of body
- formed by aorta from right ans
- split slightly to left + form tunnel of fascia

**VENA CAVA**

- level TB
- thin, right side central tendon

**RELATIONS TO CAPUT ARAEUM**

- superiorly are 3 membranes:
  - parietal pleura
  - visceral pleura
  - pericardium

**diaphragm lined by parietal peritoneum**

**two phrenic nerves:** C3, C4, C5

**further sensory from:** T7-T12
**Actions of Diaphragm**

- Main muscle of inspiration.
- In quiet breathing, it contracts ⇒ Vertical diameter of thorax.
- With ribs fixed, contraction of diaphragm pulls central tendon from T8 ⇒ T12 ⇒ 1.5 cm.
-Expiration is passive thru elastic recoil of lungs.

**Bucket Handle**

- Inf. surface of diaphragm in contact with abdominal viscera.
- When contact intra-abdominal pressure = caused, elevation of the abdomen.
- Tendon then prevented from further descent (as of intra-abdominal pressure).
- Tendon becomes fixed.
- Lower 6 ribs are lifted upwards + outwards.
- Thru lat diameter of thorax ⇒ [as two ends of ribs are higher than mid of rib].

**Pump Handle**

- Occurs higher in thorax.
- Sternum is pushed upward + downward.
- Cause: P in A-P diameter of thorax.
- Is done predominately by higher ribs.
- Diaphragm only assist.

**Summary**

- Bucket handle: Primarily diaphragm
- Pump handle: Diaphragm only assist.

- Diaphragm descends 1.5 cm in quiet respiration.
- 10 cm in deep respiration.

**Other Functions of Diaphragm**

- 0: Delegation - pco
- 5: Parturition - popping
- 3: Vomiting
- 0: Mitre - wee
THE INTERCOISTAL MUS

at 3 mm's found between adjacent ribs:

- external intercostals = outermost
- internal intercostals = middle
- intimi or innermost intercostals = deepest

membranous layer

11 on each side
1st set between ribs 1 and 2

1. EXTERNAL INTERCOISTALS

O: rib border of rib above from transverse to costo-chondral junction
A: obliquely downward + forward
I: upper border of rib below

2. INTERNAL INTERCOISTALS

O: in front of rib above from sternum ant to angle of rib (2nd rib from spine = posterior)
A: obliquely down + back
I: rib below

NB between intimi + internal intercostals = thoracic nerve, artery, vein

3. INTIMI INTERCOISTALS

= poorly developed mms
represented some as internal intercostals
run from internal surface of adjacent ribs.

ATHERM SUPPLY

anterior primary rami of adjacent thoracic nerve
ie T2 supply 1st set of intercostals

ACTIONS

externals: assist in lifting of rib below during inspiration
internal & intimi: maintaining intercostal space during respiration

contraction during inspiration makes rib protrude respiration
bulging in expiration)
LEUPTORES COSTORUM

O: small strong triangular mm between C7 + T1
I: upper border nb below near tubercle
R: down + laterally forming rt
A: elevate nb in inspiration

SEMITARS POSTERIOR SUPERIOR

O: lower pt of ligamentum nuchae + spinous process of C7 to T3
I: down + lat
R: lateral to angle of nb of A2 - A5
A: assist inspiration

SEMITARS POSTERIOR INFERIOR

O: lie deep to lat dorso
I: spinous process T11 + L2
R: horizontal
I: lower 4 nb at their angles
A: assist expiration

TRANSVERSUS THORACIS

O: on inner aspect of ant thoracic wall
I: post of spinous process
R: lower 1/2 body of sternum
I: 4-7th costal cartlages
A: lower 7 horizontal
[upper] upward + lateral
I: inner surface of 2 - 6th costal cartlages
A: equilibration
[lower] costal cartlages down
SUBCOSTALS
- Inclined slips extending across one/two intercostal spaces
- Attach to inner surface of rib near angle
- Most developed in lower thoracic
- Depress ribs: expiratory

