RESPIRATORY PHYSIOLOGY

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INTRODUCTION

The main function of the lungs is to provide continuous gas exchange between inspired air and the blood in the pulmonary circulation, supplying oxygen and removing carbon dioxide, which is then cleared from the lungs by subsequent expiration. Survival is dependent upon this process being reliable, sustained and efficient, even when challenged by disease or an unfavourable environment. Evolutionary development has produced many complex mechanisms to achieve this, several of which are compromised by anaesthesia. A good understanding of respiratory physiology is therefore essential to ensure patient safety during anaesthesia.

ANATOMY

The respiratory tract extends from the mouth and nose to the alveoli. The upper airway serves to filter airborne particles, humidify and warm the inspired gases. The patency of the airway in the nose and oral cavity is largely maintained by the bony skeleton, but in the pharynx is dependent upon the tone in the muscles of the tongue, soft palate and pharyngeal walls.

Larynx

The larynx lies at the level of upper cervical vertebrae, C4-6, and its main structural components are the thyroid and cricoid cartilages, along with the smaller arytenoid cartilages and the epiglottis, which sit over the laryngeal inlet. A series of ligaments and muscles link these structures, which, by a co-ordinated sequence of actions, protect the larynx from solid or liquid material during swallowing as well as regulating vocal cord tension for phonation (speaking). The technique of cricoid pressure is based on the fact that the cricoid cartilage is a complete ring, which is used to compress the oesophagus behind it against the vertebral bodies of C5-6 to prevent regurgitation of gastric contents into the pharynx. The thyroid and cricoid cartilages are linked anteriorly by the cricothyroid membrane, through which access to the airway can be gained in an emergency.

Trachea and bronchi

The trachea extends from below the cricoid cartilage to the carina, the point where the trachea divides into the left and right main bronchus, with a length of 12-15cm in an adult and an internal diameter of 1.5-2.0cm. The carina lies at the level of T5 (5th thoracic vertebra) at expiration and T6 in inspiration. Most of its circumference is made up of a series of C-shaped cartilages, but the trachealis muscle, which runs vertically, forms the posterior aspect.

When the trachea bifurcates, the right main bronchus is less sharply angled from the trachea than the left, making aspirated material more likely to enter the right lung. In addition, the right upper lobe bronchus arises only about 2.5cm from the carina and must be accommodated when designing right-sided endobronchial tubes.

Lungs and pleura

The right lung is divided into 3 lobes (upper, middle and lower) whereas the left has only 2 (upper and lower), with further division into the broncho-pulmonary segments (10 right, 9 left). In total there are up to 23 airway divisions between trachea and alveoli. The bronchial walls contain smooth muscle and elastic tissue as well as cartilage in the larger airways. Gas movement occurs by tidal flow in the large airways. In the small airways, by contrast, (division 17 and smaller) it results from diffusion only.

The pleura is a double layer surrounding the lungs, the visceral pleura enveloping the lung itself and the parietal pleura lining the thoracic cavity. Under normal circumstances the interpleural space between these layers contains only a tiny amount of lubricating fluid. The pleura and lungs extend from just above the clavicle down to the 8th rib anteriorly, the 10th rib laterally and the level of T12 posteriorly.

Blood supply

The lungs have a double blood supply, the *pulmonary circulation* for gas exchange with the alveoli and the *bronchial circulation* to supply the parenchyma (tissue) of the lung itself. Most of the blood from the bronchial circulation drains into the left side of the heart via the pulmonary veins and this deoxygenated blood makes up part of the normal physiological shunt present in the body. The other component of physiological shunt is from the thebesian veins, which drain some coronary blood directly into the chambers of the heart.

The pulmonary circulation is a low-pressure (25/10mmHg), low-resistance system with a capacity to accommodate a substantial increase in blood flowing through it without a

major increase in pressure. Vascular distension and recruitment of unperfused capillaries achieve this. The main stimulus which produces a marked increase in pulmonary vascular resistance is hypoxia.

MECHANISM OF BREATHING

A pressure gradient is required to generate flow. In spontaneous respiration inspiratory flow is achieved by creating a sub-atmospheric pressure in the alveoli (of the order of $-5cmH_2O$ during quiet breathing) by increasing the volume of the thoracic cavity under the action of the inspiratory muscles. During expiration the intra-alveolar pressure becomes slightly higher than atmospheric pressure and gas flow to the mouth results.

Motor pathways

The main muscle generating the negative intrathoracic pressure that produces inspiration is the *diaphragm*, a sheet separating the thorax from the abdomen. Its muscular part is peripheral, attached to the ribs and lumbar vertebrae, with a central tendon. Innervation is from the *phrenic nerves* (C3-5) with contraction moving the diaphragm downwards forcing the abdominal contents down and out. Additional inspiratory efforts are produced by the *external intercostal muscles* (innervated by their intercostal nerves T1-12) and the *accessory muscles of respiration* (sternomastoids and scalenes), although the latter only become important during exercise or respiratory distress.

