ACUTE OXYGEN TREATMENT

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Table 1 - Key to terms used

PaO_2	Tension or level of arterial oxygen
Bar	Unit of pressure, approximately 1 atmosphere (760mmHg or 101kPa)
kPa	Kilopascals = 1000 Pascals, a unit of pressure (7.5mmHg = 1 kPa)
Minute ventilation	The volume of gas breathed per minute
Peak Inspiratory Flow Rate	Maximum rate of air flow when breathing in (inspiratory breath)
< >	< = less than ; > = greater than

Introduction

Oxygen has been used in clinical practice for more than 200 years. It is probably the most widely prescribed medication in pre-hospital and hospital environments. If appropriately used it is life-saving and part of first-line treatment in many critical conditions. It is important that oxygen not only reaches the lungs but is delivered to the tissues. Therefore a good cardiac output, circulation and haemoglobin is vital and is why attention to the circulation is an early part of initial resuscitation (*The physiology of oxygen delivery, Update in Anaesthesia 1999; 10:8-14*). As with any drug, oxygen should be used when indicated, in appropriate dosage (concentration), and correctly administered for a planned duration.

OXYGEN MANUFACTURE AND STORAGE

When cooled to very low temperatures gases change to either solids, (carbon dioxide), or liquids (oxygen and nitrogen). Oxygen has to be cooled to below -118°C to change to a liquid. When the gas changes form to a liquid, it occupies a much smaller volume. Therefore when a small volume of liquid oxygen is warmed it will make a very large volume of oxygen gas. Oxygen can be stored as either a gas in cylinders or as a liquid in a special container. In the liquid form, a very large quantity of oxygen can be transported or stored in a low volume, although there are problems in keeping the liquid cold as explained below.

Vacuum Insulated Evaporator (VIE). A VIE is a container designed to store liquid oxygen. It has to be designed to allow the liquid oxygen inside to remain very cold. It consists of two layers, where the outer carbon steel shell is separated by a vacuum from an inner stainless steel shell, which contains the oxygen (figure 1). The oxygen temperature inside is about -170°C and the container is pressurised to 10.5 atmospheres (10.5 bar). Gaseous oxygen above the liquid is passed through the superheater to raise the temperature to ambient (outside) levels. It then flows into the hospital pipeline system giving a continuous supply of piped oxygen to outlets on the wards and in theatre. Heat is always able to get into the container and provides the energy to evaporate the liquid oxygen, changing it into oxygen gas which is continuously drawn off into the pipeline system. This escape of gas into the pipeline system prevents the pressure inside the container from rising. If the pressure rises too much (above 17 bar), oxygen is allowed to escape via a safety valve into the atmosphere.

In contrast, if the pressure inside the container falls because of heavy demand in the hospital for oxygen, liquid oxygen can be withdrawn, passed through the evaporator and returned to the VIE in the gaseous form to restore the pressure. The amount of oxygen available in the container is estimated by weighing the container with an in-built device.

The VIE system is used in large hospitals which have a pipeline system, and where liquid oxygen can be supplied by road tanker.

Oxygen cylinders. Oxygen can be stored under pressure in cylinders made of molybdenum steel. Cylinders may be

