Continuous oxygen delivery systems for infants, children, and adults

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INTRODUCTION — Rapid and effective oxygen delivery is an essential component of the care of critically injured patients. A variety of systems are available to deliver oxygen to spontaneously breathing patients. Factors that influence the appropriate choice for any given situation include the dose of oxygen required and how well the patient tolerates the device. For patients who require assisted ventilation, oxygen can be delivered with either a self-inflating or flow-inflating ventilation bag.

This topic will review various devices that are available to continuously deliver oxygen to spontaneously breathing infants, children, and adults. The amount of oxygen that each continuous system can deliver and the advantages and disadvantages of each method are discussed.

Oxygen conserving devices (eg, Oxymizer, Helios, or Invacare-Venture), oxygen therapy for newborns, indications for long-term oxygen supplementation, the use of oxygen in hypercapnic patients, issues regarding oxygen therapy during air travel, and basic airway management are discussed separately:

- (See "Portable oxygen delivery and oxygen conserving devices").
- (See "Oxygen monitoring and therapy in the newborn").
- (See "Long-term supplemental oxygen therapy").
- (See "The evaluation, diagnosis, and treatment of the adult patient with acute hypercapnic respiratory failure").
- (See "Traveling with oxygen aboard commercial air carriers").
- (See "Basic airway management in children" and "Basic airway management in adults").

GENERAL CONCEPTS — General principles regarding oxygen delivery include the following:

- The choice of system will depend upon the clinical status of the patient and the desired dose of oxygen (table 1). For example, a blow by system may be suitable for an alert infant or child in moderate respiratory distress that requires a low dose of oxygen. In comparison, an obtunded patient with irregular respirations needs bag-mask ventilation with as high a dose of oxygen as possible.

- Oxygen should be humidified, whenever possible, to prevent dried secretions from obstructing smaller airways.

- The effectiveness of oxygen delivery should be monitored with pulse oximetry. (See "Oxygen monitoring and therapy in the newborn", section on 'Pulse oximetry', and "Pulse oximetry in adults").

- Young children in respiratory distress may become frightened or agitated when oxygen is administered, causing their clinical conditions to deteriorate. Therefore, they should remain in a position of comfort whenever possible. Parent or caregiver can often hold the oxygen source in proximity to or over the child's face.

- As long as oxygenation is adequate, a nasal cannula may be preferable to a face mask for delivering oxygen to confused or delirious adults.

- Uncontrolled oxygen delivery may promote hypercapnia in adults with chronic obstructive pulmonary disease. (See "The evaluation, diagnosis, and treatment of the adult patient with acute hypercapnic respiratory failure").
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Hypoxemic respiratory failure conditions, including premature infants with respiratory distress syndrome, infants with bronchiolitis, and adults with respiratory rate, decreased work of breathing, and better oxygenation in patients of all ages and with a variety of causes of respiratory distress such as croup or bronchospasm.

Blow by oxygen is typically provided with oxygen tubing, corrugated tubing, or a simple mask. Alternatively, young children will accept blow by oxygen more readily if the end of the oxygen tubing is poked through the a Styrofoam or paper drinking cup. Blow by oxygen is typically held at a short distance from the child's face by a parent or other caregiver. Limited evidence suggests that only low concentrations of oxygen (<30 percent fraction inspired oxygen) can be provided using these systems [3-5].

Self-inflating (Ambu) ventilation bags do not reliably deliver oxygen to spontaneously breathing children and should not be used to provide blow by oxygen [3,6]. This type of system typically has a one-way valve to prevent rebreathing. Oxygen flows through the valve when the bag is squeezed. With a mask tightly applied to the face, some spontaneously breathing patients may be able to generate sufficient inspiratory pressure to overcome the valve. However, children cannot reliably accomplish this. In comparison, a flow-inflating (anesthesia) ventilation bag that is connected to an oxygen source provides a constant flow of oxygen. (See Ventilation bags, below.)

The following points should be considered when providing blow by oxygen to children:

- Oxygen can be best delivered at a flow rate of at least 10 L/minute through a reservoir (ie, a simple mask or large cup) [3].
- The reservoir must remain in proximity to the child's face.
- Oxygen saturation should be monitored.
- Alternative oxygen delivery systems should be considered for children who require greater than 30 percent oxygen or prolonged oxygen therapy.