During quiet breathing expiration is a passive process, relying on the elastic recoil of the lung and chest wall. When ventilation is increased, such as during exercise, expiration becomes active with contraction of the muscles of the abdominal wall and the internal intercostals. The same muscles are also used when producing a Valsalva manoeuvre *(Update in Anaesthesia, 1999, No. 10 p7).*

Central control

The mechanism by which respiration is controlled is complex. There is a group of *respiratory centres* located in the brainstem producing automatic breathing activity. This is then regulated mainly by input from *chemoreceptors* (see below). This control can be overridden by *voluntary control* from the cortex. Breath-holding, panting or sighing at will are examples of this voluntary control. The main respiratory centre is in the floor of the 4^{th} ventricle, with inspiratory (dorsal) and expiratory (ventral) neurone groups. The inspiratory neurones fire automatically, but the expiratory ones are used only during forced expiration. The 2 other main centres are the apneustic centre, which enhances inspiration, and the pneumotaxic centre, which terminates inspiration by inhibition of the dorsal neurone group above.

The *chemoreceptors* that regulate respiration are located both centrally and peripherally. Normally control is exercised by the central receptors located in the medulla, which respond to the CSF hydrogen ion concentration, in turn determined by CO_2, which diffuses freely across the blood-brain barrier from the arterial blood. The response is both quick and sensitive to small changes in arterial CO_2 ($PaCO_2$). In addition, there are peripheral chemoreceptors located in the carotid and aortic bodies most of which respond to a fall in O_2, but some also to a rise in arterial CO_2. The degree of hypoxia required to produce significant activation of the O_2 receptors is such that they are not influential under normal circumstances, but will do so if profound hypoxia (<8kPa or 60mmHg) occurs, for example at high altitude when breathing air (see later - Special circumstances). It also happens when the response to CO_2 is impaired, which can occur if the $PaCO_2$ is chronically elevated, leading to a blunting of the central receptor sensitivity. In this event the plasma bicarbonate (HCO_3^-) concentration will also be elevated.

RESPIRATORY PROCESS

Respiratory values

The various terms used to describe lung excursion (movement) during quiet and maximal respiration are shown in figure 1:

The tidal volume (500ml) multiplied by the respiratory rate (14 breaths/min) is the *minute volume* (7,000ml/min). Not all of the tidal volume takes part in respiratory exchange, as this process does not start until the air or gas reaches the respiratory bronchioles (division 17 of the respiratory tree). Above this level the airways are solely for conducting, their volume being known as the *anatomical dead-space.* The volume of the anatomical dead-space is approximately 2ml/kg or 150ml in an adult, roughly a third of the tidal volume. The part of the tidal volume which does take part in respiratory exchange multiplied by the respiratory rate is known as the *alveolar ventilation* (approximately 5,000ml/min).

Functional residual capacity (FRC) is the volume of air in the lungs at the end of a normal expiration. The point at which this occurs (and hence the FRC value) is determined by a balance between the inward elastic forces of the lung and the outward forces of the respiratory cage (mostly due to muscle tone). FRC falls with lying supine, obesity,

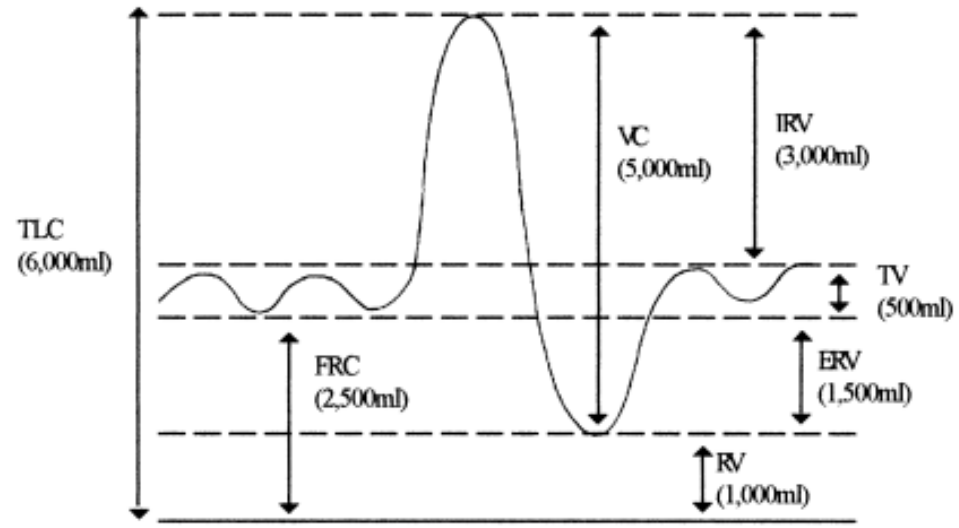

Figure 1: Lung volumes measured with a spirometer during quiet breathing with one maximum breath. Values shown are for an average-sized healthy young male.

RV	*Residual volume*	*FRC*	*Functional residual capacity*
ERV	*Expiratory reserve volume*	*TV*	*Tidal volume*
IRV	*Inspiratory reserve volume*	*VC*	*Vital capacity*
TLC	*Total lung capacity*		

pregnancy and anaesthesia, though not with age. The FRC is of particularly importance to anaesthetists because:

- During apnoea it is the reservoir to supply oxygen to the blood
- As it falls the distribution of ventilation within the lungs changes leading to mismatching with pulmonary blood flow
- If it falls below a certain volume (the closing capacity), airway closure occurs leading to shunt (see later - Ventilation/perfusion/shunt)

Resistance / compliance

In the absence of respiratory effort, the lung will come to lie at the point of the FRC. To move from this position and generate respiratory movement, two aspects need to be considered which oppose lung expansion and airflow and therefore need to be overcome by respiratory muscle activity. These are the airway resistance and the compliance of the lung and chest wall.