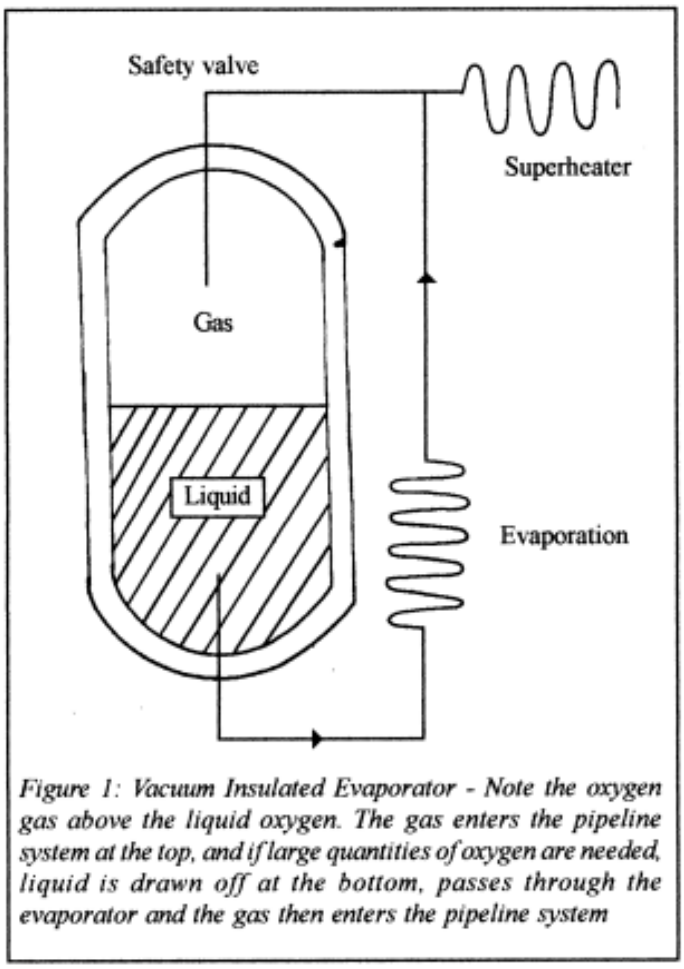

Figure 1: Vacuum Insulated Evaporator - Note the oxygen gas above the liquid oxygen. The gas enters the pipeline system at the top, and if large quantities of oxygen are needed, liquid is drawn off at the bottom, passes through the evaporator and the gas then enters the pipeline system

combined to form a bank attached to a manifold. The advantages of combining large cylinders into a bank include a reduction in cost, transportation and constant change of exhausted cylinders. Oxygen cylinders come in several sizes (table 2). In UK oxygen cylinders are black with white shoulders. The pressure inside at 15°C is 137 bar.

Table 2 - Oxygen cylinder sizes

Size	C	D	E	F	G	J
Height (in)	14	18	31	34	49	57
Capacity (litres)	170	340	680	1360	3400	6800

Oxygen concentrators An oxygen concentrator is a device which extracts oxygen from atmospheric air using canisters of zeolite. Nitrogen is filtered out and oxygen produced. The function and successful economics were described in detail. (*Oxygen concentrators for district hospitals in Update in Anaesthesia 1999;10: 57-59*). When ether is used, the oxygen concentrator should be positioned 1.5m above the floor.

HYPOXIA

Hypoxaemia is when the oxygen tension in arterial blood is less than 80mmHg (10.6kPa). **Hypoxia** is a deficiency of oxygen at the tissue level. Traditionally, hypoxia has been divided into 4 types.

1. **Hypoxic hypoxia** in which oxygen tension of arterial blood is reduced
2. **Anaemic hypoxia** in which the arterial oxygen tension is normal but the amount of haemoglobin(Hb) available to carry oxygen is reduced.
3. **Stagnant or ischaemic hypoxia** in which blood flow to the tissues is so low that oxygen is not delivered to the tissues despite normal arterial oxygen tension and Hb concentration.
4. **Histotoxic hypoxia** in which oxygen is delivered to the tissues but a toxic agent prevents the cells using the oxygen.

Recognition of hypoxia. Recognition of tissue hypoxia is not always easy as there are a number of different signs and symptoms. Clinical signs and symptoms include:

- Altered mental status (agitation, confusion, drowsiness, coma)
- Cyanosis
- Dyspnoea, tachypnoea or hypoventilation
- Arrhythmias
- Peripheral vasoconstriction often with sweaty extremities
- Systemic hypotension or hypertension depending on the underlying diagnosis
- Nausea, vomiting and other gastrointestinal disturbance

Cyanosis means blueness of the tissues and is due to an excessive amount of deoxygenated Hb in the peripheral blood vessels. Cyanosis appears whenever the arterial blood contains more than 1.5grams of deoxygenated Hb in each 100mls of blood (normal Hb15g/100ml). Cyanosis can often be detected in a patient with a normal haemoglobin level when the oxygen saturation is less than 90%. When the oxygen saturation falls in anaemic patients, cyanosis is often absent.

