BMJ

BMJ 2012;345:e6856 doi: 10.1136/bmj.e6856 (Published 18 October 2012)

PRACTICE

THERAPEUTICS

Emergency oxygen use

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This is one of a series of occasional articles on therapeutics for common or serious conditions, covering new drugs and old drugs with important new indications or concerns. The series advisers are Robin Ferner, honorary professor of clinical pharmacology, University of Birmingham and Birmingham City Hospital, and Albert Ferro, professor of cardiovascular clinical pharmacology, King's College London. To suggest a topic for this series, please email us at practice@bmj.com.

A 60 year old man with chronic obstructive pulmonary disease (COPD) requiring long term home oxygen therapy called an ambulance because of severe breathlessness. With nasal oxygen therapy at 2 L/minute, his oxygen saturation was 88%. The paramedics administered nebulised salbutamol driven by oxygen (approximately 60% oxygen) and then gave oxygen via a reservoir mask (approximately 80% oxygen) during a 27 minute journey to hospital. He became drowsy before arrival in the emergency department, and blood gases showed evidence of respiratory acidosis with pH 7.19 (normal range 7.35-7.45), elevated CO_2 level at 11.3 kPa (normal range 4.5-6.0), elevated bicarbonate level at 32 mmol/L (normal range 21.0-28.0), and high oxygen partial pressure at PaO_2 18.5 kPa (normal range 12.0-15.0) with high oxygen saturation at 100% (normal range 95-98%). He required intubation and ventilation for acidotic hypercapnic respiratory failure, but he died on the second day of ventilation.

Emergency oxygen use

Oxygen is administered to about a third of emergency ambulance patients, and about 15% of UK hospital patients receive oxygen therapy on any given day.[1 2] Common indications for emergency oxygen therapy are shown in box 1, while box 2 shows some common conditions for which oxygen was given routinely in the past but is now recommended only if the patient is hypoxaemic. Patients with carbon monoxide or cyanide poisoning and patients with some diving or altitude emergencies benefit from hyperoxaemia, but the prevention of hypoxaemia is the goal of oxygen therapy in all other conditions. Several publications have raised concerns about the risks of either insufficient or excessive oxygen therapy.[3-9]

Medical oxygen, like other medical gases, is regarded as a drug in most countries and should usually be prescribed. However, like other drugs used in medical emergencies, it is appropriate to initiate oxygen therapy immediately in emergency situations and to document this therapy once the emergency condition has stabilised.[3] Yet half of UK hospital patients receiving supplementary oxygen therapy do not have a prescription for this treatment or valid written documentation; similar concerns have been raised in several other countries.[2 3]

How effective is emergency oxygen therapy?

Oxygen is often given with the intention of relieving breathlessness, but there is no evidence that oxygen can relieve breathlessness in non-hypoxaemic patients with acute illness, so the main indication for emergency oxygen therapy is to protect patients from potentially harmful consequences of hypoxaemia. A study of 25 healthy subjects exposed to acute hypoxaemia at altitude found that errors in mental tasks occurred at mean oxygen saturation of 64% (range 45-84%), and imminent loss of consciousness occurred at mean saturation 56% (40-68%) and was reversed by oxygen therapy.[10] More sustained hypoxaemia can lead to hypoxic brain damage and potential damage to other organs such as the liver and kidneys.[3]

On the other hand, acclimatised mountaineers can tolerate short term exposure to oxygen saturation levels as low as 34%, and many patients with chronic lung disease are acclimatised to hypoxaemia.[4 11] The effectiveness of emergency oxygen therapy has not been evaluated in randomised trials involving hypoxaemic patients, so the benefits of oxygen therapy are not known in terms of numbers needed to treat (NNT) to avoid death or complications. The precise levels of hypoxaemia that are dangerous in particular disease states are not known, but four observational studies of critically ill patients have shown increased mortality among hypoxaemic patients in intensive care units with PaO_2 <8-9 kPa (equivalent to oxygen saturation <91-94%).[6 7 12 13]

However, a Cochrane review of perioperative oximetry monitoring showed that correcting modest hypoxaemia did not reduce perioperative deaths or complications, although clinicians who had access to oximetry results believed that they had averted harm by correcting hypoxaemia.[14] There are no

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Box 1: Medical emergencies where oxygen is likely to be required until patient is stable and within target saturation range[3]

Medical emergencies requiring high concentration oxygen in all cases

- Shock, sepsis, major trauma
- Cardiac arrest and during resuscitation
- Anaphylaxis
- Carbon monoxide or cyanide poisoning

Medical emergencies where patients are likely to need oxygen therapy (ranging from low to high concentration depending on disease severity), with target saturation range 94-98%

