The Australian Short Course on Intensive Care Medicine

2000 Handbook
The Australian Short Course on Intensive Care Medicine

2000 Handbook

Editor
L.I.G. Worthley
# CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1. Anatomy of the lung</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2. Respiratory physiology</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 3. Chest X-ray in respiratory assessment</td>
<td>23</td>
</tr>
<tr>
<td>Chapter 4. Respiratory function tests</td>
<td>37</td>
</tr>
<tr>
<td>Trainee Presentations</td>
<td>57</td>
</tr>
<tr>
<td>Index</td>
<td>111</td>
</tr>
</tbody>
</table>
### 2000 SHORT COURSE PROGRAMME

<table>
<thead>
<tr>
<th>March</th>
<th>27th</th>
<th>28th</th>
<th>29th</th>
<th>30th</th>
<th>31st</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FMC</td>
<td>FMC</td>
<td>RAH</td>
<td>QEH</td>
<td>FMC</td>
</tr>
<tr>
<td>0815</td>
<td>Travel to FMC</td>
<td>Travel to FMC</td>
<td>Travel to RAH</td>
<td>Travel to QEH</td>
<td>Travel to FMC</td>
</tr>
<tr>
<td>0900</td>
<td>Lecture</td>
<td>Interactive</td>
<td>Lecture</td>
<td>Lecture</td>
<td>Lecture</td>
</tr>
<tr>
<td></td>
<td>Examination of the critically ill patient L.W.</td>
<td>Clinical vignettes L.W.</td>
<td>Organ donation R.Y</td>
<td>Biochemistry in the ICU P.P</td>
<td>Acute liver failure A.H</td>
</tr>
<tr>
<td>1015</td>
<td>Lecture</td>
<td>Interactive</td>
<td>Lecture</td>
<td>Lecture</td>
<td>Interactive</td>
</tr>
<tr>
<td></td>
<td>In defence of Blood Pressure A.B.</td>
<td>Interactive Blood gases, Bacteriology B.V.</td>
<td>Diagnosis &amp; J of nosocomial pneumonia M.C.</td>
<td>Lecture Meta-analysis and relevance to ICU J.M</td>
<td>Acid base &amp; Blood gases L.W</td>
</tr>
<tr>
<td>1130</td>
<td>Clinical cases A.V A.H B.V L.W</td>
<td>Lecture Management of adult neurotrauma J.M</td>
<td>Clinical cases M.C., P.T., M.F. D.C P.S. N.E R.Y</td>
<td>Interactive ICU Imaging M.T.</td>
<td>Interactive Presentat’ns L.W</td>
</tr>
<tr>
<td></td>
<td>Respiratory assistance in airflow obstruction A.B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1245</td>
<td>Lunch</td>
<td>Travel to WCH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1400</td>
<td>Interactive</td>
<td>Interactive</td>
<td>Lecture</td>
<td>Lecture</td>
<td>Lecture</td>
</tr>
<tr>
<td></td>
<td>ECG’s L.W</td>
<td>Radiology L.W</td>
<td>Scoring Systems M.F</td>
<td>Common paediatric ICU problems N.M</td>
<td></td>
</tr>
<tr>
<td>1515</td>
<td>Lecture</td>
<td>Lecture</td>
<td>Lecture</td>
<td>Short questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Understanding Fluid &amp; Electrolytes L.W</td>
<td>Pharmacologic support of the circulation J.M</td>
<td>Clinical cases M.C., P.T., M.F.</td>
<td>N.M., A.S</td>
<td></td>
</tr>
<tr>
<td>1630</td>
<td>Interactive</td>
<td>Interactive</td>
<td>Clinical Cases D.C P.S. N.E R.Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Path Forms L.W</td>
<td>Clinical Cases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1745</td>
<td>Travel To RAH</td>
<td>Travel to RAH</td>
<td></td>
<td>**</td>
<td></td>
</tr>
</tbody>
</table>

FMC = Flinders Medical Centre  
QEH = Queen Elizabeth Hospital  
WCH = Women’s and Children's Hospital  
RAH = Royal Adelaide Hospital  

**DINNER**: Thursday 30th 7 pm: 22 William St, Hawthorn  
(registrants at RAH accommodation block will be picked up at 6.45 pm)
**REGISTRANTS**

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dr. E. Merry</td>
<td>Intensive Care Unit, Royal Adelaide Hospital, SA</td>
</tr>
<tr>
<td>2</td>
<td>Dr. G. McGrath</td>
<td>Intensive Care Unit, Royal Perth Hospital, WA</td>
</tr>
<tr>
<td>3</td>
<td>Dr. N. Ramakrishnan</td>
<td>Intensive Care Unit, Royal Melbourne Hospital, Victoria</td>
</tr>
<tr>
<td>4</td>
<td>Dr. M. Chinthamunedi</td>
<td>Intensive Care Unit, Royal Adelaide Hospital, SA</td>
</tr>
<tr>
<td>5</td>
<td>Dr. G. Choi</td>
<td>Intensive Care Unit, Prince of Wales Hospital, NSW</td>
</tr>
<tr>
<td>6</td>
<td>Dr. R. Sistla</td>
<td>Intensive Care Unit, Royal Adelaide Hospital, SA</td>
</tr>
<tr>
<td>7</td>
<td>Dr. J. Ingham</td>
<td>Intensive Care Unit, Royal Perth Hospital, WA</td>
</tr>
<tr>
<td>8</td>
<td>Dr. P. Nair</td>
<td>Intensive Care Unit, St Vincent's Hospital, NSW</td>
</tr>
<tr>
<td>9</td>
<td>Dr. J. Fraser</td>
<td>Intensive Care Unit, Princess Alexandra Hospital, Queensland</td>
</tr>
<tr>
<td>10</td>
<td>Dr. D. Durham</td>
<td>Department of Critical Care Medicine, Flinders Medical Centre, SA</td>
</tr>
<tr>
<td>11</td>
<td>Dr. E. Connolly</td>
<td>Department of Critical Care Medicine, Flinders Medical Centre, SA</td>
</tr>
<tr>
<td>12</td>
<td>Dr. R. Newman</td>
<td>Intensive Care Unit, Calvary Hospital, SA</td>
</tr>
<tr>
<td>13</td>
<td>Dr. S. Perin</td>
<td>Intensive Care Unit, The Bendigo Hospital, Victoria</td>
</tr>
<tr>
<td>14</td>
<td>Dr. G. Joyce</td>
<td>Intensive Care Unit, John Hunter Hospital, NSW</td>
</tr>
<tr>
<td>15</td>
<td>Dr. A. Whitfield</td>
<td>Intensive Care Unit, Box Hill Hospital, Victoria</td>
</tr>
<tr>
<td>16</td>
<td>Dr. B. Graham</td>
<td>Intensive Care Unit, Royal Prince Alfred Hospital, NSW</td>
</tr>
<tr>
<td>17</td>
<td>Dr. A. Karnik</td>
<td>Intensive Care Unit, Princess Alexandra Hospital, Queensland</td>
</tr>
<tr>
<td>18</td>
<td>Dr. D. Lam</td>
<td>Intensive Care Unit, Prince of Wales Hospital, Hong Kong</td>
</tr>
<tr>
<td>19</td>
<td>Dr. P. Scott</td>
<td>Intensive Care Unit, Royal Brisbane Hospital, Queensland</td>
</tr>
<tr>
<td>20</td>
<td>Dr. A. Aziz</td>
<td>Intensive Care Unit, St George Hospital, NSW</td>
</tr>
<tr>
<td>21</td>
<td>Dr. T. Brownridge</td>
<td>Intensive Care Unit, Royal Adelaide Hospital, SA</td>
</tr>
<tr>
<td>22</td>
<td>Dr. J. Lambert</td>
<td>Intensive Care Unit, Royal Prince Alfred Hospital, NSW</td>
</tr>
<tr>
<td>23</td>
<td>Dr. P. Stewart</td>
<td>Intensive Care Unit, Royal Prince Alfred Hospital, NSW</td>
</tr>
<tr>
<td>24</td>
<td>Dr. M. Davis</td>
<td>Intensive Care Unit, Liverpool Hospital, NSW</td>
</tr>
<tr>
<td>25</td>
<td>Dr. S. Newell</td>
<td>Intensive Care Unit, Cairns Base Hospital, Queensland</td>
</tr>
<tr>
<td>26</td>
<td>Dr. K. O’Connor</td>
<td>Intensive Care Unit, North Shore Hospital, New Zealand</td>
</tr>
<tr>
<td>27</td>
<td>Dr. L. Ware</td>
<td>Intensive Care Unit, Broken Hill Base Hospital, NSW</td>
</tr>
<tr>
<td>28</td>
<td>Dr. V. Patil</td>
<td>Intensive Care Unit, St George Hospital, NSW</td>
</tr>
<tr>
<td>29</td>
<td>Dr. D. Evans</td>
<td>Intensive Care Unit, Royal Adelaide Hospital, SA</td>
</tr>
<tr>
<td>30</td>
<td>Dr. A. Delaney</td>
<td>Intensive Care Unit, Gosford Hospital, NSW</td>
</tr>
</tbody>
</table>

**FACULTY**

<table>
<thead>
<tr>
<th>FMC</th>
<th>QEH</th>
<th>RAH</th>
<th>WCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. L. Worthley  (L.W)</td>
<td>Dr. M.O’Fathartaigh (M.O’F)</td>
<td>Dr. R. Young (R.Y)</td>
<td>Dr. N. Matthews (NM)</td>
</tr>
<tr>
<td>Dr. A. Vedig       (A.V)</td>
<td>Dr. J. Moran (J.M)</td>
<td>Dr. M. Finnis (M.F)</td>
<td>Dr. A. Slater (A.S)</td>
</tr>
<tr>
<td>Dr. A. Bersten     (A.B)</td>
<td>Dr. P. Panell (P.P)</td>
<td>Dr. P. Thomas (P.T)</td>
<td></td>
</tr>
<tr>
<td>Dr. A. Holt        (A.H)</td>
<td>Dr. M. Tie (M.T)</td>
<td>Dr. M. Chapman (M.C)</td>
<td></td>
</tr>
<tr>
<td>Dr. E. Everest     (E.E)</td>
<td></td>
<td>Dr. P. Sharley (P.S)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dr. D. Clayton (D.C)</td>
<td></td>
</tr>
</tbody>
</table>

**GUEST**

Dr. B. Venkatesh (B.V)  * registrants willing to undergo a 'clinical'
Dr. J. Myburgh (J.M)
PREFACE

A working knowledge of the basic sciences of, anatomy, physiology and pharmacology is the basis for the understanding and management of the critically ill patient. This year the Australian Short Course on Intensive Care Medicine handbook has included a cursory look at the basic sciences of the respiratory system with chapters on anatomy of the lung, respiratory physiology, chest X-ray in respiratory assessment, and respiratory function tests. As with the previous editions, the course registrants presentations (or those that have been submitted on time) have also been included.

The subjects that have been dealt with in the lectures and seminars (along with other reviews), that were included in previous handbooks are now published separately in the journal Critical Care and Resuscitation.

This handbook still remains the working document of the Australasian Short Course on Intensive Care Medicine and is designed to supplement the course. During the sessions, you may find it useful to mark and note the text to facilitate your recall and review of the course at a later date. Along with the previous editions I trust that you find this edition useful.

Dr. L.I.G. Worthley
Adelaide, March 2000
Chapter 1

ANATOMY OF THE LUNG

The lung is a gas exchanging organ. The total alveolar area available for gas exchange ranges from 120-140 m$^2$ and the total capillary surface area ranges from 100-125 m$^2$. The amount of blood in the pulmonary capillaries associated with gas exchange at rest is 200 mL, which increases up to 300 mL with exercise. There are approximately 300 million alveoli in the human lung (ranging from 200 to 600 million, depending on the height of the individual), each with a diameter of 0.3 mm.

AIRWAYS

The airways consist of a series of branching tubes, which have conducting and gas exchanging functions.

Conducting airways

The conducting airways have a low resistance to air flow and minimal dead-space volume. The humidification, filtration and bulk movement of gas, takes place in these divisions. The conducting zone that takes no part in gas exchange is known as the anatomic dead space and contains a volume of approximately 150 mL. The conducting airways consists of the larynx, trachea, main bronchi, and bronchi and bronchioles.

Larynx

The larynx has protective, respiratory and phonatory functions. During swallowing the larynx elevates, the epiglottis closes over the glottis and the bolus of food is directed laterally and posteriorly, into the oesophageal opening.

Trachea

The trachea has a mean diameter of 1.8 cm and a length of 11 cm. It is supported by U-shaped cartilages which are joined posteriorly by smooth muscle bands. In spite of the cartilaginous support, the trachea may be occluded by external pressures of up to 50-70 cm H$_2$O.

Main bronchi

The right main bronchus is 2.2 cm in length and has a transverse diameter of 15.5 mm. It branches into the right upper lobe and the intermediate bronchus. The right upper lobe bronchus branches into apical, anterior and posterior segments. The intermediate bronchus branches into the right middle lobe and right lower lobe bronchus. The right middle lobe bronchus arises from the anterolateral aspect of the wall almost opposite the apical (superior) bronchus of the right lower lobe, and divides into lateral and medial branches. The right lower lobe bronchus branches into the four basal segments, i.e. anterior, lateral, posterior, and medial (Figure 1.1).

The left main bronchus is 5 cm in length and has a transverse diameter of 13 mm. The left upper lobe bronchus either trifurcates into apicoposterior, anterior and lingular bronchi, or bifurcates into an upper division which gives the apicoposterior and anterior bronchi and a
lower division which gives superior and inferior lingular bronchi. The left lower lobe branches into anteromedial, posterior and lateral bronchi (Fig. 1.1). The conducting airways are lined by pseudostratified columnar ciliated epithelial cells, which have a turnover of 2-4 days and mucus secreting (goblet) and serous cells. The latter contribute to the secretion of airway mucus of 10-100 mL/day (increasing to 200-300 mL/day in chronic bronchitics).

![Diagram of the anatomy of the main bronchi and segmental divisions](image)

**Fig. 1.1** A diagram of the anatomy of the main bronchi and segmental divisions (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p234).

**Bronchi and bronchioles.**

The 1st airway division (i.e. left and right main bronchi) continues until the 16th division (i.e. terminal bronchioles) before gas exchange begins. An important change occurs at about the 11th generation where the diameter is about 1 mm. Cartilage disappears from the wall of the airways below this level and the air passages are directly embedded and held open by the lung parenchyma. Thus the calibre of the airways below the 11th generation is mainly influenced by the lung volume. Bronchioles have cuboidal epithelium. The air passages, down to the terminal bronchiole, derive their blood supply from the bronchial circulation, beyond this, their nutrition is derived from the pulmonary circulation.

The walls of the bronchi and bronchioles contain smooth muscle which are innervated by the autonomic nervous system. Parasympathetic stimulation via the vagus nerves causes the bronchi to constrict and beta-2-adrenergic receptor stimulation causes them to dilate. Although there is sympathetic innervation of tracheobronchial blood vessels and beta adrenergic receptors are present in the smooth muscle of airways, there is no direct sympathetic innervation of the smooth muscle of bronchi. The physiological role of airway smooth muscle beta-adrenergic receptors is unclear although their function seems normal in asthmatic patients.

The bronchi contain a third neural system which is termed the nonadrenergic, noncholinergic (NANC) nervous system and is similar to the intrinsic nervous system of the gastrointestinal tract. Vasoactive intestinal peptide (the most potent known relaxant of human
Anatomy of the Lung

bronchi in vitro), nitric oxide and substance P (substanceP/neurokinin A) are thought to be the likely mediators secreted by the NANC neurones (although these mediators are also found in autonomic nerves). Stimulation of the inhibitory NANC nerves causes bronchodilation due to release of vasoactive intestinal peptide (VIP) and NO. Stimulation of excitatory NANC nerves (causing release of substance P/neurokinin A) causes bronchoconstriction, mucus secretion, vascular hyperpermeability, cough, and vasodilation (i.e. ‘neurogenic inflammation’). (Figure 1.2).

Fig. 1.2 A diagram of the innervation of the bronchial smooth muscle. B = beta adrenergic receptors, M = muscarinic receptors, VIP = vasoactive intestinal peptide, V = VIP receptors, P = substance P receptors, ACh = acetylcholine (Modified from Barnes PJ. The third nervous system in the lung: physiology and clinical perspectives. Thorax 1984;39:561-567).

Gas exchanging airways

The terminal respiratory unit (TRU) is the area or zone supplied by the first-order respiratory bronchiole (i.e. 17th generation). The extra-alveolar vessels extend down to the TRU, thereafter the vessels are alveolar and therefore exposed to alveolar pressure. From the 17th to 19th generation of the airways (i.e. respiratory bronchioles) there is a gradual increase in the number of alveoli in the walls of the airways, which act as a transitional zone for gas exchange. The 20th to 22nd divisions (i.e. alveolar ducts) and finally the 23rd divisions (i.e. alveolar sacs) are
respiratory airways (Figure 1.3). Diffusion, rather than bulk gas flow, takes place in less than one second in the gas exchanging airways as the distance from the terminal bronchiole to the most distal alveolus is only 5 mm. The gas exchanging airways have a volume of 3000 mL, which acts as a buffer against wide swings in blood gases with each inspiration. The basic gas exchanging unit is the alveolus.

**Fig. 1.3** Idealized divisions ($z$) of the airways. The transition (TRANSIT) between the conducting and gas exchange (RESP.) airways occurs at the 16th airway generation (i.e. TBL = terminal bronchiole). BR = bronchus, BL = bronchiole, RBL = respiratory bronchiole, AD = alveolar duct, AS = alveolar sac. (Modified from Weibel ER. Morphometry of the human lung. Berlin, Springer-Verlag, 1963, p111).

The alveolus
The alveolus is surrounded by walls that consist of two layers of alveolar epithelium on separate basement membranes enclosing the interstitial space. The interstitial space contains the pulmonary capillaries, elastin and collagen fibres, nerve endings and occasional polymorphs
and macrophages. The capillary endothelium and alveolar epithelium are closely opposed, with a partitioning distance from gas to blood of usually less than 0.4 \( \mu \text{m} \).

1. **Pulmonary capillary endothelial cells**, which abut against one another, with relatively loose junctions allowing the passage of large molecules. They are the most numerous pulmonary cell accounting for almost 40% of the total.

2. **Alveolar epithelial cells (type I cell)**, which cover several alveoli as a continuous sheet and meet at tight junctions; these cells have a turnover of 4-6 weeks and do not replicate. The tight junctions prevent the escape of large molecules into the alveolar space, although they permit the free passage of macrophages and polymorphs in response to a chemotactic stimulus. Destruction of type I epithelium, for example by respiratory distress or acute respiratory distress syndromes (RDS and ARDS), allows plasma to flow into the alveolus. This is the morphological basis for the formation of hyaline membranes in RDS and ARDS, triggering the replication of type II cells to regenerate type I cells.

3. **Alveolar epithelial cells (type II cells)**, which are the type I stem cells, they are round in shape, are situated at the junction of septae and are the main site of release of surfactants.

4. **Pulmonary immune function cells** (e.g. macrophages, neutrophils and mast cells): macrophages may circulate or reside in the alveolar space or interstitium. Neutrophils and mast cells are also located in the walls of airways and alveoli.

### Pulmonary Lymphatics

The lungs have a ‘superficial’ or visceral pleural network of lymphatics and a ‘deep’ or peribronchovascular network of lymphatics. The superficial network covers the surface of the lung and drains toward the lung hilus, where the lymphatics anastomose with the lymphatics of the deep network. The peribronchovascular lymphatics lie in the potential space around the air passages and vessels (a space that becomes distended during pulmonary oedema) down to the 11th airway generation. It is uncertain whether lymphatic vessels extend to the alveolar level. It is thought that the pulmonary interstitium, below the 11th airway generation may act as a fluid sump, draining fluid to the terminal lymph vessels at the level of the respiratory bronchioles. Pulmonary lymph has about 50% of the concentration of albumin present in plasma. While the pulmonary lymphatic system plays an important role in removing fluid and protein from the pulmonary interstitium, the pulmonary blood capillaries drain 11 times more albumin from the alveoli than the pulmonary lymphatic system.

### Pulmonary Blood Vessels

The pulmonary blood vessels form a series of branching tubes from the pulmonary artery to the capillaries, joining again to form the pulmonary veins. Initially the arteries, veins and bronchi travel together; however, at the terminal bronchioles (i.e. at the gas exchanging airways), the veins separate from the artery and airways to pass between the lobules, whereas the artery and bronchioles travel together to the centre of the lobule. The capillaries form a dense network forming almost a continuous sheet of blood vessels in the walls of the alveoli. Each RBC spends about 0.75 s in the capillary network.

### The Bronchial Circulation

There are usually two left and one or two right bronchial arteries, arising from the intercostal arteries or directly from the aorta. The bronchial circulation supplies mediastinal structures including the oesophagus, hilar lymph nodes and the vagus as well as the airways down to the terminal bronchioles (i.e. the conducting zone). The bronchial blood is carried away via the pulmonary veins. The lung can function without this circulation (as it does with pulmonary transplantation).
SURFACTANT
Unbalanced intermolecular forces at an interface (e.g. between air and water) lead to a surface force, tending to reduce the surface area. If the pulmonary alveoli are considered as small bubbles of air surrounded by a thin film of water, the surface tension at the air water interface tends to reduce the surface area and collapse the bubble (i.e. alveolus). The behaviour of such bubbles is governed by the theorem of Laplace, which states that the surface tension is inversely related to the radius of the sphere and directly proportional to the pressure of gas in the sphere. Thus, for bubbles of air in water, the surface tension increases as the radius decreases. If small and large bubbles are connected, the smaller bubbles disappear, emptying their gaseous contents into the larger bubbles.

Pulmonary surfactant is synthesised in the alveolar type II cells where the majority is stored in lamellar bodies which are released (largely in a response to stretch) into the alveolar hypophase and, with added components (e.g. surfactant protein-A, surfactant protein-B, surfactant protein -C, surfactant protein-D) forms a lipoprotein complex. Surfactant reduces the surface tension of the alveolar-air interface to almost zero, and limits the change in surface tension during change in radius of the alveolus with inspiration and expiration, thereby providing mechanical stability and preventing alveolar collapse (i.e. atelectasis). By reducing surface tension it also reduces the pressure (by approximately 20 mmHg) which tends to cause transudation of fluid into the alveolus, thereby preventing pulmonary oedema.

More than 50% of surfactant is dipalmitoyl phosphatidylcholine, 25% consists of unsaturated phosphatidylcholines, 5-10% phosphatidylglycerol, 5% glycerol and 8-10% unidentified proteins. Unlike common phosphatidylcholines found in cell membranes, surfactant phosphatidylcholine is unusual in that a high proportion of its fatty acids are saturated (i.e. contain two palmitic acid residues), rendering it surface active. It has a hydrophilic end, which lies within the alveolar fluid, and fatty acid hydrophobic end which projects into the alveolar space. Premature infants have a decreased complement of palmitic acid and therefore have a qualitative as well as quantitative change in pulmonary surfactant, which may cause respiratory distress syndrome of the newborn.

The functions of surfactant are: 1) to maintain the gas exchanging capacity of the lung by increasing pulmonary compliance, 2) to reduce the work of breathing by reducing atelectasis and alveolar oedema, and 3) act as a water repellent, lubricant, anticorrosive, antiinflammatory and bactericidal agent.

PLEURA
The pleural interface transmits the diaphragm and chest-wall force necessary to expand the lung during inspiration. At the end of normal expiration (i.e. at functional residual capacity, FRC) the pressure at the visceral and parietal pleural interface is 5 cm H₂O less than atmospheric pressure (i.e. 5 cm H₂O negative pressure), with a driving force to resorb gas at this interface of approximately 60-70 mmHg. It is estimated that in an adult, 5-10 L of protein-free fluid traverses the pleural space daily. Large proteins are absorbed by the pleural lymphatics.

While there is a large flux of fluid from the parietal to the visceral pleura, normally only 5-20 mL of fluid remains in the pleural space. Small effusions may be seen on chest X-ray, causing obliteration of the costophrenic angle, particularly on lateral view. However, the effusion probably has to be 500 mL or more before it is reliably detected on clinical examination (i.e. stony dullness on percussion, and on auscultation reduced breath sounds and bronchial breathing, increased vocal resonance and aegophony detected at the upper and medial level of the effusion).
Anatomy of the Lung

Thoracentesis is indicated if the cause and nature of the effusion (e.g. haemorrhagic, infective, transudate) is unclear. When a large effusion exists, thoracentesis is often performed to relieve dyspnea, although the lung volumes only increase by one third the amount of the fluid removed, and arterial blood gases usually show little change.

**Pleural effusions**

Pleural effusions are often classified as either transudates or exudates, depending on their protein content (e.g. protein content of transudates < 30 g/L; protein content of exudates > 30 g/L). Rarely, conditions that normally cause a transudate may be associated with a pleural effusion with a protein content higher than 30 g/L (e.g. treatment of cardiac failure may cause faster resolution of fluid than of protein) and conditions associated with an exudate may have a pleural effusion protein content less than 30 g/L (e.g. pulmonary infarction).

**Transudates**

Transudates often have a protein content less than 30 g/L (or pleural fluid albumin is 12 g/L < than serum albumin), are often bilateral and occur when the underlying mechanism is either decreased plasma colloid osmotic pressure (although patients with a low serum albumin level often have another cause for their pleural effusion as hypoalbuminaemia per se is an uncommon cause of pleural effusion) or increased hydrostatic pressure in the pulmonary circulations (Table 1.1). Pleural effusions are not associated with right heart failure alone. Malignant pleural effusions are almost always exudates (so it is of little use to perform cytology for malignant cells in patients with transudates).

