Introduction and overview

Mike Clancy, Jerry Nolan and Jonathan Benger

Objective
The objective of this chapter is:

- to understand the purpose and scope of this manual.

Introduction
Effective airway management is central to the care of critically ill and injured patients. Competency in assessment and maintenance of the airway using basic airway manoeuvres first, followed by advanced skills such as rapid sequence induction of anaesthesia and tracheal intubation, are core skills for doctors who treat seriously ill or potentially ill patients. In the UK, this typically involves the specialties of:

- anaesthesia
- emergency medicine
- intensive care medicine
- acute medicine.

The location for emergency airway management is usually outside the relatively controlled environment of an anaesthetic room, most commonly in the resuscitation room of an emergency department, but sometimes in a variety of other in-hospital and pre-hospital settings. Emergency airway management can be difficult and challenging: it requires individuals to work in relatively unfamiliar environments under conditions of stress and uncertainty, and where the principles of elective anaesthesia need modification. Information is often incomplete, normal physiology deranged, and opportunity for delay is infrequent. The problems intrinsic to these patients, such as an unstable cervical spine, poor cardiorespiratory reserve or profound metabolic dysfunction, must be anticipated and surmounted.

Emergency airway management is not simply an extension of elective anaesthesia, and specific training is essential to safely treat this challenging and heterogeneous group of patients. Individuals must practice within the limits of their own competence and work collaboratively with experienced clinicians from several disciplines to ensure patients receive optimal care (Figure 1.1).

Skills and judgement, as well as knowledge, are essential for treating patients who require emergency airway intervention. Careful judgement is required to determine whether an intervention is appropriate, how and when it should be undertaken, and what additional personnel and equipment are needed.

Central to emergency airway management is the recognition of:
1 the fundamental importance of basic airways skills
2 the need for close collaboration with those who are already competent to enable effective clinical training. It is essential to work alongside practitioners who have established expertise in emergency airway care in order to build upon and apply theoretical learning. A clinician working alone should not attempt emergency airway interventions that are outside the limits of their own competence.

Audit and skills maintenance
Audit and peer review of clinical practice must be undertaken continuously to ensure standards are maintained. Further information can be found in Chapter 14. Medical simulators are becoming more sophisticated, and will have an increasing role in skill retention and assessment.

Summary
- This manual will not provide competence in emergency airway management, but offers a firm foundation upon which further training and assessment can be based.
- Effective emergency airway management requires commitment to a process of ongoing training, assessment, skill maintenance and audit that will last throughout the practitioner’s professional career.

Figure 1.1 A collaborative approach ensures the best patient care.
Objectives
The objectives of this chapter are to:
- understand the causes of hypoxaemia
- be familiar with devices available to increase the inspired oxygen concentration
- understand the function and use of the self-inflating bag-mask
- understand the function and use of the Mapleson C breathing system
- understand how to monitor oxygenation
- understand the principle of pre-oxygenation.

Causes of hypoxaemia
The strict definition of hypoxaemia is a partial pressure of oxygen in the arterial blood (PaO₂) below normal; however, a value of <8kPa or 60mmHg (equivalent to an arterial oxygen saturation of approximately 90%) is often used to define hypoxaemia requiring treatment. In nearly all patients hypoxaemia can usually be improved, at least initially, by increasing the inspired oxygen concentration.

Although the cause of hypoxaemia is usually multifactorial, there are several distinct mechanisms:
- alveolar hypoventilation
- mismatch between ventilation and perfusion within the lungs
- pulmonary diffusion defects
- reduced inspired oxygen concentration.

Alveolar hypoventilation
Insufficient oxygen enters the alveoli to replace that taken up by the blood. Both the alveolar partial pressure of oxygen PaO₂ and arterial partial pressure of oxygen (PaO₂) decrease. In most patients, increasing the inspired oxygen concentration will restore alveolar and arterial PO₂. When an adult's tidal volume decreases below approximately 150ml there is no ventilation of the alveoli, only the ‘dead space’, which is the volume of the airways that plays no part in gas exchange. No oxygen reaches the alveoli, irrespective of the inspired concentration, and profound hypoxaemia will follow. At this point ventilatory support and supplementary oxygen will be required. Hypoventilation is always accompanied by hypercapnia, as there is an inverse relationship between arterial partial pressure of carbon dioxide (PaCO₂) and alveolar ventilation.
Common causes of hypoventilation are as follows.

Airway obstruction:
- tongue
- blood
- vomit
- bronchospasm
- oedema (infection, burns, allergy).

Central respiratory depression:
- drugs
- alcohol
- central nervous system injury (cerebrovascular event, trauma, etc.)
- hypothermia.

