ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY TRACT

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Respiration is the utilisation of oxygen by the body in the production of energy. Much of the metabolism occurs by aerobic means, i.e. it requires the presence of oxygen.

The respiratory tract has evolved into a complex series of tubes whose primary function is to allow the exchange of gases across all aerobic cells.

Maintaining an adequate supply of oxygen to cells requires four basic steps:

1. Oxygen is taken up from the air by the blood.
2. Oxygen is carried by blood.
3. Tissues receive adequate perfusion with blood.
4. Oxygen passes from the blood to cells.

Carbon dioxide is a product of metabolism in the cells and transfer of carbon dioxide from blood to the air together with step one above are the main functions of the respiratory tract.

A good knowledge of the basic anatomy is an essential prerequisite to understanding the complex physiology of the respiratory tract. In this chapter, I shall start with the central control of respiration and proceed to give an intertwined description of function and anatomy.

RHYTHMIC CONTROL OF BREATHING

Central control of respiration has evolved such that there is an automatic and subconscious control of inspiration and expiration.

This may however be overridden by voluntary actions or the reflex actions of swallowing and speech.
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<table>
<thead>
<tr>
<th>Central factors</th>
<th>Peripheral factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex</td>
<td>Peripheral chemoreceptors</td>
</tr>
<tr>
<td>Hypothalamus</td>
<td>Pharyngeal mechanoreceptors</td>
</tr>
<tr>
<td>Pons</td>
<td>Vagal afferents</td>
</tr>
<tr>
<td>Central chemoreceptors</td>
<td>Non-respiratory reflexes</td>
</tr>
</tbody>
</table>

Broadly speaking the respiratory cycle may be divided into:

1. **Inspiratory phase**, during which pharyngeal dilator muscles start to contract, shortly followed by increasing activity of the inspiratory muscles.
2. **Expiratory phase I**, during which there is a decreased activity of the inspiratory muscles.
3. **Expiratory phase II**, during which inspiratory muscles show no activity and the expiratory muscles may be recruited if forcible expiration is necessary.

The neurones central to the repetitive and involuntary movements of respiration are concentrated in the medulla oblongata. This is under the influence of a variety of factors, summarised in Table 1.

The motor neurones are divided into two groups.

1. The **dorsal respiratory group**, the main function of which is in relation to the timing of the respiration. It lies in close relation to the tractus solitarius and is made up mainly of the inspiratory neurones, crossing over to the anterior horn cells of the other side.
2. The **ventral respiratory group**, also known as the expiratory group is controlled by the nucleus retroambigualis. The dilator functions of the larynx, pharynx and tongue are controlled by the nucleus ambiguous and the inspiratory muscles are controlled mainly by the nucleus para-ambigualis.

The pons undoubtedly contributes to the fine-tuning and modification of the respiratory rhythm but is no longer considered to be the dominant pneumotaxic centre.

**CENTRAL CHEMOCEPTORS**

These respond to changes in the pH of cerebral spinal fluid (CSF), which in turn is dependent upon pCO₂. Compensatory changes are seen in respiratory and metabolic alkalosis or acidosis.

If pCO₂ is kept abnormally high the CSF pH gradually returns to normal due to changes in CSF bicarbonate levels. Whether this is an active or passive
ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY TRACT

distribution remains uncertain, but the gradual resetting results in a pro-
longed period of hyperventilation.

PERIPHERAL CHEMOCEPTORS

The carotid bodies
These are placed close to the bifurcation of the common carotid artery
whence they have a very rich blood supply. Carotid bodies respond to
1. Falls in partial pressure of oxygen (but not content).
2. Decrease of hydrogen ion concentration.
3. Oscillations of partial pressures of carbon dioxide (in response to the rate
   of rise as well as to its concentration).
4. Hypotension (<60 mmHg).
5. Hyperthermia.
6. Drug: Sympathomimetics (acetylcholine, nicotine) and cytochrome chain
   inhibitors (cyanide, carbon monoxide).

Baroceptor reflexes – These are found in the carotid sinus and the aortic arch.
They are sensitive to changes in the circulation; a decrease in pressure causes
hyperventilation, while a rise causes respiratory depression.

Pulmonary stretch reflexes – These are involved in the classic inflation and defla-
tion reflexes (Hering–Breuer reflexes). There are three main types of receptors.

• Stretch receptors are mainly in the airways.
• Slowly adapting receptors are in the tracheobronchial smooth muscle.
• Rapidly adapting receptors are in the superficial mucosal layer. Afferents are
  conducted by the vagus or occasionally the sympathetic nervous system.
• Their role in man is minimal.

J receptors – These are C-fibre endings in close relationship to the capillaries
of the bronchial and the pulmonary microcirculation. They are activated by
tissue damage and produce bradycardia, hypotension, apnoea, bronchocon-
striction and increased mucus secretion.

Upper respiratory tract reflexes
The upper respiratory tract has developed a number of reflexes to protect
itself from ‘foreign material’:

In the nose – Water can trigger apnoea; irritants cause sneezing; cold recep-
tors trigger bronchoconstriction.