As the clinical signs are non-specific, the best method of assessing oxygenation is to measure peripheral arterial oxygen saturation (SaO_2<95% is abnormal) and oxygen partial pressure in the arterial blood

(PaO_2<80mmHg (10.6kPa). Pulse oximeters and blood gas analysis have become more widespread throughout the world. Hypoxia at tissue level may still exist even when SaO_2 and PaO_2 are within normal limits, if there is a low cardiac output, anaemia or failure of tissues to use oxygen (e.g. cyanide poisoning). In this situation the blood lactate concentration rises due to anaerobic metabolism. Lactate can be measured in some laboratories.

OXYGEN DELIVERY SYSTEMS

Oxygen can be delivered to the patient using different devices. There are two main types of devices; *fixed and variable performance masks.*

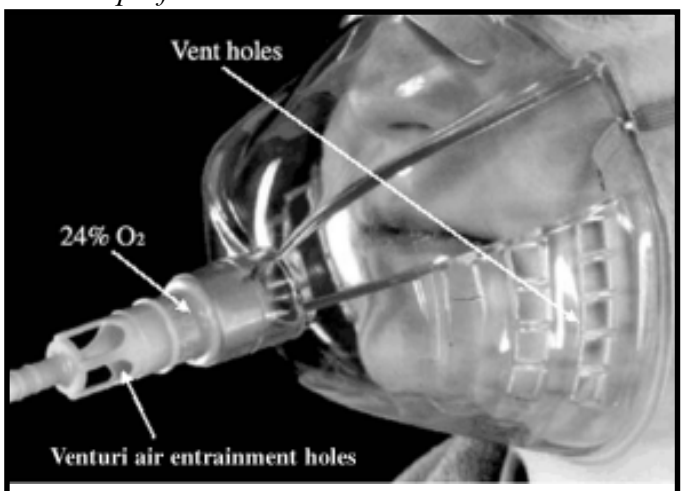

Figure 2: This is a fixed performance mask, with the Venturi entrainment device attached, and shown in detail inset. It indicates the oxygen flow rate and percentage of oxygen delivered (24%). Note the large volume of the mask and the holes which allow the gas flow to flush out expired gas

Teaching point

HAFOE masks use the Bernoulli effect to draw in or entrain a second gas via a side arm. This is the Venturi principle. Gas flowing through a tube is passed through a constriction or narrowing formed in the tube. The gas increases speed to pass through the narrowing, and therefore gains kinetic energy because of the increased velocity. The total energy of the system must remain the same, thus there has to be a fall in potential energy. The potential energy of a gas is the pressure it exerts. Therefore, if there is a fall in potential energy there will be a fall in pressure at that point. A second gas can be sucked in or entrained through a side arm into this area of low pressure (figure 3).

Fixed performance masks ensure that the patient receives a constant inspired oxygen concentration (FiO_2) despite of any changes in minute ventilation. These include:

- Closed or semi-closed anaesthetic breathing systems with a reservoir bag, attached to anaesthetic machine with pressurised gas supply.
- Head boxes for neonates - oxygen is piped into the box at a constant inspired oxygen concentration. Sufficient gas flow is needed to flush CO_2 out.
- HAFOE High Air Flow Oxygen Enrichment Devices e.g Ventimask

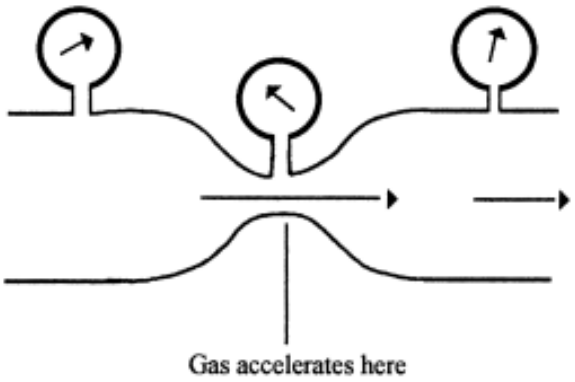

Figure 3a: The Bernoulli effect, with a flow of gas passing through a narrow tube. Note how the pressure falls at the narrow point.