**Exudates**

Exudates often occur when there is inflammation of the pleura, causing increased pleural capillary permeability, or in conditions where there is a decreased lymphatic drainage of the pleural space (Table 1.2). While, they often have a protein content greater than 30 g/L, a pleural fluid : serum protein ratio of greater than 0.5 and a pleural fluid LDH to serum LDH ratio of greater than 0.6 (or an LDH greater than 200 U/L), will indicate (with an accuracy of 94.7%) an exudate rather than a transudate. A pleural fluid pH has also been used as a diagnostic aid and should be collected in a heparinized syringe and kept anaerobically at 0°C until analysis. Pleural fluid pH values of less than 7.3 often indicates an exudative effusion secondary to malignancy, empyema, rheumatoid arthritis, tuberculosis and oesophageal rupture. A pleural fluid pH of less than 7.3 (or pH 0.3 lower than the blood pH in the presence of an acidosis), glucose less than 3.3 mmol/l (or pleural to serum glucose ratio less than 0.5) and LDH greater than 1000 U/l in a parapneumonic effusion indicate an impending empyema and often require

---

**Table 1.1 Causes of a pleural transudate**

| Congestive cardiac failure |
| Cirrhosis |
| Malnutrition |
| Nephrotic syndrome |
| Myxoedema |
| Acute glomerulonephritis |
| Meigs’ syndrome |
| Sarcoidosis |

---

**Table 1.2 Causes of an exudate**

| Tuberculosis |
| Oesophageal rupture |
| Empyema |
| Rheumatoid arthritis |
| Malignancy |

---

7
Anatomy of the Lung

chest tube drainage.\textsuperscript{34,35} Pleural fluid adenosine deaminase level above 45 IU/L or a gamma interferon level above 3.7 U/mL strongly suggests a tuberculous effusion.\textsuperscript{36,28}

**Table 1.2 Causes of a pleural exudate**

<table>
<thead>
<tr>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection (tuberculosis, viral, bacterial)</td>
</tr>
<tr>
<td>Parapneumonic</td>
</tr>
<tr>
<td>Chest trauma</td>
</tr>
<tr>
<td>Pulmonary infarction</td>
</tr>
<tr>
<td>Bronchogenic carcinoma</td>
</tr>
<tr>
<td>Metastatic lung disease</td>
</tr>
<tr>
<td>(lung, breast, ovarian, uterine, prostatic, renal, thyroid gastric, colonic, pancreatic)</td>
</tr>
<tr>
<td>Mesotheliomas, lymphoma</td>
</tr>
<tr>
<td>Asbestosis</td>
</tr>
<tr>
<td>Variceal sclerotherapy</td>
</tr>
<tr>
<td>Oesophageal rupture</td>
</tr>
<tr>
<td>Peritonitis</td>
</tr>
<tr>
<td>Abdominal surgery</td>
</tr>
<tr>
<td>Subphrenic collection</td>
</tr>
<tr>
<td>Pancreatitis</td>
</tr>
<tr>
<td>Drug sensitivity</td>
</tr>
<tr>
<td>Nitrofurantoin, amiodarone, methysergide, minoxidil, dantrolene</td>
</tr>
<tr>
<td>Methotrexate, bleomycin, mitomycin</td>
</tr>
<tr>
<td>Collagen vascular diseases</td>
</tr>
<tr>
<td>Systemic lupus erythematosus, rheumatoid arthritis</td>
</tr>
<tr>
<td>Sjogren's syndrome, Wegener's granulomatosis</td>
</tr>
<tr>
<td>Yellow nail syndrome</td>
</tr>
<tr>
<td>Chronic renal failure</td>
</tr>
</tbody>
</table>

The cholesterol level in pleural fluid has also been suggested as a diagnostic aid, with exudates having a cholesterol level greater than 1.55 mmol/L (or a pleural/serum cholesterol ratio greater than 0.3) and transudates having a cholesterol level less than 1.55 mmol/L\textsuperscript{37} (or a pleural/serum cholesterol ratio greater than 0.3);\textsuperscript{38} although, pleural/serum gradients of cholesterol (as well as bilirubin and albumin) are no better discriminators of exudates and transudates than the pleural/serum gradients of LDH and protein, previously mentioned.\textsuperscript{39}

To establish a diagnosis of a malignant effusion, malignant cells must be found either on cytological examination of the pleural fluid or histological examination of pleural tissue.\textsuperscript{40}

**REFERENCES**

Anatomy of the Lung


Chapter 2

RESPIRATORY PHYSIOLOGY

CONTROL OF BREATHING
In the normal awake individual, ventilation is stimulated by hypercapnia, hypoxaemia and acidaemia, although the cortex may override these effects when voluntary control is imposed. Afferent sensors, a central control and efferent effectors keep the arterial PO\textsubscript{2} (PaO\textsubscript{2}) and PCO\textsubscript{2} (PaCO\textsubscript{2}) within close limits despite the body’s widely differing requirements for oxygen and carbon dioxide excretion. During sleep, the control varies; for example during non-rapid-eye-movement sleep, breathing is under normal control, whereas during rapid-eye-movement-sleep, ventilation is generally less responsive to normal stimuli and the PaO\textsubscript{2} often falls by 10-20 mmHg.

Afferent sensors

Central chemoreceptors
The central respiratory chemoreceptors lie just below the ventral surface of the medulla near the exit of the ninth and tenth nerves. They respond largely to a change in the CSF (i.e. cerebral ECF) H\textsuperscript{+} concentration, stimulating respiration when the H\textsuperscript{+} concentration is increased and inhibiting respiration when the H\textsuperscript{+} concentration is decreased. The blood brain barrier inhibits HCO\textsubscript{3} and H\textsuperscript{+} entry into the CSF, although CO\textsubscript{2} diffuses easily, stimulating respiration by altering the CSF pH. Approximately 80% of the response to inhaled carbon dioxide is due to central chemoreceptor stimulation. The CSF contains less protein than blood to act as a buffer (i.e. 0.2 g/L, vs. 6 g/L), and is responsible for a lower pH than blood (i.e. 7.32 vs. 7.40) and a greater pH change in the CSF than that observed in blood for a given change in PCO\textsubscript{2}.

Peripheral chemoreceptors
In man the peripheral chemoreceptors are located in the carotid bodies at the bifurcation of the common carotid arteries. They regulate respiration but do not appear to be essential for survival, as is often demonstrated in patients who have bilateral carotid endarterectomies where both carotid bodies are lost. The aortic body receptors play no role in modulating respiration in man. The carotid body receptors respond to a decrease in PaO\textsubscript{2} and arterial pH and an increase in PaCO\textsubscript{2}. They are responsible for the immediate increase in breathing caused by hypoxia (a response that begins at a PaO\textsubscript{2} of 60 mmHg at normal arterial pH and PaCO\textsubscript{2} levels) which is lost in patients who have had bilateral carotid body resections. A reduction in arterial oxygen content does not cause carotid body stimulation, therefore anaemia, methaemoglobinemia or carboxyhaemoglobinemia does not stimulate respiration. The response of peripheral chemoreceptors to PaCO\textsubscript{2} is linear over the range 20 - 60 mmHg, although it is much less important than the response of the central chemoreceptors. The carotid bodies respond to a change in pH which is linear over the range 7.2 - 7.7 (i.e., H\textsuperscript{+} 60 - 20 n\text{mol/L}), regardless of whether the change is respiratory or metabolic, causing hyperventilation with acidosis, and hypoventilation with alkalosis. Peripheral chemoreceptor stimulation also occurs with hypotension, sympathetic stimulation, pyrexia, and with the drugs doxapram and almitrine.
Respiratory Physiology

Lung receptors
There are three types of lung receptors, all of which transmit afferent impulses via the vagus:

1. **The stretch receptors** lie within the airway smooth muscle and are stimulated by lung inflation. They are relatively resistant to adaptation, causing an increase in expiratory time and a slowing of the respiratory rate, when stimulated.

2. **The irritant receptors** lie between airway epithelial cells. They are stimulated by histamine and noxious gases, causing hyperventilation and a release of substance P and smooth muscle constriction (i.e. bronchospasm).

3. **The J receptors** (juxtacapillary receptors) lie in the alveolar walls close to the capillaries. They are stimulated when the pulmonary capillaries are engorged and the pulmonary interstitial volume is increased (e.g. pulmonary oedema), causing rapid shallow breathing.

Other receptors
These include receptors of the nose, upper airways, joints, and muscles, as well as pain and temperature receptors, all of which may alter the rate and depth of respiration.

Central control
The normal automatic process of breathing originates from three groups of brainstem neurones.

1. **The respiratory centre** resides in the reticular formation of the medulla and is responsible for the periodic nature of inspiration and expiration and may be divided into:
   - Cells of the dorsal region of the medulla, which are mainly associated with inspiration; these cells have the property of intrinsic periodic discharge and are probably responsible for the basic rhythm of ventilation.
   - Cells in the ventral region of the medulla, which are mainly concerned with expiration.

2. **The apneustic centre** resides in the lower pons. If the brain of an experimental animal is sectioned just above this site, this causes prolonged inspiratory gasps (apneusis) interrupted by transient expirations. It is not known whether this centre plays any physiological role in normal human ventilation.

3. **The pneumotaxic centre** resides in the upper pons. This centre appears to progressively inhibit inspiration, regulating the inspiratory volume and respiratory rate. It is believed that this centre has only a regulatory influence on the respiratory rhythm because respiration can exist in its absence.

Peripheral effectors
The muscles of respiration include the diaphragm, intercostal muscles and abdominal muscles.

Inspiration
**Diaphragm.** The diaphragm is supplied by the phrenic nerve which commonly arises from C3, C4 and C5. When the diaphragm contracts, both the vertical and transverse diameters of the chest are increased, although with extreme hyperinflation the diaphragm may behave as an expiratory muscle, by indrawing the costal margins (i.e. Hoover’s sign). In the adult, during tidal inspiration, the diaphragm moves 1 cm and is responsible for 100% of the air movement. During the vital capacity, the diaphragm moves by 10 cm and is responsible for approximately 75% of the air movement. The remaining 25% is due largely to the influence of intercostal muscles.

Diaphragmatic strength has been assessed indirectly by measuring the pressure generated across the diaphragm, by recording gastric and pleural (or oesophageal) pressures with balloon-catheter systems. However, the pressure difference (i.e. transdiaphragmatic pressure) has a
large variability between normal individuals. It also depends on the diaphragm muscle length and geometry (i.e. lung volumes), as well as the abdominal compliance, and has been found to be of little value in accurately assessing the diaphragmatic muscle strength in the critically ill patient.\(^8\)

Paralysis of the diaphragm produces a paradoxical movement when the patient suddenly inhales (e.g. sniffs). The diaphragm moves upward (which is observed during fluoroscopy), and the abdomen moves in. If the diaphragm is functional but the intercostal and abdominal muscles are paralysed (e.g. with a cervical spinal injury), then on inspiration the chest wall moves in and the abdominal wall moves out. The reverse occurs during expiration, and a characteristic ‘see saw’ pattern occurs during respiration. A reflex diaphragmatic dysfunction occurs after abdominal surgery, causing a reduction in the vital capacity,\(^9\) and diaphragmatic paralysis may occur after cardiothoracic surgery (particularly if a pericardial ice slush rather than cold saline is used for myocardial protection). Diaphragmatic contractility may be enhanced with aminophylline, caffeine, digoxin, or isoprenaline and with correction of hypophosphataemia or hypokalaemia.

**External intercostal and accessory muscles.** The external intercostal muscles slope downward and forward. When they contract (particularly the 5-9th muscles) the lateral and anteroposterior diameters of the thorax increase. The accessory muscles of inspiration include the scalene muscles (which elevate the first two ribs) and sternomastoid muscles (which raise the sternum).

**Expiration**
During quiet respiration, expiration is passive because the lung and chest wall are elastic and tend to return to their equilibrium position with completion of inspiration. During active exercise the muscles of the abdominal wall (e.g. rectus abdominis, internal oblique, external oblique, transversus abdominis) contract and force the diaphragm up. The internal intercostal muscles also assist by pulling the ribs down and in. The latissimus dorsi are involved in coughing.

**VENTILATION**

**Lung volumes**
The total lung capacity (TLC) is divided into four primary volumes, the inspiratory reserve volume (IRV), tidal volume (TV), expiratory reserve volume (ERV) and residual volume (RV) (Fig. 2.1). Lung capacities are made of two or more lung volumes. The values in Table 2.1 are those considered to be standard for men and women and for a newborn infant who has a respiratory rate of 50-60/min (adult rate 12-15/min). The functional residual capacity (FRC) consists of the ERV and the RV and is the volume remaining in the lung when the opposing forces of the lung and chest wall are balanced at the end of normal expiration. The vital capacity consists of the IRV, TV and ERV. The inspiratory capacity consists of the TV and the IRV. While the vital capacity is one of the commonest measurements made at the bedside, it is subject to variation of up to 5% between measurements.
Fig. 2.1 Static lung volumes and capacities. The spirometer trace indicates the lung volumes that can be measured by simple spirometry: inspiratory reserve volume, expiratory reserve volume, inspiratory capacity and tidal volume.

### Table 2.1 Lung volumes (mL) in normal humans

<table>
<thead>
<tr>
<th>Volume</th>
<th>2.5 kg infant</th>
<th>Man</th>
<th>Woman</th>
<th>% TLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspiratory reserve volume</td>
<td>90</td>
<td>3100</td>
<td>2000</td>
<td>50</td>
</tr>
<tr>
<td>Tidal volume</td>
<td>15</td>
<td>500</td>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>35</td>
<td>1200</td>
<td>800</td>
<td>20</td>
</tr>
<tr>
<td>Residual volume</td>
<td>35</td>
<td>1200</td>
<td>900</td>
<td>20</td>
</tr>
<tr>
<td>Total lung capacity</td>
<td>175</td>
<td>6000</td>
<td>4200</td>
<td>100</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>140</td>
<td>4800</td>
<td>3400</td>
<td>80</td>
</tr>
<tr>
<td>Functional residual capacity</td>
<td>70</td>
<td>2400</td>
<td>1700</td>
<td>40</td>
</tr>
<tr>
<td>Inspiratory capacity</td>
<td>105</td>
<td>3600</td>
<td>2500</td>
<td>60</td>
</tr>
</tbody>
</table>

### Gas volumes
The volume in litres (STPD) of the gram molecular weight of an ideal gas is 22.413, for oxygen it is 22.393 and for carbon dioxide it is 22.262. At rest, an adult uses 10-12 mmol of oxygen (i.e. 224-269 mL STPD) and generates 8-10 mmol of carbon dioxide (i.e. 178-223 mL STPD) per minute. The body gas stores in normal adults breathing air and oxygen are shown in Table 2.2. If a normal subject breathes 100% oxygen, the PaO₂ will reach a maximum of 600-640 mmHg (i.e. the P(A-a)O₂ ranges from 35-80 mmHg). This will allow an extra 1.55 mL/100 mL of oxygen to be dissolved, and the haemoglobin saturation to rise from 97.5 to 99.8 to carry an extra 0.48 mL/100 mL (if Hb is 15 g and 1 g of haemoglobin carries 1.39 mL O₂ when 100% saturated). If the arterial-venous oxygen content difference is 5 mL/100 mL of blood, and the mixed venous oxygen saturation is 75% at a PO₂ of 40 mmHg, then if 100% oxygen is inspired,
the arterial oxygen content will increase by 2 mL/100 mL (approximately 75% of which is dissolved), the mixed venous oxygen content will increase from 15 to 17 mL/100 mL, the saturation will increase from 75% to 85% and the mixed venous \( \text{PO}_2 \) will increase from 40-50 mmHg. The body oxygen store is increased during the breathing of 100% oxygen, largely due to the increase in oxygen stored in the FRC (i.e. from 320 mL to 2140 mL) and is the reason for ‘preoxygenation’ during anaesthetic induction. A similar increase in oxygen would require an addition of 1300 g of 97% saturated haemoglobin (i.e. 9 litres of blood or 4.5 litres of packed cells).

Table 2.2 Oxygen, carbon dioxide and nitrogen stores in mL (mmol given in parenthesis)

<table>
<thead>
<tr>
<th></th>
<th>( \text{O}_2 ) stores when breathing</th>
<th>( \text{CO}_2 ) stores</th>
<th>( \text{N}_2 ) stores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>air</td>
<td>100% oxygen</td>
<td>breathing air</td>
</tr>
<tr>
<td>In lungs at FRC</td>
<td>320 (14.3)</td>
<td>2140 (95.6)</td>
<td>150 (6.7)</td>
</tr>
<tr>
<td>In blood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial (25% BV)</td>
<td>270 (12.1)</td>
<td>290 (13.0)</td>
<td>650 (29.2)</td>
</tr>
<tr>
<td>Venous (75% BV)</td>
<td>610 (27.2)</td>
<td>670 (29.9)</td>
<td>2110 (94.8)</td>
</tr>
<tr>
<td>tissue fluids</td>
<td>50 (2.2)</td>
<td>100 (4.4)</td>
<td>12090 (543)</td>
</tr>
<tr>
<td>myoglobin</td>
<td>200 (8.9)</td>
<td>200 (8.9)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1450 (64.7)</td>
<td>3400 (151.8)</td>
<td>15000 (673.8)</td>
</tr>
</tbody>
</table>

*Abbreviations: BV = blood volume, FRC = functional residual capacity

During normal gas exchange at sea level breathing air, the partial pressures of oxygen, carbon dioxide and nitrogen are shown in Fig. 2.2.

![Fig 2.2 Partial pressures (mmHg) and concentrations (%) of oxygen, carbon dioxide and nitrogen, in blood and respiratory gas. (Redrawn from Ganong WF. Review of Medical Physiology. 11th ed. Los Altos, CA: Lange Medical Publications, 1983: 529)](image-url)
Functional volumes
The lung transports gases using a tidal exchange. Ventilation values (e.g. alveolar ventilation, total ventilation) are determined from the expired gas volumes. If the TV is 500 mL and the respiratory rate 15 then the minute expired volume is 7500 mL/min. The inspired volume is slightly greater because the RQ is often less than unity (i.e. more oxygen is needed than CO₂ expired).

Dead-space ventilation
Dead-space ventilation is that space that is not involved with gas exchange.

The anatomic dead space. This is that part of the inspired tidal volume which is expired unchanged at the beginning of expiration. It varies with body weight (roughly equivalent in mL to the patient’s weight in pounds), posture (e.g. standing 150 mL, sitting 140 mL, supine 100 mL) and lung volume (e.g. 20 mL is added per litre increase in TV). Half of the anatomical dead space exists above and half below the carina. It is commonly measured by Fowler’s method, in which the expired concentration of nitrogen is measured after a single inspiration of 100% oxygen. A dead space of 150 mL means that only 350 mL of the 500 mL TV is available for fresh gas exchange, or 5250 mL/min of the 7500 mL/min ventilation if the subject has a TV of 500 mL and respiratory rate of 15/min. The 5250 mL volume is known as the alveolar ventilation. The functional pulmonary volumes and flow characteristics for a normal man are listed in Table 2.3.

<table>
<thead>
<tr>
<th>Volume (mL)</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume</td>
<td>500 Total ventilation 7500 mL/min</td>
</tr>
<tr>
<td>Dead space</td>
<td>150 Frequency 15 /min</td>
</tr>
<tr>
<td>Alveolar gas</td>
<td>3000 Alveolar ventilation 5250 mL/min</td>
</tr>
</tbody>
</table>

Physiological dead space. This is that volume of gas which takes no part in pulmonary carbon dioxide exchange. In normal man, the physiological and anatomical dead spaces are nearly the same; however, in patients with lung disease, the physiologic dead space may be much larger because of inequality of blood flow and ventilation within the lung.

Because gas exchange only occurs from alveolar ventilation, the volume of expired carbon dioxide per minute is equal to the minute alveolar ventilation times the concentration of carbon dioxide in the mixed expired gas:

\[ \dot{V}_CO_2 = \dot{V}_A \times FE_{CO}_2 \]

Also, as the partial pressure of carbon dioxide is directly proportional to the concentration of CO₂, and as the Pₜ₅CO₂ is directly related to the Pₐ₅CO₂, as there is almost no a-A gradient for carbon dioxide the Pₐ₅CO₂ may be taken as the same as PaCO₂. Thus the PaCO₂ can be seen to be inversely related to the alveolar ventilation (e.g. as the alveolar ventilation is halved the PaCO₂ is doubled). The relationship between Pₜ₅CO₂ and Pₐ₅CO₂ varies with the tidal volume due to the variation in anatomic dead space, which increases with a large tidal volume and decreases with reduced tidal volume due to traction exerted on the bronchi by the surrounding lung parenchyma.
Regional differences in ventilation

Change in compliance
In the normal individual there is a vertical gradient in ventilation and perfusion. After expiring to residual volume, on inspiration the first portion of the inspired gas is distributed to the uppermost portions of the lung (as gravity causes a gradation in compliance with a greater airway closure in the dependent portions of the lung at residual volume.). Thus, at low lung volumes and in the upright position, the apex of the lung receives a greater portion of the ventilation than the base. With continued lung expansion the lower portions of the lung receive a greater portion of the ventilation (as more and more of the upper portions or the lung reach terminal expansion). With expiration the reverse occurs, with gas from the bases expired first and the apex last.

As the predominant influence on the sequence of areas ventilated during normal breathing is gravity, a change in body position from erect to supine or prone position will alter this sequence, although it will always be the uppermost portions of the lung receiving the first portion of the inspired gas on inspiration from residual volume, and the lowermost portions exhaled first from full inspiration (i.e. at vital capacity).

A pathological change in regional airway compliance or airway resistance will also change the ventilation to that segment of lung.

Airway closure
At reduced lung volumes, small airways, probably in the region of the respiratory bronchioles (i.e., 0.5 mm diameter), close, trapping gas in the distal alveoli excluding them from gas exchange. The oxygen is absorbed, the carbon dioxide equilibrates with the pulmonary capillary blood and the remaining nitrogen ‘stents’ the trapped airways. This phenomenon occurs at the lowermost regions of the lungs during forced expiration in normal individuals, although in the elderly it tends to occur during the latter part of normal expiration. An increased tendency to airway closure will also occur with obesity, supine posture, anaesthesia, ascites, and abdominal surgery. Airway closure in the presence of continued perfusion contributes to venous admixture.

DIFFUSION
The rate of transfer of a gas through a sheet of tissue (i.e. its diffusion) varies inversely with the tissue thickness, and is directly proportional to the area, difference in the partial pressure of gas between the two sides (alveolar-blood gradient for oxygen is 60 mmHg and for carbon dioxide it is 6 mmHg) and a diffusion constant. The diffusion constant depends on the properties of a particular tissue and the particular gas (i.e. solubility and molecular weight of the gas). The alveolar-blood barrier has an area of 120-140 m² and a thickness of less than 0.6 μm.

PULMONARY PERFUSION
The total pulmonary blood volume in an adult is approximately 700 mL, the pulmonary capillary blood is approximately 200 mL and the pulmonary blood flow is 5000 mL/min. The pulmonary vasculature may be functionally divided into alveolar and extra-alveolar vessels, with the former being subjected to alveolar pressures and the latter being subjected to pressures which are more closely related to intrapleural pressures.

Pulmonary vessels vasoconstrict in response to serotonin, noradrenaline, histamine, acidosis, and reduction in alveolar (not pulmonary blood) PO₂, beginning at values of less than 70 mmHg. The latter is part of a self-regulatory mechanism by which pulmonary capillary
blood flow is automatically adjusted to alveolar ventilation. Isoprenaline and acetylcholine cause pulmonary vasodilation.

**Recruitment**
The pulmonary vascular resistance has the capacity to decrease as the pressure within it rises, due to recruitment of pulmonary capillaries. This is one of the reasons why the PaO\(_2\) may improve when shock is corrected, as pulmonary perfusion is also improved.

**Normal regional differences in perfusion**
The distribution of pulmonary blood flow is uneven due to gravity, and may be partitioned into three zones (West zones). With MPAP = mean pulmonary artery pressure, PA = alveolar pressure and PV = pulmonary venous pressure, the zones are characterized as:

*Zone 1:* where PA > MPAP > PV. This usually occurs in the uppermost portion of the lung where there is no pulmonary blood flow. This area contributes to the dead space.

*Zone 2:* where MPAP > PA > PV. This usually occurs in the mid zone, where the blood flow is dependent on the difference between arterial and alveolar pressures and not arterial and venous pressures. As arterial pressure is increasing down this zone (but alveolar pressure is not) the pressure difference and hence the blood flow increase down this zone. Venous pressure has no effect on flow. Recruitment also increases down this zone.

*Zone 3:* where MPAP > PV > PA. In this zone both arterial and venous pressures exceed alveolar pressure, and flow is determined by the pulmonary arterial-venous pressure difference. Any increase in flow down this zone is due to increase in distension of capillaries. A fourth zone may also be defined at low lung volumes, where the resistance of the extra-alveolar vessels becomes important and a reduction in blood flow occurs at the base of the lung, where the lung parenchyma (and extra-alveolar vessel) is least expanded.

As pulmonary ventilation is also distributed vertically, distribution of ventilation and perfusion are usually well matched.

**VENTILATION-PERFUSION RELATIONSHIPS**
Mismatching of ventilation and perfusion is responsible for most of the abnormalities of blood gas exchange in pulmonary disease. Gas exchange will not occur in a pulmonary unit devoid of ventilation or one devoid of perfusion. In respiratory disease, gas exchange units may have varying degrees of either of these abnormalities (i.e. areas with low VA/Q ratios and areas with high VA/Q ratios); and functionally, the lung may be considered as a three compartmental model consisting of three gas exchange units:

1. **Ideal VA/Q:** this may be estimated by the alveolar gas equation which derives the PAO\(_2\) from the inspired oxygen concentration, temperature, barometric pressure and P\(_a\)CO\(_2\) (which is assumed to be PaCO\(_2\))

2. **Physiologic shunt:** this is the portion of blood that is perceived to bypass the pulmonary gas exchange.

3. **Physiologic dead space:** this is the portion of ventilation that is considered to take no part in pulmonary gas exchange.

**HAEMODYNAMIC EFFECTS OF VENTILATION**
Asynchronism of the left and right ventricular stroke volume occurs during the inspiratory and expiratory phase of spontaneous and artificial ventilation.\(^{11,12}\) The effect is largely due to a biventricular alteration in preload and afterload caused by the intrathoracic pressure (and therefore transmural pressure) changes associated with respiration. Chamber volume limitations
imposed by the pericardium and interventricular septum, normally play a minor role, although their effects may be more important during severe respiratory disorders.

Transmural pressure (i.e. the pressure difference between the inside and outside of a cardiac chamber) is the effective filling pressure, and therefore relates more closely to the end-diastolic volume (i.e. preload). Internal cavity pressures are often measured directly using intravascular catheters, whereas atmospheric pressure is often used as the intrapericardial pressure reference. Intrapericardial pressure in the normal adult during spontaneous ventilation varies from -3 to -6 mmHg, and may change markedly depending upon the lung volume, pulmonary compliance, and airway pressure, throughout a range of ±100 mmHg. The intrapericardial pressures are greater than normal during positive pressure ventilation, PEEP, pleural effusion, pneumothorax, haemothorax, constrictive pericarditis, cardiac tamponade, severe ascites or during the Valsalva manoeuvre, and less than normal during restricted inspiration (e.g. Müller’s manoeuvre), and will not be accurately reflected using an atmospheric pressure reference.

Spontaneous ventilation
During inspiration the right ventricular preload is increased, due to an increase in transmural right ventricular end-diastolic pressure, and right ventricular afterload is decreased, due to an increase in transmural pulmonary artery pressure. Both effects are responsible for the slight increase in the right ventricular stroke volume (RVSV) on inspiration. On the other hand, the left ventricular preload is decreased due to a decrease in the left ventricular compliance (a pericardial and septal effect) and left ventricular afterload is increased due to a reduction in transmural (i.e. thoracic outlet) aortic pressure. Both effects are responsible for the slight reduction in the left ventricular stroke volume (LVSV) on inspiration. The effect of inspiration decreases with time (e.g. if the subject holds inspiration), as the increase in RVSV increases the left ventricular preload and therefore the LVSV. The reverse occurs on expiration.

Positive pressure ventilation
During the inspiratory phase of positive pressure ventilation, the RVSV decreases due to a reduction in preload and increase in afterload. The LVSV increases due to a reduction in afterload, due to the effect of an increase in intrathoracic pressure on the left ventricle and aorta. This reduction in afterload or thoracic pump action is also believed to play a major part in forward blood flow during CPR, and some suggest that intermittent positive pressure ventilation may be a valuable form of left ventricular assist in patients with severe left ventricular failure, in addition to improving the oxygen exchange capacity of the oedematous lung and reducing the oxygen requirement of breathing. If the inspiratory phase is prolonged the left ventricular preload decreases, due to a decrease in left atrial transmural pressure and RVSV, causing a reduction in LVSV. The effects of mechanical ventilation on the circulation are exacerbated by hypovolaemia. In mechanically ventilated patients without cardiac failure, cardiac output improves when spontaneous ventilation is resumed.

Because positive pressure ventilation decreases both right ventricular preload and left ventricular afterload, an increase in ECF volume will occur in patients who have been ventilated for some time. When spontaneous ventilation is resumed there is an increase in right ventricular preload and left ventricular afterload, both of which cause an increase in left atrial pressure which may precipitate pulmonary oedema in patients who have marginal left ventricular reserve.

Positive end-expiratory pressure
In patients who have left ventricular failure, pulmonary oedema and hypoxia, intermittent positive pressure ventilation with PEEP or spontaneous ventilation with CPAP reduces...
pulmonary venous pressure and pulmonary oedema by reducing right ventricular preload and left ventricular afterload. PEEP improves arterial oxygenation in both cardiogenic pulmonary oedema and ARDS by reducing airway closure.

