Respiratory System – Revision notes

- Cells need energy for all metabolic activities

- Most energy is derived from chemical reactions
  - Can only take place in presence of oxygen
  - Main waste product is carbon dioxide

- Respiratory system supplies the route by which oxygen enters the body – also provides the route for excretion of carbon dioxide

- Condition of atmospheric air entering body varies according to the external environment
  - Dry
  - Cold
  - Moist
  - Hot

- As inhaled air moves through the air passages to reach lungs it is cooled or warmed by body temperature
  - Moistened to become saturated with water vapour and ‘cleaned’ as particles of dust stick to the mucus lining membrane

- Blood transports oxygen and carbon dioxide between lungs and cells of body
  - Oxygen from lungs to cells
  - Carbon dioxide from cells to lungs

- Exchange of gases between:
  - Blood and lungs = external respiration
  - Blood and cells = internal respiration

Nose and Nasal cavity

- Main route of air entry

- Consists of a large irregular cavity divided into two equal passages by a septum
  - Posterior-bony part – formed by the perpendicular plate of the ethmoid bone and the vomer
  - Anteriorly – consists of hyaline cartilage

- Roof – formed by the cribriform plate of the ethmoid bone and sphenoid bone, frontal bone and nasal bones
Floor – formed by the roof of mouth – consists of hard palate and soft palate
  - Consists of involuntary muscle
  - Composed of maxilla and palatine bones

Medial wall – formed by the septum

Lateral walls – formed by maxilla, ethmoid bone and inferior conchae

Posterior wall – formed by posterior wall of the pharynx

**Lining of the Nose**

- Lined with vascular ciliated columnar epithelium (*ciliated mucous membrane*)
  - Contains mucus-secreting goblet cells

- At anterior nares (*nostrils*) membrane blends with the skin

- Posteriorly extends into nasal part of pharynx

**Openings into the Nasal Cavity**

- Anterior nares are openings from the exterior into nasal cavity

- Nasal hairs coated in sticky mucus are present

- Posterior nares are openings from nasal cavity to the pharynx

- Paranasal sinuses are cavities in bones of the face and cranium – contain air
  - Tiny openings between Paranasal sinuses and nasal cavity
    - Lined with mucous membrane
    - Continuous with nasal cavity
  - Main sinuses:
    - Maxillary sinuses – lateral walls
    - Frontal and sphenoidal sinuses – in roof
    - Ethmoidal sinuses – upper part of lateral walls
  - Sinuses function in speech and lighten the skull

- Nasolacrimal ducts extend from lateral walls of nose to conjunctival sacs of eye (drain tears)
Respiratory Function of the Nose

- Begins process by which air is warmed, moistened and filtered

- Projecting conchae increase surface area and cause turbulence, spreading inspired air over the whole nasal surface
  - Maximises warming, humidification and filtering
- Warming: due to immense vascularity of the mucosa

- Filtering and cleaning: occurs as hairs at anterior nares trap large particles. Smaller particles (dust and microbes) settle and adhere to mucus
  - Protects underlying epithelium from irritation and prevents drying
  - Synchronous beating of the cilia wafts the mucus towards the throat where it is swallowed or coughed up (expectorated)

- Humidification: as air travels over the moist mucosa it becomes saturated with water vapour
  - Irritation of nasal mucosa results in sneezing – reflex action that forcibly expels an irritant

Olfactory Function

- Nerve endings detect smell
  - Located in roof of nose in area of cribriform plate of ethmoid bones and superior conchae
  - Stimulated by airborne odours
  - Resultant nerve impulses – conveyed by olfactory nerves to the brain where sensation of smell is perceived

Pharynx

Position

- Tube 12-14cm – extends from base of skull to level of 6th cervical vertebra
- Lies behind the nose, mouth and larynx – wider at upper end
Structures associated with the Pharynx

- **Superiorly** – inferior surface of the base of the skull
- **Inferiorly** – continuous with oesophagus
- **Anteriorly** – wall – incomplete due to openings into nose, mouth and larynx
- **Posteriorly** – areola tissue, involuntary muscle and bodies of first 6 cervical vertebrae