Resistance of the airways describes the obstruction to airflow provided by the conducting airways, resulting largely from the larger airways (down to division 6-7), plus a contribution from tissue resistance resulting produced by friction as tissues of the lung slide over each other during respiration. An increase in resistance resulting from airway narrowing such as bronchospasm leads to obstructive airways disease.

> ***Teaching point***
>
> *In obstructive airways disease, it might be expected that airflow could be improved by greater respiratory effort (increasing the pressure gradient) to overcome the increase in airways resistance. Whilst this is normally true for inspiration, it is not necessarily the case during expiration, as the increase in intrapleural pressure may act to compress airways proximal to the alveoli, leading to further obstruction with no increase in expiratory flow and air-trapping distally. This is shown in figure 2 and demonstrates why expiration is usually the major problem during an asthmatic attack.*

Compliance denotes distensibility (stretchiness), and in a clinical setting refers to the lung and chest wall combined, being defined as the volume change per unit pressure change. When compliance is low, the lungs are stiffer and more effort is required to inflate

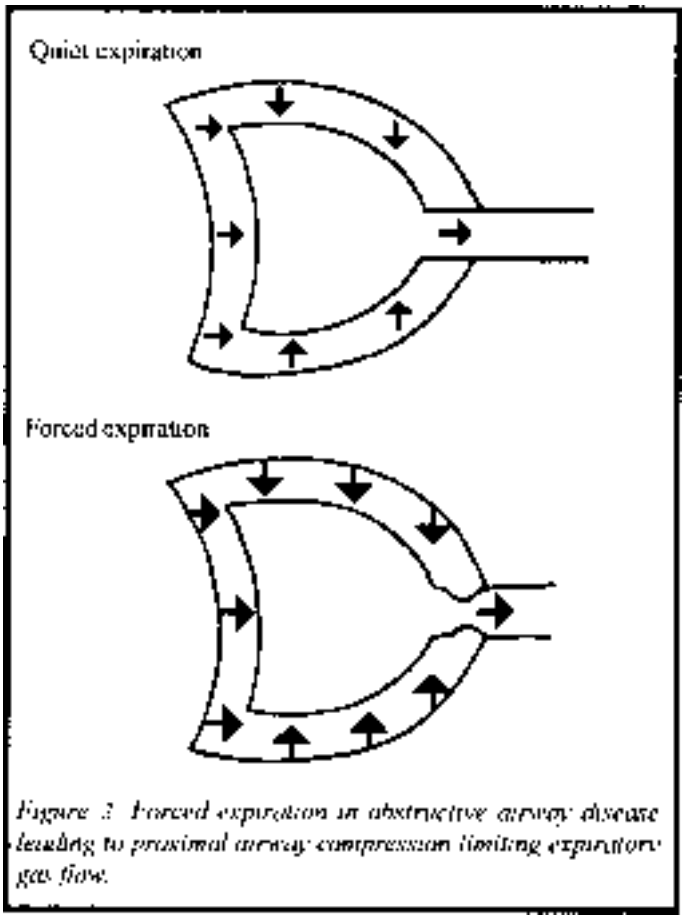

Figure 2: Forced expiration in obstructive airway disease leading to proximal airway compression limiting expiratory gas flow.