**Bucket handle of ribs**
- Predominantly in lower ribs 7-10
- Axis thru costo-vertebral joint to chondro-sternal joint

---

Rib lift upward + outward
Due to: axis of movement
ii. Plane motion of costo-transverse joints
iii. Transverse diameter of thorax
- costo-transverse joint → inspiration: upward slide of rib rib on transverse process
- costo-sternal → imp: sup roll + int slide
  expire: opposite
- sternal-costal → imp: sup roll + int slide
  expire: opposite
PUMP HANDLE AT RIB

occur in upper rib \( \Rightarrow \) 2 \( \Rightarrow \) 5

muscles rotate/extend joint to costo-transverse joint

extends able to lift upwards + forwards

arcuate/convergent relationship of articular surfaces in costo-transverse joint

allows rolling of rib

by accessory mns of inspiration (+ intercostals)
Chest Wall Viscera

- Layers of pleura (outside > inside)
  - int surface of thoracic wall:
    - made up of sternum, ribs, costal cartilage's, intercostal mms & membranes, sides of Tx vertebræ
  - endothoracic fascia - thin loose layer of connective tissues
  - parietal pleura -
    - consists of 4 parts:
      - costal
      - mediastinal
      - diaphragmatic
      - cervical pleura
  - pleural cavity -
    - filled with serous pleural fluid
    - surface tension of fluid provides cohesion which keeps lung in contact with thoracic wall
  - visceral pleura
  - lung
Lung

Bronchial tree Anatomy

- trachea -
  - located in superior mediastinum
  - bifurcates at level of transverse thoracic plane

- > main bronchi:
  - right = wider, shorter, runs more vertically
  - left = passes:
    - posterior to arch of aorta
    - ant to oesophagus & thoracic aorta to reach hilum

- main bronchi > secondary lobar bronchi:
  - 2 lobar bronchi on L
  - 3 lobar bronchi on R
  - supply each lobe

- each lobar bronchi > several tertiary segmental bronchi - supply bronchopulmonary segments

- bronchopulmonary segments =
  - largest subdivision of lobe
  - pyramidal shaped: apex facing lung root & bases at pleural surface
  - separated from other segments by connective tissue septa
  - supplied independently by tertiary branch of pulmonary artery
  - drained by pulmon veins which lie in connective tissue inbetween adjacent segments
  - 10 segments R lung, 8-10 in L lung
  - surgically resectable

- beyond tertiary segmental bronchi > 20-25 generations of conducting bronchioles > terminal bronchioles

- terminal bronchioles = smallest conducting bronchioles:
  - features:
    - lack cartilage
    - not involved in gas exchange

- terminal bronchioles > respiratory bronchioles > 2-11 alveolar ducts > 5-6 alveolar sacs

- resp bronchioles & below = involved in gas exchange directly

- alveolar ducts =
  - elongated airways
  - densely lined with alveoli
  - lead to common spaces = sacs

- 300million alveoli

- still gaining alveoli until ~8yrs old

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Airway Resistance Through Generations

Vasculature of Lungs & Pleura

**Pulmonary A&V**

- each lung has
  - 1 pulmon artery supplying
  - 2 pulmon veins draining
- each artery divides into secondary lobar arteries > segmental arteries
  - then follow into segments as described above
- R & L superior lobe arteries arise before pulmon artery enters hilum
- veins:
  - superior & inf pulmonary vein on each side drain to LA
  - middle lobe vein is a tributary to R superior pulmonary vein
**Bronchial A&V**

- bronchial arteries supply blood & nutrition to structures of
  - root of lung
  - supporting tissues of lung
  - visceral pleura
  - upper oesophagus
- 2 L bronchial arteries - directly from Tx aorta
- 1 R bronchial artery - varied origin ie either:
  - upper posterior intercostal arteries (most common)
  - aorta
  - common trunk with L superior bronchial artery
- bronchial veins
  - drain only parts of lung supplied by bronchial arteries ie proximal lung
  - other parts supplied by bronchial arteries drained separately
  - R bronc vein > azygous vein
  - L bronc vein > accessory hemiazygous vein or L superior intercostal vein

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