**Nasopharynx:**
- Nasal part
- Lies behind nose above the level of soft palate
- On lateral walls – two openings of auditory tubes – one leading to each middle ear
- Posterior wall – pharyngeal tonsils (adenoids) – contain lymphoid tissue

**Oropharynx**
- Oral part
- Lies behind mouth – extends from below level of soft palate to level of upper part of the body of the 3rd cervical vertebrae

**Lateral walls of pharynx blend with the soft palate** – forms two folds on each side
- Collection of lymphoid tissue (palatine tonsil)
- During swallowing – nasal and oral parts are separated by soft palate and uvula

**Laryngopharynx**
- Laryngeal part
- Extends from oropharynx above
- Continues as oesophagus below from 3rd – 6th cervical vertebrae

Structure

- **Mucous membrane lining:**
  - In Nasopharynx
    - Continuous with lining in nose
    - Ciliated columnar epithelium
  - In oropharynx and laryngopharynx
    - Formed by stratified squamous epithelium
    - Continuous with lining of mouth and oesophagus
    - Lining protects underlying tissues from abrasive action of foodstuffs passing through
Fibrous tissue:
- Intermediate layer
- Thicker in Nasopharynx
- Little muscle
- Becomes thinner towards lower end where muscle layer becomes thicker

Smooth muscle:
- Several involuntary constrictor muscles – important in swallowing
- Upper end of oesophagus is closed by lower constrictor muscle, except during swallowing

Blood and Nerve Supply

- Blood supplied by several branches of facial artery
- Venous return is into facial and internal jugular veins
- Nerve supply – from pharyngeal plexus – formed by parasympathetic and sympathetic nerves
- Parasympathetic supply is by vagus and glossopharyngeal nerves
- Sympathetic supply is by nerves from the superior cervical ganglia

Functions

- Passage way for air and food – organ involved in respiratory and digestive systems
  - Air passes through the nasal and oral sections
  - Food passes through the oral and laryngeal sections
- Further warming and humidifying
- Taste – olfactory nerve endings in epithelium of oral and pharyngeal parts
- Hearing
- Protection – lymphatic tissue produce antibodies
- Speech
**Larynx**

**Position**
- Larynx extends from the root of the longue and hyoid bone to the trachea
- Lies in front of the laryngopharynx at the level of the 3rd to 6th cervical vertebrae

**Structure associated with the Larynx**
- Superiorly – hyoid bone and root of tongue
- Inferiorly – continuous with trachea
- Anteriorly – muscles attached to hyoid bone and muscles of neck
- Posteriorly – the laryngopharynx and 3rd – 6th cervical vertebrae
- Laterally – lobes of thyroid gland

**Structure**
- Cartilages:
  - Composed of several irregularly shaped cartilages attached to each other by ligaments and membranes
    - 1 thyroid cartilage
    - 1 cricoid cartilage
    - 2 Arytenoid cartilages
    - 1 epiglottis
  - Hyaline cartilage
  - Elastic fibrocartilage
- Thyroid cartilage
  - Consists of two flat pieces of hyaline cartilage (laminae), fused anteriorly, forming the laryngeal prominence
  - Laminae are separated forming a V-shaped notch – thyroid notch
  - Incomplete posteriorly – border of each lamina is extended to form two processes called the superior and inferior cornu
  - Upper part – lined with stratified squamous epithelium
  - Lower part – lines with ciliated columnar epithelium
  - Many muscles attached to outer surface
  - Forms most of anterior and lateral walls of larynx
Cricoid cartilage
- Lies below thyroid cartilage
- Composed of hyaline cartilage
- Shaped like a signet ring – encircling larynx with narrow part anteriorly – broad part posteriorly
  - Articulates with arytenoid cartilages and inferior cornu
- Lined with ciliated columnar epithelium, muscles and ligaments attached to outer surface
- Lower border marks end of upper respiratory tract.