Impaired mechanics of ventilation:
- pain
- pneumothorax
- haemothorax
- pulmonary oedema
- diaphragmatic splinting
- pre-existing lung disease.

Mismatch between ventilation and perfusion within the lungs

Normally, ventilation of the alveoli (V) and perfusion with blood (Q) are well matched (V/Q = 1), ensuring that haemoglobin in blood leaving the lungs is saturated with oxygen (Figure 2.1). If this process is disturbed (V/Q mismatch) regions develop where:

1. perfusion exceeds ventilation (V/Q < 1), resulting in haemoglobin with reduced oxygen content, e.g. pneumothorax, pneumonia
2. ventilation exceeds perfusion (V/Q > 1). This can be considered wasted ventilation as very little additional oxygen is taken up when haemoglobin is already almost fully saturated (98%), e.g. hypotension.

At its most extreme, some regions of the lung may be perfused but not ventilated (V/Q = 0): blood leaving these areas remains ‘venous’, and is often referred to as shunted blood. This is then mixed with oxygenated blood leaving ventilated regions of the lungs. The final oxygen content of blood leaving the lungs is dependent on the relative proportions of blood from these two regions:
- blood perfusing ventilated alveoli has an oxygen content of approximately 20ml/100ml blood (assuming a haemoglobin concentration of 15g dl⁻¹)
- blood perfusing unventilated alveoli remains ‘venous’, with an oxygen content of 15ml/100ml blood.

The effect of small regions of V/Q mismatch can be corrected by increasing the inspired oxygen concentration; however, once more than 30% of the pulmonary blood flow passes through regions where V/Q < 1 hypoxaemia is inevitable, even when breathing 100% oxygen. This is because the oxygen content of the pulmonary

2 Delivery of oxygen

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blood flowing through regions ventilated with 100% oxygen will increase by only 1ml/100ml blood (to produce 21ml of oxygen per 100ml blood), and this is insufficient to offset regions of low V/Q, where the oxygen content will be only 15ml/100ml blood.

For an equivalent blood flow, regions of $V/Q < 1$ decrease blood oxygen content more than increasing the alveolar oxygen concentration in regions of $V/Q > 1$.

### Pulmonary diffusion defects
Any chronic condition causing thickening of the alveolar membrane, e.g. fibrosing alveolitis, impairs transfer of oxygen into the blood. This is treated first by
giving supplementary oxygen to increase the $\text{PaO}_2$ partial pressure of oxygen in the alveoli, and then treating the underlying problem.

**A reduced inspired oxygen concentration**

As the inspired oxygen concentration is a prime determinant of the amount of oxygen in the alveoli, reducing this will lead to hypoxaemia. At ambient pressure there are no circumstances where it is appropriate to administer less than 21% oxygen.

**Devices used for delivery of oxygen**

**Spontaneous ventilation**

*Variable-performance devices: masks or nasal cannulae* These are adequate for the majority of hypoxaemic patients. The precise concentration of oxygen inspired by the patient is unknown, as it depends on the patient’s respiratory pattern and the oxygen flow (usually 2–15 l min$^{-1}$). When breathing through a mask the inspired gas consists of a mixture of:

- oxygen flowing into the mask
- oxygen that has accumulated under the mask during the expiratory pause
- alveolar gas exhaled during the previous breath that has collected under the mask
- air entrained during inspiration from the holes in the side of the mask and from leaks between the mask and face.

Examples of this type of device are Hudson and Mary Caterall (MC) masks (Figure 2.2). As a guide, they increase the inspired oxygen concentration to 25–60% with oxygen flows of 2–15 l min$^{-1}$.

Patients unable to tolerate a facemask, but who can nose breathe, may find either a single foam tipped catheter or double catheters, placed just inside the vestibule of the nose, more comfortable (Figure 2.3). Lower flows of oxygen are used: 2–4 l min$^{-1}$ increases the inspired oxygen concentration to 25–40%.

If higher inspired oxygen concentrations are needed in a spontaneously breathing patient, a Hudson mask with a reservoir (non-rebreathing bag) can be used (Figure 2.4). A one-way valve diverts the oxygen flow into the reservoir during expiration. During inspiration, the contents of the reservoir, along with the high flow of oxygen (12–15 l min$^{-1}$), ensure minimal entrainment of air, raising the inspired concentration to approximately 80%, providing that the reservoir bag inflates and deflates with each breath. This requires a well-fitting, functioning mask and reservoir, and is often overlooked in clinical practice. An inspired oxygen concentration of 100% can be achieved only by using a close-fitting facemask with an anaesthetic breathing system, combined with an oxygen flow of 12–15 l min$^{-1}$ (see below).