However, PEEP also increases right ventricular afterload which, if it is severe, may shift the septum leftward and decrease the left ventricular diastolic volume. Normally, the mean pressure in the left ventricle (50 mmHg) is five times that of the right ventricle (10 mmHg); thus for any systolic septal shift to occur, the right ventricular pressure has to be increased greatly, because a reduction in left ventricular pressure to a level that would cause normal right ventricular pressures to have an effect on the septum would be to levels that are not compatible with survival. In patients with pulmonary hypertension who are mechanically ventilated with PEEP, septal movement during systole has been documented to cause a reduction in left ventricular diastolic volume and a decrease in LVSV. Conversely, leftward septal displacement has been reported to enhance left ventricular mechanics by minimizing the energy required in the initial septal movement by the left ventricle. If pulmonary compliance is reduced severely, then the major effect of PEEP is to increase the pulmonary arterial pressure and right ventricular afterload as the transmission of the increase in airway pressure to the pleura is diminished, reducing its effect on venous return. Experimentally, the differing mechanisms (i.e. decrease in right ventricular preload and increase in right ventricular afterload) cause cardiac output to be equally depressed with PEEP, irrespective of the lung compliance, although volume loading will only improve cardiac output when a reduction in preload has caused the reduction in cardiac output. While some have described a humoral myocardial depressant factor associated with PEEP, others have not confirmed its existence. If the right atrial pressure is elevated to a level greater than left atrial pressure then, if the foramen ovale is still patent, a R-L cardiac shunt may worsen the hypoxia.

The effects of PEEP in reducing airway closure and improving oxygen exchange, decreasing cardiac output and, rarely, increasing right atrial pressure and causing a R-L shunt, cause the oxygen delivery to increase, remain unchanged or decrease. Therefore, PEEP should be monitored carefully, particularly in patients who have pulmonary hypertension and right ventricular failure.

REFERENCES


Chapter 3

CHEST X-RAY in RESPIRATORY ASSESSMENT

An inspection routine of the chest X-ray (Tables 3.1 and 3.2) and a comparison of the chest X-ray with old films (if available) ensures a thorough radiological examination of the chest. Daily and postprocedure chest X-rays are required for all critically ill patients, to diagnose and monitor cardiorespiratory disease and evaluate the intrathoracic placement of catheters, tubes and wires. 1,2,3,4

Table 3.1 An inspection routine for the posteroanterior or anteroposterior chest X-ray

<table>
<thead>
<tr>
<th>Technical aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projection, supine, erect, centred, degree of inspiration, exposure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Catheters, tubes and artefacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETT, CVP, S-G catheter, intra-aortic balloon, pacing wires UWSD, NG tube, ECG leads, Sengstaken-Blakemore tube</td>
</tr>
<tr>
<td>Hair plats, clothing, skin folds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cardiac, mediastinal and hilar shadows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung fields</td>
</tr>
<tr>
<td>Compare both sides for lung markings and translucency</td>
</tr>
<tr>
<td>Upper zone (apex)</td>
</tr>
<tr>
<td>Mid zone</td>
</tr>
<tr>
<td>Lower zone (cardiophrenic and costophrenic angles)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diaphragm and pleura</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bony outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>clavicles, sternum, ribs, vertebral bodies, humeri and scapulae</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soft tissue shadows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck, axilla, breast, below diaphragm</td>
</tr>
</tbody>
</table>

Abbreviations: CVP = central venous pressure, ETT = endotracheal tube, NG = nasogastric, S-G = Swan-Ganz, UWSD = under water seal drain.
Table 3.2 An inspection routine for the lateral chest X-ray

<table>
<thead>
<tr>
<th>Clear spaces</th>
<th>Vertebral translucency</th>
<th>Diaphragm outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrosternal space</td>
<td>Loss of translucency (e.g. right ventricular hypertrophy, thymoma)</td>
<td>Loss of outline (e.g. consolidation, collapse or effusion)</td>
</tr>
<tr>
<td>Loss of translucency</td>
<td>Hyperlucent (e.g. emphysema, asthma)</td>
<td></td>
</tr>
<tr>
<td>(e.g. right ventricular hypertrophy, thymoma)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrocardiac space</td>
<td>Loss of translucency (e.g. left atrial or ventricular hypertrophy)</td>
<td></td>
</tr>
<tr>
<td>Loss of translucency</td>
<td>Increased density (e.g. consolidation, collapse or effusion)</td>
<td></td>
</tr>
<tr>
<td>(e.g. left atrial or ventricular hypertrophy)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebrae translucency</td>
<td>Increased density (e.g. consolidation, collapse or effusion)</td>
<td></td>
</tr>
<tr>
<td>Diaphragm outline</td>
<td>Loss of outline (e.g. consolidation, collapse or effusion)</td>
<td></td>
</tr>
</tbody>
</table>

TECHNICAL ASPECTS

**Projection.** While the posteroanterior (PA) and left or right lateral views (left or right indicating the side closest to the film) are the standard chest X-ray projections, the portable supine anteroposterior (AP) view is often the standard radiological examination in the acutely ill patient. Penetrated views (to assess opaque lesions, cavitation or calcification), lordotic views (to assess apical and middle lobe lesions) decubitus views (to detect a pneumothorax or pleural fluid) and expiratory views (to detect a pneumothorax or an obstructive emphysematous bullae) may occasionally be performed in difficult cases. Ultrasound can be used to identify pleural effusions (particularly if loculated) and computed tomography (CT) scanning of the chest is used to evaluate hilar and mediastinal masses, pleural and chest wall lesions and for staging malignancies.

The supine AP view differs in a number of aspects from the erect PA view. For example:
- The focal distance (or source-to-image receptor distance) is often less than 2 m causing the heart and mediastinal features to be larger
- The patient is supine, causing the diaphragm to be higher and the pulmonary vasculature to be more prominent
- The scapula shadows remain within the apical area and may obscure apical pulmonary shadows

**Centring.** The film is well centred and the patient is correctly positioned if the medial ends of the clavicle are equidistant from the vertebral spinous processes at the level of T4, with the medial clavicular shadow overlying the posterior portions of the 4th ribs.

**Degree of inspiration.** On full inspiration the anterior ends of the 6th ribs or the posterior ends of the 10th ribs are above the diaphragms.

**Exposure.** The vertebral bodies, but not the intervertebral discs, should be just visible through the cardiac shadow.

CATHETERS, TUBES and ARTEFACTS
These include internal artefacts such as cardiac catheters, gastric tubes, endotracheal tubes, pleural drains, and intraaortic balloon catheters, as well as external artifacts such as hair plats, clothing, oxygen tubing, drainage tubing, etc., and may be delineated by demonstrating that the edges of the artefact extend beyond normal tissue boundaries.

The study of tubes and lines placed in critically ill patients (‘tubology’6) is important in the;
Chest X-rays

1) *post procedural chest X-ray review*, to verify correct placement (i.e. the tube is in the correct cavity, the tip is at the correct site and there is no knotting, kinking or fracture), and
2) *daily chest X-ray*, to ensure against catheter or tube displacement.\(^7,^8\)

**CARDIAC AND MEDIASTINAL SHADOWS**

**Heart**

Normally, two-thirds of the cardiac shadow lies to the left of the midline and one-third to the right.

**Mediastinal shadows**

The larynx overlies the vertebral bodies of C4, C5 and C6. The tracheal translucency on the PA film extends from the vocal cords (overlying C5-C6) to the carina (overlying T6), shifting slightly from left to right. It is approximately 12 cm long. The midtrachea is opposite the medial ends of the clavicles (overlying T3-T4) and ends at the carina (overlying T6).\(^7\) The angle of the carina is 60-75° and may widen due to an enlarged left atrium or lymphadenopathy. The azygos vein lies in the angle between the right main bronchus and trachea, and enlarges in the supine position and also with portal hypertension, inferior vena cava obstruction, superior vena cava obstruction, right ventricular failure, overtransfusion and constrictive pericarditis.

**Hilum, pulmonary vasculature and fissures**

The right hilum is usually 0.5-1.5 cm lower than the left and consists, from above down, of the right upper lobe bronchus, right pulmonary artery (maximum diameter of the right descending pulmonary artery is 17 mm),\(^9\) the intermediate bronchus and pulmonary veins. The left hilum, from above down, consists of the left pulmonary artery, left main bronchus and pulmonary veins. The hila may be displaced due to collapse or fibrosis, or enlarged due to vascular prominence (e.g. pulmonary hypertension), carcinoma or lymphadenopathy.

In the upper lobes, the veins are lateral and inferior to their respective arteries, due to the fact that the pulmonary arterial system arises above the venous system. In the lower lobes the veins have a relatively horizontal position whereas the arteries run an almost vertical course.

The horizontal fissure is seen in 60% of routine PA chest X-rays. It runs from the hilum (right 4th rib anteriorly) to the region of the 6th rib in the axillary line; it may be straight or have a slight downward curve and is often incomplete.

Both oblique fissures commence posteriorly at approximately T5 and, in the lateral film, pass through the hilum. They pass downwards and forwards, meeting the 6th rib in the mid axillary line and follow this rib until it reaches the inferior border of the lung at the 6th costochondral junction. The oblique fissures correspond to the medial border of the scapula when the hand is placed on the back of the head. Accessory fissures may also be present; for example, azygos fissure at the right apex in 1/200 normal subjects, superior accessory fissure (separating apical from basal segments), inferior accessory fissure (separating medial basal from other basal segments) and left-sided horizontal fissure. Displacement up or down of the left or right hilum or fissures may indicate collapse or fibrosis of the lung on the same side.

**LUNG FIELDS**

Pulmonary abnormalities are often described in terms of:

1. *Position* (upper, mid or lower zone): the upper zone is the area of lung above a line drawn horizontally at the anterior end of the second rib, the lower zone is the area of lung
below a horizontal line drawn at the anterior end of the fourth rib, the mid zone is the area between these two horizontal lines.

2. Structure (i.e. linear, patchy, cystic, homogeneous, ill-defined, diffuse)

3. Density (i.e. opacification, translucency, radiolucency, density)

However, certain terms are reserved for specific abnormalities, for example miliary or fine mottling (lesions less than 2 mm in diameter), mottling (discrete or semiconfluent shadows greater than 2 mm and less than 5 mm in diameter), coarse mottling or nodular shadows (shadows of 5 - 20 mm), oval or circular shadows (shadows > 20 mm), reticular or reticulation (fine linear shadows that form a network) and honeycomb (small regular ring shadows of 5 - 10 mm in diameter). Also, interstitial and alveolar opacifications have a characteristic appearance, as described below.

Alveolar opacification
When patchy alveolar opacifications are present they appear as ill defined fluffy ‘cotton wool’ shadows. An air bronchogram occurs when there is confluent alveolar opacification with patent bronchi (i.e. consolidation), whereas airway opacification and obstruction will lead to a homogeneous opacification without an air bronchogram (i.e. collapse).

Consolidation
Consolidation characteristically produces a reduction in air in the lung in association with a normal lung volume. The radiological appearance is that of a relatively homogeneous opacification occupying the normal position of a lobe or a segment without significant displacement of the contiguous fissures. Some loss of lung volume may occur; an air bronchogram excludes an effusion or collapse, although absence of it does not exclude consolidation.

Right upper lobe consolidation is easily recognised on the PA and lateral film, the apical opacification being demarcated inferiorly by the horizontal fissure and posteriorly by the oblique fissure (Fig. 3.1). Right middle lobe consolidation appears as a triangular opacification in the PA film, with a sharp upper border and a poorly defined lateral border (Fig. 3.2). The medial border blends with and obscures the cardiac border. The wedge-shaped defect in the lateral projection is diagnostic. Right lower lobe consolidation produces a dense opacification that blends with and obscures the diaphragm and extends up to a surprisingly high level in the PA film, progressively decreasing in density with a poorly defined upper border (Fig. 3.3). In the lateral film the oblique fissure clearly demarcates the consolidated lower lobe.

Left upper lobe consolidation is similar to right upper lobe consolidation except that the inferior margin is not clearly defined (Figs. 3.1 and 3.2). Left lower lobe consolidation is similar to the right lower lobe consolidation except that a penetrated film may be required if the air bronchogram is to be seen through the heart (Fig. 3.3).

Collapse
Partial or complete loss of lung volume is termed atelectasis or collapse, contrasting with consolidation, in which there is a reduction of air in the lung associated with a normal lung volume. Right or left lung collapse is also associated with narrowing of rib interspaces, whereas massive effusion has often widened rib interspaces.

Right upper lobe collapse causes the lobe to reduce in size and become densely opaque, the horizontal fissure to elevate and the right lower lobe to become more translucent (Fig. 3.4).
Chest X-rays

Fig. 3.1 A diagrammatic representation of the chest X-ray appearance of consolidation of the left upper division of the left upper lobe, right upper lobe, and segments. Top row: (from left to right) consolidation in the right upper lobe (right lateral), right and left upper division of the left upper lobe (PA), and left upper division of the left upper lobe (left lateral). Second row: apical segment consolidation. Third row: posterior segment consolidation. Lower row: anterior segment consolidation, of the right and left upper lobes (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p 235-238).

Right middle lobe collapse is best seen in the lateral projection, where a wedge shaped opacification running from the hilum to the anterior costophrenic angle is observed (Fig. 3.4). In the AP projection there may only be an obscuring of the right lateral border of the heart (i.e. silhouette sign), although a lordotic view will render the collapsed lobe more obvious. Right lower lobe collapse may blur the upper border of the right diaphragm, displace the right hilum downward and cause opacification at the right cardiophrenic angle without obliterating the right heart border (Fig. 3.4).

Left upper lobe collapse causes an anterior displacement of the oblique fissure on the lateral projection. The anterior view reveals an ill-defined hazy opacity in the upper, mid and sometimes lower zones, which is densest near the hilum. The aortic knuckle is usually obscured and, if the lingula is involved, the left heart border is also obscured. The hilum is elevated and the trachea is often deviated to the left (Fig. 30.5). Left lower lobe collapse causes the hilum to be displaced downwards, the left upper lobe to appear hyperinflated and a wedge-shaped opacity with a sharp lateral line appears behind the cardiac shadow (Fig. 30.5).
Chest X-rays

Fig. 3.2 A diagrammatic representation of the chest X-ray appearance of consolidation of the right middle lobe, left lingula division of the left upper lobe, and segments. Top row (from left to right): consolidation in the right middle lobe (right lateral), right middle and left lingula division of the left upper lobe (PA), and left lingular division of the left upper lobe (left lateral). Middle row: consolidation of the lateral segment of the right middle lobe and superior segment of the lingula. Lower row: consolidation in the medial segment of the right middle lobe and the inferior segment of the lingula. (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p 235-238).

Silhouette sign
This permits localisation of a lesion on the PA film by studying the mediastinal and diaphragmatic outlines which are normally distinct because the adjacent tissues are of different densities (i.e. air and fluid or tissue). If the border of the mediastinum or diaphragm is obliterated (provided that the film is adequately penetrated, as a false positive sign can occur with an underpenetrated film), then adjacent borders are of equal density (e.g. there is overlying collapse, consolidation or fluid). Conversely, if the border is retained and the abnormality is superimposed, the lesion must be either anterior or posterior to the mediastinal or diaphragmatic border. The ascending aorta and left and right borders of the heart are anterior structures, whereas the descending aorta and aortic knob are posterior structures.

Interstitial opacification
Thickening of the perivascular (interstitial) tissues may appear radiologically as reticulonodular, honeycomb or linear (septal) opacifications.

Septal opacifications or Kerley lines are due to interlobular septal thickening caused by oedema, fibrosis, malignant cells, dust or metal particles. These opacifications occur commonly in patients who have, an increase in pulmonary venous pressure, pneumoconiosis,
Chest X-rays

sarcoidosis or lymphangitis carcinomatosis (which may be associated with carcinoma of the breast, lung, stomach, colon, pancreas, kidney). They are classified as:

Fig. 3.3 A diagrammatic representation of the chest X-ray appearance of consolidation in the left and right lower lobes, and segments. Top row: consolidation in the superior segments. Second row: consolidation in the medial basal segments. Third row: consolidation in the anterior basal (of the right lower lobe) and the anteromedial basal segments (of the left lower lobe). Fourth row: consolidation in the lateral basal segments. Fifth row: consolidation in the posterior basal segments. Lower row: consolidation in all segments of the right and left lower lobes. (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p 235-238).
Chest X-rays

Fig. 3.4 A diagrammatic representation of the chest X-ray appearance of collapse of the lobes of the right lung (a = right diaphragm, b = left diaphragm). Top row: two PA and one right lateral projection of collapse of the right upper lobe. Middle row: collapse of the right middle lobe (PA and right lateral projections). Lower row: the PA and right lateral projection appearance of collapse of the right lower lobe. (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p 235-238).

1. Kerley A lines, which may be detected in the middle third of the lung fields. They are up to 4 cm long, are slightly curved and radiate out from the hilum.

2. Kerley B lines, which are 0.5-1 mm thick and 1-1.5 cm long and are usually detected at the costophrenic angles, although they may rarely occur in the apex. If they are caused by left ventricular failure then they are usually transient, unless prolonged failure has been present and fibrin and haemosiderin deposits have caused them to remain. Ossified nodules may also develop in areas of chronic interstitial oedema.

3. Kerley C lines are rarely if ever detected in life and have no special significance. They were initially thought to be caused by subpleural surface lymphatics but are probably end-on projections of surface septa which cause a ‘spider web’ appearance.

THE DIAPHRAGM AND PLEURA

The diaphragm
In 90% of normal individuals the right hemidiaphragm is higher than the left by one-half interspace (1-3 cm). Displacement of the right diaphragm below the anterior end of the 7th rib usually indicates overinflation, i.e. acute asthma or emphysema; the diaphragms may also be
Chest X-rays

flat in the latter. Elevation of diaphragms above the 5th rib anteriorly indicates that the patient did not inspire normally or there is a unilateral or bilateral:
- Diaphragm disorder (e.g. rupture, phrenic nerve paralysis, myopathy, eventration)
- Sub pulmonary effusion
- Reduction in pulmonary compliance (e.g. pulmonary oedema, fibrosis, pneumonia, collapse or embolism)
- Pleural or chest cage restriction (e.g. pain or skeletal deformity)
- Abdominal disorder (e.g. ascites, obesity, pregnancy, abdominal neoplasm, pancreatitis gastric or colonic distension, subphrenic abscess, peritonitis).

Fig. 3. 5 A diagrammatic representation of the chest X-ray appearance of collapse of the lobes of the left lung (a = right diaphragm, b = left diaphragm, c = retrosternal herniation of the right upper lobe to the left hemithorax). Top row: two PA and the left lateral projection of collapse of the upper segment of the left upper lobe. Middle row: (from left to right) a PA and left lateral projection of a collapse of the left upper lobe (with herniation of the right upper lobe into the left hemithorax), and a PA and left lateral projection of a collapse of the lingular division of the left upper lobe. Lower row: a PA and left lateral projection of a collapse of the left lower lobe. (Modified from Meschan I. Synopsis of roentgen signs. Philadelphia. WB Saunders. 1962 p 235-238)

The pleura

Pleural thickening and calcification
This may be caused by the resolution of a haemothorax or empyema or be caused by asbestos inhalation.

Pleural fluid
All pleural fluids produce similar radiological shadows. The position and morphology of the shadow depends on the amount of fluid, the state of the underlying lung, whether the fluid is free and the position of the patient. The most dependent recess of the pleura is the posterior costophrenic angle. A small effusion will therefore tend to collect posteriorly and at least 200
Chest X-rays

mL will be required before fluid will be seen in the AP projection. A decubitus view will be necessary to detect effusions of only a few millilitres.

In the PA erect film, pleural fluid typically causes a uniform opacity, filling-in the costophrenic angles, obscuring the diaphragmatic shadow and extending up the chest wall with a concave upper edge. It is higher laterally than medially. If the film is taken with the patient supine the effusion may only appear as a cap at the apex, and a generalised diffuse increase in opacification of the lung on that side. A massive pleural effusion may displace the heart to the opposite side, although generally the heart is not displaced. Loculated effusions may be sub-pulmonary (simulating an elevated diaphragm) or in the horizontal or oblique fissures (causing a lens like opacification), or they may appear as a convex opacity adjacent to the costal margin. If there is a diagnostic dilemma, ultrasound or CT scan may provide the answer.

Pneumothorax
A pneumothorax consists of air in the pleural cavity. A small pneumothorax in a free pleural space in an erect patient collects at the apex, and a sharp white line of the visceral pleura may be visible at the apex, which is separated from the chest wall by a radiolucent space devoid of lung markings. The chest X-ray may have to be examined under a bright light to see the sharp visceral pleura white line, although an expiratory or lateral decubitus film may make the pneumothorax more obvious. A tension pneumothorax may cause depression of the ipsilateral diaphragm and displacement of the mediastinum to the opposite side. An encysted pneumothorax appears as a pulmonary cystic cavity or bulla.

In a supine patient air in the pleural space collects anteromedially and towards the base of the lung and produces:
- a relative increase in translucency of the lower chest and upper abdominal quadrant
- deepening of the lateral costophrenic sulcus in relation to the other side, which may also be associated with a depression of the diaphragm.
- appearance of the anterior costophrenic sulcus
- sharp delineation of the diaphragm and the inferior apical border of the heart by air
- anteromedial air collection.

CHEST X-RAY SIGNS OF PULMONARY DISEASE

Inflammatory lung diseases
Bronchopneumonia often causes patchy alveolar infiltrates that coalesce to form patchy or confluent areas of consolidation. Lobar consolidation typically occurs with pneumococcal pneumonia. A pulmonary abscess often appears as a cystic lesion within an area of consolidation, with the surrounding wall often thickening as the lesion progresses.

Obstructive pulmonary diseases
In 50% of patients with chronic bronchitis the chest X-ray is normal. Nonspecific changes associated with chronic bronchitis include accentuation of bronchovascular markings.

Patients who have emphysema may have chest X-ray changes of:
1. A reduction in size and number of small vascular markings in the mid and outer third of the lung
2. An enlargement of the main pulmonary arteries and thus prominent hilar shadows
3. An increase in lung volume (e.g. the diaphragm is flattened and extends below the 11th rib, there is sub cardiac transillumination, the retrosternal air space increases)
4. Cystic bullae (i.e. rounded or oval translucencies) which may become evident and demonstrate air trapping with an expiratory film (Macleod’s syndrome).
Chest X-rays

Asthma patients characteristically have a normal chest X-ray between attacks. During an attack, the chest X-ray may show signs of hyperinflation (i.e. depression of the diaphragm and an increase in the retrosternal airspace), mediastinal emphysema (due to rupture at the terminal bronchiole) and atelectasis (due to mucus plugging).

**Bilateral pulmonary oedema**

*Cardiogenic*

Pulmonary venous congestion causes:
1. A redistribution of blood to the upper zones with lower lobe venous vasoconstriction
2. Interstitial oedema (septal lines, perivascular and peribronchial cuffing)
3. Alveolar oedema (confluent shadows of uniform density in the central hilar areas with clearer peripheral lung fields; Bat’s wing or butterfly shadows, air bronchogram)
4. Pleural effusions.

Although the chest X-ray has been used to estimate pulmonary venous and arterial pressures in patients who have cardiac failure, it may be normal in spite of an elevated left atrial pressure, or it may remain abnormal for 1-4 days despite a return of the left atrial pressure to normal.

*Noncardiogenic (ARDS)*

Interstitial and alveolar opacifications occur as with cardiogenic pulmonary oedema; however, septal lines, venous congestion and pleural effusions are not characteristic of ARDS

**Unilateral pulmonary oedema**

Unilateral pulmonary oedema may be cardiogenic (e.g. ruptured posterior leaflet of the mitral valve causing right sided pulmonary oedema due to the regurgitant stream directed to the right pulmonary veins, occlusion of pulmonary venous drainage by myxoma or pulmonary tumor) or non-cardiogenic (e.g. aspiration, reexpansion after chronic lung collapse with pneumothorax or effusion drainage, pulmonary thromboendarterectomy).

**Fibrotic lung disorders**

*Silicosis*

This often causes reticulation and multiple nodular shadows 2-5 mm in diameter in the mid and upper zones. Hilar lymph node enlargement with calcification may also occur (i.e. egg shell appearance); extensive fibrosis with pulmonary outflow tract prominence occurs late. Pleural changes are rare. If there is tuberculosis (TB) present, cavitation may occur.

*Asbestosis*

This causes fibrosis, pleural plaques and calcification and is associated with mesothelioma.

*Sarcoidosis*

Sarcoidosis may pass through three characteristic radiological stages:
1. Enlarged hilar nodes only, which may have egg shell calcification
2. Enlarged nodes with pulmonary lesions (e.g. small or large nodules, reticulation, reticular nodular or fibrosis)
3. Pulmonary lesions only.
Chest X-rays

Chest trauma
Injury to the chest may cause fractured ribs, ruptured diaphragm, pulmonary contusion, pulmonary oedema, pneumothorax, subcutaneous emphysema, and airway or mediastinal injuries.

Fractured ribs.
The 4th to the 9th ribs are commonly broken with chest wall trauma. While some believe that fracture to the upper two ribs is associated with excessive thoracic force and thus more likely to be associated with bronchial or intrathoracic vessel damage, this is not necessarily so. Fractures to the lower three ribs (i.e. 10, 11 or 12) may be associated with trauma to the spleen on the left, or the liver on the right.

Ruptured diaphragm.
The left hemidiaphragm is more often ruptured than the right and is often associated with herniation of peritoneal contents (i.e. stomach, colon, spleen, etc.) into the thoracic cavity. The characteristic picture is one of a dilated stomach producing a hyperlucent area in the mid and lower left thoracic zone and a compressed left lower lobe lying above. A ruptured right diaphragm is often difficult to diagnose as the dome only appears to be elevated.

Pulmonary contusion and oedema
This is caused by a haemorrhagic exudation into the pulmonary interstitium and alveoli. It appears on chest X-ray as a patchy area of alveolar infiltrate within the first 6 h of injury. The infiltrate often clears within 3 days. If it does not clear, a haematoma is probably present, which commonly cavitates within 3 days of the injury and then resolves. It may be accompanied by a non cardiogenic pulmonary oedema (ARDS).

Pneumothorax and subcutaneous emphysema
Pneumothorax has been previously described. Pneumomediastinum describes a condition where there is air between the tissue planes of the mediastinum. It may be caused by interstitial pulmonary emphysema (i.e. alveolar-wall rupture caused by asthma, severe coughing, IPPV or crush injury with air dissecting along the perivascular sheath to reach the mediastinum), perforation of the oesophagus, trachea or bronchus, or penetrating chest injury or has dissected up from a pneumoperitoneum. The air may dissect into the head, neck, chest wall, abdomen and scrotum. If the pneumomediastinum is extensive, there may be lateral displacement of the mediastinal pleura, which may appear like a pneumothorax or pneumopericardium. The former will outline the anterior pleural sulcus whereas the latter will not extend beyond the aortic root or where the aorta meets the hilum on the left cardiac border. Mechanical ventilation and PEEP may also increase the incidence of pulmonary barotrauma, causing subcutaneous emphysema, mediastinal emphysema, pneumothorax and subpleural air cysts.

Airway or mediastinal injuries
Uncommon traumatic chest injuries include ruptured larynx, trachea, bronchus, oesophagus, heart and large vessels (e.g. aorta, pulmonary artery or veins).

REFERENCES
Chapter 4

RESPIRATORY FUNCTION TESTS

Respiratory function tests are used to assess the presence, physiological type and extent of a respiratory disorder, and the effectiveness of therapy and course of a disease; they are only rarely used to make a definitive diagnosis of a disease. The tests should be accurate, reproducible and sensitive, and in the critically ill patient they should be able to be performed at the bedside. In ventilator-dependent patients, the circuit characteristics (e.g. dead space, compression volume, resistance, etc) also need to be considered.

VENTILATORY TESTS

Most respiratory volumes are performed on expired gases using spirometry and, in the case of residual volume, gas-dilution methods. The volume of a gas is inversely related to pressure and directly related to temperature, thus measurements of respiratory gas volumes often need to be converted due to the influence of temperature and pressure as well as partial pressure of water vapour (see Appendix II). Flow rate or rate of volume change may also be measured during spirometry and is usually performed throughout inspiration and expiration.

Gas dilution methods

Residual volume is usually measured by closed circuit helium dilution, which calculates the volume when a known volume of 10% helium is added to, and therefore diluted by, the functional residual capacity (FRC). Dilution methods have inaccuracies when they are used in patients who have airway obstruction, and body plethysmography is often used to assess the total lung capacity in such patients; although, even body plethysmography may be inaccurate when used to assess total lung volume in this group of patients.