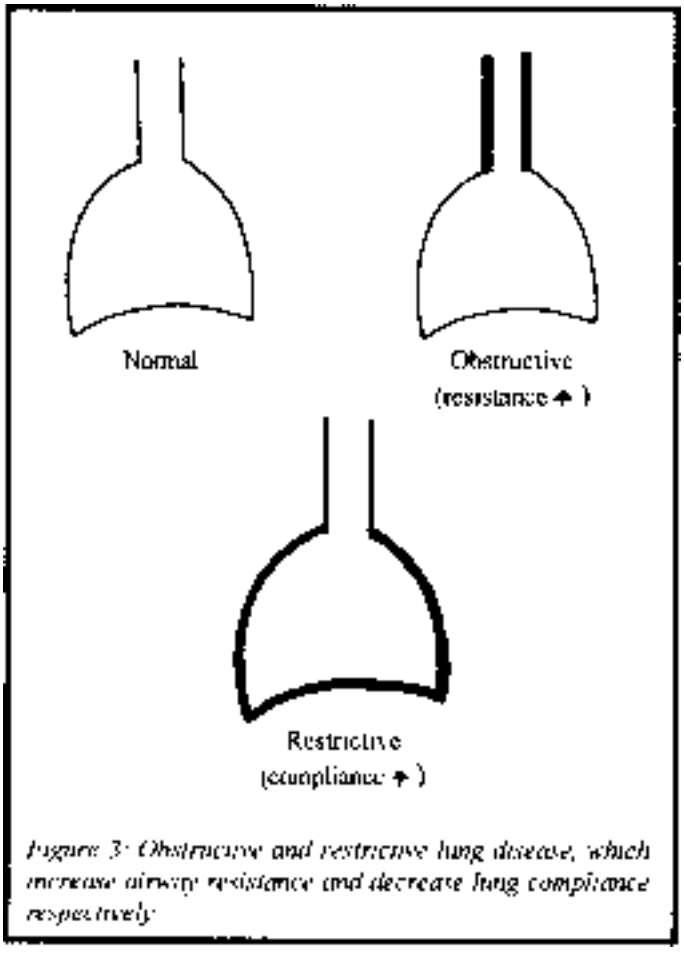

Figure 3: Obstructive and restrictive lung disease, which increase airway resistance and decrease lung compliance respectively.

the alveoli. Conditions that worsen compliance, such as pulmonary fibrosis, produce *restrictive lung disease*.

Compliance also varies within the lung according to the degree of inflation, as shown in figure 4. Poor compliance is seen at low volumes (because of difficulty with initial lung inflation) and at high volumes (because of the limit of chest wall expansion), with best compliance in the mid-expansion range.

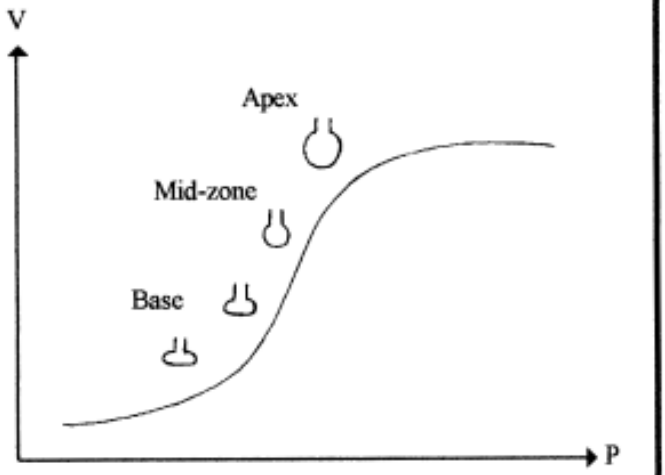

Figure 4: Compliance curve, showing compliance within the lung at different levels of inflation. At FRC in the young healthy person, the apices are well inflated (towards the top of the curve) and therefore less ventilated than the mid-zones and bases, which are on the lower, steeper part of the compliance curve.

Work of breathing

Of the two barriers to respiration, airway resistance and lung compliance, it is only the first of these, which requires actual work to be done to overcome it. Airway resistance to flow is present during both inspiration and expiration and the energy required to overcome it, which represents the actual *work of breathing*, is dissipated as heat.

Although energy is required to overcome compliance in expanding the lung, it does not contribute to the actual work of breathing as it is not dissipated but converted to potential energy in the distended elastic tissues. Some of this stored energy is used to do the work of breathing produced by airways resistance during expiration.

The work of breathing is best displayed on a pressure-volume curve of one respiratory cycle (figure 5) which shows the different pathways for inspiration and expiration, known as *hysteresis*. The total work of breathing of the cycle is the area contained in the loop.

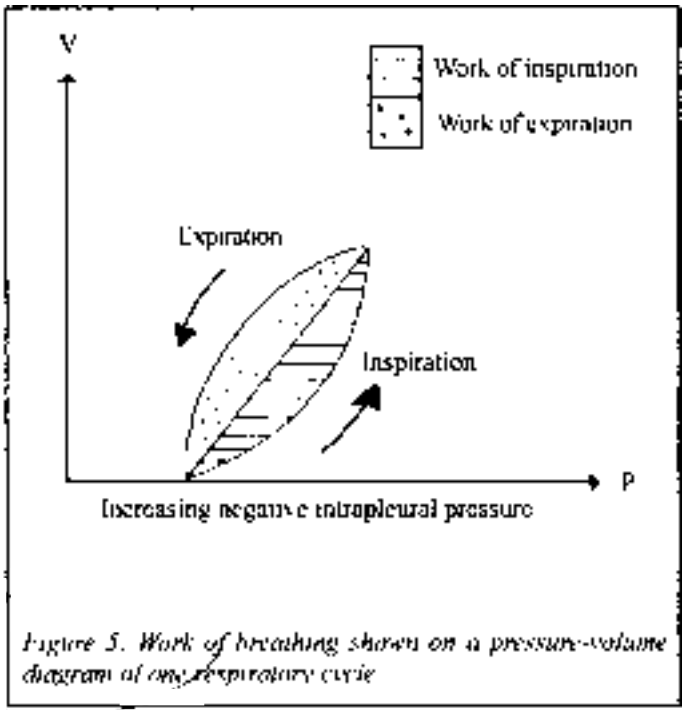

Figure 5. Work of breathing shown on a pressure-volume diagram of one respiratory cycle

Teaching point

With high respiratory rates, faster airflow rates are required, increasing the frictional forces. This is more marked in obstructive airways disease - such patients therefore generally minimise the work of breathing by using a slow respiratory rate and large tidal volumes. In contrast, patients with restrictive lung disease (poor compliance) reach the unfavourable upper part of the compliance curve soon as the tidal volume increases. The pattern of breathing seen in such patients usually involves small tidal volumes and a fast respiratory rate.