Arytenoid cartilages
- Pyramid-shaped hyaline cartilages
- Sit on top of the broad part of the cricoid cartilage forming part of the posterior part of the larynx.
- Give attachment to the vocal cords and to muscles
- Lined with ciliated columnar epithelium

Epiglottis
- Leaf-shaped fibroelastic cartilage attached to the inner surface of the anterior wall of the thyroid cartilage immediately below the thyroid notch.
- Rises obliquely upwards behind the tongue and the body of the hyoid bone
- Covered with stratified squamous epithelium
- Closes off the larynx during swallowing – protecting the lungs from accidental inhalation of foreign objects.

Ligaments and Membranes
- There are several ligaments that attach the cartilages together and to the hyoid bone

Blood and Nerve Supply
- Blood is supplied to the larynx by the superior and inferior laryngeal arteries and drained by the thyroid veins – join the internal jugular vein
- Parasympathetic nerve supply is from the superior laryngeal and recurrent laryngeal nerves, which are branches of the vagus nerves.
- Sympathetic nerves are from the cervical ganglia, one on each side
  - Provide motor nerve supply to the muscles of the larynx and sensory fibres to the lining membrane
Interior of the Larynx

- Vocal cords are two pale folds of mucous membrane with cord-like free edges
  - Extend from the inner wall of the thyroid prominence anteriorly to the arytenoid cartilages posteriorly

- When muscles controlling the vocal cords are relaxed, the vocal cords open and the passageway for air coming up through the larynx is clear
  - Vocal cords – abducted

- Pitch of the sound produced by vibrating vocal cords in this position is low

- When the muscles controlling the vocal cords contract, cords are stretched out tightly across the larynx (are adducted/closed)
  - When stretched and vibrated by passing air pitch produced is high

- Pitch is therefore determined by tension applied to the vocal cords by appropriate sets of muscles

- When not in use vocal cords are adducted

- Space between the vocal cords is the glottis

Functions

- Production of sound
  - Sound has properties:
    - Pitch
    - Volume
    - Resonance
  - Pitch of voice depends on length and tightness of the cords
  - Puberty – male vocal cords grow longer causing a lower pitch
  - Volume of voice depends on force at which cords vibrate – greater the force of expired air – more cords vibrate and louder the sound produced
  - Resonance/tone depends on the:
    - Shape of mouth
    - Position of tongue and lips
    - Facial muscles and air in Paranasal sinuses

- Speech
Occurs during expiration when sounds produced by vocal cords are manipulated by:
- Tongue
- Cheeks
- Lips

**Protection of the Lower Respiratory Tract**
- During swallowing (deglutition) larynx moves upwards, occluding the opening into it from pharynx – epiglottis closes over the larynx
- Ensures that food passes into the oesophagus rather than the lower respiratory passages

**Passageway for Air**
- Between pharynx and trachea

**Humidifying, Filtering and Warming**
- Processes continue as inspired air travels through the larynx

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**Trachea**

**Position**
- Continuation of larynx and extends downwards to level of 5th thoracic vertebrae
- Divides (bifurcates) at carina into right and left primary bronchi – one to each lung
- Approximately 10 – 11cm long
- Lies mainly in median plane in front of oesophagus

**Structures associated with the Trachea**
- Superiorly – larynx
- Inferiorly – right and left bronchi
- Anteriorly – upper part, isthmus of thyroid gland; lower part, arch of aorta and sternum
- Posteriorly – oesophagus separates trachea from vertebral column
- Laterally – lungs and lobes of thyroid gland
Structure

- Composed of three layers of tissue
- Held open by 16 – 20 incomplete (posteriorly) C-shaped rings of hyaline cartilage
- Connective tissue and involuntary muscle join cartilages together – form posterior wall
- Soft tissue posterior wall is in contact with oesophagus
- Three layers of tissue cover cartilages of trachea:
  - Outer layer – fibrous and elastic tissue – encloses the cartilages
  - Middle layer – cartilages and bands of smooth muscle – wind around trachea in a helical arrangement; some areolar tissue containing blood and lymph vessels and autonomic nerves
  - Inner lining – ciliated columnar epithelium, containing mucus-secreting goblet cells