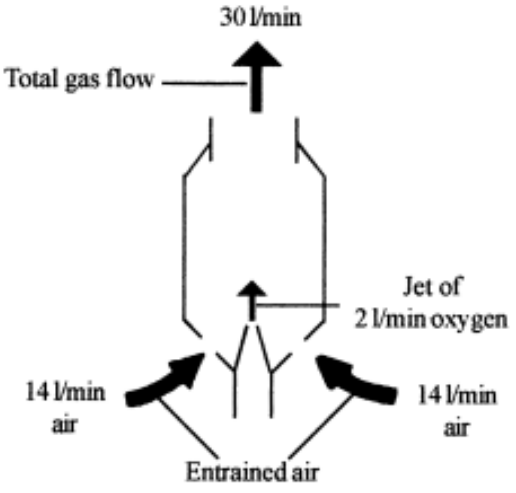

Figure 3b: Venturi valve - a low flow of oxygen, 2l/min passing through a narrow tube draws in 28l/min air, the hole size ensures the correct mixture of oxygen and air.

HAFOE masks (figure 2) are colour coded and each mask states the flow of oxygen in litres per minute required to achieve a specific inspired oxygen concentration. There are holes which allow entrainment of room air by the Venturi principle. Relatively high flows of oxygen are needed: e.g. 8 l/min to ensure an inspired oxygen concentration of 40% and 15 l/min to ensure an inspired oxygen concentration of 60%. The flows of 2, 4 and 6 l/min will provide 24, 28 and 31% oxygen respectively. The patient breathes a fixed concentration of oxygen enriched air because the gas flow is greater than the peak inspiratory flow rate of the patient. Thus there is minimal dilution from atmospheric air. The high gas flow flushes expired gas from the mask preventing rebreathing.

Variable performance masks/devices. The second type of oxygen delivery system includes those which deliver a variable concentration of oxygen. The oxygen concentration delivered depends on patient minute ventilation, peak inspiratory flow rate and oxygen flow rate. For example, when a patient is breathing with a **low** minute ventilation and is given a **high** oxygen flow, oxygen concentration will be relatively high. If the patient breathes more without an increase in oxygen flow, there will be a fall in inspired oxygen concentration. Using these masks the oxygen concentration is not fixed or accurate, but in most situations a flow rate of 2l/min provides 25-30% O_2 and 4 l/min provides 30-40% O_2. Examples of these devices include:

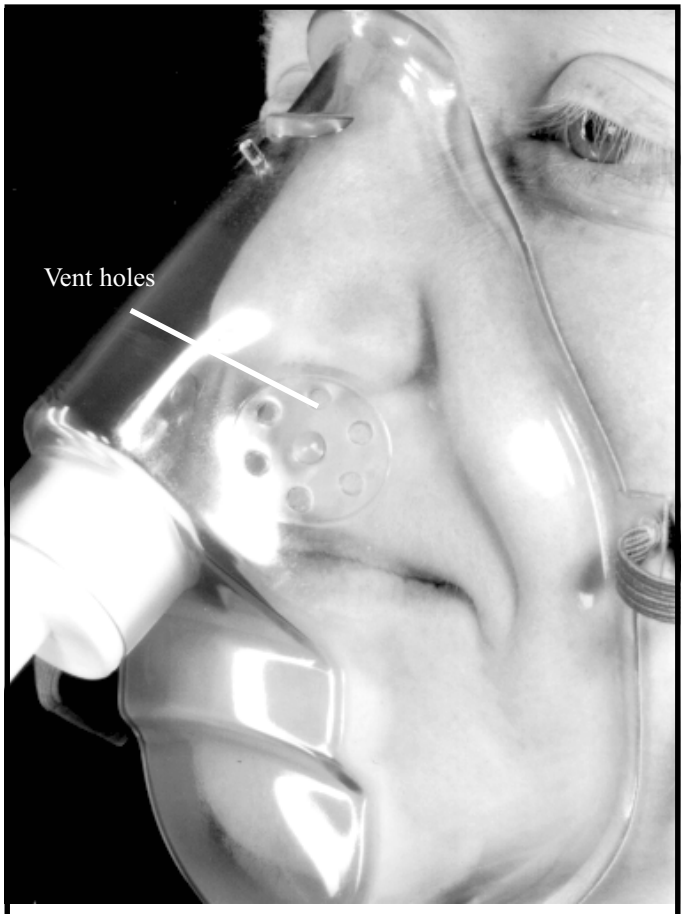

Figure 4: This is a common variable performance mask. Note that the volume of the mask is small, thus as the patient breathes in, air from outside is drawn in.

- **Nasal cannula.** These do not increase dead space. Inspiratory oxygen concentration depends on the flow rate. No rebreathing occurs.
- **Nasal catheters**, 8FG, can be inserted into the nose as far as the pharynx, so that they can just be observed behind the soft palate. A gas flow of 150ml/kg/min gives an inspired oxygen concentration of 50% in children less than 2 years. No rebreathing occurs.

  The same concept can be used in adults and the cannula may be fashioned from any soft tipped fine catheter (a fine nasogatric tube or urinary catheter may be used in emergencies).

  When using nasal cathers they must be taped securely in place so that they cannot migrate down into the oesophagus.
- **Plastic oxygen masks** (figure 4) have a small dead space. The effect of the dead space depends on the patient's minute ventilation and oxygen flow. There is usually a small amount of rebreathing.

OXYGEN THERAPY

The American College of Chest Physicians and National Heart, Lung and Blood Institute published recommendations for instituting oxygen therapy. These include:

- Cardiac and respiratory arrest (give 100% oxygen)
- Hypoxaemia (PaO_2 < 59mmHg (7.8 kPa), SaO_2 <90%)
- Systemic hypotension (systolic blood pressure <100mmHg)
- Low cardiac output and metabolic acidosis (bicarbonate <18mmol/l)
- Respiratory distress (respiratory rate > 24/min)
- In anaesthesia, "added oxygen" should be used during and after anaesthesia as previously described, (*The physiology of oxygen delivery, Update in Anaesthesia 1999;10: 8-14*).

Table 1

Patients who do not require controlled oxygen therapy	Asthma Pneumonia Bronchiolitis Respiratory distress Cardiac or respiratory arrest Pulmonary embolus Shock - septic hypovolaemic cardiac failure myocardial infarction Carbon monoxide poisoning
Patients who require controlled oxygen therapy	Chronic obstructive pulmonary disease with hypoxic drive Premature infants

Teaching Point
Patients who can be harmed by high concentrations of oxygen are mentioned because they are encountered only occasionally. MOST patients benefit from uncontrolled oxygen and it should be given freely to those with cardiac or respiratory arrest, those with respiratory distress, asthma or hypotension.

Prescribing oxygen - controlled or uncontrolled?

As with any drug, oxygen should be prescribed. It may be prescribed as *controlled* oxygen therapy where the concentration is prescribed using a HAFOE device. However oxygen is more commonly prescribed at a recommended flow rate using a variable oxygen administration device - this is known as *uncontrolled* oxygen therapy.