Diffusion

The alveoli provide an enormous surface area for gas exchange with pulmonary blood (between 50-100m^2) with a thin membrane across which gases must diffuse. The solubility of oxygen is such that its diffusion across the normal alveolar-capillary membrane is an efficient and rapid process. Under resting conditions pulmonary capillary blood is in contact with the alveolus for about 0.75 second in total and is fully equilibrated with alveolar oxygen after only about a third of the way along this course. If lung disease is present which impairs diffusion there is therefore still usually sufficient time for full equilibration of oxygen when at rest. During exercise, however, the pulmonary blood flow is quicker, shortening the time available for gas exchange, and so those with lung disease are unable to oxygenate the pulmonary blood fully and thus have a limited ability to exercise.

For carbon dioxide, which diffuses across the alveolar-capillary membrane 20 times faster than oxygen, the above factors are less liable to compromise transfer from blood to alveoli.

Ventilation / perfusion / shunt

In an ideal situation the ventilation delivered to an area of lung would be just sufficient to provide full exchange of oxygen and carbon dioxide with the blood perfusing that area. In the normal setting, whilst neither ventilation (V) nor perfusion (Q) is distributed evenly throughout the lung, their matching is fairly good, with the bases receiving substantially more of both than the apices (figure 6).

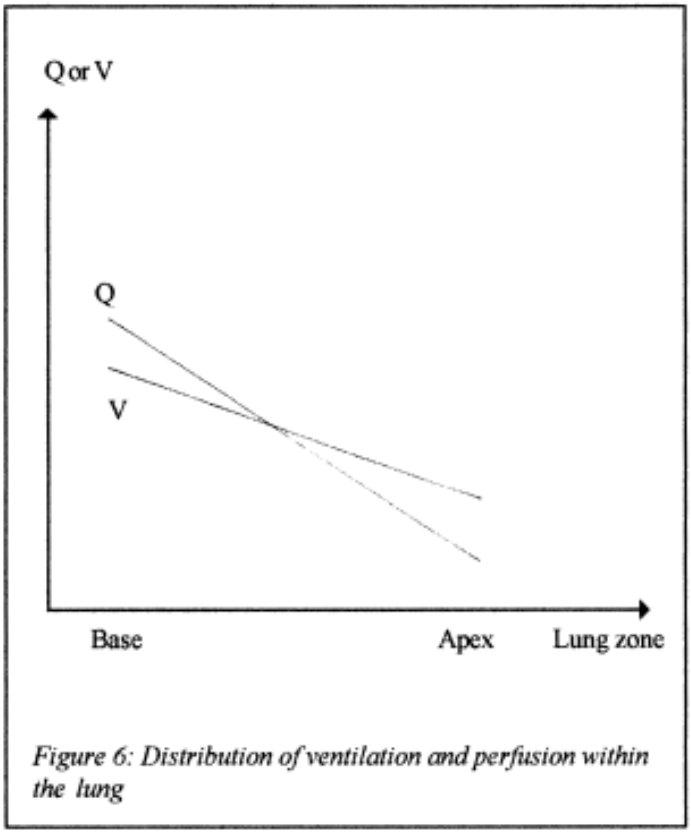

Figure 6: Distribution of ventilation and perfusion within the lung

For *perfusion*, the distribution throughout the lung is largely due to the effects of gravity. Therefore in the upright position this means that the perfusion pressure at the base of the lung is equal to the mean pulmonary artery pressure (15mmHg or 20cmH_2O) plus the hydrostatic pressure between the main pulmonary artery and lung base (approximately 15cmH_2O). At the apices the hydrostatic pressure difference is subtracted from the pulmonary artery pressure with the result that the perfusion pressure is very low, and may at times even fall below the pressure in the alveoli leading to vessel compression and intermittent cessation of blood flow.

The distribution of *ventilation* across the lung is related to the position of each area on the compliance curve at the start of a normal tidal inspiration (the point of the FRC). Because the bases are on a more favourable part of the compliance curve than the apices, they gain more volume change from the pressure change applied and thus receive a greater degree of ventilation. Although the inequality between bases and apices is less marked for ventilation than for perfusion, overall there is still good V/Q matching and efficient oxygenation of blood passing through the lungs.

Disturbance of this distribution can lead to V/Q *mismatching* (figure 7). For an area of low V/Q ratio the blood flowing through it will be incompletely oxygenated, leading to a reduction in the oxygen level in arterial blood (hypoxaemia). Providing some ventilation is occurring in an area of low V/Q, the hypoxaemia can normally be corrected by increasing the FiO_2, which restores the alveolar oxygen delivery to a level sufficient to oxygenate the blood fully.