In the pharynx – Mechanoreceptors cause activation of pharyngeal dilator
muscles, whilst irritants can cause bronchodilatation.

In the larynx – Mechanical stimulation via the superior laryngeal nerve causes
cough, laryngeal closure and bronchospasm.
In addition the cough reflex has evolved. This involves the inspiration of a volume of air into the lungs followed by contraction of the lungs against a closed glottis. This results in forced expiration through narrowed airways allowing a forceful jet of air to expel irritant materials out into the pharynx. The pressure generated may be as high as 300 mmHg.

**THE ROLE OF THE SPINAL CORD IN CONTROL OF RESPIRATION**

Messages from the upper control centres are transmitted to the lower motor neurones via three groups of fibres in the spinal tracts.

1. In the *ventrolateral* cord – nerve fibres originating from the dorsal and ventral respiratory groups of the medulla.
2. In the *dorsolateral* and *ventrolateral* quadrants of the cord – transmitting nerve fibres relating to the voluntary control of breathing especially speech.
3. A disparate group of fibres innervating the diaphragm, controlling its rhythmic contraction.

All of these fibres converge onto the anterior horn cells in the spinal cord from which emerge the lower motor neurones.

There are two *efferent* fibres

- The alpha fibres passing directly to the neuromuscular junction of the spinal cord.
- The gamma fibre that ends directly on the intrafusal part of the muscle spindle.

Contraction of the intrafusal fibres causes stimulation of the annulospiral endings. These will send off an impulse via the dorsal root that will then cause an excitatory effect on the alpha fibres, thus closing a reflex loop.

![Diagram](image)
ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY TRACT

The muscles of respiration

The chest wall is a moderately flexible anatomical entity that contains all the structures surrounding the lungs and pleura. The chest wall behaves as an elastic container when relaxed. In the absence of any pressure difference across the chest wall, it comes to its unstressed volume, which is roughly 75% of total lung capacity.

If the chest wall muscles were to be relaxed (as in quiet expiration), when the pleural pressure is below atmospheric, the chest wall is pulled inwards. When the pleural pressure rises above atmospheric pressure (Pw is positive), the chest wall bows out. In certain disease states the chest wall may stiffen, causing a restrictive ventilatory defect.

The only active phase of the respiratory cycle is the phase of inspiration under resting conditions.

The inspiratory muscles include:

1. The diaphragm: The normal expiratory excursion is about 1.5 cm and occurs as the insertion and origin of the diaphragm pull against each other.
2. The intercostals: External intercostals are primarily inspiratory; Internal intercostals are primarily expiratory.
3. The scalenes: These are active in inspiration by lifting up the rib cage to counteract the diaphragmatic pull.
4. **Sternocleidomastoid**: They are potent accessory muscles during forced inspiration.

These muscles work to overcome two main sources of resistance:

- The work against elastic recoil.
- The work against resistance to gas flow.

The optimal rate and depth of respiration is in proportion to the resistance offered by either during the respiratory cycle. The work of breathing is measured in Joules.

The **expiratory muscles** include:

1. Rectus abdominis
2. External obliques
3. Internal obliques
4. Transversalis

The elastic recoil of the expanded chest cavity drives the phase of expiration. Expiratory muscles are normally silent in quiet breathing and usually chip in when the minute volume is in excess of 40 l/min.

The pressure difference across the chest wall will have no relationship to its size if the respiratory muscles are being used either to move the chest or to keep it at a particular volume.

**The pleura**

The lungs are paired organs lying within the thoracic cavity. The left lung has two lobes, and the right has three. The left lung is smaller than the right because of space occupied by the heart.

The lungs are encased with the chest wall. Within this, it lies in the **pleura** – a thin membrane which lines the walls of the thoracic cavity – **the parietal pleura** and the lung surfaces – **visceral pleura**.

These two sides are continuous, meeting at the lung hilum; they are directly opposed to one another, and the entire potential space within the pleura contains only a few millilitres of serous pleural fluid.

Anatomically, the parietal pleura starts at the dome of the pleura overlying the apex of the lung reaching as high as the lower edge of the neck of the first rib, then moving medially to form the costal pleura.

This can be traced down to the inner margin of the first rib. It then proceeds down just behind the sternoclavicular joint to the median plane behind the sternum where the left and right sides are in contact with each other down to the fourth costal cartilage.
ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY TRACT

It sweeps laterally on the right side down to the posterior surface of the xiphisternum while on the left side; it sweeps up to 25 mm away from the midline to the sixth costal cartilage.

On each side it sweeps laterally so as to cross the tenth rib in the mid-axillary line and is just below the twelfth rib at the costo-vertebral junction. The visceral pleura adhere tightly to the surface of the lung being reflected off the structures in the hilum.

The surrounding forces exert an Intrapleural pressure (Ppl) within the pleural space. During quiet breathing, the pleural pressure is negative; that is to say, below atmospheric pressure.