Spirometry

Spirometry is a medical test that measures the volume of air an individual inhales or exhales as a function of time. Flow, or the rate at which the volume is changing as a function of time, may also be measured. Spirometers used for monitoring the ventilatory capacity of patients at home need to be cheap, robust and reliable and often do not require the same accuracy as that required for diagnostic spirometry (e.g. within 5% rather than 3% of a reading). Diagnostic spirometry may be performed in the respiratory laboratory using a Tissot spirometer and a Douglas bag. In intensive care units these methods are too cumbersome, and so the respiratory volumes are often measured in critically ill patients using:

1. Mechanical spirometers (e.g. Wright respirometer): the Wright respirometer is a portable apparatus that uses a rotating vane to measure gas flow. It begins to register a flow at 2.5 L/min, has its greatest accuracy (± 2%) at 16 L/min and an accuracy of + 5% to + 10%, at 60 L/min. Within the limits of 4 and 24 L/min, the Wright respirometer is accurate to within 5%.

2. Pneumotachograph spirometers: pneumotachographs measure gas flow by integrating the pressure difference across a parallel resistive network of small tubes (which are easily blocked by mucus and moisture, even if they are heated). When calibrated and working effectively, these devices have an accuracy to within 3%. 
3. **Dry rolling-seal spirometer:** the dry rolling-seal spirometer is the most accurate of all simple devices. It is able to record volumes of greater than 50 L with an accuracy of at least ± 1%.  

Diagnostic spirometry equipment should be standardized: 2,1  
1. **Quality:**  
   a. **Volume:** Spirometers must be capable of measuring volumes of at least 8 L (BTPS) with flows between 0-14 L/s with a volume accuracy of at least ± 3% of the reading from 0.5 to 8 L or ± 0.050 L, which ever is greater. Flow-rate measurements should be within ± 5% of the reading with resistance to airflow at 14 L/s being less than 1.5 cm H₂O/L/s. The volume accuracy should be tested once a day with a calibrated syringe with a volume of 3 L. The system should also be tested daily for leaks (e.g. the spirometer outlet is occluded and 3 cm H₂O pressure is applied to the spirometer; any observed volume change after 1 min is indicative of a leak). The expired volumes should be expressed in litres per minute (body temperature and pressure, saturated with water vapour-BTPS).  
   b. **Linearity:** the volume and flow measurements should be checked over the entire range every 3 months.  
   c. **Resolution:** this determines the ability of the device to detect the end of a test.  
2. **Graphic display** of flow versus volume or volume versus time should be available, to assess whether the contour of the trace is smooth and without interruption.  
3. **Ambient temperature and pressure measurements** should be available.  

**Forced expiratory volume tests**  
Spirometry of forced expiratory volumes requires an effort-dependent maneuver that needs understanding, coordination, and cooperation by the patient, who must be carefully instructed. A minimum of three tests are performed. After examining all available graphs, the maximum forced vital capacity (FVC) and FEV₁ (implying that maximal effort has been achieved) are the measurements which are recorded (even if the two values do not come from the same curve). The FEF₂₅₋₇₅% (see later) should be obtained from the single best test.  

1. **Forced vital capacity (FVC)**  
Forced vital capacity is the maximum volume of air exhaled with a maximally forced effort from a position of maximum inspiration. The largest and second largest FVC should not vary by more than 5%. Similarly, the largest and second largest FEV₁ should not vary by more than 5%. Vital capacity (VC) is the maximum volume of air exhaled from a position of maximum inspiration with slow exhalation. The difference between FVC and VC may be significant in patients with airflow obstruction and accordingly the device for measuring VC must be able to accumulate volume over at least 30 seconds (the device for measuring FVC must be able to accumulate volume for at least 15 s).  

2. **Timed forced expiratory volume (FEV₁)**  
This is a volume of air exhaled in a particular time during the performance of the FVC, for example the FEV₁ is the volume of air exhaled during the first second of the FVC. Normally the FEV₁ is at least 80% of the FVC (e.g. if the FEV₁ is 4.0 L, the FVC should be no greater than 5.0 L, giving an FEV₁/FVC ratio of 80%).  

The FVC and the FEV₁ are the commonest measurements performed at the bedside and are usually performed before and after the patient inhales a bronchodilator (e.g. 2 inhalations of a
Respiratory Function Tests

salbutamol MDI, i.e. 200 µg). The FVC and FEV₁ vary with height, age and posture. The FVC in mL (≥ 500 mL) is approximately height (cm) x 25 for males and height (cm) x 20 for females. The FVC decreases approximately 100 mL/10 years from the age of 20 to 60. The FVC measured in the standing subject, decreases by approximately 500-1000 mL when the subject is supine, due to a decrease in FRC. The predictive equations for forced expiratory lung volumes are listed in Appendix II.

Ventilatory defects
Based on the measurement of the FEV and FEV₁, the ventilatory defects are defined as either an:

1. **Obstructive ventilatory defect:** this is defined as an FEV₁/FVC of less than 70% of the mean predicted value (if 60-70%, the defect is slight, if 50-60% the defect is moderate, if 40-50% the defect is severe, and if < 80% the defect is very severe). If a significant response to bronchodilators occurs i.e. if the FVC or FEV₁ shows an increase of at least 15%, the obstructive defect is said to be reversible. Classically, patients who have asthma have a reversible obstructive defect, whereas patients who have COPD have a nonreversible obstructive defect. However, there are many variations within these groups. Furthermore, some patients may show significant improvement in their obstructive defect following prolonged bronchodilator therapy, where little or no spirometric change following acute administration of the bronchodilator occurs. Also, in some young asthmatics, the FEV₁ may be greater than 70% of the FVC or exceed 80% of the predicted FEV₁, although an obstructive defect exists which is revealed by a significant increase in FEV₁ after bronchodilation.

2. **Restrictive defect:** this is defined as an FEV₁ greater than 70%, FVC less than 80% of the mean predicted value and a ratio of FEV₁/FVC of 80% or greater (e.g. if the FVC is 3.1 L and the FEV₁ 2.8 L, the FEV₁/FVC is 90%). There should be no significant improvement after bronchodilation. This defect occurs classically with pulmonary restrictive defects (e.g. fibrotic lung disease, pulmonary oedema, ARDS, pneumonia) although it is nonspecific and may occur with chronic chest wall restriction, neuromuscular weakness, abdominal distension, obesity and in the immediate postoperative period.

3. **Combined defect:** this occurs if an obstructive defect exists, with FEV₁ greater than 50% of the mean predicted value, associated with a FVC of less than 80% of the mean predicted value, indicating that a restrictive ventilatory defect also exists.

**FEF₂₅-₇₅%**
This is the mean forced expiratory flow during the middle half of the FVC, formerly known as the maximal midexpiratory flow rate (MMEF), it represents an effort-independent measurement and is a more accurate reflection of the true mechanical state of the airways. This segment represents the effort independent slope of the flow volume curve.

**The peak expiratory flow rate (PEF)**
The peak expiratory flow is the largest expiratory flow achieved with a maximum forced effort from a position of maximum inspiration, expressed in L/s (BTPS). The instrument must measure the PEF within an accuracy of ± 10% or ± 0.300 L/s whichever is greater. The measurement is patient- and device-dependent and so recordings tend to vary independent of pulmonary disease. Nevertheless, measurement of this value, using a Wright meter, is a convenient clinical assessment to identify airflow obstruction and its response to therapy. In males the normal value ranges from 450-700 L/min, and in females from 300-500 L/min. It may be approximated by the formulae, 150 x FEV₁.
**Respiratory Function Tests**

**Maximum voluntary ventilation (MVV) or maximum breathing capacity (MBC)**
This test involves the maximum voluntary ventilation at a rate of about 60 breaths per minute and a volume of about 60% of the FVC for about 12-15 s. It is designed to test the speed and efficiency of filling and emptying of the lungs during maximum respiratory effort. However, the test is very patient dependent and because it bears a close correlation with the FEV₁ (i.e. 35 x FEV₁) the MVV is not often performed.

**Flow-volume curve**
This plots gas flow (rather than volume) on the y axis, against time on the x axis. The trace reveals a flow that rapidly increases from zero and reaches a maximum at about 80% of the vital capacity, after which the flow decreases in a consistent manner associated with the change in lung volume until the flow is zero at residual volume. The curve consists of an effort-dependent portion, which extends from the total lung capacity to about the first 30% of the expired vital capacity, and an effort-independent portion which extends from this point to residual volume. The latter is caused by the development of an equal pressure point within the large airways where pressure surrounding the airways begins to exceed the pressure within.¹⁰

**BLOOD GAS MEASUREMENTS**
Before a blood gas sample is taken, the inspired oxygen concentration and PEEP value should have been constant for at least 10 min previously (or for 30 min in patients with COPD).¹¹,¹² While the normal PaO₂ progressively decreases with age (see Appendix II), there is no change in pH or PCO₂ with age.

**Blood gas tension measurement**

**Blood sample collection**
A blood gas sample for analysis requires only enough heparin to fill the dead space of the syringe. Too much heparin or too little blood will artifactually lower the PCO₂, HCO₃⁻ and pH and increase the PO₂. This becomes significant when the heparin solution is more than 10% of the volume of the sample.¹³,¹⁴ Air bubbles must be removed from the syringe within 2 min and the syringe placed in iced water.¹⁵ If the syringe is not placed in iced water and the measurement is not performed within 5 min, the PO₂ falls by 2-3 mmHg/min (an effect which is particularly marked when the PO₂ is over 400 mmHg and the patient has a leucocytosis).¹³,¹⁴ The fall in PO₂ in blood samples stored in iced water with an initial PO₂ of less than 150 mmHg, is less than 2 mmHg/h and the rise in PCO₂ is even slower.¹³,¹⁴

**Measurements**
For clinical purposes the accuracy of PO₂ and PCO₂ should be within 2-4% and pH within 0.01 units. The solubility and therefore partial pressure of a gas in a liquid varies with temperature; accordingly the partial pressure of blood gases vary with the patient’s temperature. During hypothermia, the partial pressures of oxygen and carbon dioxide decrease, with the reduction in PCO₂ causing an increase in pH. However, the assessment of the acid-base abnormality should be based on the changes in blood PCO₂ and pH measured at 37°C and not on the values derived from temperature correction formulae, because both the pH and neutral point of water increase with a decrease in temperature.¹⁶ The neutral point of water specifies the state of ionization of enzymes, so the biologically normal pH should be higher than 7.4 at temperatures below 37°C. It is recommended that during temperature change, the PaCO₂ should be maintained at a level that yields an uncorrected (i.e. value at 37°C) pH of 7.40.¹⁷ Temperature correction formulae
Respiratory Function Tests

should only be used when calculating the alveolar-arterial PO\textsubscript{2} and PCO\textsubscript{2} differences (see Appendix II).

**Oxygen tension (PO\textsubscript{2})** The Clark polarographic oxygen electrode is the most commonly used system for the measurement of oxygen tension (in mmHg or kPa) in blood. Oxygen molecules diffuse across a plastic membrane to reach a small platinum or gold cathode where they are reduced to hydroxyl ions. As a result, a current flows between the cathode and the anode which is proportional to the partial pressure of oxygen in the sample.\textsuperscript{18}

**Carbon dioxide tension (PCO\textsubscript{2})** The partial pressure of carbon dioxide (in mmHg or kPa) may be measured in blood samples using an electrode system sensitive to H\textsuperscript{+}. Carbon dioxide diffuses through a selectively permeable membrane into an aqueous electrolyte. This causes a change in the H\textsuperscript{+} ion concentration within the electrolyte which is measured with a conventional glass electrode. The output voltage is logarithmically related to the PCO\textsubscript{2} of the sample.

**pH** The pH (or H\textsuperscript{+} nmol/L) of blood is measured using a glass electrode porous only to H\textsuperscript{+} ions. This develops a transmembrane potential proportional to the log of the H\textsuperscript{+} ion activity. This potential is then compared with the potential developed using a standard solution of selected pH value.

**Bicarbonate concentration** The plasma bicarbonate value (HCO\textsubscript{3}\textsuperscript{-}, in mmol/L) is derived using the Henderson equation (see Appendix II).

**Base Excess (BE)** This is an empirical expression which approximates the amount of acid or base (nmol/l) necessary to titrate 1 litre of blood to a pH of 7.40 at a PCO\textsubscript{2} of 40 mmHg in vitro\textsuperscript{19} or in vivo\textsuperscript{20,21} (see Appendix II).

**Respiratory failure**

Based on blood gas measurements, hypoxaemia may be defined as a PaO\textsubscript{2} of 80 mmHg or less, hypercapnia may be defined as a PaCO\textsubscript{2} greater than 45 mmHg and respiratory failure may be defined as either:

- a PaO\textsubscript{2} less than 60 mmHg, breathing air at sea level, in the absence of an intracardiac R-L shunt, or
- a PaCO\textsubscript{2} of 50 mmHg or greater in the absence of metabolic alkalosis.\textsuperscript{22}

Respiratory failure is always associated with hypoxaemia and is either normocapnic or hypocapnic (i.e. type I) or hypercapnic (i.e. type II). Hypoxic, normocapnic or hypocapnic respiratory failure is caused by pulmonary diseases that have a low ventilation-perfusion ratio (e.g. pulmonary oedema, pneumonia, pulmonary fibrosis), and may be exacerbated by disorders that reduce the mixed venous oxygen tension (e.g. anaemia, reduction in cardiac output and shift to the left of the oxygen-haemoglobin dissociation curve).

Hypoxic-hypercapnic respiratory failure is caused by diseases associated with a high ventilation-perfusion ratio (e.g. chronic obstructive pulmonary disease, asthma) or hypoventilation (e.g. narcotic or sedative overdosage, Ondine’s curse, sleep apnoea syndrome, high spinal cord damage, polio, motor neurone disease, polyneuropathy, neuromuscular junction disorders, myopathies, structural abnormalities of the chest wall).\textsuperscript{23,24}

The clinical features of hypoxia in the unacclimatized individual include a loss in short term memory when the PaO\textsubscript{2} is 55 mmHg, agitation and a decrease in conscious state when the PaO\textsubscript{2} is 40 mmHg or less, and a loss of consciousness when the PaO\textsubscript{2} is 30 mmHg or less.\textsuperscript{25,26}

The clinical features of hypercapnia include agitation and decrease in conscious state when the PaCO\textsubscript{2} is 80 mmHg or greater and loss of consciousness when the PaCO\textsubscript{2} is 100 mmHg or greater.\textsuperscript{25,26}
Transcutaneous gas tension measurement
The transcutaneous oxygen tension ($P_{tc}O_2$) measurement varies with skin thickness, blood pressure, blood volume, peripheral perfusion and pressure on the electrode, and has not been particularly helpful in monitoring oxygen therapy in adult clinical practice.\textsuperscript{27,28} With normal cardiac output, the $P_{tc}O_2$ tracks partial pressure of the arterial $PO_2$, whereas with reduced cardiac output it tracks oxygen delivery\textsuperscript{29,30}. Devices which measure $P_{tc}O_2$ have been largely replaced in clinical practice by the pulse oximeter, although it has been used in patients with peripheral vascular disease to assess peripheral limb perfusion. In neonatal clinical practice the transcutaneous measurement of oxygen tension has been useful in guiding oxygen therapy as pulse oximetry often fails to provide an adequate assessment of hyperoxia.\textsuperscript{31}

Transcutaneous carbon dioxide tension ($P_{tc}CO_2$) values are less affected by reduction in skin flow and are a more accurate estimate of $PaCO_2$ than $PE'CO_2$.\textsuperscript{30,32} The electrode site should be changed regularly as it is heated (usually to 42-45°C), and skin burns may occur if it remains in the one place for more than a few hours.

HAEMOGLOBIN OXYGEN SATURATION (SO$_2$)

Arterial haemoglobin oxygen saturation ($SaO_2$)
The haemoglobin oxygen saturation (functional saturation) is the percentage of oxyhaemoglobin to the total amount of deoxy- and oxyhaemoglobin (i.e. active or effective haemoglobin) and in arterial blood is normally between 95% and 98%. It is measured by oximetry either directly or indirectly (i.e. noninvasively) and may also be derived from the $PO_2$ using formulae which assume a normal $P_50$.\textsuperscript{33,34,35} The latter are inaccurate when applied to critically ill patients.\textsuperscript{36,37} The oxyhaemoglobin fraction (fractional saturation) is the percentage of oxyhaemoglobin to the total haemoglobin (i.e oxy-, deoxy-, met-, carboxy-, sulph- and unidentified inactive haemoglobin)\textsuperscript{38} and may be derived by multiplying the $SO_2$ by the ratio of effective haemoglobin to total haemoglobin.

Pulse oximeter
The arterial blood haemoglobin oxygen saturation is often measured noninvasively and continuously using a pulse oximeter.\textsuperscript{39,40,41} It is determined by comparing the pulsatile changes in light transmission (the variation in transmitted light with each pulse is due entirely to arterial blood) through the finger, ear or toe, spectrophotometrically, by measuring the differential absorption of two wavelengths (660 and 940 nm) of light by oxy- and deoxy haemoglobin. Oximeters must use at least as many wavelengths as the number of haemoglobin species present, to be able to calculate the concentration of each species. Normally, pulse oximeters are insensitive to forms of haemoglobin other than oxy- and deoxyhaemoglobin and may give misleading results in the presence of carboxy- and methaemoglobin, particularly when used to estimate the oxyhaemoglobin fraction. The accuracy of most instruments ranges from $\pm$ 6 - 10%,\textsuperscript{42} therefore a recorded saturation of 90% in an oximeter with an accuracy of $\pm$ 6%, indicates that the $PaO_2$ may lie be between 50 - 500 mmHg (i.e. it is more accurate in determining hypoxia than hyperoxia). Most instruments are calibrated with saturations above 70% therefore calibrations below this are speculative;\textsuperscript{42} at saturations of 55%, the mean value error in many instruments is commonly greater than 6% with standard deviations greater than 10%.\textsuperscript{42}

The advantages of the pulse oximeter include noninvasiveness, no requirement for calibration, an acceptable clinical error, continuous monitoring with real-time information, rapid response time (i.e. 10-20 s depending on the algorithm used), portability and it may be
left in place for days. In weaning a patient from a ventilator, pulse oximetry has been found to be of greater value than capnometry as the former is more sensitive in identifying hypoxaemia than the latter is in identifying hypercapnia. However, many conditions may alter the pulse oximeter reading (Table 4.1), for example:

<table>
<thead>
<tr>
<th>Conditions causing inaccurate pulse oximetry recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Artificially low recordings</strong></td>
</tr>
<tr>
<td>- Fetal haemoglobin (a correction formulae is required)</td>
</tr>
<tr>
<td>- Methaemoglobinaemia</td>
</tr>
<tr>
<td>- Jaundice</td>
</tr>
<tr>
<td>- Skin pigmentation</td>
</tr>
<tr>
<td>- Venous pulsation</td>
</tr>
<tr>
<td>- Severe anaemia (Haemoglobin &lt; 5g/100 mL provides an inadequate signal)</td>
</tr>
<tr>
<td>- Reduction of pulsatile flow</td>
</tr>
<tr>
<td>- Peripheral vasoconstriction</td>
</tr>
<tr>
<td>- Hypothermia</td>
</tr>
<tr>
<td>- Hypotension (usually MAP less than 50 mmHg)</td>
</tr>
<tr>
<td>- Sphygmomanometer cuffs</td>
</tr>
<tr>
<td>- Venous congestion or pulsating venous blood</td>
</tr>
<tr>
<td>- (e.g. tricuspid regurgitation, pulmonary hypertension</td>
</tr>
<tr>
<td>- severe cardiac failure)</td>
</tr>
<tr>
<td>- Intravascular or other dyes</td>
</tr>
<tr>
<td>- Methylene blue</td>
</tr>
<tr>
<td>- Indocyamine green injection</td>
</tr>
<tr>
<td>- Blue nail polish</td>
</tr>
<tr>
<td>- Dried blood</td>
</tr>
<tr>
<td>- Skin dyes</td>
</tr>
<tr>
<td><strong>Artificially high recordings</strong></td>
</tr>
<tr>
<td>- Carboxyhaemoglobin</td>
</tr>
<tr>
<td>- External light source</td>
</tr>
</tbody>
</table>

1. Carboxyhaemoglobin (COHb) alters the pulse oximetry readings by a ratio of 1:1 (i.e. if COHb is 8% and the pulse oximeter saturation is reading 100%, the fractional saturation is likely to be 92%, i.e. pulse oximeters see COHb as additional HbO₂).

2. Methaemoglobinaemia (MetHb) absorbs both 660- and 940-nm light and up to a MetHb of 20% reduces the pulse oximetry readings by about 50% of its concentration (i.e. if MetHb is 10% and the pulse oximeter saturation is reading 90%, the functional saturation is likely to be 95% and the fractional saturation 86%). However at high methaemoglobin levels (i.e. greater than 30% methaemoglobin), its large absorbence may overwhelm the signal produced by oxyhaemoglobin and reduced haemoglobin, and erroneously cause the pulse oximeter to read near 85% regardless of the patients saturation (i.e. there is a possibility that at low saturation levels (i.e. less than 85%) falsely elevated saturation readings may occur).

**Mixed venous haemoglobin oxygen saturation (SvO₂)**

At low oxygen tensions (20-40 mmHg) a linear relationship exists between haemoglobin oxygen saturation (35-75%) and tension (i.e. there is approximately a 2% fall in SvO₂ for each
Respiratory Function Tests

1 mmHg fall in \( P_{O_2} \). The development of improved fibre-optic oximetry systems in pulmonary artery flotation catheters has enabled the continuous bedside measurement of \( S\bar{V}O_2 \). The three-wavelength catheter system are more accurate than the two wavelength system. Mixed venous haemoglobin oxygen saturation may be altered directly by four oxygen transport variables: cardiac output, arterial haemoglobin oxygen saturation, haemoglobin content and tissue oxygen uptake. The \( P\bar{V}O_2 \) may alter with alteration of the oxygen-haemoglobin dissociation curve as well as alteration in one of the four oxygen transport variables. 

As the tissue oxygen uptake and haemoglobin content are usually steady over a prolonged period, the \( S\bar{V}O_2 \) is largely altered from moment to moment by alterations in the cardiac output or \( PaO_2 \). Thus continuous monitoring of the \( S\bar{V}O_2 \) is one method of easily deriving 'best' PEEP for patients. Sepsis, however, may be associated with normal \( S\bar{V}O_2 \) in the presence of a significantly reduced hepatic venous saturation (due to an increase in regional metabolic rate), therefore the measurement is of limited value in determining the presence of flow-limited regional oxygen consumption in these patients. It is possible that alterations in \( S\bar{V}O_2 \) that result from changes in some of the variables (e.g. tissue oxygen uptake or haemoglobin content) may not cause the same physiological consequences as changes that are produced from changes in the other variables (i.e. cardiac output or arterial saturation).

Although many use continuous \( S\bar{V}O_2 \) measurement in managing critically ill patients, to date published evaluations of the efficacy of \( S\bar{V}O_2 \) have yet to demonstrate clinical utility of this measurement.

CARBON DIOXIDE CONTENT

The carbon dioxide content (\( CaCO_2 \) and \( CvCO_2 \) in mL/100 mL) of blood (see Table 4.2) consists of:

<table>
<thead>
<tr>
<th>Table 4.2 Whole blood CO2 (mmol/L)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cell fraction</td>
</tr>
<tr>
<td>Dissolved CO2</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Carbamino CO2</td>
</tr>
<tr>
<td>Plasma fraction</td>
</tr>
<tr>
<td>Dissolved CO2</td>
</tr>
<tr>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Carbamino CO2</td>
</tr>
<tr>
<td>Total CO2 (mmol/L)</td>
</tr>
<tr>
<td>mL/100 mL</td>
</tr>
</tbody>
</table>

* Haemoglobin 15 g/100 mL, temperature 37°C

1. Dissolved carbon dioxide.
2. Bicarbonate: within the RBCs and under the influence of RBC carbonic anhydrase, carbon dioxide is converted to \( H^+ \) and \( HC0_3^- \). The bicarbonate shifts into the plasma, in exchange for the \( Cl^- \) ion which shifts into the RBC, and the \( H^+ \) is buffered by the deoxyhaemoglobin.
3. Carbamino compounds: these do not require carbon dioxide to be hydrated, therefore they form even in the presence of carbonic anhydrase inhibition.
Of the 48 mL (21.5 mmol/L) of carbon dioxide per 100 mL in arterial blood, 2.5 mL (1.1 mmol/L) is dissolved, 2.5 mL (1.1 mmol/L) is in carbamino compounds and 43.0 mL (19.3 mmol/L) is in HCO$_3^-$ in the tissues. In the tissues, of the 4.0 mL of carbon dioxide added per 100 mL of blood (reducing the pH to 7.36 and increasing the PCO$_2$ to 46 mmHg), 0.4 mL (10% or 0.17 mmol/L) is dissolved, 1.3 mL (32.5% or 0.6 mmol/L) forms carbamino compounds and 2.3 mL (57.5% or 1.03 mmol/L) forms HCO$_3^-$.

RESPIRATORY GAS MEASUREMENTS

**Oxygen concentration**
Oxygen is measured by the parametric, polarographic or fuel-cell methods. While the parametric devices are the most accurate, fuel cell devices are commonly used because they are robust and reliable. These devices depend on the consumption of a small quantity of oxygen to generate a voltage proportional to the oxygen tension. The accuracy of these devices is generally only within 3%. If breath-by-breath analysis of oxygen is required, then rapid response times using mass spectrometry may be used.

**Carbon dioxide concentration**
Carbon dioxide concentrations are often measured by capnography using infrared absorption analysis. These devices require a warm-up period and careful calibration. The analysers are of two types: mainstream and sidestream analysers. Mainstream analysers have the detector in line with the breathing circuit, sidestream analysers sample gases at a rate of 0.4-1.5 L/min (i.e. gas is lost from the breathing system). The capnograph appears most useful in detecting ventilator disconnection which appears as a sudden absence of expired carbon dioxide. It is relatively insensitive to the development of hypercapnia, particularly when using the instrument to wean patients from a ventilator.

*End-expired pCO$_2$ (PE'CO$_2$)*
In normal individuals, end expired pCO$_2$ is an approximation of alveolar partial pressure of carbon dioxide, and therefore PaCO$_2$. However, as an estimation of PaCO$_2$ in patients during anaesthesia or in patients with COPD or during rapid shallow ventilations, the plateau is difficult to estimate and even the difference between the PE'CO$_2$ and PaCO$_2$ may vary from moment to moment. If the PE'CO$_2$ is low, the patient is not being effectively ventilated (or is suddenly being hyperventilated) or the patient’s lungs are not being effectively perfused (e.g. decreased cardiac output). This may occur with disconnection of the patient from the ventilator, oesophageal intubation, cardiac arrest, severe hypotension, pulmonary thromboembolism, fat, amniotic fluid or air embolism, or hypothermia. If the PE'CO$_2$ rises, the patient is hypoventilating, rebreathing or there is an increased carbon dioxide production, for example malignant hyperpyrexia, adrenaline infusion, carbon dioxide insufflation (e.g. laparoscopy), or NaHCO$_3$ infusion.

DIFFUSION TESTS
Carbon monoxide is often used to assess diffusion through the alveolar-blood barrier because the amount which can be taken up by the blood is large and not limited by the amount of blood available (i.e. it is diffusion limited, compared with nitrous oxide which rapidly equilibrates with the capillary blood and is largely perfusion limited). Oxygen is both perfusion and diffusion limited. Normally the partial pressure of oxygen equilibrates with the capillary blood...
Respiratory Function Tests

by the time it is one-third of the way through its capillary transit, which normally takes about 0.75 of a s, thereafter the transfer of oxygen is perfusion limited.

Carbon monoxide diffusion is often measured by the single breath method, where the rate of disappearance of a dilute mixture 0.3% of carbon monoxide from alveolar gas during a 10 s breath hold is calculated by measuring the inspired and expired concentrations of carbon monoxide (TLCO). The value is dependent on area and thickness of the alveolar-blood barrier (reduced with interstitial fibrosis), haemoglobin concentration (a correction factor should ideally be applied to account for anaemia) and volume of blood in the pulmonary capillaries (e.g. reduced in emphysema due to a reduction in area and volume of blood in capillaries).