Blood and Nerve Supply, Lymph Drainage

- Atrial supply – mainly inferior thyroid and bronchial arteries
- Venous return – by inferior thyroid veins into the brachiocephalic veins
- Parasympathetic nerve supply – recurrent laryngeal nerves and other branches of vagi
- Sympathetic supply – nerves from sympathetic ganglia
- Parasympathetic stimulation constricts the trachea – sympathetic stimulation dilates it
- Lymph from respiratory passages drains through lymph nodes
  - Situated around trachea and in carina – area where divides into two bronchi

Functions

- Support and patency
  - Arrangement of cartilage and elastic tissue prevents kinking and obstruction of airway when head and neck moves
Absence of cartilage posteriorly allows trachea to dilate and constrict in response to nerve stimulation, and for indentation as oesophagus distends during swallowing. Cartilage prevents collapse of trachea when internal pressure is less than intrathoracic pressure—at end of forced expiration.

**Mucociliary escalator**
- Synchronous and regular beating of cilia of mucous membrane lining that wafts mucus with adherent particles upwards towards larynx where swallowed or coughed up.

**Cough reflex**
- Nerve endings in larynx, trachea and bronchi—sensitive to irritation—generates nerve impulses conducted by vagus nerves to the respiratory centre in brainstem.
- Reflex motor response is deep inspiration followed by closure of the glottis:
  - Abdominal and respiratory muscles then contract and suddenly the air is released under pressure expelling mucous and/or foreign material from mouth.

**Warming, Humidifying and Filtering**
- Continue in nose—air normally saturated and at body temperature at trachea.

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**Lungs**

**Position and Gross Structure**

- Two lungs—one each side if the midline in thoracic cavity.
- Cone-shaped.

- They have:
  - An apex
  - A base
  - A costal surface
  - A medial surface

- Apex
  - Rounded and rises into root of neck
  - 25mm above level of middle third of the clavicle
  - Lies close to first rib and blood vessels and nerves in root of neck.
Base
  o Concave and semilunar
  o Lies on thoracic surface of diaphragm

Costal surface
  o Convex
  o Lies against costal cartilages, ribs and intercostal muscles

Medial surface
  o Concave – roughly shaped triangular-shaped (hilum)
  o At level of 5th – 7th thoracic vertebrae
  o Structures forming root of lung enter and leave hilum – include primary bronchi, pulmonary artery supplying lung and two pulmonary veins draining it, the bronchial artery and veins and lymphatic and nerve supply
  o Area between lung – mediastinum
    ▪ Occupied by:
      • Heart
      • Great vessels
      • Trachea
      • Right and left bronchi
      • Oesophagus
      • Lymph nodes
      • Lymph vessels
      • Nerves
  o Right lung – divided into three lobes
    ▪ Superior
    ▪ Middle
    ▪ Inferior
  o Left lung is smaller – heart occupies space of midline – divided into two lobes
    ▪ Superior
    ▪ Inferior

Pleura and Pleural Cavity

  ➔ Pleura consists of closed sac or serous membrane (one for each lung) – contains a small amount of serous fluid

  ➔ Lung is invaginated (pushed into) sac – forming two layers:
    o One adheres to the lung
    o One adheres to wall of thoracic cavity
Visceral pleura – adheres to lung covering each lobes – passing into fissures that separate them

Parietal pleura – adherent to inside of chest wall and thoracic surface of diaphragm – remains detached from adjacent structures in the mediastinum and is continuous with the visceral pleura around edges of hilum

Pleural cavity – only a potential space. In health – two layers are separated by a thin film of serous fluid – allows layers to glide over each other, preventing friction during breathing. Serous fluid is secreted by epithelial cells of membrane

Two layers of pleura, with serous fluid in between, behave in same way as two pieces of glass separated by a layer of water – glide over each other easily but are difficult to pull apart because of surface tension between the membranes and fluid. If either layer of punctured – underlying lung collapses owing to its inherent property of elastic recoil.