- Pneumonia
- Asthma
- Acute heart failure
- Pulmonary embolism

Medical emergencies where patients are likely to need controlled oxygen, with target saturation range 88-92%

- Acute exacerbation of chronic obstructive pulmonary disease (COPD)
- Acute illness in patients with cystic fibrosis
- Acute respiratory illness in patients with obesity hypoventilation syndrome or morbid obesity
- Acute respiratory illness in patients with chronic neuromuscular or musculoskeletal conditions

Box 2: Common medical emergencies for which oxygen was given routinely in the past but is now advised only if the patient is hypoxaemic[3]

- Myocardial infarction or unstable coronary artery syndrome
- Stroke
- Ongoing management of survivors of cardiac arrest with restored spontaneous circulation
- Sickle cell crisis or acute anaemia
- Obstetric emergencies
- Most poisonings (other than carbon monoxide or cyanide poisoning)
- Metabolic and renal disorders with tachypnoea due to acidosis (Kussmaul breathing)

randomised trials to evaluate the effectiveness of oxygen therapy in critically ill patients who are not hypoxaemic. The recommendation to administer oxygen during the immediate management of all critically ill patients is based on expert advice that oxygen saturation measurements may be unreliable in critical illness, especially in prehospital care; a target saturation range should be set as soon as the patient has stabilised.

How safe is emergency oxygen therapy?

Too little oxygen or too much oxygen can cause death. A report by the UK National Patient Safety Association identified at least nine deaths (and potentially up to 35 deaths) between 2004 and 2009 that were attributable to incorrect oxygen therapy, including four cases of insufficient oxygen and four cases of excessive oxygen therapy.[8] Equipment failure such as empty or disconnected oxygen supplies or accidental connection to air outlets instead of oxygen outlets accounted for most of the incidents associated with underuse of oxygen. It is likely that these figures are gross underestimates, and many deaths related to oxygen therapy may not be easily recognised. For example, the first randomised trial of controlled oxygen therapy in acute exacerbations of COPD found that mortality was 9% when high concentration oxygen was given, but mortality was only 4% when controlled oxygen was given with a target saturation range of 88-92%.[5] The British Thoracic Society's Emergency Oxygen Guideline recommends a near normal oxygen saturation target range of 94-98% for most acutely unwell patients and a target range of 88-92% for most patients at risk of hypercapnic respiratory failure (the more appropriate course in our case scenario).[3]

It was established more than 100 years ago that high concentrations of oxygen may cause lung injury.[15] Pure oxygen is irritating to mucus membranes and may generate tissue injury by causing release of free radicals.[3] Recent cohort studies have shown increased mortality associated with hyperoxaemia in the first 24 hours among survivors of cardiac arrest who were treated in intensive care units and among general intensive care patients.[6 7] Other authors also identified increased mortality associated with hyperoxaemia in cohort studies of intensive care patients and survivors of cardiac arrests, but these authors reported no residual excess mortality in the hyperoxaemic group after multivariable analysis.[12 13]

High concentration oxygen increases the risk of hypercapnic respiratory failure in acute exacerbations of COPD.[4] The first randomised trial of high concentration oxygen compared with controlled oxygen therapy in acute exacerbations of COPD found mortality of 9% in the group given high concentration oxygen versus 4% mortality in patients given controlled oxygen with a target saturation range of 88-92%.[5] A UK audit of 9716 cases of acute COPD exacerbation reported overall mortality of 7.7%: mortality was higher when >35% oxygen was given compared with that for lower concentrations of oxygen (11% *v* 7%); the need for ventilator support was also higher with >35% oxygen (22% *v* 9%).[16] These recent studies lend support to the recommendation in the British Thoracic Society Emergency Oxygen Guideline that oxygen therapy in acute exacerbations of COPD should be titrated to achieve an oxygen saturation level between 88% and 92%.[3]

Recent controlled trials have shown that high concentration oxygen is also associated with increased risk of hypercapnia in acute asthma and pneumonia and in obesity-hypoventilation syndrome.[17-19] In the acute asthma study, 106 patients were randomised to receive high concentration oxygen (8 L/min via simple facemask) or titrated oxygen therapy to achieve saturation targets of 93-95% for 60 minutes.[17] All 10 cases of hypercapnia in this trial occurred among the patients given high concentration oxygen. This raises the possibility that most cases of hypercapnic respiratory failure in acute asthma (near-fatal asthma) may be caused by excessive oxygen therapy.

What are the precautions?

Oxygen supports combustion, and there is a risk of fire or explosion, especially if patients or carers should smoke or light matches near the oxygen source. Oxygen is contraindicated in paraquat poisoning and in bleomycin lung injury because it accentuates lung damage in these conditions.[3]

Uncontrolled oxygen therapy and high concentration oxygen therapy are contraindicated in COPD and in other conditions such as morbid obesity or musculoskeletal or neurological conditions such as severe kyphoscoliosis or motor neurone disease, where oxygen may cause or aggravate hypercapnic respiratory failure.[3]

How cost effective is it?