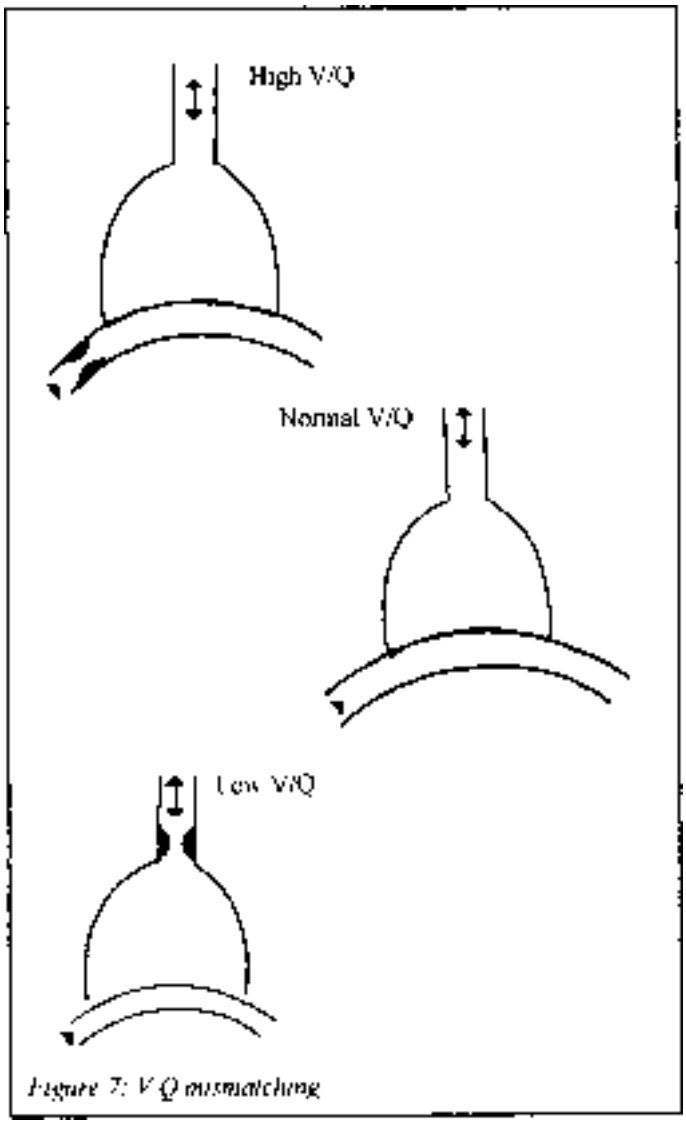

Figure 7: V/Q mismatching

V/Q mismatch occurs very commonly during anaesthesia because the FRC falls leading to a change in the position of the lung on the compliance curve. The apices, therefore, move to the most favourable part of the curve whilst the bases are located on a less favourable part at the bottom of the curve.

At the extremes of V/Q mismatch, an area of lung receiving no perfusion will have a V/Q ratio of ∞ (infinity) and is referred to as *alveolar dead-space*, which together with the anatomical dead-space makes up the *physiological dead-space*. Ventilating the dead space is, in effect, wasted ventilation, but unavoidable.

In contrast an area of lung receiving no ventilation, owing to airway closure or blockage, its V/Q ratio will be zero and the area is designated as shunt. Blood will emerge from an area of shunt with a PO_2 unchanged from the venous level (5.3kPa or 40mmHg) and produce marked arterial hypoxaemia. This hypoxaemia cannot be corrected by increasing the FiO_2, even to 1.0, as the area of shunt receives no ventilation at all. The well-ventilated parts of the lung cannot compensate for the area of shunt because Hb is fully saturated at a normal PO_2 . Increasing the PO_2 of this blood will not increase the oxygen content substantially (*see Oxygen Carriage later*).

In the case of shunt, therefore, adequate oxygenation can only be re-established by restoring ventilation to these areas using measures such as physiotherapy, PEEP or CPAP, which clear blocked airways and reinflate areas of collapsed lung. Because closing capacity (CC) increases progressively with age, and is also higher in neonates, these patients are at particular risk during anaesthesia as the FRC may fall below CC and airway closure result.

Teaching point

A physiological mechanism exists which reduces the hypoxaemia resulting from areas of low V/Q ratio, by producing local vasoconstriction in these areas and diverting blood to other, better-ventilated parts of the lung. This effect, known as hypoxic pulmonary vasoconstriction (HPV), is mediated by unknown local factors. The protective action of HPV is, however, inhibited by various drugs, including inhalational anaesthetic agents.

Surfactant

Any liquid surface exhibits surface tension, a tendency for the molecules on the surface to pull together. This why, when water lies on a surface, it forms rounded droplets. If the surface tension is reduced, such as by adding a small amount of soap, the droplets collapse and the water becomes a thin film.