**Interior of the Lungs**

- Composed of:
  - Bronchi
  - Smaller air passages
  - Alveoli
  - Connective tissue
  - Blood vessels
  - Lymph vessels
  - Nerves

- All embedded in an elastic connective tissue matrix

- Each lobe if made up of a large number of lobules

**Pulmonary Blood Supply**

- Pulmonary trunk divides into right and left pulmonary arteries – transport deoxygenated blood to each lung

- Each pulmonary artery divides into many branches - eventually end in a dense capillary network around walls of alveoli
Walls of alveoli and capillaries consist of one layer of flattened epithelial cells

Exchange of gases between air in the alveoli and blood in the capillaries takes place across these two very fine membranes (together – respiratory membrane)

Pulmonary capillaries join up, forming two pulmonary veins in each lung – leave lungs at hilum and carry oxygenated blood to the left atrium of the heart

Blood capillaries and blood vessels in the lungs are supported by connective tissue

**Bronchi and Bronchioles**

- Two primary bronchi are formed when the trachea divides about level of 5th thoracic vertebra
  - Right bronchus
    - Wider, shorter and more vertical than left bronchus – more likely to become obstructed by an inhaled foreign body
    - Approximately 2.5cm long
    - After entering right lung at hilum it divides into three branches – one to each lobe
    - Each branch subdivides into numerous smaller branches
  - Left bronchus
    - 5cm long
    - Narrower than right bronchus
    - After entering left lung at hilum it divides into two branches – one to each lobe
    - Each branch subdivides into progressively smaller tubes within the lung substance

**Structure**

- Bronchi are composed of the same tissues as the trachea and are lined with ciliated columnar epithelium

- Progressively subdivide into:
  - Bronchioles
  - Terminal bronchioles
  - Respiratory bronchioles
- Alveolar ducts
- Alveoli

- Towards distal end on bronchi – cartilages become irregular in shape and are absent at bronchiolar level

- In absence of cartilage – smooth muscle in walls of bronchioles becomes thicker – responsive to autonomic nerve stimulation and irritation

- Ciliates columnar mucous membrane changes gradually to non-ciliated cuboidal-shaped cells in the distal bronchioles.

- The wider passages are conducting airways – function – to bring air into the lungs and walls are too thick to permit gas exchange

**Blood and Nerve Supply, Lymph Drainage**

- Arterial supply to walls of bronchi and smaller air passages is through branched of right and left bronchial arteries

- Venous return is mainly though bronchial veins

- On right side – empty into azygos vein

- On left side – empty into superior intercostal vein

- Vagus nerves (parasympathetic) stimulate contraction of smooth muscle in bronchial tree causing bronchoconstriction

- Sympathetic stimulation causes bronchodilatation

- Lymph – drained from walls of air passages in a network of lymph vessels

- Passes through lymph nodes situated around trachea and bronchial tree then into thoracic duct on left side and right lymphatic duct on the other side
Functions

- Control of air entry
  - Diameter of respiratory passages in altered by contraction or relaxation of involuntary muscles in their walls – regulating volume of air entering the lungs
  - Controlled by autonomic nerve supply
    - Parasympathetic stimulation causes constriction
    - Sympathetic stimulation causes dilatation

- Warming

- Humidifying

- Support and patency

- Removal of particulate matter

- Cough reflex

Respiratory Bronchioles and Alveoli

- Structure
  - Within each lobe – lung tissue is divided by sheets of connective tissue into lobules
    - Each lobule is supplied with air by a terminal bronchiole – further subdivides into respiratory bronchioles, alveolar ducts and large numbers of alveoli
  - Approximately 150 million alveoli in adult lung
    - In alveoli – gas exchange occurs
  - As airways progressively divide and become smaller their walls gradually become thinner until muscle and connective tissue disappear leaving a single layer of epithelial cells in alveolar ducts and alveoli
  - Distal respiratory passages are supported by a loose network of elastic connective tissue in which macrophages, fibroblasts, nerves, blood and lymph vessels surrounded by a dense network of capillaries
  - Exchange of gases in lung (external respiration) takes place across a membrane made up of alveolar wall and the capillary wall fused firmly together (respiratory membrane)
  - Lying between squamous cells are septal cells that secrete surfactant, a phospholipid fluid which prevents the alveoli from drying out
    - Surfactant reduces surface tension and prevents alveolar walls collapsing during expiration
- Secretion of surfactant into distal air passages and alveoli begins about 35th week of fetal life