**NASAL CANNULA** — A nasal cannula provides oxygen through oxygen supply tubing with two soft prongs that are inserted into the patient's anterior nares. Both low and high-flow oxygen delivery may be delivered by nasal cannula. Oxygen flows from the cannula into the patient's nasopharynx. Oxygen flowing into the nasopharynx mixes with room air. Consequently, the concentration of oxygen that can be delivered by these methods vary depending upon factors such as the patient's respiratory rate, tidal volume, oxygen flow rate, and extent of mouth breathing.

**Low flow** — One hundred percent oxygen is typically run through a bubbler humidifier at a rate of 1 to 4 L/minute. The oxygen concentration that is delivered varies from 25 to 40 percent, depending upon factors such as the patient's respiratory rate, tidal volume, and extent of mouth breathing [7,8]. Flow rates greater than 2 L/minute are very irritating to the nares, unless the oxygen is heated and humidified. The nares may become dry and prone to bleeding after prolonged use. Flow rates greater than 2 L/minute are not recommended for routine use in newborns and infants because inadvertent administration of positive airway pressure may occur at higher flow rates [9,10]. (See High flow, below.)

Low flow nasal cannulae are used to deliver oxygen to an adult with a low oxygen requirement or to an infant or child with patent nares who requires low levels of supplemental oxygen and does not accept a simple mask. This system is lightweight, inexpensive, and mobile. In addition, the infant can feed without interruption of oxygen delivery. Low flow nasal cannulae are of limited use during the stabilization of acutely ill patients, since they cannot reliably deliver high concentrations of oxygen.

**High flow** — High-flow nasal cannula oxygen therapy involves delivery of heated and humidified oxygen via special devices (eg, Vapotherm, Comfort Flo, or Optiflow) at rates up to 8 L/minute in infants and up to 60 L/minute in children and adults. In patients with respiratory distress or failure, humidified high-flow nasal cannula may be better tolerated than oxygen by face mask in terms of comfort and, in observational studies, has been associated with decreased...
In adults with acute hypoxemic respiratory failure without hypercapnia, high-flow oxygen therapy by nasal cannula is a reasonable alternative to standard oxygen therapy or noninvasive positive pressure ventilation. Such patients should be managed in settings with appropriate monitoring (eg, emergency departments or intensive care units). In a multicenter trial of 310 adults with hypoxemic respiratory failure without hypercapnia that compared high-flow oxygen therapy by nasal cannula with standard oxygen therapy by face mask or noninvasive positive pressure ventilation (NPPV), the intubation rate was not significantly different for patients receiving high-flow oxygen (38 percent) compared with standard therapy (47 percent) or NPPV (50 percent) but in post-hoc analysis was significantly lower for patients with severe hypoxemia (PaO₂:FI O₂ ≤200 mmHg) who received high-flow oxygen therapy rather than the other two therapies. All patients who received high-flow oxygen therapy did have significantly lower 90-day mortality (19 percent [standard oxygen] and 25 percent [NPPV]) and required significantly fewer days of mechanical ventilation (four versus six days [standard oxygen] and nine days [NPPV]) [14,15]. Most patients in this study had pneumonia. The finding that NPPV was associated with the longest duration of mechanical ventilation, and highest 90-day mortality may reflect a greater degree of lung injury in this treatment group and warrants confirmation in a larger randomized trial [15]. Prior studies that have compared NPPV to standard therapy have found a mortality benefit for NPPV in patients with hypoxic respiratory failure, especially when patients are able to manage their oral secretions. (See "Noninvasive positive pressure ventilation in acute respiratory failure in adults", section on 'Hypoxic respiratory failure'.)

The safe use of oxygen in patients with hypercapnia is discussed separately. Noninvasive positive pressure ventilation may avoid the need for endotracheal intubation and is preferred to high-flow oxygen therapy in these patients. (See "The evaluation, diagnosis, and treatment of the adult patient with acute hypercapnic respiratory failure", section on 'Titration of oxygen'.)

Although used for acute respiratory insufficiency in infants, especially when caused by bronchiolitis, further study of high flow nasal cannula therapy is needed to better define pediatric indications and effectiveness. (See "Bronchiolitis in infants and children: Treatment; outcome; and prevention", section on 'HFNC and CPAP'.)

The use of high flow nasal cannula for the treatment of respiratory distress syndrome in premature infants is discussed in greater detail separately. (See "Oxygen monitoring and therapy in the newborn", section on 'High flow nasal cannula'.)