When a liquid surface is spherical, it acts to generate a pressure within the sphere according to Laplace's law:

$P = \frac{4T}{R}$ if there are 2 liquid surfaces *(such as a bubble)*

$P = \frac{2T}{R}$ if there is 1 liquid surface *(such as lining an alveolus)*

P Pressure in sphere
R Radius of sphere
T Surface tension of liquid

The film of liquid lining the alveoli exhibits surface tension in such a manner to increase the pressure in the alveoli, with a greater rise in small alveoli than in large ones. Surfactant is a substance secreted by type II alveolar epithelial cells, which lowers the surface tension of this respiratory surface liquid markedly. Mainly consisting of a phospholipid (dipalmitoyl lecithin), its physiological benefits are:

- an increase (improvement) in overall lung compliance
- a reduction in the tendency for small alveoli to empty into large ones, leading to collapse
- a reduction in the fluid leak from pulmonary capillaries into the alveoli, as the surface tension forces act to increase the hydrostatic pressure gradient from capillary to alveolus

OXYGEN TRANSPORT

From an atmospheric level of 21kPa (21%), the partial pressure of oxygen falls in 3 stages before the arterial blood is reached. Firstly the inspired air is humidified by the upper respiratory tract, the saturated vapour pressure of water (6.2kPa or 47mmHg) reducing the PO_2 to around 19.7kPa (148mmHg) - *Update in Anaesthesia, 1999, No10*, p.8. In the alveoli the continuous exchange of carbon dioxide for oxygen reduces the PO_2 to about 14.4kPa (108mmHg) and finally the small physiological shunt normally present reduces it to approximately 13.3kPa (100mmHg).

Oxygen carriage

After transfer of oxygen across the alveolar capillary membrane, an efficient carriage system is needed to transport it to the tissues for use in cellular respiration. The *oxygen content* in the blood is the sum of that bound to haemoglobin (Hb) and that dissolved in plasma, which is normally a minor contribution in patients breathing air. Hb is a large protein containing 4 subunits, each containing a ferrous (Fe^{2+}) ion within a haem group. Up to 4 oxygen molecules can bind reversibly to each Hb molecule, one to each of the Fe^{2+} sites. The main factor that determines the extent of oxygen binding to Hb is the PO_2, the relationship between which is shown in figure 8.

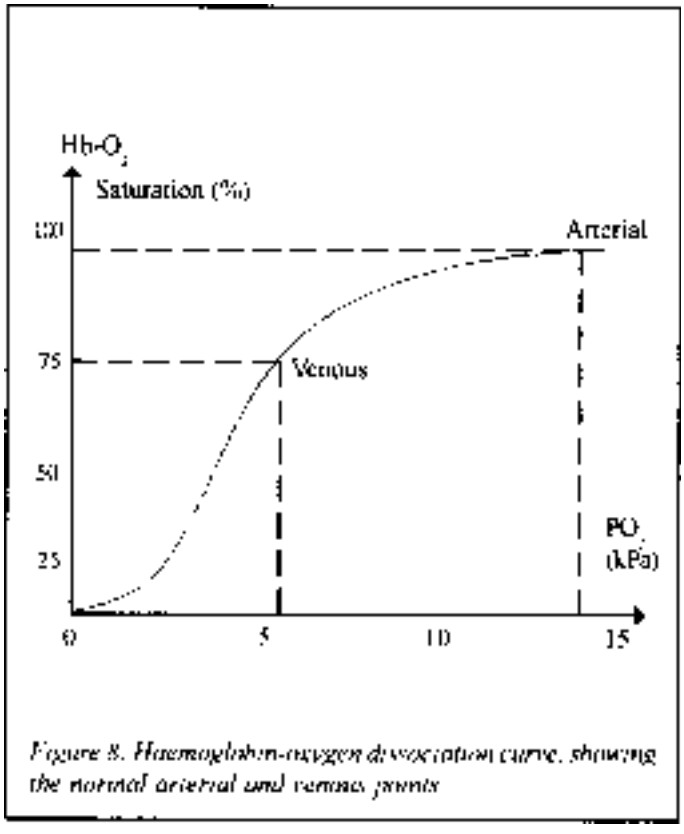

Figure 8. Haemoglobin-oxygen dissociation curve, showing the normal arterial and venous points

The initial flat part of the curve occurs because the binding of the first oxygen molecule causes a small structural change to Hb facilitating the binding of subsequent oxygen molecules. The shape of the curve means that a fall in PO_2 from the normal arterial value will have little effect on the Hb saturation (and therefore oxygen content) until the steep part of the curve is reached, normally around 8kPa (60mmHg). Once the PO_2 has reached this level, however, a further decrease in PO_2 will result in a dramatic fall in the Hb saturation.

Several factors can change the affinity of Hb for oxygen, resulting in the curve moving to the right (acidosis, temperature ↑ or 2,3-DPG ↑ (2,3 diphosphoglycerate) or to the left (foetal Hb, alkalosis, temperature ↓ or 2,3-DPG ↓). An index of the position of the Hb-O_2 dissociation curve is given by the P_{50}, the PO_2 at which Hb is 50% saturated.

Movement of the curve to the right decreases the affinity of Hb for oxygen. This is physiologically useful in the tissues, where the slightly acidic environment serves to improve oxygen unloading from the blood - the Bohr Effect. A left shift of the curve increases the affinity of Hb for oxygen, producing a higher saturation at a given PO_2. This acts to improve oxygen loading in the pulmonary capillary (slightly alkaline) and is greatly advantageous in the foetus, where the PO_2 is low (see later).

1g of Hb can carry 1.34ml of oxygen if fully saturated. At a PO_2 of 13.3kPa (100mmHg), Hb is normally about 97% saturated with oxygen. If the Hb concentration is 150gm/litre (15gm/100ml), arterial blood will therefore hold approximately 200ml/litre. With a cardiac output of 5 litre/min, the amount of oxygen available in the circulation is 1,000ml/min. Of this, approximately 250ml/min is used at rest, the Hb in venous blood being about 75% saturated.