The pressure gradient in the erect person drops exponentially down the lung decreasing 1 cm H₂O for every 3 cm drop. This has a profound effect on many features of pulmonary function including airways closure, ventilation/perfusion ratios and gaseous exchange.

The lungs are totally separated from the abdomen by a sheet of skeletal muscle – the diaphragm, which is dome shaped before lung expansion but flattens during breathing in.

During active expiration, the abdominal muscles are contracted to force up the diaphragm and the resulting pleural pressure can become positive. Positive pleural pressure may temporarily collapse the bronchi and cause limitation of airflow.

Anatomy of the upper airway

This describes the portion of the airway that lies above the vocal cords and includes:

1. The nasal passages (septum, turbinates, and adenoids)
2. The oral cavity (teeth and tongue)
3. The pharynx (tonsils, uvula, and epiglottis)
4. The glottis

Breathing normally occurs through the nose or mouth and the direction it takes is under voluntary control utilising the soft palate, tongue and lips.

Normally the mouth is closed and the tongue is applied to the hard palate to allow nasal breathing. This is the physiological way to breathe, as the nose is specially adapted for this function. The nose provides:

1. Hairs to filter off particulate matter.
2. Humidification and warming of the air over the increased surface area provided by the turbinates.
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The mouth is brought into play when the respiratory minute volume is greater than 35 l/min. Forced mouth breathing is affected by a functional anatomical change that arches the soft palate upwards and backwards against the band of the superior constrictor of the pharynx, effectively closing off the nasopharynx.

The pharynx has two components: The oropharynx, i.e. the throat area and the nasopharynx is an extension of the throat upwards towards the nasal passages. The opening into the airways from the oropharynx is called the glottis, which is closed off during swallowing by a small flap called the epiglottis.

After the glottis, the air enters the larynx, a structure of cartilage and ligaments that forms the Adam's apple. The entire structure is supported by muscles that suspend the larynx from a small bone in the neck called the hyoid.

Within the larynx are folds of cartilage that form the vocal cords. Air flowing over these cords causes them to vibrate and so produce sound. Their tension
ANATOMY AND PHYSIOLOGY OF THE RESPIRATORY TRACT

determines the tone or pitch of the sound; small muscles that pass from the
cords to the cartilage of the larynx capsule can alter this.

Innervation of the upper airway

The upper airway is innervated by three main cranial nerves:

Trigeminal nerve (Cranial nerve V): Branches of the trigeminal nerve inner-
vate the nose and the anterior two thirds of the tongue.

Glossopharyngeal (Cranial nerve IX): Branches of the glossopharyngeal nerve
innervate the posterior third of the tongue, roof of pharynx and tonsils.

Vagus (Cranial nerve X): The two major divisions of the vagus nerve in airway
innervation are the superior laryngeal and the recurrent laryngeal nerves.

Sensory innervation

1. Trigeminal nerve – the sensory innervation of the nasal mucosa arises from
two divisions:
   - The anterior ethmoidal nerve supplies the anterior septum and lateral
     wall;
   - The nasopalatine nerves from the sphenopalatine ganglion innervate
     the posterior areas.
2. Glossopharyngeal nerve – supplies the posterior third of the tongue, soft
   palate, epiglottis, faucae and the pharyngo-oesophageal junction.
3. Superior laryngeal nerve – the internal branch of the vagus nerve inner-
vates mucosa from the epiglottis to and including the vocal cords.
4. Recurrent laryngeal nerve – a branch of the vagus nerve innervates mucosa
   below the vocal chords to the trachea.

Motor innervation

1. The external branch of the superior laryngeal nerve is responsible for inner-
vation of the cricothyroid muscle.
2. The recurrent laryngeal nerve provides a motor supply to all the muscles of
   the larynx (posterior and lateral cricoarytenoid muscles) except the
   cricothyroid muscle.
   - The lateral cricoarytenoid adducts the cords
   - The posterior cricoarytenoid abducts the cords

Unilateral damage to the recurrent laryngeal nerve causes hoarseness.
Bilateral damage causes respiratory distress and stridor whilst chronic dam-
age can cause aphonia.
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**Anatomy of the lower airway**

This describes the portion of the airway below the vocal cords. In an adult, the vocal cords are the narrowest portion of the airway.

The lower airway can be divided into:

The larynx is found at the level of the fourth to the sixth of the cervical vertebrae. Protection of the airway remains its most important function. However it has developed further as the organ of speech. The larynx is made up of nine cartilages:

1. Unpaired (thyroid, cricoid, and epiglottis). The cricoid cartilage is the only complete cartilaginous ring the respiratory system. It lies below the thyroid cartilage.
2. Paired cartilages (arytenoids, corniculate, and cuneiform).

![Diagram of the closure of the vocal cords.](image)

**Fig. 4: Diagrammatic representation of the closure of the vocal cords.**

![Diagram of the superior aspect of the larynx.](image)

**Fig. 5: Superior aspect of the larynx.**

The larynx also has two groups of muscles:

1. Muscles that open and close the glottis (lateral cricoarytenoid, post cricoarytenoid, and transverse arytenoid).