**MASKS** — Masks are the most frequently used oxygen delivery system for patients who are breathing spontaneously. General considerations when using a mask include the following:

- The mask should fit over the patient’s nose and mouth. It is secured around the head with an elastic strap.
- A variety of sizes must be available from which to choose the proper size for any given patient.
- Transparent masks should be used whenever possible.
- Masks may be difficult to use for some patients who become more anxious and uncooperative when a mask is strapped to their face.
- Oxygen masks may pose a risk for aspiration in the vomiting patient.

Characteristics of the mask, mask fit, and the addition of a reservoir determine the amount of oxygen that can be delivered. The types of masks that are typically used include simple (Venturi), partial rebreathing, and nonrebreathing systems.

In contrast to the common simple mask, the Oxymask directs oxygen towards the mouth and nose using a patented “diffuser system”. The ability to provide a wide range of oxygen concentration by one device and avoidance of carbon dioxide rebreathing are possible benefits for this mask although evidence is very limited [16].

A specialized face mask is also used for noninvasive positive pressure ventilation in patients with acute respiratory failure. (See "Noninvasive positive pressure ventilation in acute respiratory failure in adults", section on 'Interface'.)

**Simple masks** — Simple masks (eg, Venturi) fit loosely over the nose and mouth. With oxygen flow rates between 6...
The plastic mask itself serves as a reservoir for oxygen that is delivered through a small-bore tube connected at the base of the mask. Exhaled gas escapes through holes (exhalation ports) on each side of the mask. Room air enters through these ports and mixes with oxygen, thereby decreasing the percentage of oxygen delivered to the patient. An oxygen flow rate greater than 5 L/minute is recommended to prevent rebreathing of CO₂ [10,18].

A simple mask is useful for patients who need moderate amounts of oxygen to maintain acceptable oxygen saturation. It can provide higher concentrations of oxygen than a nasal cannula. However, precise concentrations of oxygen cannot be reliably delivered.

**Partial rebreathing masks** — A partial rebreathing mask consists of a simple mask with an attached reservoir. Oxygen concentrations from 50 to 60 percent can be achieved with oxygen flow rates between 10 and 12 L/minute [10,19].

With this system, air is drawn during inspiration predominantly from the fresh oxygen inflow and the reservoir. Entrainment of room air through the exhalation ports is minimized.

Gas in the reservoir is oxygen rich, despite the fact that it contains some exhaled gas. This is because the early exhaled air that flows into the reservoir (from respiratory dead space in the mouth and upper airways) is oxygen rich and contains little carbon dioxide [19-21]. In order to maintain a high percentage of oxygen in the reservoir and minimize CO₂ rebreathing, the oxygen flow rate must be adjusted to keep the reservoir from collapsing.

A partial rebreather mask is used primarily to conserve oxygen supply (for instance, during transport) for patients who require higher oxygen concentrations. Although the concentration of oxygen that is delivered is more reliable than a simple mask, it is diluted by room air that can still be drawn into the system through the exhalation ports.

**Nonrebreathing masks** — A nonrebreathing mask is a mask and reservoir system modified with two valves that limit the mixing of exhaled gases and room air with the oxygen supply. With oxygen flow rates of 10 to 15 L/minute and a mask with a good seal, inspired oxygen concentrations of up to 95 percent can be achieved with a nonrebreather mask [19,22].

A one-way valve over one of the exhalation ports of the mask allows the egress of expired gas during exhalation and prevents room air from entering the mask during inspiration. As a safety precaution, only one of the two exhalation ports on the mask has a one-way valve. That way, the patient can still receive room air through the open port if the flow of oxygen to the mask is inadvertently interrupted [23].

The second one-way valve is located between the reservoir and the mask. It prevents flow of exhaled gas into the reservoir [19-21]. In addition, oxygen flow into the mask is adjusted to prevent collapse of the reservoir.

A nonrebreather mask reliably supplies the highest concentration of oxygen that can be provided to a spontaneously breathing patient.

**ENCLOSURE SYSTEMS** — Enclosure systems such as oxygen hoods or tents may be used for infants or children who require prolonged administration of oxygen but cannot tolerate a nasal cannula or mask. They are not usually used in adults. Hoods and tents can also supply good humidification and temperature control. Both systems are very noisy for the patient [24].