The cost effectiveness of emergency oxygen therapy cannot be calculated because the clinical effectiveness of oxygen therapy has not been evaluated in controlled trials for most conditions where it is used. Oxygen is a cheap drug, but even short term use requires the use of a facemask or cannulas and tubing, which may cost more than the oxygen used. Audits in the UK and other countries have tended to report overuse rather than underuse.[1 2] The 2011 British Thoracic Society Emergency Oxygen Audit of 41 000 UK hospital patients found that only 32% of those patients using supplementary oxygen had a prescription or other written order for oxygen in 2008, rising to 48% by 2011; of those with a specified target oxygen saturation range, 10% were below this range but 23% were above it.[20] These audits suggest that cost effectiveness could be improved if oxygen therapy was restricted to those who require it, potentially avoiding hyperoxia and its complications.

How is it administered and monitored?

Oxygen delivery devices

Clinicians need to become familiar with four or five types of delivery device to deal with most emergency oxygen use (see box 3). The advantages and disadvantages and special considerations for each of these devices are described in detail in the British Thoracic Society's Emergency Oxygen Guideline, which also provides advice about the use of different oxygen sources including piped oxygen and a wide range of cylinder sizes.[3]

Bedside monitoring

Unlike most drugs, emergency oxygen therapy should not be prescribed at a fixed dose. The prescribing clinician should specify the target oxygen saturation range that is safest for the patient (usually either 94-98% or 88-92%).[3] The administering team (usually nurses) should adjust the inspired oxygen concentration to achieve this target range and ensure that the oxygen delivery system is documented clearly as recommended in UK guidelines.[3] If oxygen requirements increase, patients require review by a doctor, as the cause of worsening hypoxaemia needs to be identified and treated. All patients requiring emergency oxygen therapy should have regular monitoring, ideally using a recognised "track and trigger" system such as a modified early warning score.[3] Some newer early warning scores include oximetry results, but patients with respiratory illnesses may need protection from hyperoxaemia as well as from hypoxaemia and may be harmed by a "normal" oxygen saturation level.[21] Future early warning scores will need to reflect this.

Saturation monitoring

Cheap and reliable finger oximeters are now available in almost all situations where emergency oxygen therapy is used. However, oximetry may not be possible in cases of shock, and it may be misleading in some circumstances, such as carbon monoxide poisoning (because carboxyhaemoglobin gives a similar signal to oxyhaemoglobin). Therefore, regularly monitor other vital signs, especially the respiratory rate; these signs may alert clinicians to clinical deterioration before any fall in the oxygen saturation level.

Avoid the precautionary use of oxygen in non-hypoxaemic patients, as the increase in blood oxygen content is minimal in normoxaemic patients while the artificially high oxygen level renders pulse oximetry almost useless as a means of monitoring ventilation and gas exchange and may delay recognition of clinical deterioration.[3 9]

Monitoring for toxicity and effectiveness

Hypoxaemic patients and those at risk of hypoxaemia need careful monitoring as described above. Effectiveness of oxygen therapy can be monitored directly by pulse oximetry and blood gas measurements and indirectly by improvement in other vital signs. Toxicity is best recognised among patients at risk of hypercapnic respiratory failure (such as those with COPD, obesity-hypoventilation, or chronic neuromuscular disease).[3-5]

Clinical signs of carbon dioxide retention include vasodilation, drowsiness, and flapping tremor, but the only reliable way to diagnose hypercapnia (and acidosis) is to check blood gases. For this reason, blood gases should be requested for all patients at risk of hypercapnic respiratory failure who require emergency oxygen therapy. Transcutaneous carbon dioxide sensors are not yet as reliable as finger oximeters, and they are not recommended for clinical use in the management of medical emergencies.[3]

How does oxygen compare with other drugs?

There are no other drugs for the specific indication of hypoxaemia, but there are several other methods to improve oxygen delivery to the tissues (box 4). For patients with modest hypoxaemia, these strategies may be more effective than simply increasing the concentration of inhaled oxygen.

Competing interests: The author has completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declares: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Provenance and peer review: Commissioned; externally peer reviewed.

Patient consent not required (patient anonymised, dead, or hypothetical).