The amount of oxygen dissolved in plasma is 0.23ml/litre/kPa (0.03ml/litre/mmHg). Whilst this is only about 3ml/litre when breathing air, it can be raised substantially by the use of hyperbaric pressure, reaching a level adequate to supply tissue requirements by breathing 100% oxygen at 3 atmospheres pressure. This can be used to sustain oxygenation if the patient's Hb is either insufficient or ineffective.

Special circumstances

It is useful to study the various specific physiological responses and adaptations which occur in response to changes in circumstances, in order to understand more clearly the different physiological mechanisms already described and the effects of anaesthesia and disease. These include:

Exercise

During exercise oxygen consumption can rise from 250 to over 3,000ml/min. Changes in response to this increased oxygen demand include:

- cardiac output ▲
- ventilation ▲
- extraction of oxygen from the blood ▲

Above a certain level, oxygen delivery cannot meet tissue demands, and anaerobic metabolism occurs, leading to lactic acid production.

Altitude

The acute response to the low arterial PO_2 resulting from high altitude is driven by the action of peripheral chemoreceptors to produce hyperventilation (as well as an increase in cardiac output). The resulting fall in the alveolar PCO_2 leads to an increase in the alveolar PO_2 (by the alveolar gas equation) which increases the arterial PO_2. The associated decrease in arterial PCO_2, however, reduces the drive at the central chemoreceptors, limiting the hyperventilation response. Metabolic compensation occurring over the next 2-3 days, involving an increase in renal HCO_3^- excretion and a subsequent fall in plasma and CSF HCO_3^-, reduce this unwanted effect.

Later responses that improve oxygen carriage include:

- 2,3 DPG ↑, leading to a right shift of the dissociation curve
- polycythaemia

Foetus

Oxygenation of foetal blood comes from the maternal circulation via the placenta. Blood leaving the placenta in the umbilical vein has a PO_2 of only around 4.0kPa (30mmHg) and yet has an oxygen content of approximately 130ml/litre. The mechanisms by which this is achieved are:

- a left shift of the foetal Hb-O_2 dissociation curve, with a P_{50} of 2.5kPa (19mmHg) [compared with a P_{50} for adult Hb of 4.0kPa (30mmHg)]
- a raised Hb concentration (180gm/litre - 18gm/100ml - at term)

The increased Hb concentration increases the oxygen carrying capacity, whilst the left shift of the Hb-O_2 dissociation curve results in an increase in Hb affinity for oxygen (see earlier) and therefore a higher saturation at low PO_2.

Causes of hypoxia

Hypoxia indicates the situation where tissues are unable to undergo normal oxidative processes because of a failure in the supply or utilisation of oxygen. The causes of hypoxia can be grouped in to 4 categories:

Hypoxic hypoxia

Hypoxic hypoxia is defined as an inadequate PO_2 in arterial blood. This can result from an inadequate PO_2

in the inspired air (such as at altitude), major hypoventilation (from central or peripheral causes) or from inadequate alveolar-capillary transfer (such as shunt or V/Q mismatch).

Anaemic hypoxia

The oxygen content of arterial blood is almost all bound to Hb. In the presence of severe anaemia, the oxygen content will therefore fall in proportion to the reduction in Hb concentration, even though the PO_2 is normal. The normal compensatory mechanism to restore oxygen delivery is an increase in cardiac output, but when this can no longer be sustained tissue hypoxia results. Conditions in which Hb is rendered ineffective in binding oxygen, such as carbon monoxide poisoning, produce a reduction in oxygen carriage similar to anaemia.

Circulatory or stagnant hypoxia

If circulatory failure occurs, even though the oxygen content of arterial blood may be adequate, delivery to the tissues is not. Initially tissue oxygenation is maintained by increasing the degree of oxygen extraction from the blood, but as tissue perfusion worsens this becomes insufficient and tissue hypoxia develops.

Histotoxic hypoxia

This describes the situation where cellular metabolic processes are impaired to prevent oxygen utilisation by the cells, even though oxygen delivery to the tissues is normal. The best-known cause of histotoxic hypoxia is cyanide poisoning, which inhibits cytochrome oxidase.

NON-RESPIRATORY LUNG FUNCTIONS

Whilst the main function of the lung is for respiratory gas exchange, it has several other important physiological roles.

These include:

- reservoir of blood available for circulatory compensation
- filter for circulation: thrombi, microaggregates etc
- metabolic activity: activation: angiotensin I∂II
  inactivation: noradrenaline, bradykinin, 5 H-T, some prostaglandins
- immunological: IgA secretion into bronchial mucus

In summary, the article has outlined the many complex processes by which gas exchange in the body is maintained and regulated. With a fuller understanding of how these processes can be disturbed, the anaesthetist is better placed to manage the resulting problems logically and effectively. Readers are recommended to read this article with The Physiology of Oxygen Delivery (*Update in Anaesthesia, 1999, No. 10, pp 8-14*) and Volatile Anaesthetic Agents (*Update in Anaesthesia, 2000, No. 11, p79*)