A small group of patients with chronic obstructive pulmonary disease (COPD) have raised CO_2 levels and depend on hypoxia to stimulate respiration (hypoxic respiratory drive). This is in contrast to the normal patient where the blood level of CO_2 drives respiration. They have a long history of chest disease, are cyanosed, sleepy, have signs of cor pulmonale but are not breathless. In these patients high dose oxygen can reduce respiration and cause respiratory depression. They will develop increased CO_2 retention, respiratory acidosis and subsequently will require mechanical ventilation. These patients should receive carefully controlled oxygen therapy, starting at 24-28%, which is progressively increased, aiming to achieve an arterial oxygen tension, ideally, above 50mmHg (6.6kPa) or an SpO_2 of 85-90%. These patients are rarely encountered in anaesthetic practice, but the possibility of this situation should be considered in people with severe COPD. Unfortunately the risk of hypercapnia in patients with severe COPD is often overestimated, resulting in inadequate oxygen therapy and death from hypoxia.

Monitoring of oxygen therapy

Clinical monitoring includes observation of conscious level, respiratory and heart rates, blood pressure, peripheral circulation (capillary refill, normally 1-2 sec.) and cyanosis. If available, additional monitoring can be provided by blood gas analysis and pulse oximetry. Check arterial oxygen blood tension and saturation before administering oxygen whenever possible. After starting oxygen, blood gases or oximetry should be repeated adjusting inspired oxygen concentration to achieve PaO_2 more than 59mmHg (7.8kPa) or SaO_2 more than 90%. Oximetry provides continuous monitoring of oxygen saturation and is especially helpful if blood gas analysis is difficult or unavailable.

However in the small group of patients with chronic lung disease who depend on their hypoxic drive, respiratory depression can be detected by seeing the patient become more drowsy and a rise in arterial CO_2 level. Note that oxygen saturation will not decrease until a late stage.

Risks of oxygen treatment

- **Fire** - oxygen supports combustion of other fuels. **Do not** smoke when on oxygen!
- **Absorption atelectasis**. Prolonged administration of high concentrations of oxygen can result in atelectasis particularly at lung bases. It is most common following chest or upper abdominal surgery and in those patients with poor lung function and sputum retention.
- **Retrolental fibroplasia**. High arterial oxygen tensions are a major factor in causing retrolental fibroplasias in neonates, which may result in blindness. The condition is caused by blood vessels growing into the vitreous, which is followed later by fibrosis. The low birth weight very premature infant is at risk up to 44 weeks postconceptual age. The level of PaO_2 required to cause retinal damage is not known, but an umbilical PaO_2 of 60-90mmHg (8-12kPa) is safe. Some doctors believe that the normal term infant is also at risk and that arterial saturation must not exceed 95%. However if the baby is hypoxic or requires resuscitation, oxygen **must** be given. Oxygen in normal concentrations is also safe for short periods during anaesthesia.
- **Patients on chemotherapy**. It is recognized that patients who have received bleomycin are at risk of developing pulmonary fibrosis if they are given excessive concentrations of oxygen during and after anaesthesia. In these patients controlled oxygen therapy should be prescribed to maintain SaO_2 90-95%.

Teaching Point

The oximeter is a very useful instrument, but the clinician must not forget its limitations. It only measures oxygen saturation and therefore when interpreting the readings the shape and importance of the oxygen saturation curve must be remembered. The curve is flatter when the oxygen saturation is more than 93%. Therefore relatively large increases in oxygen tension (PaO_2) will cause small increases in saturation. In contrast, when the saturation falls below 90%, the oxygen tension will fall rapidly with falls in oxygen saturation.

Conclusion

Oxygen is widely used across all medical specialities. In many acute situations, it is the first drug to be given and is life saving. It should always be considered along with management of the airway, delivery system, the importance of the circulation, constant monitoring and reassessment of the treatment. Dangers of oxygen therapy should be always remembered but should **never** prevent oxygen form being given.

References

Bateman NT and Leach RM. ABC of oxygen : Acute Oxygen Therapy. British Medical Journal 1998; 317:798-801