- Nerve supply to bronchioles
  - Parasympathetic fibres from the vagus nerve cause bronchoconstriction
  - Absence of supporting cartilage means the small airways may be completely closed off by constriction of their smooth muscle
  - Sympathetic stimulation relaxes bronchiolar smooth muscle

- Functions
  - External respiration
  - Defence against microbes
  - Warming
  - Humidifying

**Respiration**

- Exchange of gases between body cells and the environment

- Involves two main processes
  - Breathing (pulmonary ventilation) – movement of air into and out of lungs
  - Exchange of gases – takes place:
    - In lungs: external respiration
    - In the tissues: internal respiration

**Breathing**

- Supplies oxygen to the alveoli

- Eliminates carbon dioxide

**Muscles of Breathing**

- Expansion of chest during inspiration occurs as a result of muscular activity, partly voluntary and partly involuntary

- Main muscles used in normal, quiet breathing are:
  - Intercostal muscles
  - Diaphragm
During deep breathing assisted by muscles of
  o Neck
  o Shoulders
  o Abdomen

**Intercostal Muscles**

- 11 pairs that occupy spaces between 12 pairs of ribs
- Arranged in two layers
  - External intercostal muscles – muscle fibres
    - Extend downwards and forwards from the lower border of rib above to the upper border of rib below
  - Internal intercostal muscles – muscle fibres
    - Extend downwards and backwards from the lower border of rib above to upper border of rib below, crossing the external intercostal muscle fibres at right angles
    - First rib is fixed, so when intercostal muscles contract they pull all the other ribs towards the first rib
    - Because of shape and sizes of ribs they move outwards when pulled upwards, enlarging the thoracic cavity
    - Intercostal muscles are stimulated to contract by the intercostal nerves

**Diaphragm**

- Dome-shaped muscular structure separating the thoracic and abdominal cavities
- Forms the floor of thoracic cavity and the roof of the abdominal cavity
- Consists of a central tendon from which muscle fibres radiate to be attached to the lower ribs and sternum and to the vertebral column by two crura

- When muscle of diaphragm is relaxed – central tendon is pulled downwards to level of 9th thoracic vertebra, enlarging the thoracic cavity in length
  - Decreases pressure in thoracic cavity
  - Increases pressure in abdominal and pelvic cavities
- Supplied by phrenic nerves
Intercostal muscles and diaphragm contract simultaneously, enlarging the thoracic cavity in all directions
- Back to front
- Side to side
- Top to bottom

**Cycle of Breathing**
- Average respiratory rate = 12 to 15 breaths per min

Each breath consists of three phases:
- Inspiration
- Expiration
- Pause

**Inspiration**
- When capacity of thoracic cavity is increased by simultaneous contraction of intercostal muscles and diaphragm – parietal pleura moves with walls of thorax and diaphragm
  - Reduces pressure in pleural cavity to a level lower than atmospheric pressure
- Visceral pleura follows the parietal pleura pulling lungs
  - Expands the lungs
  - Pressure within alveoli and in air passages falls
  - Air is drawn into the lungs as a result and aims to equalise atmospheric and alveolar air pressures
- Process of inspiration is active – needs energy for muscle contraction
- Negative pressure created in thoracic cavity aids venous return to heart and is known as respiratory pump
- At rest inspiration lasts around 2 seconds
Expiration

- Relaxation of intercostal muscles and diaphragm results in downward and inward movement of the rib cage and elastic recoil of the lungs
- Pressure inside lungs exceeds that in the atmosphere and so air is expelled from the respiratory tract
- Lungs still contain some air
- Prevented from collapse by the intact pleura
- Process is passive – does not require energy
- At rest expiration lasts about 3 seconds
- There is a pause after respiration before the next cycle begins