Box 3: Devices for oxygen administration

- Reservoir mask (non-rebreathing mask) for critical illness or severe hypoxaemia (fig1⇓)
- Venturi mask for controlled oxygen therapy (especially for oxygen-sensitive patients) (figs 2⇓ and 3⇓)
- Nasal cannulas for most medium dose oxygen therapy (adjust flow to increase or decrease blood oxygen level) (fig 4⇓)
- Simple facemask—works in a similar manner to nasal cannulas, but most patients prefer nasal cannulas to masks, and some rebreathing may occur (fig 5⇓)
- Tracheostomy masks for "neck breathing" patients (fig 6⇓)

Box 4: Alternative methods to increase tissue oxygen delivery

- Safeguarding the airway
- Optimising circulating volume to maintain tissue perfusion
- Correcting severe anaemia
- Enhancing cardiac output
- Avoiding or reversing respiratory depressants such as benzodiazepines or opiates
- Increasing fraction of inspired oxygen (FIO_2) if the patient is hypoxaemic
- Establishing and treating the underlying cause of hypoxaemia (such as bronchospasm, heart failure)
- More specialised treatments, including non-invasive or invasive ventilation for seriously ill patients after assessment by senior clinicians

Tips for prescribers

- Advise patients not requiring oxygen and their families that oxygen was overused in the past and is not required in most circumstances unless the blood oxygen level is low, even if breathlessness is present
- Excessive oxygen therapy (hyperoxaemia) in seriously ill patients (such as survivors of cardiac arrest or those admitted to intensive care units), may be associated with increased mortality
- Aim for oxygen saturation of 94-98% for most patients and 88-92% for most patients at risk of hypercapnic respiratory failure (some hypercapnic patients may have a lower individualised target range based on previous blood gas results)
- Issue a personal "Oxygen Alert Card" and educational materials to patients with a history of hypercapnic respiratory failure to ensure that they are not endangered by excessive oxygen therapy[3]
- Prescribing oxygen to a target range is simple and safer than trying to prescribe a fixed "dose" of oxygen. The target range needs to be set just once for each patient, although the device and flow rate may need to be changed several times if the patient's condition changes. Document all such changes on the bedside observations chart alongside the oxygen saturation
- Allowing the clinicians who are administering oxygen to select the most appropriate device and flow rate while maintaining the patient within the desired saturation range enhances patient safety and patient comfort
- Ensure that bedside air outlets (which could be mistaken for an oxygen outlet in an emergency) are either removed, covered, or clearly labelled

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Accepted: 20 September 2012

Cite this as: *BMJ* 2012;345:e6856

Figures

Fig 1 High concentration reservoir mask (non-rebreathing mask). (Reproduced from O'Driscoll et al *Thorax* 2011[2])

Fig 2 Venturi mask. (Reproduced from O'Driscoll et al *Thorax* 2011[2])

Fig 3 Venturi mask barrels with range of oxygen concentrations available. (Reproduced from O'Driscoll et al *Thorax* 2011[2])

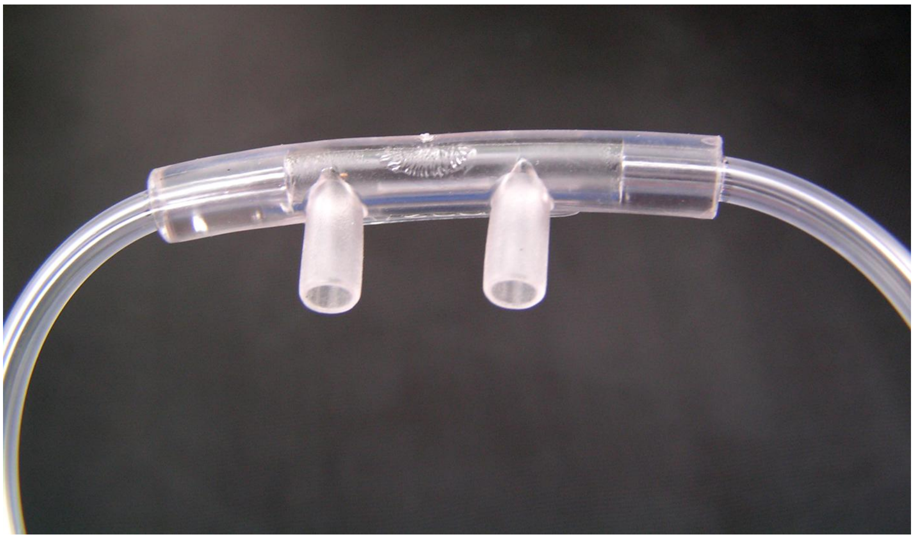

Fig 4 Nasal cannulas. (Reproduced from O'Driscoll et al *Thorax* 2011[2])

Fig 5 Simple facemask. (Reproduced from O'Driscoll et al *Thorax* 2011[2])

Fig 6 Tracheostomy mask. (Reproduced from O'Driscoll et al *Thorax* 2011[2])