VENTILATION-PERFUSION TESTS

By measuring the PO₂ and PCO₂ in the arterial blood and expired gases, one can derive the ventilation-perfusion indices of physiological dead space, alveolar-arterial PO₂ difference and intrapulmonary shunt (Fig. 4.1).

![Fig. 4.1 A diagrammatic representation of lung function as a three-compartment model, ‘ideal’ alveoli, alveolar dead space (which consists of true alveolar dead space and a component caused by ventilation-perfusion scatter), and venous admixture or shunt (which consists of true shunt and a component caused by ventilation-perfusion scatter). Gas exchange only occurs in the ‘ideal’ alveoli (Modified from Nunn JF. Applied physiology. 3rd ed. London: Butterworths; 1987:156).](image)

Physiological dead space

This refers to that volume of gas which takes no part in pulmonary CO₂ exchange. Bohr’s method derives this volume (assuming that the inspired carbon dioxide is zero) by considering the excretion of CO₂ (i.e., \( V_T \times F_{E}CO_2 \)) as that which has only occurred from alveolar ventilation (or non dead space ventilation). For example,

46
Respiratory Function Tests

\[ V_T \times F_E \text{CO}_2 = V_A \times F_A \text{CO}_2 \]

and

\[ V_T = V_D + V_A \quad (\text{i.e., } V_A = V_T - V_D); \]

substituting for \( V_A \)

\[ V_T \times F_E \text{CO}_2 = (V_T - V_D) \times F_A \text{CO}_2 \]

As dead-space ventilation varies with the tidal volume,\(^6\) the equation is often expressed as a ratio of dead space to tidal volume, that is

\[ \frac{V_D}{V_T} = \frac{F_A \text{CO}_2 - F_E \text{CO}_2}{F_A \text{CO}_2} \]

where

- \( V_D \) = physiological dead space ventilation,
- \( V_T \) = tidal volume,
- \( V_A \) = alveolar ventilation,
- \( F_E \text{CO}_2 \) = mixed expired carbon dioxide concentration,
- \( F_A \text{CO}_2 \) = alveolar carbon dioxide concentration,

As the concentration of carbon dioxide is proportional to the partial pressure of carbon dioxide, and as diffusion abnormalities do not restrict carbon dioxide excretion, if the intrapulmonary shunt is less than 20\% (i.e. there is no defect in carbon dioxide excretion due to the shunt), then \( P_A \text{CO}_2 = P_{\text{aCO}_2} \) and the above equation may be rewritten as,

\[ \frac{V_D}{V_T} = \frac{P_{\text{aCO}_2} - P_E \text{CO}_2}{P_{\text{aCO}_2}} \]

Where

- \( P_{\text{aCO}_2} \) = arterial carbon dioxide tension,
- \( P_E \text{CO}_2 \) = mixed expired carbon dioxide tension,

The normal ratio is in the range of 0.2 to 0.35 during resting ventilation. If the effect of shunt on the dead space/tidal volume ratio is taken into consideration (which it should be if the shunt is greater than 20\%) then the above equation more accurately becomes\(^9\)

\[ \frac{V_D}{V_T} = \frac{X - P_E \text{CO}_2}{X} \]
Respiratory Function Tests

Where \( X = P_ACO_2 \)

\[
= \frac{P\nabla CO_2 \cdot PaCO_2}{1 - \frac{Q_8}{Qt}}
\]

\[
\frac{Q_8}{Qt} = \text{intrapulmonary shunt}
\]

\( P\nabla CO_2 = \text{mixed venous carbon dioxide tension.} \)

**The alveolar gas equation \((P_AO_2)\) and the alveolar-arterial \(PO_2\) difference \((P(A-a)O_2)\)**

The alveolar gas equation assumes that the mixed expired gas consists of dead-space gas (which is identical in composition with the inspired gas except that it is fully saturated with water vapour at body temperature) and ideal alveolar gas. It also assumes that the dead space for carbon dioxide and oxygen are the same. The below equations do not require a steady state, although the first equation does assume that there is no carbon dioxide in the inspired gas (normally the \(FICO_2\) is 0.03%).

\[
P_AO_2 = P_CO_2 - P_ACO_2 \cdot X \cdot \frac{P_CO_2 - PCO_2}{PECO_2}
\]

If there is a significant carbon dioxide concentration in the inspired gas (e.g. during rebreathing) the \(PAO_2\) should be calculated from the equation:

\[
P_AO_2 = \frac{PECO_2 - P_CO_2 \cdot X}{1 - X}
\]

Where \(P_CO_2 = (P_B - PH_2O) \cdot FIO_2\)

\(P_AO_2 = \text{alveolar oxygen tension},\)

\(PH_2O = \text{partial pressure of H}_2\text{O at body temperature},\)

\(P_B = \text{barometric pressure},\)

\(FIO_2 = \text{inspired oxygen concentration},\)

\(P_ACO_2 = \text{alveolar carbon dioxide tension (commonly assumed to be = PaCO}_2,\)

\(PECO_2 = \text{mixed expired carbon dioxide tension},\)

\(PEO_2 = \text{mixed expired oxygen tension},\)

\(FIO_2 = \text{inspired oxygen concentration},\)

\(PICO_2 = \text{inspired carbon dioxide tension},\)

\(R = \text{respiratory quotient}\)

\(X = \frac{(P_ACO_2 - PE CO_2)}{(P_ACO_2 - PICO_2)}\)

The approximation of the alveolar gas equation of \(^{23,74}\)

\[
P_AO_2 = P_CO_2 - \frac{P_ACO_2}{R}
\]
is only useful when the patient inspires gas with low oxygen concentration (e.g. 21% oxygen) and the PaCO\(_2\) is low. And the approximation of the alveolar gas equation of

\[ \text{PAO}_2 = \text{P}_{I}\text{O}_2 - \text{PaCO}_2 \]

is only useful when the oxygen concentration is high (i.e. it is accurate when the F\(_I\)O\(_2\) is 100%).

The alveolar-arterial difference for PO\(_2\) (i.e. P(A-a)O\(_2\)) is normally between 5-20 mmHg and depends on the age of the patient. The value also increases with increase in F\(_I\)O\(_2\) (up to 35-80 mmHg) with no further increase with an F\(_I\)O\(_2\) of 60% or greater.\(^{75}\) The P(A-a)O\(_2\) increases with pulmonary disorders that increase physiological dead space or intrapulmonary shunt.

**Intrapulmonary shunt**

The standard formula requires a measurement of mixed venous blood and arterial blood content (which is often derived from the haemoglobin content and saturation):

\[
\frac{Q_s}{Q_t} = \frac{C_{c'O2} - C_{aO2}}{C_{c'O2} - C_{vO2}}
\]

Where

- \(C_{c'O2}\) = pulmonary end capillary oxygen content
- \(C_{aO2}\) = pulmonary arterial oxygen content
- \(C_{vO2}\) = mixed venous oxygen content.
- \(Q_s\) = physiological shunt
- \(Q_t\) = cardiac output

The pulmonary end capillary oxygen tension is usually assumed to be the same as the ideal alveolar gas tension, which is derived from the alveolar gas equation. In an endeavour to reverse all respiratory shunt abnormalities due to ventilation-perfusion inequality effects, some measure the shunt after the patient inspires 100% oxygen for 20 minutes to fully saturate the pulmonary capillary blood. However, this procedure increases the intrapulmonary shunt by redistributing blood flow to non ventilated areas, due to pulmonary vasodilation and reabsorption atelectasis.\(^{76,77}\)

**Other indices**

Other oxygen tension indices used to estimate the intrapulmonary shunt in patients with acute respiratory failure (often used when mixed venous blood samples are not readily available) are P(A-a)O\(_2\), \(\text{PaO}_2/\text{FiO}_2\), P(A-a)O\(_2\)/P\(_{aO}_2\) and PaO\(_2\)/P\(_{A}O_2\). However, most of these indices are affected by F\(_I\)O\(_2\), haemoglobin, cardiac output, oxygen consumption and cardiac shunt, as well as the intrapulmonary shunt effect,\(^{78,79}\) and have been found to be unreliable when used as indices of intrapulmonary shunting in acutely ill patients.\(^{80}\)

**MECHANICS OF BREATHING**

**Compliance**

This is the respiratory volume change per unit change of pressure across the lung. Compliance has a static and a dynamic component, the latter taking into account airways resistance. In normal subjects, a tidal volume of 500 mL requires a transpleural pressure change of about 3 cm H\(_2\)O (i.e. static component), and during a normal inspiratory air flow rate of 1 L/s, a pressure drop of approximately 2 cm H\(_2\)O is required (i.e. dynamic component). During
spontaneous ventilation, intrapleural pressure is required to assess pulmonary compliance, although the oesophageal pressure is often used instead. Pulmonary compliance is influenced by lung volume and is greatest at maximum inspiration. It is influenced by the elastic and collagen fibres of the lung parenchyma and the alveolar surface tension forces.

Measurement of the static compliance due to both lung and chest wall components, is often made in mechanically ventilated patients in order to assess the patient’s status and progress; it is conventionally made by dividing the inflation volume by the difference between the pressure measured at the airway opening during end-inspiratory airway occlusion (i.e. ‘plateau’ pressure with a breath-hold for 1-2 s) and zero or the PEEP set by the ventilator, which requires that expiration is complete (this may require a measurement with end-expiratory hold for 1-2 s to negate ‘auto’ PEEP).\(^8\)

**Work of breathing**

Work of breathing is most conveniently measured as the product of pressure (intrapleural pressure which is often approximated by measuring oesophageal pressure) and volume. This requires integration of the pressure and volume changes if an accurate assessment of work of breathing is required. Total work has inspiratory and expiratory components due to dynamic (flow resistive) and static (elastic) components. In the patient who is is breathing through a respiratory circuit, in addition to the physiologic flow and elastic work there is also flow and elastic work imposed by the breathing apparatus. Ideally, when using mechanical ventilation, the imposed work should be negligible and both inspiratory and expiratory work should be reduced.\(^8\)

Compliance affects the work of breathing, and patients who have a reduced lung compliance tend to take rapid small breaths to reduce their static component (if mechanical ventilation is used it is only required to reduce the inspiratory work), and patients with airways obstruction tend to breathe slowly to reduce their dynamic component (if mechanical ventilation is used it is required to reduce both the inspiratory and expiratory work). In normal subjects at rest, the oxygen utilisation of the respiratory muscles accounts for approximately 2% of total oxygen consumption.\(^8,8\) This increases up to 25% in patients who have an increased work of breathing\(^8,8\) and may be reduced by mechanical ventilation.\(^8\) The increase in \(\text{VO}_2\) with change from mechanical to spontaneous ventilation is often assumed to be due to the oxygen requirement of respiratory muscles. However, \(\text{VO}_2\) is pH dependent and will decrease with a decrease in pH, independent of work of breathing; thus with spontaneous ventilation, there may be a decrease in \(\text{VO}_2\) due to a decrease in pH, underestimating the effect of spontaneous ventilation on \(\text{VO}_2\). Also, spontaneous ventilation is often associated with an increase in sympathetic activity which can increase the \(\text{VO}_2\), independent of work of breathing.\(^8\)

**FIBRE-OPTIC BRONCHOSCOPY**

Fibre-optic bronchoscopy may be performed for diagnostic or therapeutic reasons (Table 4.3).\(^8\) Transbronchial or direct biopsy and brushings are performed to diagnose pulmonary malignancy; and bronchoalveolar lavage, brushings (or protected specimen brush) or transbronchial biopsy, are performed to diagnose pulmonary infiltrative disorders.\(^8,8\)
Table 4.3  Indications for fibre-optic bronchoscopy

**Diagnostic**
- Lung lesions of unknown aetiology
  - (e.g. atypical pneumonia, atelectasis, collapse, pulmonary opacity)
- Airway patency
- Haemoptysis, abnormal sputum cytology
- Vocal cord or diaphragm paralysis
- Upper airway trauma
- Tracheo-oesophageal fistula
- Chronic cough

**Therapeutic**
- Retained secretions, foreign bodies
- Abnormal endobronchial tissue
- Difficult intubations

**Bronchoalveolar lavage**
Bronchoalveolar lavage (BAL) to remove respiratory secretions has been used for many years to treat asthma and cystic fibrosis when bronchial obstruction due to mucus plugging has been unresponsive to conventional therapy. Repeated BAL with heparin and N-acetylcysteine to remove proteinaceous material has also been used to prolong survival of patients with alveolar proteinosis.

Rigid bronchoscopes and double-lumen endotracheal tubes are often used when large volume lavage procedures are performed.

**Diagnosing pulmonary infiltrates**
Fibre-optic bronchoscopy and BAL has also been used to diagnose pulmonary infiltrates, particularly in immunocompromised patients (e.g. to diagnose *Pneumocystis carinii*, cytomegalovirus, aspergillosis, *Candida, Nocardia, Legionella* and TB), and to diagnose and stage patients with diffuse lung diseases (e.g. sarcoidosis, cryptogenic fibrosing alveolitis, extrinsic allergic alveolitis, alveolar proteinosis, connective tissue disorders and ARDS).

The procedure is performed by gently wedging the fibre-optic bronchoscope into a subsegmental bronchus (usually the right middle lobe or lingula are used as they are often easiest to wedge into and the lavage return is the greatest when compared to upper or lower lobe bronchi) and 20-60 mL aliquots of prewarmed sterile saline are instilled and aspirated up to a cumulative amount of 200-300 mL, with pulse oximeter and ECG monitoring.

In the spontaneous breathing patient BAL is not attempted if the PaO$_2$ is < 70 mmHg, platelet count is < 20,000 x 10$^9$/L, INR > 1.5, or the FEV$_1$ is < 1 L. In the mechanically ventilated patient BAL is not attempted if the PaO$_2$ is < 70 mmHg with an F$_{102}$ of > 70%, PEEP 15 cm H$_2$O or greater, MAP < 65 mmHg on vasopressor therapy, or the platelet count is < 20,000 x 10$^9$/L.

It is estimated that BAL produces a sample of cells from 10$^6$ alveoli, with the returned fluid representing a 100 fold dilution of the epithelial lining fluid. The BAL fluid in normal nonsmoking individuals contains 5 x 10$^6$ to 10 x 10$^6$ cells/100 mL (smokers may have up to 4 times this cell count) which consist of; 80%-90% macrophages, 5%-15% lymphocytes (T cells 47%, B cells 19% null cells 34%), 1-2% neutrophils and < 1% eosinophils, as well as IgA, IgG and low levels of IgE and occasionally detectable IgM and complement.
REFERENCES
17. Ream AK, Reitz BA, Silverberg G. Temperature correction of PCO2 and pH in estimating acid base status: An example of the emperor's new clothes? Anesthesiology 1982;56:41-44.
Respiratory Function Tests

77. Shapiro BA, Cane RD, Harrison RA, Steiner MC. Changes in intrapulmonary shunting with administration of 100 percent oxygen. Chest 1980;77:138-141.
TRAINEE PRESENTATIONS

Each registrant has prepared a five minute talk and summary on the topics listed below. The summaries that were received in time for publication have been included (unedited).

1. Discuss the action, indications and complications of intravenous aminophylline. Dr. A. Whitfield 59
2. Discuss the aetiology and management of a patient with hypokalaemia (1.4 mmol/l) who has rhabdomyolysis, acute renal failure and episodes of torsades des pointes. Dr. S. Perrin 62
3. Discuss the clinical presentation and management of patient with a dissecting aortic aneurysm. Dr. D. Durham 65
4. Discuss and compare the management of cardiac arrest caused by asystole with that caused by VF. Dr. M. Davis 68
5. Discuss the management of paraquat poisoning Dr. T. Brownridge 71
6. Describe the features and discuss the treatment of acute paraquat poisoning. Dr. P. Scott 75
7. Discuss management of a loculated haemothorax. Dr. S. Newell 78
8. Discuss the actions, indications and doses of the antithrombin agents. Dr. R. Newman 80
9. Discuss the causes and management of epiglottitis in an adult. Dr. E. Merry 82
10. Discuss the risk factors of MRSA ventilator associated pneumonia and its management. Dr. V. Patil 86
11. Discuss the management of fulminant asthma in a patient who has become unconscious. Dr. M. Chinthamuneedi 88
12. Discuss the indications, complications and dose of intravenous human immunoglobulin. Dr. J. Fraser 91
13. Discuss the management of a patient with an acute coronary syndrome. Dr. G. Joyce 94
14. What are the determinants of cardiac index? What range should it be kept in the critically ill patient and why? Dr. B. Graham 97
15. Outline your clinical examination of the cranial nerves in an unconscious patient. Dr. P. Nair 99
16. Discuss the acute haemodynamic effect of intravenous hydrocortisone Dr. D. Lam 101
17. Discuss the management of a cocaine ‘body packer’ (i.e. patient who has ingested latex baloons filled with cocaine) who develops symptoms of cocaine toxicity due to rupture of the packages. Dr. E. Connolly 102
18. Discuss the indications and complications of intravenous albumin. Dr. A. Aziz 105
19. Discuss the clinical features and management of salicilate poisoning. Dr. A. Karnik
20. Discuss the emergency management of a patient who has severe upper airway obstruction. Dr. P. Stewart
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Discuss the ECG features and treatment of hyperkalaemia.</td>
<td>Dr. L. Ware</td>
</tr>
<tr>
<td>22</td>
<td>Discuss the indications and complications of muscle relaxants, sedative and analgesic agents used to settle a mechanically ventilated patient.</td>
<td>Dr. J. Lambert</td>
</tr>
<tr>
<td>23</td>
<td>Discuss the management of a patient with severe hypotherma.</td>
<td>Dr. G. McGrath</td>
</tr>
<tr>
<td>24</td>
<td>Discuss the indications for intravenous potassium acetate (5mmol/L).</td>
<td>Dr. N. Ramakrishnan</td>
</tr>
<tr>
<td>25</td>
<td>Discuss the indications for intravenous magnesium sulphate (2 mmol/mL).</td>
<td>Dr. K. O'Connor</td>
</tr>
<tr>
<td>26</td>
<td>Discuss the management of a child with severe croup.</td>
<td>Dr. J. Ingham</td>
</tr>
<tr>
<td>27</td>
<td>Discuss the risks and benefits of intravenous pralidoxime in a patient with acetylcholinesterase poisoning.</td>
<td>Dr. G. Choi</td>
</tr>
<tr>
<td>28</td>
<td>Discuss the reasons for ‘daily dose gentamicin’.</td>
<td>Dr. R. Sistla</td>
</tr>
<tr>
<td>29</td>
<td>Discuss the management of a patient with anaemia (Hb 70g/L) and congestive cardiac failure.</td>
<td>Dr. D. Evans</td>
</tr>
<tr>
<td>30</td>
<td>Discuss the use of helical computed tomography and the diagnosis of pulmonary embolism.</td>
<td>Dr. A. Delaney</td>
</tr>
</tbody>
</table>
DISCUSS THE ACTIONS, INDICATIONS AND COMPLICATIONS OF INTRAVENOUS AMINOPHYLLINE

Dr. A. Whitfield, Intensive Care Unit, Epworth Hospital, Victoria

Xanthine derivative. Complex of theophylline with ethylenediamine.

ACTIONS

At a cellular level
- non-selective phosphodiesterase inhibition of both cAMP and cGMP pathways resulting in increased intracellular cAMP and cGMP
- competitive antagonist at adenosine receptors
- inhibition of pyridoxal kinase

Reported therapeutic effects in asthma
- bronchodilatation
- increased diaphragmatic contractility
- improved mucociliary transport
- decreased release inflammatory mediators by mast cells
- decreased pulmonary arterial pressures
- central respiratory stimulation with enhanced hypoxic respiratory drive

Exact mechanism of these beneficial actions in asthma not understood

Theories concerning bronchodilatation
- ? due to adenosine blockade, but the propylxanthine enprofylline is a more potent bronchodilator despite having no adenosine blocking action
- ? due to phosphodiesterase inhibition, but these effects are negligible at therapeutic concentrations and better inhibitors (e.g. dipyridamole) have no bronchodilating action

Other effects
- CNS stimulation:
  - Insomnia, tremor, agitation, nausea, vomiting, confusion, fitting at toxic level
- CVS:
  - Positive inotropic and chronotropic action on the heart, peripheral vasodilatation
  - Tachyarrhythmias, hypotension at upper level of therapeutic and toxic levels
- Renal:
  - Diuresis secondary to increased CO and GFR and decreased tubular reabsorption. Can result in hypokalaemia, hypomagnesaemia
- GIT:
  - Increased gastric acid secretion. Decreased LES pressure and other GIT muscle relaxation

2. INDICATIONS

Acute severe asthma (and acute severe exacerbation of COAD with bronchospasm)

Most studies show no benefit when aminophylline is added to beta-agonists and steroids. Concerns regarding toxicity and side effects. Therefore consider its use in a life-threatening episode that is not responding to maximal therapy with beta-agonists and steroids and monitor levels closely.

Dose: Loading dose 3 - 5mg/kg over 30 min followed by infusion at 0.5mg/kg/hr
Omit loading dose if on oral theophylline.
3. COMPLICATIONS

Narrow therapeutic index with therapeutic range 55-110 mmol/l.

Pharmacokinetics:

10% renal excretion unchanged.

90% liver metabolism - cytochrome P-450 system. System variably saturable at therapeutic concentrations resulting in marked interpatient variability in half-life (4 - 12 hr). Also many interactions resulting in marked intra-patient variability.

Half-life (& potentially serum concentration) increased by:

- CCF, APO, cor pulmonale, CORD and other lung disease
- acute febrile illnesses, pneumonia, viral infections
- severe hypoxia
- hypothyroidism
- liver impairment
  - drugs metabolised by cytochrome P-450 system
    - macrolide antibiotics, quinolone antibiotics, Ca-channel blockers, H2-receptor antagonists, mexilitine, oral contraceptives

Half-life shortened by

- in the young (1 - 9yr)
- smokers
- excess alcohol intake without liver impairment
- drugs that induce the cytochrome P-450 system
  - phenytoin, carbamazepine, rifampicin

Complications during administration for asthma

May be seen:

- in therapeutic range
- if inadvertent toxic level due to interactions
- if too rapid administration of loading dose

Half life and potential for toxic levels increased by factors that may be observed in the acute asthma attack:

- acute febrile illnesses, pneumonia, viral infections
- hypoxia
- drugs - macrolide antibiotics, quinolone antibiotics, H2- receptor antagonists, oral contraceptives

Complications include aminophylline side effects and toxic effects and rarely aminophylline allergy.

Side effects are common and can occur within the therapeutic range:

- tremor, anxiety, insomnia, headache
- palpitations
- indigestion, anorexia, nausea and vomiting
- diuresis (potential for profound hypokalaemia secondary to diuresis and β-agonists).
- can cause fitting at upper level of therapeutic range

Potential life-threatening toxic effects include

- unstable tachyarrhythmias such as VT, VF especially if hypoxic, acidotic, hypokalaemic, hypomagnesaemic. kiso AF, MAT, SVT.
- hypotension
• focal and generalised fitting. May progress to status epilepticus and not respond to benzodiazepines and phenytoin.
Aminophylline allergy (due to ethylenediamine)
• Urticaria, rash, angio-oedema, bronchospasm

References
1. MIMS Annual 1999.
DISCUSS THE AETIOLOGY AND MANAGEMENT OF A PATIENT WITH HYPOKALAEMIA (1.4 MMOL/L) WHO HAS RHABDOMYOLYSIS, ACUTE RENAL FAILURE AND EPISODES OF TORSADES DE POINTE

Dr. S. Perrin. Intensive Care Unit, The Bendigo Hospital, Victoria

Priorities in this patient
1. Control the episodes of Torsades de Pointes (TdP)
2. Treatment of hypokalaemia (hK) in the presence of renal failure
3. Identification and treatment of other metabolic derangements
4. Treat underlying cause of Rhabdomyolysis (RML)
5. Treat other comorbidities contributing to acute renal failure (ARF)
6. Minimise renal damage from myoglobinuria
7. Manage renal failure

Immediate control of sustained TdP with syncope can be achieved with defibrillation if syncope is present or MgSO\(_4\) 2gms (5mmol) i.v. if haemodynamics maintained. Lignocaine 1mg/Kg is controversial but most favoured of the traditional anti-arrhythmics. Sustained TdP + profound hypokalaemia (hK) is an indication for immediate potassium bolus 0.05mmol/Kg.\(^3\)

Ongoing correction of hK should be initiated with KCl infusion at 60 mmol/hr with [K\(^+\)] measured hourly and the infusion reduced to 40 mmol/hr when symptoms controlled or plasma [K\(^+\)] > 2.0 mmol/L. There are few studies to guide the clinician only anecdotal reports. Conventional wisdom limits infusion rates of potassium to 40mmol/hr.\(^5\) There are few reports guiding safe limits of therapy for this profound life-threatening level of hK.\(^4\) Magnesium deficiency is an almost invariable accompaniment of hK and is a primary therapy for TdP. A simultaneous infusion with MgSO\(_4\) 3.5 mg/Kg/hr should be commenced and continued until serum [Mg\(^{2+}\)] > 1.5 mmol/L.

If bradycardia is present or precedes TdP temporary cardiac pacing should be considered. Isoprenaline could only be considered if VT has been excluded, hK corrected and logistics prevent rapid insertion of temporary pacemaker. Assessment is initially directed to other aetiologies of TdP in particular concurrent drug therapy class Ia or III antiarrhythmics, phenothiazines, butyrophenones, H\(_1\)-antagonists, cisapride particularly in combination with erythromycin, cimetidine or ketonazole. Inspect ECG for prolonged or unstable QT.

Next, the origin of hK should be addressed as this will determine the ongoing aggressiveness of K\(^+\) replacement. In profound hK intracellular redistribution is invariably present and with correction of underlying disorder reverse redistribution can be anticipated potentially resulting in hK requiring treatment. Redistribution causing hK can result from:\(^1\)

*\(B_2\) adrenoreceptor activation
*Action of insulin - exogenous insulin, hyperalimentation
*Alkalosis/correction of acidosis
*Xanthine derivatives
*Anabolism e.g. recovery phase SIRS/MODS, hyperalimentation
*Periodic paralysis

*denotes causes potentially operating in this patient depending on the underlying problem and stage in natural history of co-morbidities.

In addition, the likelihood of total body potassium deficit total should be addressed. This loss can be non-renal (GIT, skin, dialytic therapies) or renal. Renal losses fall into 4 categories:\(^1\)
(i) **High renin** - Malignant H/t, renovascular disease, renin tumour
(ii) **Low renin** - Hyperkaemia e.g. early RML, 1º hyperaldosteronism, adrenal hyperplasia, Cushings disease, exogenous mineralocorticoid
(iii) **Renal tubular acidosis** - intrinsic renal disease, acetazolamide, RML
(iv) **High plasma [HCO₃]** - vomiting, diuretics, 1º Aldosteronism, gentamicin, cisplatin, carbenicillin, Mg depletion, hK itself

During clinical assessment attention should focus on potential causes of RML usually self-evident: **Traumatic** (crush, ischaemia, burns, hyperthermic/serotonergic syndromes, epilepsy) **Medical** (electrolyte deficiencies, hyperosmolar syndromes, infections - bacterial, viral, legionella, inflammatory disorders, pancreatitis and sickle cell disease) **Toxins** (snake bites, psychotropic drugs, substance abuse)

Ongoing compartment compression should be assessed by palpation of muscle groups, biochemistry parameters e.g. CPK and myoglobin levels. Tc⁹⁹biphosphonate scans can localise occult muscle injury. Fasciotomy will be required if vascular, neurological compromise is evident or intrafascial pressure exceeds 30mmHg. Management of RML is essentially control of underlying conditions, correction of metabolic derangements e.g. the hK in this patient may be contributed to by the renal loss and therapy during the early hyperkalaemia and acidosis associated with RML.

Establishment of a diuresis is useful in preventing tubular damage from myoglobin. Best achieved by volume expansion + mannitol 0.5mg/Kg. ARF 2º to RML is uncommon in the absence of other risk factors of ARF 6 particularly hypovolaemia and ongoing SIRS or sepsis. Extreme levels of myoglobinaemia have been controlled with CVVHF 7.