Physiological Variables affecting Breathing

- Elasticity
  - Ability of lungs to return to normal shape after each breath
  - Loss of elasticity and connective tissue in lungs necessitates forced expiration and increased effort on inspiration
- Compliance
  - Measure of distensibility of lungs – effort required to inflate alveoli
  - Healthy lung is compliant and inflates with little effort
  - When compliance is low more effort is required – in some diseases where elasticity is reduced or when insufficient surfactant is present
  - Compliance and elasticity are opposing forces
- Airway resistance
  - When increased – in bronchoconstriction – more respiratory effort is required to inflate lungs
**Lung Volumes and Capacities**

- Normal quiet breathing around 15 complete respiratory cycles per minute

- Lungs and air passages are never empty as exchange of gases only occurs across the walls of alveolar ducts and alveoli

- Remaining capacity of respiratory passages is the anatomical dead space 150ml

- Tidal volume (TV) is amount of air passing into and out of lungs during each cycle of breathing 500ml at rest

- Inspiratory reserve volume (IRV) extra volume of air that can be inhaled into the lungs during maximal inspiration – over and above normal TV

- Inspiratory capacity (IC) amount of air that can be inspired with maximum effort - consists of TV and IRV

- Functional residual capacity (FRC) amount of air remaining in the passages and alveoli at the end of quiet expiration

- Expiratory reserve volume (ERV) largest volume of air expelled from lungs during maximal expiration

- Residual volume (RV) cannot be directly measured – volume of remaining air in the lungs after forced expiration

- Vital capacity (VC) maximum volume of air which can be moved into and out of lungs
  - \[ VC = TV + IRV + ERV \]

- Alveolar ventilation volume of air that moves into and out of the alveoli per minute – equal to tidal volume minus the anatomical dead space multiplied by the respiratory rate:
  - \[ \text{Alveolar ventilation} = (TV - \text{anatomical dead space}) \times \text{respiratory rate} \]
    - \[ = (500-150) \text{ml} \times 15 \text{ resps per min} \]
    - \[ = 5.25 \text{ litres per min} \]

- Lung function tests are carried out to determine respiratory function
  - Based on parameters outlined above
  - Results of these tests can help in diagnosis and monitoring of respiratory disorders
Exchange of Gases

- Gas exchange at the respiratory membrane and in tissues is continuous
- Diffusion of oxygen and carbon dioxide depends on pressure differences – between atmospheric air and the blood – blood and tissues

Composition of Air

- Atmospheric pressure at sea level is 101.3 kilopascals (kPa) or 760 mmHg
- With increasing height above sea level, atmospheric pressure is reduced
  - At 5500m pressure is half that at sea level
- Under water pressure increases by around 1 atmosphere per 10m below sea level
- Air is a mixture of gases
  - Nitrogen
  - Oxygen
  - Carbon dioxide
  - Water vapour
  - Small quantities of inert gases
  - Each of these gases in the mixture exerts a part of the total pressure proportional to its concentration
    - Parietal pressure
      - $PO_2$
      - $PCO_2$

Alveolar Air

- Composition remains fairly constant
- Different from atmospheric air
- Saturated with water vapour
- Contains more carbon dioxide and less oxygen
- Saturation with water vapour provided 47mmHg – reducing parietal pressure of all other gases present
Gaseous exchange between the alveoli and bloodstream (external respiration) is a continuous process – alveoli are never empty

- Independent of respiratory cycle
- During each inspiration cycle only some of the alveolar gases are exchanged

**Expired Air**

- Mixture of alveolar air and atmospheric air in dead space

**Diffusion of Gases**

- Exchange of gases occurs when a difference in partial pressure exists across a semipermeable membrane
- Gases move by diffusion from a higher concentration to a lower concentration until equilibrium is established
- Atmospheric nitrogen is not used by the body so its partial pressure remains unchanged – same in inspired and expired air, alveolar air and in the blood

**External Respiration**

- Exchange of gases by diffusion between alveoli and blood in the alveolar capillaries across respiratory membrane
- Each alveolar wall is one cell thick and surrounded by a network of tiny capillaries – these walls are also one cell thick
- Total area of respiratory membrane for gas exchange in the lungs is equivalent to the area of a tennis court
Venous blood arriving at the lungs has travelled from all tissues of the body, contains high levels of carbon dioxide – low levels of oxygen

Carbon dioxide diffuses from venous blood down its concentration gradient into the alveoli until equilibrium with alveolar air is reached