**Hoods** — Oxygen hoods are clear, plastic cylinders that encompass the infant's head. Oxygen concentrations of 80 to 90 percent can be achieved with oxygen flow rates of ≥10 to 15 L/minute [19].

Oxygen enters the hood through a gas inlet. Exhaled gas exits through the opening at the neck [24].

The hood is usually well tolerated by newborns. Infants in an oxygen hood are accessible for monitoring and other care. Most hoods are too small to use for infants older than one year of age [19].

**Tents** — Oxygen tents are clear, plastic shells that surround the child’s head and upper body. Although a tent can provide up to 50 percent oxygen using high-oxygen flow rates, mixing with room air occurs whenever the tent is opened. As a result, oxygen tents are generally not a sufficient source of oxygen for children who require concentrations greater than 30 percent [19].

Oxygen tents limit access to the child by family and clinical staff. In addition, highly humidified air typically results in condensation and the formation of mist, which obscures the patient from view, preventing the early recognition of changes in the child's condition such as cyanosis or obtundation.
Flow-inflating bags can be used to provide supplemental oxygen to spontaneously breathing children. (See ‘Blow by’ above.)

**Self-inflating bags** — A self-inflating (Ambu) bag reinflates with a recoil mechanism. It does not require a gas source to re-expand. However, during reinflation with an oxygen source, room air is entrained in the system, diluting the concentration of oxygen that is delivered to the patient. Therefore, in order to consistently deliver high concentrations of oxygen, a reservoir must be attached to the bag. (See “Basic airway management in children”, section on ‘Bag-mask ventilation’ and “Basic airway management in adults”, section on ‘Bag-mask ventilation’.)

Flow-inflating bags — Flow-inflating (anesthesia) bags require a gas source to remain inflated. When oxygen is used as the source, 100 percent oxygen can be delivered to the patient. These systems are more complicated to use than a self-inflating bag. The flow of oxygen and an outlet control valve must be adjusted to ensure safe and effective ventilation. Consequently, flow-inflating bags should only be used by clinicians with specific training and experience.

**SUMMARY AND RECOMMENDATIONS**

- Critically ill or injured patients frequently require oxygen therapy. The choice of an oxygen delivery system will depend upon the clinical status of the patient and the desired dose of oxygen (table 1). For patients who are breathing spontaneously, the appropriate delivery system depends upon the dose of oxygen that they require and how well they tolerate the system. These patients should remain in a position of comfort whenever possible. (See ‘General concepts’ above.)

- Blow by (wafting) oxygen can be provided with oxygen tubing, corrugated tubing, or a simple mask to infants or children who require less than 30 percent oxygen for short periods of time. Self-inflating (Ambu) bags should not be used as a source of blow by oxygen. Pulse oximetry should be monitored to ensure that oxygen is being effectively delivered. (See ‘Blow by’ above.)

- A low flow nasal cannula can deliver 25 to 40 percent oxygen, depending upon the patient’s respiratory rate, tidal volume, and extent of mouth breathing. Flow rates 2 L/minute or less are recommended for infants. (See ‘Low flow’ above.)

- High-flow nasal cannula oxygen therapy involves delivery of heated and humidified oxygen via special devices (eg, Vapotherm, Comfort Flo, or Optiflow) at rates up to 8 L/minute in infants and up to 60 L/minute in children and adults. (See ‘High flow’ above.)

- In adults with acute hypoxemic respiratory failure without hypercapnia, high-flow oxygen therapy by nasal cannula is a reasonable alternative to standard oxygen therapy or noninvasive positive pressure ventilation. Such patients should be managed in settings with appropriate monitoring (eg, emergency departments or intensive care units). (See ‘High flow’ above.)

- A simple mask with 6 to 10 L/minute of oxygen flow delivers 35 to 50 percent oxygen. Partial and nonrebreathing masks with oxygen reservoirs deliver maximum concentrations of 60 and 95 percent oxygen, respectively. (See ‘Masks’ above.)

- Enclosure systems include hoods and tents and are appropriate for infants and children. Hoods can deliver up to 90 percent oxygen and may be used for infants less than one year of age. Tents deliver less oxygen (up to 50 percent). Mist that accumulates in the tent may obscure the child from view. (See ‘Enclosure systems’ above.)

- Ventilation bags are used to provide oxygen to patients who require assisted ventilation. A reservoir must be attached to self-inflating bags in order to provide high concentrations of oxygen. (See ‘Ventilation bags’ above.)

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**REFERENCES**