**Management Established Acute Renal Failure**

- Adequate nutrition
- Attention to fluid balance
- Maintain urine output (if possible) - Exclude hypovolaemia MAP > 80mmHg, loop diuretics
- Investigate and control sources of sepsis
- Adjust drug dosages
- Indications for CVVHDF - overload, acidosis, uraemic encephalopathy, hyperkalaemia.

**Aetiology and management of hypokalaemia**¹

1. Redistribution
   - Beta-2-adrenoreceptor activation
   - Xanthines
   - Alkalosis/Correction Acidosis
   - B₁₂
   - Insulin
   - Hypothermia
   - Periodic Paralysis
   - Anabolism
2. Non-Renal loss-GIT (<20mmol/day) - Fistula - Laxatives - Diarhoea - Adenoma - Skin - Dialytic therapies

3. Renal Loss
   - Low Renin - Primary Aldosteronism - Adrenal Hyperplasia - Cushings dis. - Exogenous mineralocorticoid
   B. Normotensive pt. – Low [HCO₃]_{serum} - Renal tubular Acidosis
   High [HCO₃]_{serum} - Vomiting - Diuretics - Bartter’s - Primary hyperaldosteronism - gentamicin, cisplatin, carbenicillin - Mg depletion - Hypokalaemia

Sequential management of profound hypokalaemia²,³,⁴,⁵

<table>
<thead>
<tr>
<th>Symptom Level</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.0 mmol/L + cardiac arrest</td>
<td>0.05 mmol/Kg stat³</td>
</tr>
<tr>
<td>&lt;2.0 mmol/L + symptoms</td>
<td>60 mmol/hr³ T ½ ~ 10 min Review hourly</td>
</tr>
<tr>
<td>&lt;2.0 mmol/L</td>
<td>40 mmol/hr⁴</td>
</tr>
<tr>
<td>2.5 - 3.5 mmol/L</td>
<td>20 mmol/hr</td>
</tr>
<tr>
<td>&gt; 3.5 mmol/L</td>
<td>10 mmol/hr T ½ ~ 20 min</td>
</tr>
</tbody>
</table>

NB. Profound hypokalaemia nearly always associated with redistribution, awareness that there may not be a total body deficit is important. With correction of underlying problem may result in intracellular to extracellular flux and consequent hyperkalaemia.

References
DISCUSS THE CLINICAL PRESENTATION AND MANAGEMENT OF A PATIENT WITH A DISSECTING AORTIC ANEURYSM

Dr. D. Durham. Department of Critical Care Medicine, Flinders Medical Centre, SA

Predisposing factors
Increased stress in arterial wall
- hypertension
- aortic dilatation with wall thinning
- bicuspid or unicommissural aortic valve
- coarctation
- hypoplastic aortic arch
- iatrogenic (surgery, percutaneous catheters)
- spontaneous rupture of vasa vasorum

Reduced resistance of arterial wall
- age
- Marfan’s syndrome
- pregnancy

Presentation
- Pain: sudden onset, severe, with sweating
  - retrosternal (ascending aorta), interscapular (descending aorta)
  - progression to abdomen with extension of dissection
  - syncope, dyspnoea, weakness

Findings
- Shock hypovolaemia tamponade
  - aortic regurgitation
- Apparent shock - cold, clammy, with normal or raised BP common
- Hypertension
- Loss or inequality of pulses (25% upper, 25% lower limbs; R arm & L leg more common)
- Aortic regurgitation (over 50%)
- Pleural or pericardial effusion
- Ischaemia from arterial obstruction
  - carotid (hemiplegia, hemianaesthesia)
  - spinal cord (paraplegia)
  - bowel
  - kidney (haematuria)
  - myocardium
- Compression
  - Horner’s syndrome
  - SVC syndrome
  - Hoarseness, dysphagia, airway obstruction

Management

Diagnosis
- CXR
  - widened mediastinum
  - enlarged aortic contour
  - obliteration of aortic knob or loss of AP window
  - calcified aortic rim >6mm from aortic border
  - displacement of trachea, oesophagus or L main bronchus
  - L pleural fluid
Echo Transthoracic diagnostic in 75% type A, 40% type B
  shows AR, pericardial effusion, LV function
TOE more sensitive but more difficult
  both miss distal ascending aorta, aortic branches, entry site
  operator dependent
  sensitivity 95-100%, specificity 85-90%
CT misses entry site, partially views aortic branches
  plain CT sensitivity only 65-85%; spiral 80-100%, specificity 95-100%
MRI defines flow, shows branches; no contrast, difficult and slow
  95-100% sensitivity and specificity
Angiography identifies entry point (56% sensitivity)
  intimal flap (70%)
  true and false lumina (87%) branches
  misses intramural haemorrhage
  contrast exposure, slow

Classification
Stanford Type A involves ascending aorta
Type B no involvement of ascending aorta
  (origin distal to L subclavian)
De Bakey I both ascending and descending (type A)
  II ascending aorta only (type A)
  III descending aorta only

Treatment Medical Resuscitation, pain relief
  Control BP to systolic ≤100 if tolerated
  reduce Dp/dt β-blockers  IV metoprolol, atenolol bolus
  IV esmolol, labetalol infusion
  add SNP as necessary
Surgery Type A risk of rupture 90% → immediate surgery
  replace ascending aorta ± aortic arch
  reconstruct aortic root to restore valve ± AVR
  direct distal flow to true lumen
  operative mortality 10 - 25%
Type B lower risk, ~20% with medical management
  surgical mortality ~ 35%
  indications for surgery progression of dissection
  continued pain
  impending rupture
  aortic diameter >5cm
  refractory hypertension
  end - organ ischaemia
Stenting trialled for both Type A & B
  percutaneous transfemoral approach
  mortality 0 - 16%
  morbidity 0 - 24%
  lower risk of paraplegia
Long-term control BP with \( \beta \)-blockers ± ACE inhibitors
pursue and treat cerebrovascular and coronary artery disease
surveillance every 3-12 months with MRI or spiral CT
echo surveillance of aortic valve
consider prophylactic Bentall procedure in Marfan’s syndrome

References
DISCUSS AND COMPARE THE MANAGEMENT OF CARDIAC ARREST CAUSED BY ASYSTOLE WITH THAT CAUSED BY VF

Dr. M. Davis. Intensive Care Unit, Liverpool Hospital, New South Wales

The algorithm for the management of cardiac arrest is essentially divided into two groups, namely that for VF/ pulseless VT and that for non VF/ VT (which includes asystole). The common features to management of both groups are those measures aimed at restoring myocardial perfusion eg, adrenaline, CPR, intubation. The essential difference between the groups however is aim for early defibrillation in the VF group. Antiarrhythmics play a secondary role in the VF group but have not been shown to improve long term outcome. A more detailed comparison is listed below.

<table>
<thead>
<tr>
<th>Ventricular Fibrillation</th>
<th>Asystole</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Most common primary rhythm in sudden cardiac arrest</td>
<td>- All electrical rhythms associated with cardiac arrest if untreated will</td>
</tr>
<tr>
<td>- Uncommon primary rhythm in children</td>
<td>deteriorate to asystole</td>
</tr>
<tr>
<td>- Majority of survivors come from this group</td>
<td>- Common primary rhythm in children</td>
</tr>
<tr>
<td>- Usually caused by ischaemic heart disease</td>
<td>- Prognosis in this group is much less favorable</td>
</tr>
<tr>
<td>- Management is based on the premise that early defibrillation is the most important factor in achieving a successful outcome</td>
<td>- Many causes</td>
</tr>
<tr>
<td>- Precordial thump may be delivered in witnessed or monitored arrest if defibrillator not immediately available</td>
<td>- Defibrillation is of no use. Management aimed at treating cause and restoring myocardial perfusion</td>
</tr>
<tr>
<td>- Pacing has no role</td>
<td>- Precordial thump has no role</td>
</tr>
<tr>
<td>- Atropine has no role</td>
<td>- Pacing may be considered in cases of complete heart block where P waves are seen</td>
</tr>
<tr>
<td>- Antiarrhythmics have secondary role (see below)</td>
<td>- Atropine 3mg IV may be considered on the basis that increased vagal tone could contribute to the development or unresponsiveness of this arrhythmia</td>
</tr>
<tr>
<td>- Reperfusion strategy needs to be considered if VF caused by acute coronary syndrome</td>
<td>- Antiarrhythmics have no role</td>
</tr>
<tr>
<td></td>
<td>- Reperfusion has no role</td>
</tr>
</tbody>
</table>
ADULT CARDIORESPIRATORY ARREST

BLS Algorithm if appropriate

Attach Defib - monitor

VF / VT

Assess rhythm / pulse

Defibrillate X 3 as necessary
- 1st time: 200J, 360J
- Subsequent: 200J, 360J
- CPR 1 min Correct reversible causes

NON VF / VT

CORRECT REVERSIBLE CAUSES
- Hypoxaemia
- Hypovolaemia
- Hypothermia
- Hyper/hypokalaemia & metabolic disorders
- Tamponade
- Tension pneumothorax
- Toxins / poisons / drugs
- Thromboembolism / obstruction

CPR up to 3 min Correct reversible causes

DURING CPR
If not already done:
- Check electrode / paddle positions & contact
- Attempt / verify: ETT IV access
- Give adrenaline 1mg every 3 minutes

CONSIDER
- Antiarrhythmics for VF / VT:
  - lignocaine 1-1.5 mg/kg
  - amiodarone 5.0 mg/kg
  - K⁺ 5 mmol
  - Mg²⁺ 5 mmol
- Buffers: NaHCO₃ 1 mmol/kg
- Atropine 1-3 mg /- pacing for asystole / severe bradycardia

Assess rhythm and pulse etc.
i.e. repeat pathway
Antiarrhythmic agents

lignocaine 1mg/kg
- associated with a higher rate of return to spontaneous rhythm
- higher rate of hospitalisation alive
- no difference in hospital discharge or survival Heritz et al. Resuscitation 33(3):199-205, 1997

magnesium 5 mmol
- some reports of increased survival, consider in torsades de pointes, hypokalaemia, dig toxicity
- prospective, randomised, double-blinded control trial in VF/VT Fatovich, Prentice, Dobb. Resuscitation 35(3):237-41, 1997 showed no difference to placebo in ECG rhythm, return to spontaneous circulation, survival to leave ED, survival to leave ICU or survival to hospital discharge.

bretylium 5mg/kg
- controversial, previously considered second-line after lignocaine but no longer available

amiodarone 5mg/kg
- increased survival to ED but not discharge
- may be considered for recurrent VF

procainamide 250-500mg
- not routinely used, may be considered if lignocaine contraindicated

sotalol
- unproven, not routinely used

calcium 7 mmol (10mls of 10% CaCl₂)
- seldom indicated as may increase myocardial and cerebral cell death
- use for hyperkalaemia, hypocalcaemia, Ca-channel blocker overdose

References
DISCUSS THE MANAGEMENT OF PARAQUAT POISONING

Dr. T. Brownridge. Intensive Care Unit, Royal Adelaide Hospital, SA

Chemistry

*Paraquat*ernary bipyridyl

\[ \text{CH}_3\text{N} \quad \text{NCH}_3 \]

- highly toxic, water soluble base
- readily reduced to a stable free radical (brown → blue/violet)

Background

- discovered in 1932 & used as a redox indicator for many years
- herbicidal properties discovered in 1955
- commercially available in Australia since 1965
  - formulated as 10 - 20% w/v, with stenching agent, emetic & blue dye
  - 40% available in some countries
- first deaths reported 1966 from accidental ingestion
- major reason now is suicide, occasionally murder & accidental
- LD\(_{50}\) 3 – 5g, or 10 – 15 ml of 20% formulation

Kinetics

- rapidly transits stomach, but only 5 – 10% absorbed, rest excreted in faeces
- peak plasma concentrations reached at ½ - 2 hours
- redistributes rapidly, with reservoirs in lung & skeletal muscle
- excreted unchanged in urine (clearance higher than creatinine)

\[ \text{FIGURE 3: Contour graph showing relation between the plasma concentrations of paraquat on the ordinate (mg/L), time after ingestion on the abscissa and the probability of survival. Reproduced, with permission, from Hart TB et al.}^* \]
Clinical manifestations

Ingestion – dose dependent

> 40mg/kg: fatal within hours to days from MOF
  severe corrosive effects to mouth/pharynx/oesophagus/stomach with ulceration, inflammation, perforation → mediastinitis

20 – 40 mg/kg: fatal in days to weeks
  characterised by - GIT symptoms/signs
    - renal dysfunction within 24 hours
    - progressive respiratory failure due to pulmonary fibrosis

< 20mg/kg: mild toxicity or asymptomatic
  limited to GIT, however transient abnormalities of gas exchange and vital capacity are detectable

Inhalation
  - may be fatal, but generally considered safe in occupational exposure due to considerable dilution and large droplet size

Topical
  - deaths have been reported but are rare
  - systemic toxicity possible if
    - prolonged exposure
    - undiluted product
    - skin abraded
  - eyes → severe irritation which can denude corneal epithelium & conjunctiva

Pulmonary toxicity
  - lung targeted because of active uptake & accumulation of PQ by type 1 and 11 alveolar cells (10 – 20 X plasma levels)
  - PQ structure enables it to use polyamine uptake mechanism
  - alveolar injury caused by
    - formation of O₂ free radicals
    - depletion of NADPH (essential for surfactant synthesis & glutathione peroxidase systems
    - depletion of glutathione
  - 2 phases of injury
    - destructive: acute alveolitis, proteinaceous pulmonary oedema, infiltration of lung parenchyma by macrophages & polymorphs
    - proliferative: fibroblast proliferation, collagen deposition, pulmonary fibrosis, impaired gas exchange, hypoxia and death
Management

History
- accidental or suicidal?
- name and concentration of product?
- diluted or not?
- volume ingested?
- time since ingestion?
- time of last meal?
- extent and timing of vomiting?
- GIT symptoms?
- respiratory symptoms?

Examination
- oropharyngeal inflammation/ulceration?
- respiratory distress?
- dehydration?

Investigations
- urinary or preferably plasma PQ level
- U&E/LFT/coags/ABG
- CXR/ECG
- Endoscopy, to identify extent & severity of any mucosal lesions. Gives prognostic information

Treatment
1. **Prevention of high plasma concentrations**
   - Gastric lavage (if < 1 hour, and no GIT ulceration)
   - Fullers earth (1L 15% suspension) or charcoal, followed by 200 ml of 20% mannitol 4-6/24
   - Skin washing
   - Adequate hydration to optimise renal function
   - Haemodiafiltration ??if commenced within 2/24

2. **Minimise lung toxicity**
   No antidote available yet
   - aim for lowest F\(_{\text{I}O_2}\), trial CPAP/PEEP before \(\text{\textasciitilde}O_2\) concentration
   - prevent PQ uptake (polyamines, D propranolol)
   - \(\text{\textasciitilde}\text{efflux from lungs (cyclophosphamide, PQ specific antibody)}\)
   - prevent redox recycling (low F\(_{\text{I}O_2}\), vitamin E, superoxide dismutase, ascorbic acid, desferrioxamine, selenium, niacin, N-acetylcysteine)
   - dampen fibrotic reaction (steroids, immunosuppressives, radiotherapy, fibrinolytic agents, colchicine)

3. **Lung transplantation**
   - reported successes and failures
   - transplanted lung can develop PQ toxicity

**References**
DESCRIBE THE FEATURES AND DISCUSS THE TREATMENT OF ACUTE PARAQUAT POISONING

Dr. P. C. Scott. Intensive Care Unit, Royal Brisbane Hospital, Queensland

Significant ingestion of herbicides containing paraquat may occur either accidentally or intentionally. Absorption from the gut is approximately 5% but is the usual route of poisoning. Gut absorption may be reduced by a recent meal and some commercial preparations contain an emetic. Minimal absorption occurs via the respiratory tract and skin. The LD50 in humans is approximately 3-5g. The clinical course depends upon the amount of paraquat ingested.

1. <20 mg/kg: Either asymptomatic or mild toxicity related to the gastrointestinal tract.
2. >20-40 mg/kg: Inflammation and ulceration of the mouth and upper gastrointestinal tract. Ulceration may take 1-2 days to develop. Renal failure due to acute tubular necrosis develops after about 24 hours. Hepatic enzyme abnormalities may occur. Dyspnœa, cough and progressive respiratory failure subsequently develop due to pulmonary fibrosis. Death occurs from a few days to several weeks post ingestion.
3. >40mg/kg: Corrosion of oropharynx and upper gastrointestinal tract. Perforation of oesophagus may occur. Multiorgan failure develops involving the heart, cerebral oedema, adrenal cortical necrosis, hepatic and renal necrosis and haemorrhagic pulmonary oedema or ARDS. Death occurs within a few hours to days.

Prognostic factors
Nomograms relating survival to plasma levels and time from ingestion have been developed. Higher absorbed doses have a poorer outcome. Accordingly, a poorer outcome is predicted by higher urinary concentrations of paraquat, greater quantities of paraquat cleared by haemodialysis or haemoperfusion, and the development of ulceration of the upper gastrointestinal tract.1,2

Pathophysiology1,2
Peak plasma concentrations occur at 0.5-2 hours post ingestion. Paraquat rapidly redistributes to organs including the lung, kidney and muscle. The kidney clears paraquat by filtration and secretion such that clearance exceeds creatinine clearance. Most of the absorbed paraquat is renally excreted within 24 hours of ingestion. The kidneys may excrete more than 1000 mg/litre of urine. As renal function deteriorates, elimination half-life increases from less than 12 hours to greater than 120 hours. As plasma levels decrease, the muscles and lungs act as reservoirs slowly releasing paraquat for several weeks post ingestion. Paraquat actively taken up by Type I and II pneumocytes via a receptor for endogenous polyamines.

Intracellularly, paraquat accepts an electron from NADPH then reacts with oxygen to form a superoxide radical and reforming paraquat in its previous form. Superoxide radicals react to form hydrogen peroxide and with iron to form hydroxyl radicals which lead to lipid peroxidation and cell death. Hydrogen peroxide is cleared from the cell by glutathione peroxidase in a process requiring glutathione and NADPH. NADPH depletion may allow further cellular injury by other free radicals.

Pathologically, during the first few days an acute alveolitis develops characterised by loss of type I and type II pneumocytes, infiltration by inflammatory cells and haemorrhage. Subsequently, fibrosis occurs.
Management options

1. Minimisation of absorption by gastric lavage within 1 hour of ingestion and subsequent administration of absorbents - Fuller's earth or activated charcoal. A cathartic and further doses are given until adsorbent is evident in the stool. Charcoal has a theoretical disadvantage of desorption as it passes through the gut.

2. Removal of paraquat from plasma. Kidneys are very efficient at clearing paraquat. Haemodialysis or haemoperfusion to augment this is best when plasma concentrations are maximal within two hours post ingestion. This is generally not possible in practice and studies have not shown an improvement in mortality. Renal clearance is not aided by forced diuresis.

3. Inhibition of entry of paraquat to alveolar epithelial cells: putrescine, spermidine, and propranolol block the uptake of paraquat via the polyamine receptors in vitro but no benefit has been shown in vivo.

4. Immunotherapy with monoclonal antibody fragments against paraquat or the active transport mechanism to prevent entry of paraquat into the alveolar cells: would need to be administered before significant tissue distribution.

5. Antioxidants and free radical scavengers: Vitamins C and E, desferoxamine, superoxide dismutase, clofibrate, selenium, and glutathione peroxide have been tested in animal models with no or insignificant improvement. Animal studies of N-acetylcysteine - a precursor of glutathione - showed a moderate protective effect but the clinical significance was considered doubtful. Niacin, which increases NADPH synthesis, has some protective effects in rats, but is not proven in humans.

6. Breathing hypoxic mixtures does not prevent lung toxicity but oxygen has been shown to increase lung injury.

7. Prevention of fibrosis would be of benefit for moderate ingestions. Three published studies of steroids and cyclophosphamide are limited by methodological problems. Two showed better outcome and one no improvement. Lin et al. gave 16 patients with moderate to severe poisoning (on basis of urinary testing) cyclophosphamide 1 g daily for 2 days and methylprednisolone 1 g daily for three days. Mortality was 4/16 and was compared with historical controls 12/17. Minimisation of paraquat absorption and haemoperfusion for 8 hours were followed by pulses of cyclophosphamide and methylprednisolone over 2 hours. Leucopenia occurred in ~35% of patients but recovered within 1 week in these patients. Lung irradiation, NSAIDSs, colchicine or collagen synthesis inhibitors to prevent lung fibrosis are of unproven value in humans.

8. Lung transplantation. Persistent low levels of paraquat cause fibrosis in the transplanted lungs despite immunosuppression. Patients are often psychiatrically unsuitable.

Case Reports:

1. Successful single lung transplant ~ 6 weeks post paraquat poisoning.

2. Good recovery in 50 y.o. male after ingestion of 160mg/kg of paraquat. Treatment included minimisation of absorption, haemodialysis and antioxidant treatment with desferoxamine (100 mg/kg) for 24 hours and an N-acetylcysteine infusion (loading dose of 150mg/kg followed by 300mg/kg/day for 21 days).

Summary of management:

In addition to general supportive measures, absorption should be minimised and oxygen therapy restricted. Haemodialysis and haemoperfusion do not improve survival. Antioxidants are under investigation. Outcome for patients with moderate ingestions may be improved by prevention of fibrosis with cyclophosphamide and steroids.
References
DISCUSS MANAGEMENT OF A LOCULATED HAEMOTHORAX

Dr. S. Newell. Intensive Care Unit, Cairns Base Hospital, Queensland

- Definition - implies failure of adequate drainage by tube thoracostomy. Incidence 5-30%.
- Management depends on - treatment thus far, cause, complications, infection, size, patient, local and surgical preferences.
- Spectrum management - nil (small non-complicated), further maximisation of tube drainage ± radiological guidance, surgery, pleural thrombolytics
- Surgery - open, limited, thoracoscopic (VATS)
- Empyema - incidence post trauma Liu 2 -25%, Richardson 5-10%, Coselli 3.8%, Smith 2-6%. Risk factors - retained loculated haemothorax, ICC, abdominal injury, pneumonia, not particularly open vs closed injury, impaired patient.
- Incidence empyema post retained loculated haemothorax - Eddy 50%, Coselli 22%
- Relevance of empyema - high morbidity/mortality - Huang review 1 - 61%/ own study 24%, Coselli 10%. Prevention obviously best = early removal of blood.
- Does size matter? Richardson “300 mL”, Smith “500 mL” or 1/3 thorax (CT) - suggest surgical intervention - conservative management acceptable for smaller collections if no infection.
- Associated injuries - may increase indication for surgical intervention.
- When (timing) to treat surgically? All suggest earlier surgery easier with less complications; Liu 7 days Lewis 4-10 days, Coselli 5 days, Smith 10 days Richardson 4 days.
- VATS - usefulness - pleural pathology, diaphragmatic injury, advantages/disadvantages - Less invasive but must have accessable pleural space and tolerate 1 lung ventilation. Relative contra indications; acutely unstable chest trauma and if left too long (pleural adherence)
- Success VATS for removal retained loculated haemothorax; Smith 8 of 9 (one failure day 21), Abolhoda 9 of 13, Liu 50 of 50
- Pleural thrombolytics - run of reports 70’s - 80’s with variable success - some enthusiasts - some detractors. No comparisons with current VATS. Role? - frail patient, surgery not available, incomplete resolution but no strong indication for surgery otherwise. Contra indication - extensive loculations, organised haematoma, fibrothorax, within 2-3 days of trauma, post-op cases. Side effects- few Fever, allergy, not particularly bleeding.
- Aye 1991 success 13 of 14 - loculated haemothorax and empyema with failure initial tube drainage, really just a series of anecdotal reports with little patient data otherwise.
References


DISCUSS THE ACTIONS, INDICATIONS AND DOSES OF THE ANTITHROMBIN AGENTS

Dr. R. Newman, Intensive Care Unit, Modbury Hospital, SA

ACTIONS:
Direct thrombin inhibitors inhibit clot-bound thrombin as well as fluid phase thrombin (cf heparin inhibits only fluid phase thrombin via AT III) with the following potentially therapeutic effects:
- Prevent clot formation and extension
- Inhibit thrombin-induced platelet activation (the most powerful stimulus of platelet aggregation which is not inhibited by aspirin)
- Not inhibited by platelet products (e.g. Platelet factor IV)
- May indirectly facilitate clot lysis (and influence effects of thrombin on platelets, fibrin and endothelium): when fibrin-bound thrombin is exposed during clot lysis (pharmacological or endogenous) further thrombin is generated via prothrombinase complex. Antithrombins inhibit this feedback loop.

Figure 1. Interaction of coagulation system, platelets and vessel wall in thrombosis.

INDICATIONS:
- Early administration of a direct thrombin inhibitor (hirudin) either before or during thrombolytic therapy improves vessel patency rates by decreasing rethrombosis with a reduction in death and MI rates at 30 days (GUSTO 2 b) and better flow in infarct-related artery (HERO 1) compared to heparin. HERO 2 is addressing efficacy of antithrombin therapy before thrombolytics.
• Significantly decrease the incidence of cardiac endpoints in acute ischaemic syndromes (following thrombolysis for myocardial infarction, unstable angina and non-Q wave infarction and coronary angioplasty). **(NB benefits obtained during short term treatment are not sustained in the long term).**
• Heparin induced thrombocytopaenia (possibly combined with GP IIb/IIIa inhibitors)
• Prevention and treatment of venous thromboembolism.

**DOSAGE:**
• Hirudin: bolus of 0.1 ug/kg/hr (GUSTO 2 b and TIMI 9 b⁵)
• Bivalirudin (Hirulog): bolus of 0.25 mg/kg followed by 0.5 mg/kg for 12 hours and 0.25 mg/kg for 36 hours (HERO 2) prior to streptokinase.

**ADVERSE EFFECTS:**
• Increased bleeding risk (including intracerebral haemorrhage) with higher dose hirudin (GUSTO 2 a⁶).
• Hirudin prevents thrombin from activating Protein C therefore suppressing a natural anticoagulant pathway (unlike Bivalirudin).

**OTHER:**
• At least one antithrombin agent is orally bioavailable.
• Do not require monitoring.
• Not associated with immune thrombocytopaenia.

**References**
DISCUSS THE CAUSES AND MANAGEMENT OF EPIGLOTTITIS IN AN ADULT

Dr. E. Merry, Intensive Care Unit, Royal Adelaide Hospital, SA

**Epiglottitis (or supraglottitis)** describes inflammation of the epiglottis, arytenoids and aryepiglottic folds but can involve the whole hypopharynx. It is most commonly due to infection.

Epiglottitis may cause abrupt fatal upper airway obstruction from either the swollen epiglottis itself or laryngospasm from secretions.