Oxygen diffuses from the alveoli into the blood

Slow flow of blood through the capillaries increases time available for gas exchange to occur

When blood leaves alveolar capillaries oxygen and carbon dioxide concentrations are in equilibrium with those of alveolar air

**Internal Respiration**

Exchange of gases by diffusion between blood in the capillaries and body cells

Gaseous exchange does not occur across walls of arteries carrying blood from the heart to the tissues because walls are too thick
  - PO$_2$ of blood arriving at the capillary bed is therefore the same as blood leaving the lungs

Blood arriving at the tissues has been cleanse of CO$_2$ and saturated with O$_2$ during passage through the lungs
  - Therefore higher PO$_2$ and lower PCO$_2$ than the tissues
  - Creates concentration gradients between capillary blood and the tissues
  - Gaseous exchange occurs

O$_2$ diffuses from the bloodstream through the capillary wall into the tissues

CO$_2$ diffuses from the cells into the extracellular fluid then into the bloodstream towards the venous end of the capillary

**Transport of Gases in the Bloodstream**

Transport of oxygen and carbon dioxide is essential for internal respiration to occur
Oxygen

- Oxygen is carried in the blood in:
  - Chemical combination with haemoglobin – oxyhaemoglobin 98.5%
  - Solution in plasma water 1.5%

- Oxyhaemoglobin is an unstable compound that under certain conditions readily dissociates releasing oxygen

- Factors that increase dissociation include:
  - Low levels of $O_2$
  - Low pH
  - Raised temperature

- In active tissues there is increased production of carbon dioxide and heat which leads to increased release of oxygen
  - Oxygen is available to tissues in greatest need

- When oxygen leaves the erythrocyte, the deoxygenated haemoglobin turns purplish in colour

Carbon Dioxide

- Waste product of metabolism

- Excreted by lungs

- Transported by three mechanisms
  - As bicarbonate ions ($HCO_3^-$) in plasma 70%
  - Carries in erythrocytes, loosely combined with haemoglobin – carbaminohaemoglobin 23%
  - Some dissolved in plasma 7%

Control of Respiration

- Normally involuntary

- Voluntary control is exerted during activities such as speaking and singing but is overridden if blood $CO_2$ rises (hypercapnia)
Respiratory Centre

- Formed by groups of nerves in medulla – respiratory rhythmicity centre
  - Control respiratory pattern
    - Rate and depth of breathing

- Regular discharge of inspiratory neurones within this centre set the rate and depth of breathing

- Activity of this centre is adjusted by nerves in the pons (pneumotaxic centre and apneustic centre) in response to input from other parts of the brain

- Motor impulses leaving centre pass in the phrenic and intercostal nerves to the diaphragm and intercostal muscles respectively

Chemoreceptors

- Receptors that respond to changes in partial pressures of oxygen and carbon dioxide in the blood and cerebrospinal fluid – located centrally and peripherally

- Central chemoreceptors
  - Located on surface of medulla oblongata
  - Bathed in cerebrospinal fluid
  - When arterial PCO₂ rises (hypercapnia) the central chemoreceptors respond by stimulating the respiratory centre, increasing ventilation of the lungs and reducing PCO₂
  - Sensitivity of central chemoreceptors to raised PCO₂ is important factor in controlling normal blood gas levels
  - Small reduction in PO₂ (hypoxaemia) same but less pronounced effect – substantial reduction depresses breathing

- Peripheral chemoreceptors
  - Situated in arch of aorta and carotid bodies
  - More sensitive to small rises in arterial PCO₂ than to small decreases in PO₂ levels
  - Nerve impulses generated in peripheral chemoreceptors – conveyed by glossopharyngeal and vagus nerves to medulla and stimulate respiratory centre
  - Rate and depth of breathing is increased
  - Increase in blood acidity (decreased pH or raised [H⁺]) stimulates the peripheral chemoreceptors resulting in
    - Increased ventilation
    - Increased CO₂ excretion
    - Increased blood pH
Other Factors that Influence Respiration

- Breathing
- Temperature
- Hering-Breuer reflex