*Fixed-performance devices* These are used when it is important to deliver a precise concentration of oxygen, unaffected by the patient’s ventilatory pattern. These devices work on the principle of high-airflow oxygen enrichment (HAFOE). Oxygen is delivered to a Venturi that entrains a much greater, but constant, flow of air (Figure 2.5). The total flow into the mask may be as high as 45 l min$^{-1}$. The high
2 Delivery of oxygen

Figure 2.2 Hudson mask.

Figure 2.3 Nasal cannulae.
2 Delivery of oxygen

Table 2.1. Effect of type of Venturi valve and oxygen flow on inspired oxygen concentration

<table>
<thead>
<tr>
<th>Venturi valve colour</th>
<th>Oxygen flow rate (litres min$^{-1}$)</th>
<th>Inspired oxygen concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>White</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Yellow</td>
<td>6</td>
<td>35</td>
</tr>
<tr>
<td>Red</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Green</td>
<td>12</td>
<td>60</td>
</tr>
</tbody>
</table>
gas flow has two effects: it exceeds the patient’s peak inspiratory flow, reducing entrainment of air, and flushes expiratory gas, reducing rebreathing.

These devices deliver a fixed concentration for a given flow, and there are several interchangeable Venturis to vary the oxygen concentration (Table 2.1).

The above systems all deliver dry gas to the patient, which may cause crusting or thickening of secretions, difficulty with clearance, and patient discomfort. For prolonged use, a HAFOE system should be used with a humidifier.

Assisted ventilation
Patients whose ventilation is inadequate to maintain oxygenation despite an increase in the inspired oxygen concentration using one of the devices described above, or who are apnoeic, will require oxygenation using a mechanical device. The simplest and most widely used device is the bag-mask (Figure 2.6). An alternative is an anaesthetic breathing system (Figures 2.9 and 2.10).

In selected patients improved oxygenation, as well as ventilatory assistance, can be achieved using either continuous positive airway pressure (CPAP) or bi-level positive airway pressure (BiPAP). These forms of non-invasive ventilatory support are described in Chapter 12.

The bag-mask device In its simplest form this consists of a self-inflating bag: when squeezed, the contents are delivered to the patient via a non-return
valve and facemask. On release, the bag entrains air as it returns to its original shape. Expired air from the patient is prevented from reaching the bag by a one-way valve. In this manner, the patient’s lungs are ventilated with air (21% oxygen). The use of modern, clear plastic facemasks has several advantages over traditional opaque masks: regurgitated stomach contents can be seen sooner, ‘fogging’ of the plastic during exhalation indicates that gas (oxygen) is going into and out of the lungs, and the masks are disposable, reducing the risk of cross-infection.

The oxygen concentration in the gas delivered from the bag can be increased in two ways:

1. By connecting a high flow of oxygen (10–15 l min\(^{-1}\)) to an inlet port, usually adjacent to the air entrainment valve at the opposite end of the bag to the mask. In this way, when the bag refills, it does so with a mixture of air and oxygen. The oxygen concentration delivered to the patient will depend upon several factors including oxygen flow, rate of ventilation and volume delivered. In the average adult, the concentration is unlikely to exceed 50% (Figure 2.7).

2. In addition to the above, a reservoir can be attached over the air entrainment valve. As the bag is squeezed to ventilate the patient’s lungs, the oxygen flow is diverted and accumulates within the reservoir. As the bag is released it refills from the contents of the reservoir and the oxygen flow, thereby virtually eliminating air entrainment. In this manner, providing the oxygen flow exceeds the minute ventilation of the lungs, close to 100% oxygen can be delivered (Figure 2.8).

Oxygen delivery with this device in any configuration is dependent on:

1. The practitioner being able to maintain a good seal between the facemask and the patient’s face, so that there is minimal escape of gas around the mask when the bag is squeezed. This is best achieved by using a two-person technique: one holds the facemask with both hands, while the other squeezes the bag.

2. Not using high pressures to ventilate the patient’s lungs. High pressures will force gas down the oesophagus and into the stomach. This will reduce ventilation of the lungs and predispose to regurgitation and aspiration.

The commonest reason for requiring high pressures to ventilate the patient’s lungs is failure to maintain a patent airway. This is commonly caused by:

1. Poor airway control: this can often be overcome by using a two-person technique.

2. Foreign material in the airway, e.g. vomit, blood: this must be removed using a safe and effective suction technique.

Although a patient can breathe oxygen spontaneously from a bag-mask device, this is sub-optimal because effort is needed to overcome the resistance to inspiratory and expiratory flow. Spontaneously breathing patients should be given oxygen using one of the devices described above, or via an anaesthetic breathing system.