**Incidence**: 1-2 per 100,000 population p.a. in adults. May be affected by increased awareness and by introduction of Hib vaccine (given as meningitis prophylaxis to children)

**Male: Female** 2-4:1

**Age**: 16-60, mean age 47y

**Causes**: Infection, mostly bacterial

Only 30% are culture positive but mostly

**Haemophilus influenzae type b**

Also:
- Beta haemolytic streptococci
- Streptococcus pneumoniae
- Staphylococci
- Klebsiella
- Anaerobes
- Viral (herpes simplex)
- Candida

Atypical infections more likely if immunocompromised

**Differential Diagnosis**

Any other cause of sore throat and upper airway obstruction:

- Bacterial laryngotracheobronchitis
- Abscess (retropharyngeal, tonsillar)
- Infectious mononucleosis
- Allergy
- Angioedema
- Foreign body
- Chemical inflammation (reflux oesophagitis)
- Diphtheria
- Ludwig’s angina
- Laryngeal tumour/ trauma
- Crack cocaine (thermal injury from metal)
**Presentation**
Consider diagnosis in any adult presenting with severe sore throat
Usually a prodrome of upper respiratory tract symptoms for hours to days
Associated with smoking

**Symptoms and signs**
1. Sore throat (98-100%) out of proportion to physical findings
2. Fever (76%)
3. Dysphagia (76%)
4. Muffled voice (54%)
5. Drooling
6. Dyspnoea (sitting upright with neck extended) 25-78%
7. Tachycardia
8. Lymphadenopathy
9. Neck tender to palpation

Only positive predictor for intubation is respiratory distress

**Diagnosis**

**Visualisation of epiglottis and airway**
- Gold standard
- Direct or indirect laryngoscopy
- Fibreoptic nasendoscopy better tolerated

**Lateral soft tissue neck X-rays**
- Variable sensitivity and specificity
- May delay treatment or result in unnecessary transfer of compromised patients

**White blood cell count**
Can be normal or elevated

**Blood cultures, epiglottic swab cultures**
Not often positive (only 30% of adult cases)
Take 24-48 hours and should not delay empirical treatment

**Management (after visualisation)**

**Generally accepted:**

1. Antibiotics
   - To cover Haemophilus
   - Often ampicillin resistant so use 2nd or 3rd generation cephalosporin e.g. ceftriaxone 2g/24hrs
   - Intravenous for 3-4 days then 2 weeks oral
   - Ensure cultures taken first
   - Change as dictated by sensitivities
2. **Humidified oxygen**

3. **Monitoring of respiratory parameters**

**More controversial:** When and where to intubate?

**Principles:**
- Avoid transfer of unstable/compromised patient
- Oxygenation is priority
- Avoid rapid sequence induction (may precipitate complete obstruction)
- Inhalational induction may be difficult in adults (excitatory phase, prolonged procedure, may completely obstruct)
- If treating conservatively ensure facilities and equipment immediately available for intubation and surgical airway, together with personnel experienced enough to use them
- 20-25% of patients with epiglottitis need incubation, best predictor is respiratory distress
- Risk of acute severe deterioration in respiratory status very small if do not present with dyspnoea
- Emergency cricothyrotomy has higher complication rate than planned procedure

**Suggested protocol**
1. If symptomatic with respiratory distress or > 75% narrowing of upper airway on inspection, immediate intubation in Emergency Department.
2. If not symptomatic and airway patent, observe for 12-24 hrs in Intensive Care Unit (need immediate access to intubation and surgical airway)
3. When stable transfer to ward or High Dependency Unit for close monitoring.
4. If increasing or new dyspnoea develops, repeat examination and transfer to ICU
5. Usual criteria for extubation plus visualise improvement in airway first
6. If persistent fever/elevated WBC/symptoms, look for abscess or pneumonia
7. If recurrent epiglottitis suggests underlying disorder e.g. malignancy, immunocompromised

**Other therapies**
- Steroids used to decrease inflammation but no hard evidence of benefit
- Adrenaline (IM/nebulised) often used to "buy time" while preparations made for airway control. No good evidence for benefit.

**Prophylaxis**
- For close contacts to eradicate carriage of Haemophilus
- Rifampicin 20 mg/kg/24hrs for 4 days

**Outcome**
- Mortality from most recent series 1-7% (previously 20%)
- Mortality in children with epiglottitis 1%
- Improvement is probably due to increased clinical awareness and increased availability of ENT personnel and fibreoptic equipment.
SUMMARY

**Adult Epiglottitis: causes and management**
Inflammation of hypopharynx resulting in occasional fatal upper airway obstruction
1-2 cases per 100,000 p.a.
M > F
Peak incidence 40’s
Mortality 1-7% (decreasing in adults)

**Cause:**
30% culture positive, most often *Haemophilus influenzas type b*, also other Strep, Staph, viral, anaerobes.

**Clinical:**
Hours to days of upper respiratory symptoms, mainly sore throat, dysphagia, fever, dyspnoea
NB Dyspnoea is only positive predictor of need for intubation

**Diagnosis:**
Visualise upper airway with fibre-optic nasendoscopy
X-rays, white cell count, cultures not helpful

**Treatment:**
- 2nd or 3rd generation cephalosporin e.g. ceftriaxone 2g/day for 3 days then 2 weeks oral (cultures first)
- Humidified oxygen
- Monitoring
- **Airway control:**
  1. If symptomatic or obstructing, intubate ASAP in ED
  2. Other patients can be observed in ICU if equipment and personnel are available for immediate intubation and surgical airway (low risk of sudden deterioration)
  3. Persistent fever may mean abscess or pneumonia

Steroids, adrenaline no evidence of benefit
Rifampicin prophylaxis for Haemophilus

**References**
6. Rippe JM, Irwin RS, Fink MP, Cerra FB (eds) Intensive Care Medicine, 3rd edition Little and Brown
DISCUSS THE RISK FACTORS OF MRSA VENTILATOR-ASSOCIATED PNEUMONIA AND ITS MANAGEMENT

Dr. V. P. Patil. Intensive Care Unit, St George Hospital, New South Wales

PATIENT RELATED RISK FACTORS

Predisposing colonisation by impairment of host defensive function

Main Risk Factors:
• Coma GCS <9 FOR >24hrs
• Presence of comorbidities like COPD, DM, Renal Failure and APACHE >16
• Prolonged hospitalisation especially in institutions with endemic MRSA infection

Contributory factors:
• Severe acute or chronic illness
• Malnutrition
• Impaired airway reflexes and neuromuscular disease
• Hypotension and metabolic acidosis

INFECTION CONTROL RELATED RISK FACTORS

Transmission from one patient to other patient
• Not washing hands or changing gloves between two patients
• Use of contaminated resp.therapy devices and equipments

INTERVENTION RELATED RISK FACTORS

Main Risk Factors:
• Duration of mechanical ventilation >7 days
• Use of steroids and cytotoxic agents
• Prolonged and inappropriate use of higher generation antibiotics (imipenem, 3rd generation cephalosporins, fluroquinolones)

Contributory factors
• Use of sedatives and paralysis
• Unnecessary reintubation
• Presence of NG tube
• Low intracuff pressures<20
• Failed subglottic suction
• Supine position
• Patient transport
• Stress ulcer prophylaxis with H2 blockers
GENERAL PREVENTIVE STRATEGIES

PHARMACOLOGICAL STRATEGIES

• Timely use of proper antibiotics and avoidance of prolonged course of empirical combination therapy
• Prophylactic treatment of patients with neutropenia with GC-SF and prophylactic antibiotic
• Stress ulcer prophylaxis limited to high-risk patients only
• Chlorhexidine oral rinse

NONPHARMACOLOGICAL STRATEGIES

• Use of formal infection control programme
• Effective hand washing and the use of protective gowns and gloves
• Semirecumbent positioning of patients
• Avoidance of large gastric volumes
• Provision of adequate nutritional support
• Oral intubation
• Continuous subglottic suctioning
• Maintenance of adequate pressure in endotracheal tube cuff

References
DISCUSS THE MANAGEMENT OF FULMINANT ASTHMA IN A PATIENT WHO HAS BECOME UNCONSCIOUS

Dr. M. P. Chinthamuneedi. Intensive Care Unit, Royal Adelaide Hospital, South Australia

Fulminant Asthma\textsuperscript{1,5}: This distinct entity affects a subset of asthmatic population. Pathophysiology appears to be different from the slowly progressive status asthmaticus. Onset is usually late, begins after 40 years of age, presents as a sudden unexpected increase in air flow obstruction leading to decreased conscious state secondary to severe ventilatory failure.

Management\textsuperscript{1} Decreasing conscious state in the setting of progressive hypercapnia and associated hypoxia warrants protection of airway (intubation) and mechanical ventilation. Management in this situation is divided into optimisation of preintubation management, Plan of intubation and application of ventilatory strategies, aimed at improving minute ventilation, oxygenation, prevention and treatment of the gas trapping and associated complications. (increased intrathoracic pressure, cardiovascular collapse and pulmonary barotrauma).

Preintubation: Optimising ongoing therapy (a. administration of 100\% oxygen. b. bronchodilator therapy with $\beta_2$ agonist continuous nebs and or iv $\beta_2$ agonists, anticholinergics, adrenaline iv/nebs. c. steroids. d.aminophylline infusion. e. trial of non invasive ventilation) has shown to improve the patient's condition.

Intubation\textsuperscript{1}: Once all the efforts are failing intubation should be performed ideally before respiratory arrest.

Rapid sequence orotracheal intubation with relatively bigger size tube is advised, usual induction agents are Propofol, midazolam and ketamine.

Muscle relaxants: Suxamethonium and or Rocuronium.

Nasal intubation with or without the help of fiberoptics to reduce patient discomfort is a practice in some centers.

Post intubation\textsuperscript{1,3,4,7}

Initial ventilator setting: deep sedation and paralysis (initially) alleviate the exhaustion and patient-ventilator inco-ordination. Also it facilitates the physicians to check different ventilatory parameters to assess adequacy of ventilation and dynamic hyperinflation (air trapping).

Fio\textsubscript{2} 100\% oxygen

Minute ventilation: Respiratory rate 6-8 breaths/minute Tidal volume: 8-10 mL/kg I:E ratio 1:4 or more (best set as per flow volume graphics on the ventilator aiming at adjusting the E time to the return of flow and volume to baseline before the next breath)

PEEP its use has no logic (as such end expiratory lung volume EELV is high)

Inspiratory flow 80 to 100 L/min (to reduce work of breathing and inspiratory time used by Tuxen et al ) in this setting PIP is not measured to asses gas trapping. In practice this approach is associated with enormous rise in PIP. The earlier studies with this strategy showed high incidence of barotrauma.
Strategies to assess and avoid gas trapping

Aggressive measures to improve minute ventilation will invariably result in gas trapping proportional to the air flow obstruction

**Permissive Hypercapnia**: usually aimed at 60 to 90 mmHg is a useful (as high as 200mmHg were reported) strategy to prevent gas trapping and barotrauma (treating respiratory acidosis with NaHCO$_3$ hasn’t shown benefits)

**Peak Inspiratory pressure (PIP)** aimed at 50 cmH$_2$O measures the pressure developed in the proximal airways before stress relaxation. It is not a good predictor of alveolar pressure or alveolar over distention.

**P plateau**: Pressure measured by 0.5 seconds end inspiratory occlusion gives a reasonable measure of end expiratory alveolar pressure.

**Intrinsic PEEP (PEEPi)** is the lowest average alveolar pressure obtained by an end expiratory hold manoeuvre.

**EVI**: total exhaled volume measured between 20 to 60 seconds during apnoea comprises the sum of tidal volume and entrapped gas.

*Strategies to decrease barotrauma and hypotension while improving ventilation were* $^{1,3}$

- PIP <50 cmH2O,
- P plateau <30 cmH$_2$O, PEEPi < 15 cmH$_2$O EVI < 20mL/Kg.

In a study comparing Pplat, PEEPi and VEI as predictors of barotrauma and hypotension VEI < 20mL/kg had a high predictive value

Other options tried to treat bronchial unresponsiveness like Halothane, Ketamine infusion, heliox, magnesium

ECMO have resulted in inconsistent outcomes.

**Complications:**

- **Immediately after intubation**. Hemodynamic collapse secondary to dynamic hyperinflation is not uncommon, (Lazarus Phenomenon) usually improved with disconnecting the patient from the ventilator for 20-30 seconds, and applying gradual chest wall compression to expel trapped gas.
- subcutaneous emphysema.
- Pneumothorax and pneumomediastenum.
- Increased ICP and intracranial hemorrhage (avoid permissive hypercapnia and the use of ketamine and Halothane in patients in whom raising ICP is a potential problem)

**Weaning** usually planned soon after reduction in bronchial hyperresponsiveness (within 24 hours)

Weaning is delayed in some due to persistent air way spasm, associated parenchymal disease (pneumonia) or not uncommonly secondary to myopathy.

**References**


7. Cooper DJ, Cailes JB, Scheinkestel CD, Tuxen DV. Does bicarbonate improve cardiac or respiratory acidosis and acute severe asthma. Am Rev Resp Dis 1993;147:A 614
DISCUSS THE INDICATIONS, COMPLICATIONS AND DOSAGE OF INTRAVENOUS HUMAN IMMUNOGLOBULIN (IVIG)

Dr J. Fraser  Intensive Care Unit, Princess Alexandra Hospital, Brisbane, Queensland

Background
IVIG first administered 1979
Isolated from up-to 20,000 donations of pooled blood
Preparations involves a number of processes including:
- Purification – extraction of other Ig (M and A especially, though significant quantities of IgA remain.)
- Stabilisation of IgG – with dissolution in sucrose/ mannitol-containing solution, preventing precipitation of IgG.
- Viral deactivation - by a number of different processes including heat treatment and solvent detergent deactivation.

Indications
Correction of Immunodeficiency – Primary or Secondary

IVIG provides passive immunity with the administration of a wide range of IgG antibodies

1 Primary immunodeficiencies including:
   - X linked agammaglobulinaemia
   - Wiskott Aldrich syndrome
   - Ataxia telangectasia
   - Primary lymphangectasia
   - IgG subset deficiencies – especially IgG2.

2 Secondary immunodeficiency states, including:
   - Chronic lymphatic leukaemia – trial evidence to support its use in reducing incidence of infection
   - AIDS-associated infections in children
   - High risk neonates, particularly the premature
   - Drug-induced hypogammaglobulinaemia
   - RSV infected children/those children at high risk of RSV – trial evidence supporting IVIG use

Treatment of Immuno-haematologic conditions
The discovery of IVIG use in these conditions was fortuitous. IVIG was used in 1981 to treat the immunodepressed state of a patient with Wiskott-Aldrich syndrome, when the platelet count was seen to rise dramatically. There have been multiple trials in various types of thrombocytopenia since. Conditions frequently treated with IVIG include:
   - Acute and chronic idiopathic thrombocytopenia purpura. IVIG is given for 2 days, and generally a rise in platelet count of >30,000/mm³ is witnessed within 48 hours. If this occurs, IVIG is continued for five days in total. Children with acute ITP respond most quickly to the treatment. The success is slightly lower (62%) with the chronic form of the disease, and in both conditions, adults fair less well.
   - The proposed mechanism for ITP is the reaction of auto-antibodies to glycoprotein IIa/IIb and Ib/IX receptors on platelet surface.
Factor VIII and IX inhibitors. – Hemophiliacs, who require repeated factor transfusion, have a high incidence of anti-factor antibodies (between 8 and 20%). Pretreatment with IVIG, and occasionally cyclophosphamide is associated with a reduction in anti-factor antibodies, and, hence less bleeding events due to increased available levels of factors.

Other immunoaematologic conditions IVIG has been used for includes
1. Parvovirus B19 induced red cell aplasia
2. Immune neutropoenia
3. SLE-associated thrombocytopenias

Treatment of non-haematological autoimmune disorders
Guillain Barre – Standard of care previously was plasmaphoresis, which was associated with improved outcome in severe Guillain Barré. The Dutch trial group in a randomized control trial of plasmapheresis (5 plasma exchanges of 200-250m/kg) vs 5 days of 0.4g/kg per day, showed that there were less complications associated with IVIG; that there was less need for ventilation (both with p < 0.05). There was a significant improvement in motor score with IVIG treatment (p < 0.05). Time to improvement of one motor grade was more rapid with IVIG cf. plasmapheresis (p = 0.05). The conclusion was that IVIG was as effective, if not more so, than plasmapheresis. There is some speculation whether there is additive benefit.

Trial evidence also supports IVIG administration in
1. Dermatomyositis
2. Chronic inflammatory demyelinating neuropathies
3. Kawasaki syndrome

IVIG is also used as a substitute for plasmapheresis in a number of immunologic conditions, including
1. Myasthenia gravis. No trial has established efficacy, but observational work shows improvement in 70% of patients treated by day 4-5. This improvement continues for months.
2. Stiff Man syndrome – GABA deficiency due to anti glutamic acid decarboxylase Ab’s.

Treatment of severe sepsis
Multiple trials of monoclonal antibodies, including anti-endotoxin, anti-receptor antibodies, etc caused great excitement, but have never been shown to result in any substantial clinical benefit. A recent meta-analysis by the Cochrane Group, including 23 trials from a initial group of 45 trials showed that polyclonal IVIG significantly reduces mortality and can be used as an adjuvant treatment for sepsis and septic shock. They concluded that the use of monoclonal antibodies remains experimental.

Complications
1. Immediate – These adverse effect generally arise from triggering an inflammatory response – from aggregate IgG molecules; from small concentrations of IgA in patients with total IgA deficiency states, and from complement activation. 62% develop headache and there is an appreciable incidence of anaphylactoid reactions.
2. Delayed – Renal dysfunction, particularly in those with impaired renal function –possibly related to high osmolality or the stabilizing carbohydrates. Hyperviscosity syndromes – resulting in myocardial/cerebrovascular and venous thromboembolic disease.
Aseptic meningitis – Up-to 11% in some case series. CSF shows pleocytosis and increased CSF protein
Very occasionally, haemolysis, leucopenia, skin rashes and arthritis occur.

3. Late – Infective events. Alcohol treatment in production results in HIV deactivation. No cases of HIV transmission have ever occurred. Hepatitis B has been transmitted, but not since screening has been improved. Approximately 450 cases of Hepatitis C transmission have been reported, but altered production techniques has made this a much less common phenomenon. 1 case of Parvovirus B19 has been transmitted. The risk of prion transmission is, as yet, unknown. Experimental work suggests that fractionation results in the infective agents of scrapie being removed from the final IVIG.

Dosage
1. Immunodeficiency states - Dosages vary from 100mg/kg every 4 weeks to 400mg/kg every 3 weeks. Most studies/opinions favour individual titration either to serum level of IgG (> 3.5g/L) or incidence of apparent infections.
2. Thrombocytopenias – Generally 400mg/kg for 2 days. If improvement occurs, treatment continues at same dose for a further 3 days.
3. Guillain Barre - 400mg/kg for 5 days, as with Myasthenia Gravis
4. Kawasaki Syndrome – 2g/kg as single dose, together with long term aspirin.

References
DISCUSS THE MANAGEMENT OF A PATIENT WITH AN ACUTE CORONARY SYNDROME

Dr. G. Joyce, Intensive Care Unit, John Hunter Hospital, New South Wales

Definition
Spectrum includes unstable angina, non Q wave infarction and Q wave infarction

Braunwald classification of Angina
• Severity
  1. Acute angina at rest
  2. Subacute angina at rest
  3. New onset of accelerated angina

• Context
  1. Presence of intercurrent disease
  2. MI < 2/52 ago

• ECG changes +/-

Risk stratification /Management strategies
• 80% patients presenting with unstable angina will stabilize in 48 hours with medical therapy
• After stabilization risk stratification is undertaken
• See "unstable angina strategy"²

Biochemical stratification:
• Troponin elevation predicts increased risk of death within six weeks
• CRP predicts increased risk
• Elevation of both represents higher risk than elevation of only one

ECG:
• New or reversible ST deviation of 0.5mm or more or LBBB on admission 2 x incidence death or MI at one year
• T inversion not a prognostic marker

Stress testing:
• Abnormal thallium uptake by lung associated with higher event rate
• Reversible or fixed perfusion defect associated with a higher event rate

Risk factors for failure of medical therapy:

• TIMI IIIB
  Reversible ST-depression
  History of angina
  Prior aspirin or heparin use
  Family history
  Old age
  None present failure < 38% , all present failure 90%
MEDICAL THERAPY

Aspirin
- Reduces risk of death > 50% in unstable angina

Ticlopidine
- Aspirin alternative in unstable angina 46% reduction in death and non fatal MI at 6/12
- Adjunct to aspirin post stenting

Clopidogrel
- Aspirin /Ticlopidine alternative similar efficacy favorable side effect profile

Platelet IIb/IIIa Antagonists
- Provide maximum inhibition of the final common pathway
- Three classes antibodies, peptides, non peptides
- Adjunct to coronary interventions combined with aspirin/heparin
- In unstable angina/non Q MI reduction in death/MI at 30d when combined with aspirin heparin. No mortality benefit demonstrated
- Optimal dosing and combinations not established

Unfractionated heparin
- 33% reduction MI/death with aspirin/heparin combination in Unstable angina (JAMA 1996)

Fractionated heparin
- Efficacy variable
- Varying anti Xa anti IIa ratios

Warfarin
- As effective as aspirin in prevention of MI/death
- Role of combination therapy inconclusive

Thrombolysis
- Increases mortality in non Q MI/unstable angina

Beta Blockade
- Undisputed benefit in MI
- Less data in unstable angina
- Meta analysis(Yusuf) 13% reduction in risk of MI

Nitrates
- Mortality benefit not demonstrated
- Symptomatic therapy

Calcium antagonists
- Increased mortality with nifedipine in non beta blocked patients
- Diltiazem/verapamil may improve outcome in patients with normal systolic function and no congestion
- Role in those with Beta B. contraindication or intolerance
REVASCULARIZATION
• Meta CABG/PTCA in moderate risk no prognostic difference BUT substantial increase in recurrence and re-intervention in PTCA
• PTCA in refractory unstable angina carries substantial risk
• Stenting has reduced a number of the PTCA risks
• Surgical v endo-vascular decision is based on multiple variables

OVERVIEW OF APPROACH TO ACUTE CORONARY SYNDROMES

1. Stratify risk based on history /presenting features
2. Medical therapy for initial stabilization
3. Develop investigation plan based on presentation and hospital course ( outpatient v inpatient investigation)
4. Long term treatment strategy based on 1. and 3. (medical/endovascular/surgical)

References
WHAT ARE THE DETERMINANTS OF CARDIAC INDEX? IN WHAT RANGE SHOULD IT BE KEPT IN CRITICALLY ILL PATIENTS AND WHY?

Dr. B. Graham. Intensive Care Unit, Royal Prince Alfred Hospital, New South Wales

CI = \( \frac{CO}{BSA} = \frac{SV \times HR}{(MAP - CVP) \times k} = \frac{(MAP - CVP) \times k}{(SVR \times BSA)} \times SVRI \)

HR: Determined by intrinsic rhythmicity (usually of SA node), sympathetic/parasympathetic balance, circulating chronotropic hormones/drugs.

Stroke Volume; Determined by preload (blood volume, intrathoracic pressure, body position, atrial contraction); afterload (Aortic valve, vascular distensability, SVR) and contractility. Ejection fraction is related to afterload and contractility.

BSA: (usually) constant in any one patient

Normal cardiac index is about 2.5 in infants, peaks during teens ~ 3-5, then slowly falls. It is 2.5-3.5 (L/min/m\(^2\)) in older adults. Values less than 2.0 are significantly abnormal.

Cardiac index may be increased or decreased during sepsis. Spontaneously increased C.I. is associated with improved prognosis in sepsis, and patients whose C.I. increases with fluid loading have a better prognosis than those whose CI does not improve, but other measures to elevate CI to supranormal levels (e.g. inotropes) have been unsuccessful at improving prognosis. Non-randomised studies provide evidence for the use of isotopes in low cardiac output states, and randomised controlled trials do not appear to have been performed. The use of IABP in cardiogenic shock secondary to AMI has shown trends towards improved survival, and is currently the subject of a controlled trial. In the absence of better data these results can be generalised to other causes of low cardiac output. Biochemical parameters are adjuncts in decision making. Base deficit and blood lactate most often move in parallel. Raised lactate is a strong predictor of poor prognosis, but is probably frequently not caused by anaerobic metabolism per se. If fluid resuscitation or inotropic support lead to a fall in blood lactate in a patient, then the intervention is likely to have been beneficial, and this is most likely to occur in patients who have low cardiac output increased to normal.

Shoemaker et al. proposed that \( O_2 \) consumption in critically ill patients is ‘supply dependent’ and that increasing delivery by increasing cardiac output by either fluid loading or inotropic support improves prognosis. They demonstrated that patients who achieved higher C.I. by venous manoeuvers had better prognosis than those who did not. This study was criticised on the basis that improvement in prognosis of the active arm of the study could be accounted for by improved prognosis of patients who respond to fluids, that the active interventions were merely physiological stressors which patients with better underlying prognosis were more likely to respond favorably to, and that inotropes would be expected to increase oxygen consumption per se and thus obscure the purported end point. Meta-analysis of studies aimed at improving outcome by raising CO to achieve some oxygen delivery target has not shown any improvement in outcome.

I provide cardiovascular support to septic patients with the following end points: urine OP > 0.5 mL/kg/hr and MAP > 65 mmHg. If these are not achieved with fluid, and if physical examination suggests that low cardiac output is likely to be a problem, then I use inotropes (or IABP) and PAC aiming for CI 2.5% and MAP of at least 65. If the patient is vasodilated and hypotensive with a high C.I. then I use vasoconstrictors aiming for a MAP of 65 (which would be expected to reduce the C.I. towards normal).
References
OUTLINE YOUR CLINICAL EXAMINATION OF THE CRANIAL NERVES IN THE UNCONSCIOUS PATIENT

Dr. P. Nair, Intensive Care Unit, St Vincent’s Hospital, New South Wales

INTRODUCTION
Clinical examination of the cranial nerves involves evaluation of the motor, sensory, special sensory (i.e. smell, taste, etc.) and reflex components of the individual nerves. In the unconscious patient, one largely has to rely on objective signs (e.g. pupillary size) and the reflex component. It is assumed that the patient has been neither sedated nor paralysed.

EVALUATION

First (olfactory) nerve
Cannot be assessed in the unconscious patient.

Second (optic), third (occulomotor), fourth (trochlear) and sixth (abducens) nerves
These three nerves need to be considered together, since the reflexes they control are interlinked.

1. Eyelids
   Ptosis is a feature of ipsilateral third nerve palsy, but must be distinguished from that due to Horner’s syndrome which is due to sympathetic involvement.

2. Pupils
   Anisocoria (unequal pupils)
   Normal pupillary size is 3-5mm.
   Unilaterally dilated pupil could signify ipsilateral third nerve palsy.
   Bilaterally dilated pupils could signify raised intracranial tension.
   A pupil which is small to start with and then begins to dilate may herald tentorial herniation (Hutchinson’s pupil).

3. Eyeball position
   In sixth nerve palsy the eyeball is deviated medially (due to the unopposed action of the third nerve) and fails to move even when eliciting the oculocephalic reflex, thus distinguishing itself from gaze paralysis due to frontal lobe lesions.

4. Menace Reflex
   Blinking in response to a threat may indicate that the visual pathways are intact, although blinking in response to a bright light may occur when the EEG is isoelectric.

5. Light Reflex
   Afferent is the second nerve and the efferent is the third nerve.
   Various abnormalities:
   a. Ipsilateral third nerve lesion-Direct reflex and ipsilateral consensual reflex lost but contralateral consensual reflex preserved.
   b. Ipsilateral second nerve lesion- Ipsilateral direct reflex and contralateral consensual reflex is lost but ipsilateral consensual reflex is preserved.
   c. Bilateral second nerve lesion- Bilateral direct and consensual reflexes are lost
   d. Bilateral Third nerve lesion- Bilateral direct and consensual reflexes are lost as seen in raised ICP or in midbrain lesions.
Fifth (trigeminal) and seventh (facial) nerves
Corneal and conjunctival reflexes - The fifth nerve is the afferent and the seventh nerve is the efferent with the centre in the pons.
Various abnormalities:
1. Ipsilateral fifth nerve lesion- absent ipsilateral direct reflex but preserved ipsilateral indirect reflex. Contralateral indirect reflex will be absent.
2. Ipsilateral seventh nerve lesion - Absent ipsilateral direct and indirect reflex but preserved contralateral indirect reflex.
3. Bilateral fifth nerve lesion - Bilateral absent direct and indirect corneal reflex
4. Bilateral seventh nerve lesion - Bilateral absent direct and indirect reflex.
Jaw Jerk - A preserved jaw jerk indicates integrity of the afferent and efferent component of the fifth nerve as well as that of the pons. An exaggerated jaw jerk is indicative of supranuclear lesion while a lesion in the pons may lead to its absence.
Facial grimace to pain applied in the distribution of the trigeminal nerve - While its presence is indicative of integrity of the 5th and 7th nerve its absence could occur in deep coma.

Eighth (vestibulocochlear) nerve
This nerve forms an important part of various brainstem reflexes.
Cold caloric test - Normally, nystagmus occurs, with the slow component towards the irrigated ear. As consciousness is lost, the fast component progressively disappears with the slow component carrying the eyes tonically towards the irrigated ear.
Canal paresis - If the semicircular canals or the 8th nerve are damaged, a defective response to both hot or cold water in the affected ear will be found.
Directional preponderance - The central connections of the vestibular nerve are such that cold water in one ear has the same effect as hot water in the other. If nystagmus cannot be induced on one side, the vestibular nucleus of that side is defective. This is known as directional preponderance.
Oculocephalic reflex - It has as its afferents the cervical and the vestibular nerves and via the medial longitudinal fasciculus, is connected to the third, fourth and the sixth nerves. The eyes move in the opposite direction to the head movement indicating intact brainstem connections, while in pathological situations, leads to roving movements of the eye.

Ninth (glossopharyngeal) and tenth (vagus) nerve
Together form an important component of the gag and cough reflexes.

Eleventh (accessory) and twelfth (hypoglossal) nerves
Cannot be tested in the unconscious patient.

Additional bedside tests - may help with clinical assessment of cranial nerves in the unconscious patient include evoked potentials i.e. Visual evoked response (Optic nerve) and Brainstem Auditory evoked response (Vestibulocochlear nerve).

References
DISCUSS THE ACUTE HAEMODYNAMIC EFFECTS OF INTRAVENOUS HYDROCORTISONE

Dr. D. Lam. Intensive Care Unit, Prince of Wales Hospital, Hong Kong

Glucocorticoids help maintain vascular tone and cardiac contractility. A deficiency of plasma cortisol (as in Addison’s disease) causes an increase in capillary permeability and inadequate vasomotor response to catecholamines. Most of the acute haemodynamic effects of hydrocortisone are described with stress doses 300 mg (c.f. physiological dose 30 mg) in septic patients.

Effects on systemic circulation
- increases systemic vascular resistance
- increases mean arterial blood pressure
- improves vasopressor responsiveness of peripheral vessels to catecholamines in the setting of pressor-dependent septic shock

Theories (exact mechanism unknown)
1. Overproduction of nitric oxide in sepsis causes an impaired vasopressor response in septic patients. Hydrocortisone inhibits the expression of inducible nitric oxide synthetase in vascular endothelial cells and hence restores the vasopressor responsiveness.
2. Desensitization and/or down regulation of β receptor may occur in sepsis. Administration of hydrocortisone restores the number of receptors.
3. Mineralocorticoid effect

Effects on pulmonary circulation
- responsiveness of pulmonary vessels not affected substantially

Effects on myocardial performance
- no change in heart rate
- little change in cardiac index (can increase or decrease)
- RVEF / RVEDV / LVSWI not changed

Effects on O2 transport and O2 consumption
- no change

References
DISCUSS THE MANAGEMENT OF A COCAINE BODY-PACKER WHO DEVELOPS
SYMPTOMS OF COCAINE TOXICITY

Dr. E. Connolly, Department of Critical Care Medicine, Flinders Medical Centre. SA

Cocaine body-packers are people who transport cocaine by concealing it in packages which are then swallowed or inserted per rectum, to be retrieved after the body-packer has cleared customs. Each can contain 2 - 15g of cocaine. Up to 200 such packages have been recovered from a single body-packer. The rupture of a single package may lead to massive fatal cocaine poisoning (median lethal dose in humans = 500mg cocaine) but the packages do not have to rupture to cause cocaine poisoning as the wrapping may serve as a semi-permeable membrane allowing cocaine to diffuse out.

As body-packers are rarely cocaine users themselves the development of symptoms and signs of cocaine toxicity is a suspected body-packer suggests wither rupture/leakage of a package or leaching of cocaine through an intact package semi-permeable wall.

There are two management goals in such a patient;
1. Removal of the packages as a matter of urgency. Further leaching or rupture will compound the problem.
2. Management of the cocaine toxicity that results in from the cocaine already absorbed from the GIT.

It will be necessary to confirm the presence and location of the intracorporeal packages, and if possible to determine the type of packages. Plain abdominal X-rays will quite often demonstrate multiple packages, however carry a significant false negative rate (2-33%). A CT scan of the abdomen is a more sensitive test and may be more helpful in suspected but unproven body-packers. (Contrast studies and USS have not been shown to be consistently reliable).

Urinalysis is a rapid sensitive test for cocaine absorption. There is a good correlation between the presence of cocaine or its metabolises in the urine and the presence of packages in the body. However it will not distinguish between contamination of the outside of the packages with cocaine and rupture or leaching of a package. Plasma levels of cocaine will be more sensitive. However in a patient with severe signs of cocaine toxicity, confirmation with plasma levels may take too long and will not necessarily change the emergency management of the patient.

Surgical removal of packages in all body-packers is no longer indicated, and most bodypackers are managed with purgation or occasionally emesis. Aggressive purgation is not indicated and may be dangerous as may purgation with mineral oils or paraffin as these may lead to rupture of the latex balloons or condoms. Surgical removal may be indicated depending on:

1. type of package:- McCarron type 1 packages are at high risk of rupture
2. location of packages
3. prolonged length of time since ingestion
4. evidence of bowel obstruction
5. evidence of cocaine poisoning (as in this case)
Endoscopic removal of packages is not recommended as it carries a high risk of perforation and leakage. Laparotomy with a single enterotomy is usually sufficient as the packages can be ‘milked’ to the site and manually removed. 3

**Cocaine Toxicity**

Effects of cocaine are via blockade of reuptake of central and peripheral nervous system adrenaline, noradrenaline, dopamine and serotonin. It may also stimulate presynaptic release of catecholamines and appears to enhance platelet aggregation, increase anticardiolipin antibody formation and possible release of endothelin.

Symptoms and signs include: agitation, diaphoresis, tachycardia, palpitations, hypertension, hyperthermia, disorientation, hallucinations, paranoid behaviour, cold peripheries and widely dilated pupils.

**Cardiovascular effects:** increased sympathetic stimulation, tachycardia and hypertension, increased cardiac output and vasospasm, may be complicated by myocardial ischaemia, infarction, cardiomyopathy and myocarditis, atrial and ventricular dysrhythmias.

**Central nervous system:** confusion, agitation, delirium to cerebral infarction, haemorrhage, seizures, decreased level of consciousness and coma.

**Renal complications:** ATN secondary to rhabdomyolysis - 2° to prolonged vasoconstriction of intramuscular arteries, direct myofilirillar degeneration, prolonged seizures or compartment syndrome.

**Gastrointestinal:** Acute haemorrhage → 2° to prolonged intense vasoconstriction, subsequent necrosis and ulceration. Also infarcted or perforated small or large bowel.

**Pulmonary:** Aspiration, cardiogenic and non cardiogenic pulmonary oedema

The management of cocaine toxicity is supportive and will depend on the severity of the symptoms and signs.

**Basic rules apply**

Airway
Breathing
Circulation

Depending on the amount absorbed some patients may require benzodiazepines and intravenous fluids to control their symptoms while others may be in full cardiovascular collapse, requiring aggressive haemodynamic monitoring and resuscitation including inotropic support.

**Investigations**
Radiological investigations and urinanalysis as above

ECU  
LFT’s  
CK, CKMB, Troponin T  
Coagulation screen  
Arterial blood gases  
ECG  
CXR  
Hepatitis/HIV screens  
Continuous ECG and invasive BP monitoring in an intensive care setting
Control of seizures with benzodiazepines, phenytoin and barbituates if required. Some patients may require intubation, ventilation to facilitate adequate doses of antiepileptic medications, and/or to control body temperature. Hyperpyrexia is a common complication and is severe may require aggressive control: heavy sedation, cold nasogastric, IDC lavage, CVVHD etc.

Hypertension may respond to sedation alone or may require further intervention. Medications used with reported success include phentolamine and phenoxybenzamine (alpha blockers). GTN has the added advantage of coronary vasodilation. Beta blockers have not been favored in the treatment of cocaine toxicity in the past as they were thought to allow unopposed alpha stimulation, thereby worsening hypertension and increasing coronary vasospasm. However recent studies have suggested that the use of cardioselective beta blockers, in conjunction with a multifactorial approach combined with peripheral vasodilators may be beneficial.

Atrial and ventricular arrhythmias may be managed with electrical cardioversion or with pharmacological therapy. Lignocaine should be used cautiously as 1) lignocaine is often found mixed as an impurity with cocaine, therefore a significant amount may already be absorbed, and 2) both lignocaine and cocaine have proarrhythmic and proconvulsant effects mediated through sodium-channel blockade. Calcium channel blockers may be useful to counteract the coronary vasospasm induced by cocaine. Associated ventricular arrhythmias may respond to sodium bicarbonate administration (NaHCO\textsubscript{3} has been shown to reverse cocaine induced QRS prolongation).

Myocardial infarction is not an uncommon complication of cocaine toxicity. ECG’s may be difficult to interpret. Primary angioplasty or thrombolitics may be indicated bearing in mind the increased risk of intracerebral hemorrhage associated with cocaine toxicity.\textsuperscript{6}

The definitive management of a known body-packer with symptoms of cocaine toxicity is the urgent removal of the packages via a laparotomy. Control of the effects of cocaine toxicity - CNS, cardiac etc. must be initiated as soon as they become obvious and will require a multifactorial approach to combat both central nervous system and peripheral effects, but the removal of the packages is a matter of urgency.

References
5. O Brien at al, Critical Care Medicine, 1999;27:784 - 789.
DISCUSS THE INDICATIONS AND COMPLICATIONS OF INTRAVENOUS ALBUMIN

Dr. A. Aziz. Intensive Care Unit, St George Hospital, New South Wales

Human albumin is a single polypeptide chain of 584 amino acids with a molecular weight of 66,248. (Compared with fibrinogen MW 340,000 and 1gG MW 150,000). In health, albumin synthesis = catabolism = 9-12 g/day. (No hepatic albumin stores).

Albumin distribution: Extravascular (skin, muscle, viscera) > intravascular albumin-mass. Extravascular (14g/L, 1l L) vs Intravascular (40g/L, 3L).

Serum albumin concentration is determined by many factors including; pre-existing malnutrition, dynamic equilibrium between albumin synthesis and catabolism, capillary membrane permeability and albumin loss (exudative, haemorrhage and renal or gut losses) or leakage into interstitial space, lymphatic function (re-circulation of albumin), Intravascular volume status and fluid shifts (Starling equation), type of fluid replacement (dilutional), disease states etc.

Currently albumin is prepared from pooled donor plasma by fractionation in ethanol, purification and then heat treatment at 60 degrees Celsius for 10 hours.

Commercially available are 4% and 25% normal serum human albumin

Albumin’s functions include.
1. Binding (4 Sites per molecule) and transport of free fatty acids, Bilirubin, Thyroxine, amino acids, Cortisol, trace metals (Cu. Ag, Hg ), ions (Ca) and Drugs (Aspirin, Frusemide, Phenothiazines, Benzodiazepines, Warfarin, Phenytoin, NSIADS, etc.)
2. Colloid Osmotic Pressure effect: Albumin is 1/2 the intravascular protein mass, 3/4 of the total numbers of protein molecules and exerts 75-80 % of plasma colloid osmotic pressure.
3. Free Radical Scavenging: Albumin is the major extravascular source of Thiols (Reduced sulphhydryl groups = Scavengers of reactive oxygen and nitrogen spp.) significance ??
4. Anticoagulant effect: Albumin binds nitric oxide, inhibiting its rapid inactivation → prolonged anti-aggregatory platelet effects. Role as priming fluid for CPB circuit ??
5. Capillary membrane permeability: Increased vascular permeability with low serum albumin concentration. The increased vascular permeability is not reversed with albumin replacement in settings of low serum albumin. Albumin infusions can increase capillary permeability.

The many useful physiological properties of albumin make a rapid return to normal serum albumin level appear desirable. The rational for treating low serum albumin include restoration of the colloid osmotic pressure, reduction of interstitial oedema, restoration of intravascular volume, unproved organ perfusion/function and improved outcome. However, the studies have failed to consistently show any significant differences in outcomes

The normal half life of albumin is ~ 20 days. In patients with normal vascular permeability it takes 7-10 days for exogenous albumin to equilibrate with the extravascular pool. Only a temporary beneficial effect on colloid osmotic pressure and reduction in peripheral oedema with albumin administration is observed. (As the administered albumin escapes from the capillary into the interstitium, and if it is unable to be cleared by the lymphatics, it will retain additional fluid, leading to further oedema.) In septic patients, up to 2/3 of the administered albumin will have crossed into the interstitium after 4 hours! (The benefits of administering albumin are at best transient and with lymphatic dysfunction, may worsen oedema.)
Decreased serum albumin concentration is a non-specific finding commonly associated with disease states.

Albumin is a “negative acute phase protein” (compared with other acute phase proteins eg: fibrinogen C-reactive protein etc.). During acute phase response liver dramatically increases synthesis of acute phase proteins and albumin synthesis is reduced. Acutely, low albumin concentration caused by increased vascular permeability and re-distribution of albumin (Intravasc. → Interstitial), dilutional effects of fluid therapy and albumin loss haemorrhage, exudation etc.

Various relatively small studies of albumin supplementation in patient sub-groups and diseases have failed to consistently demonstrate a clear improvement in patient outcome (length of stay, mortality etc.). Earlier studies on hypoalbuminaemic post-op patients treated with albumin supplementation (to serum albumin level > 25 g/L) showed a trend towards longer ICU stay, longer ventilatory requirements and longer hospital stay compared with patients not given targeted albumin supplementation. (these albumin effects on pulmonary function have not been consistently confirmed by other studies. In some studies, patients received large doses of albumin over 24-48 hours, representing gross fluid challenge requiring diuretics, digoxin, prolonged ventilatory support and delayed weaning etc.)

In patients with cirrhosis and spontaneous bacterial peritonitis, treatment with intravenous albumin in addition to an antibiotic reduced the incidence of renal failure and mortality, compared with treatment with antibiotic alone. (Study did not compare other synthetic colloids or isotonic crystalloids with albumin ). Also studies comparing albumin with other colloids and crystalloids have failed to consistently show any advantage with albumin in patient outcome. Two recent meta-analysis of studies comparing albumin or synthetic colloids with crystalloids showed conflicting results ranging from no difference in pulmonary oedema mortality, or length of stay between isotonic crystalloids and colloid resuscitation (But crystalloid resuscitation associated with lower mortality in trauma patients), to increased mortality in critically ill patients treated with albumin. Another meta-analysis concluded that the combination of hypertonic saline with dextran 70 may be more elective than isotonic crystalloids in trauma resuscitation with respect to survival. Large well designed randomised trials are needed to achieve sufficient power to detect small differences in treatment effects and to formulate evidence based guidelines for albumin use.

Newer synthetic colloids e.g. hydroxyethyl starch (high molecular weight hetastarch) are larger molecules and hopefully do not leak into the extravascular space. (Hetastarch also reduces platelet aggregation, prolongs bleeding time and decreases Factor VIII levels)

Low pre-op serum albumin concentration and persistently low albumin concentration associated with increased morbidity and mortality especially in critically ill patients. Serum albumin is included as a prognostic indicator in APACHE 3 illness severity scoring systems (Surgical patients with serum albumin < 25 g/L have a 4 fold increase in complications and a 6 fold increase in mortality compared with patients with nominal serum albumin).

In illness, albumin concentration is not a predictor of nutritional status. In adults, low serum albumin concentration is a consequence of disease (and inversely proportional to illness severity) and successful treatment of underlying disease should result in gradual normalisation of serum albumin concentration. Maintenance of adequate nutrition (enteral or parenteral nutrition) in critically ill patients is associated with an improved outcome. (In congenital Analbuminaemia, only half the patients have oedema and they have no other adverse effects from lack of albumin)
Indications for intravenous albumin

There are currently no research based absolute indications for intravenous albumin administration in critically ill patients. The following list is based on current clinical experience and practice and represents only relative indications for intravenous albumin administration. (There is controversy regarding the recent meta-analysis and indications for albumin use)

- Intravenous albumin during ascites drainage/paracentesis, (role in large exudate pleural effusion drainage) to maintain intravascular volume and organ perfusion.
- Chronic liver disease/cirrhosis with ascites complicated by spontaneous bacterial peritonitis patients when treated with intravenous albumin in addition to antibiotics had a reduction in incidence of renal failure and death.
- Intravenous albumin as replacements fluid in therapeutic plasma exchange. Albumin has similar efficacy as fresh frozen plasma but with fewer side effects and infection transmission risk. (May require Calcium supplementation with albumin replacement fluid)
- Patients with protein losing enteropathies and associated hypoalbuminaemia and oedema (Also patients with ascitic drainage from surgical drains post-op)
- Clinical situation in which critically ill patients have a triad of hypoalbuminaemia, oedema and hypovolaemia requiring fluid resuscitation - Role of intravenous 20% albumin.
- Resuscitation of critically ill patients with large exudative losses from increased capillary membrane permeability (e.g. burns, sepsis, anaphylaxis etc.) and who are not anaemic or coagulopathic, and a colloid with a longer half life is required.
- Critically ill patients with hypoalbuminaemia and associated oedema given a combination of 20% albumin and diuretic in an attempt to mobilise interstitial oedema fluid into intravascular space.
- Situations where resuscitation with a colloid (with a longer half-life) is required and the patient is not anaemic.(eg, post-op patients, HHH therapy in management of cerebral vasospasm associated with subarachnoid haemorrhage.) Or in elderly patients who are at risk of pulmonary/interstitial oedema if given crystalloids in large volumes for intravascular volume expansion, when similar intravascular results may be achieved with smaller colloid volume and albumin used for its relatively longer half life.
- Albumin as pump priming solution for cardiopulmonary bypass may be indicated for patients with poor LV function, repeat surgery, or in combination with RBC for anaemic patients.
- Current studies support use of crystalloids or combination of hypertonic saline and dextran 70 in trauma patients.
- Use of intravenous albumin for correction of hypoalbuminaemia in ARDS patients is associated with prolonged mechanical ventilation and ICU stay
- The presumed advantages of albumin over other synthetic colloids need to be weighed against the increased cost and limited resources of albumin.

Complications of intravenous albumin

- Albumin is dangerous in overdose (as are other intravenous fluids!) and it cannot cure conditions characterised by hypoalbuminaemia. Fewer complications occur with selective use of albumin and careful titration to achieve desired intravascular volume expansion.
- Patients with increased capillary permeability + lymphatic dysfunction have a short intravascular half life of albumin which leaks into the interstitial space → reduced intravascular colloid oncotic pressure → pulmonary interstitial oedema (often persistent and requiring prolonged mechanical ventilation, especially in ARDS) → Hypoxia Also, the increased interstitial albumin concentration promotes further interstitial oedema formation and delayed resolution of the oedema in the recovery from the illness. (albumin infusion can also increase capillary membrane permeability)
- Similarly, overtransfusion of albumin → hypervolaemia (especially in the auric patients) → congestive cardiac failure → acute pulmonary oedema → hypoxia.
- Risk of transmission of infectious diseases. HBV, HCV and HIV are heat labile and the pasteurisation prevents their transmission via albumin. Parvovirus and HAV (non-enveloped) are relatively heat resistant. (PCR - detectable parvovirus DNA in 3/12 batches of albumin from 3 different manufacturers, ?? infectious status of this material) Also, concerns exist about the possibility for transmission of CJD, but no evidence so far. Of the fractionated plasma products, albumin probably has the lowest chance of transmitting the infectious agents responsible for CJD. Recombinant albumin production in future will eliminate this risk.
- Albumin inhibits platelet aggregation and enhances anti-thrombin 3 inhibition of factor 10a. This anticoagulant property may be detrimental in haemorrhagic shock. Other alternative synthetic colloids also affect haemostasis. (Hetastarch reduce platelet aggregation, prolongs bleeding time and decreases Factor VIII levels), (Gelatin based plasma substitutes e.g. Gelofusine can impair primary haemostasis via reduced von Willebrand Factor and thrombin generation), (Dextran may lower factor VIII levels and prolongs bleeding time.)
- Albumin may cause hypotension (caused by vasoactive peptides) however, other synthetic colloids may also cause hypotension (e.g. anaphylaxis)
- Albumin may increase the progression of renal failure (especially in nephrotic syndrome) Other synthetic colloids can affect renal function acutely
- Risk of Hypocalcaemia if frequent plasmapheresis and replacement solution is albumin and no supplemental calcium given (also risk of aluminium toxicity with large volume albumin infusion.)
- Albumin requires refrigeration and large volume rapid infusion, without fluid warming, may cause or contribute to hypothennia post-op → coagulopathy etc.

References

INDEX

Accessory muscles of inspiration, 13
Adult respiratory distress syndrome. See ARDS
Airway closure, 17
Airway trauma, 34
Albumin, 105
Alveolar area, 1
Alveolar epithelial cells, 5
Alveolar gas equation, 48
Alveolar opacification, 26
Alveolar proteinosis, 51
Alveolar ventilation, 16
Alveolus, 5
immune function cells, 5
type I cells, 5
type II cells, 5
Aminophylline
intravenous, 59
Antithrombin agents, 80
Apneustic centre, 12
ARDS, 20, 33, 34, 39
Asbestosis, 33
Asthma
fulminant, 88
Base excess
measurement of, 41
Bicarbonate
measurement of, 41
Blood gas measurements, 40
Blood sample collection, 40
Body oxygen store, 15
Bohr's method, 47
Breathing
control of, 11
Bronchial circulation, 6
Bronchial obstruction, 51
Bronchioles
structure, 2
Bronchoalveolar lavage, 51
Bronchoscopy
fibre-optic, 51
Bronchus
left main
branches of, 2
right main
branches of, 1
Carbamino compounds, 45
Carbon dioxide
dissolved, 45
Carbon dioxide concentration
measurement of, 45
Carbon dioxide content, 44
Carbon monoxide
diffusion of, 46
Carboxyhaemoglobin, 42, 43
Cardiac arrest, 68
Cardiac index
determinants of, 97
Carotid body
chemoreceptors, 11
Central chemoreceptors, 11
Cerebrospinal fluid
pH, 11
Chest trauma, 34
Chest X-ray, 23
artefacts, 24
cardiac and mediastinal shadows, 25
collapse, 26
consolidation, 26
lung fields, 25
silhouette sign, 28
technical aspects of, 24
Chronic obstructive pulmonary disease. See COPD
Clark electrode, 41
Cocaine toxicity, 102
Compliance, 50
change of, 17
dynamic, 50
static, 50
COPD, 39
Coronary syndrome
acute, 94
Cranial nerves
examination of, 99
Dead space
anatomic, 16
physiologic, 16, 47, 49
Dead space ventilation, 16
Deoxyhaemoglobin, 42
Diaphragm, 12, 30
rupture, 34
Diffusion, 17
Diffusion tests, 46
Dipalmitoyl phosphatidylcholine, 6
Dissecting aortic aneurysm, 65
Double lumen tubes, 51
Doxapram, 12
End-expired PCO₂, 45
Epiglottitis
  adult, 82
Expiration, 13
Expiratory reserve volume, 13
External intercostal muscles, 13
Extra alveolar vessels, 4
FEV₁, 39
Fibrotic lung disease, 39
Flow volume curve, 40
Foramen ovale, 20
Forced expiratory volume tests, 38
Forced vital capacity, 38. See FVC
Functional residual capacity, 13
Functional volumes, 16
FVC, 39
Gas exchanging airways, 4
Gas volumes, 14
Gram molecular weight of an ideal gas, 14
Haemoglobin oxygen saturation, 42
Haemothorax
  loculated, 78
Helium dilution, 37
Human immune globulin
  intravenous, 91
Hydrocortisone
  haemodynamic effects of, 101
Hypokalaemia, 62
Hypoxia, 20
Ideal alveolar gas tension, 49
Inspiration, 12
Inspiratory capacity, 13
Inspiratory reserve volume, 13
Interstitial opacification, 28
Interstitial pulmonary emphysema, 34
Intrapericardial pressures, 19
Intrapulmonary shunt, 46, 49
Kerley lines, 28
  A, 30
  B, 30
  C, 30
Larynx
  function of, 1
Left ventricular afterload, 19
Left ventricular failure, 19
Left ventricular preload, 19
Lung
  anatomy of, 1
  conducting airways, 1
Lung diseases
  fibrotic, 33
  inflammatory, 32
  obstructive, 32
Lung receptors
  irritant, 12
  J (juxtacapillary), 12
  stretch, 12
Lung volumes, 13
Maximal mid-expiratory flow rate, 39
Maximum voluntary ventilation. See MVV
Mechanics of breathing, 50
Methaemoglobin, 42, 43
Mixed venous haemoglobin oxygen saturation, 44
Müller’s manoeuvre, 19
MVV, 40
N-acetylcysteine, 51
Nonadrenergic, noncholinergic nervous system, 3
Obstructive pulmonary diseases, 32
Oxygen concentration measurement of, 45
Oxygen consumption, 50
Oxyhaemoglobin, 42
Oxyhaemoglobin fraction, 42
Paradoxical movement, 13
Paraquat poisoning, 71, 75
PCO₂ measurement of, 40
Peak expiratory flow rate. See PEF
PEEP, 20, 50
PEF, 39
pH measurement of, 41
Phrenic nerve, 12
Physiological dead space, 18, 46
Physiological shunt, 18
Pleura
  function of, 7
Pleural effusion, 7
Pleural exudate, 7
causes of, 8
Pleural fluid, 31
  adenosine deamidase, 8
  biochemistry of, 8
  cholesterol, 8
  LDH, 8
  pH, 8
  protein, 8
  serum protein ratio, 8
Pleural transudate, 7
  causes of, 7
Pneumomediastinum, 34
Pneumopericardium, 34
Pneumotachograph, 37
Pneumotaxic centre, 12
Pneumothorax, 32, 34
PO$_2$
  measurement of, 40
Positive end-expiratory pressure. See PEEP
Preoxygenation, 15
Pulmonary artery pressure
  transmural, 19
Pulmonary blood vessels, 5
Pulmonary capillary area, 1
Pulmonary contusion, 34
Pulmonary end-capillary oxygen tension, 49
Pulmonary hypertension, 20
Pulmonary infiltrates
  diagnosis of, 51
Pulmonary infiltrative disorders, 51
Pulmonary lymphatics, 5
Pulmonary oedema, 34
  cardiogenic, 20, 33
  noncardiogenic, 33
  unilateral, 33
Pulmonary perfusion, 17
  regional differences of, 18
Pulmonary vessels, 17
Pulse oximeter, 42
  accuracy of, 43
Recruitment, 18
Residual volume, 13, 37
Respiratory centre, 12
Respiratory failure, 41
  type I, 41
  type II, 41
Respiratory function tests, 37
Ribs
  fractures of, 34
Right ventricular afterload, 19
Right ventricular end diastolic pressure, 19
Right ventricular preload, 19
R-L cardiac shunt, 20
Sarcoidosis, 33
Sepsis
  regional oxygen requirement, 44
  Septal opacifications, 28
Shunt
  intrapulmonary, 49
Silicosis, 33
Spirometer
  mechanical, 37
  rolling-seal, 38
  Wright, 37
Spirometry, 37
Spontaneous ventilation, 19
Standard temperature pressure dry (STPD), 14
Subcutaneous emphysema, 34
Sulphaemoglobin, 42
Surfactant, 6
  function of, 6
Terminal respiratory unit, 4
Thoracentesis, 7
Thoracic pump, 19
Tidal volume, 13
Timed forced expiratory volume, 38
Total lung capacity, 13
Trachea
  anatomy of, 1
Transbronchial biopsy, 51
Transcutaneous gas tension measurement, 42
Transcutaneous PCO$_2$, 42
Transcutaneous PO$_2$, 42
Transmural pressure, 19
Valsalva manoeuvre, 19
Ventilation, 13
  haemodynamic effects of, 18
  positive pressure, 19
Ventilation-perfusion, 18
Ventilation-perfusion tests, 46
Ventilator associated pneumonia, 86
Ventilatory defects, 39
  obstructive, 39
  restrictive, 39
<table>
<thead>
<tr>
<th>Ventilatory tests, 37</th>
<th>Work of breathing, 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital capacity, 13</td>
<td>Wright respirometer, 37</td>
</tr>
<tr>
<td>West zones, 18</td>
<td></td>
</tr>
</tbody>
</table>