REVIEW

Oxygen administration in infants

B Frey, F Shann

The main methods of oxygen administration to infants are reviewed. Some methods are more economical and therefore more useful in developing countries. All the methods have potential complications and therefore need to be carefully supervised.

There are several different methods of non-invasive oxygen administration: head box oxygen, holding an oxygen source close to the infant’s face, facemask, nasal prongs, nasal catheter, and nasopharyngeal catheter (fig 1). Oxygen administration is a routine procedure in the care of ill neonates and infants and therefore it is important to know the efficacy, the risks, and the impact on lung function of the methods used.

Arterial oxygen saturation is one of the determinants of oxygen transport. Pulmonary diseases with ventilation-perfusion inequalities lead to diminished arterial oxygen saturation and are amenable to oxygen treatment—that is, administration of an increased fraction of inspired oxygen (FIO2). In neonates and infants, such diseases include hyaline membrane disease, pneumonia, bronchopulmonary dysplasia, bronchiolitis, and pulmonary oedema.

“In developing countries, safe, simple, effective, and inexpensive methods of oxygen administration are favoured.”

World wide, acute infections of the lower respiratory tract kill more than 4 million children every year, most of them less than 5 years of age. They are the leading cause of death in that age group and 99% of the deaths occur in developing countries.1 Oxygen therapy is often life saving. There is a substantial reduction in mortality when oxygen is given to hypoxic patients with very severe pneumonia, as shown for children in Papua New Guinea.2 3 Looked at from this worldwide perspective, the safety and cost of oxygen therapy are most important. In developing countries, safe, simple, effective, and inexpensive methods of oxygen administration are favoured. The World Health Organisation (WHO) recommends nasopharyngeal catheters and nasal cannulae as safe and efficient means of oxygen administration.4 These methods are also useful in the industrialised world because they have the potential to reduce the risks of treatment. Therefore, the present review applies to the practice in developing and developed countries equally.

There are few infant data on headbox and facemask oxygen, although these methods are regularly used in practice in developed countries. Therefore, this review concentrates on oxygen delivery by nasal cannula, nasal catheter, and nasopharyngeal catheter. The studies on the latter methods were performed in infants weaned from ventilation for respiratory distress syndrome and heart surgery, and in infants requiring supplemental oxygen flow for apnoea of prematurity, bronchopulmonary dysplasia, and pneumonia.

HEADBOX OXYGEN (FIG 1A)

Of the methods discussed, this is the only one that allows the FIO2 to be determined precisely. The oxygen concentration should be measured by an oxygen analyser placed near the baby’s mouth. There is no increased risk of airway obstruction by mucus and gastric distension. Humidification is not necessary.1 Headbox oxygen is generally well tolerated, although the limitations placed on mobility are undesirable when prolonged oxygen treatment is required. Furthermore, the enriched oxygen environment is disturbed when feeding or suctioning is required.5 Giving oxygen by headbox needs relatively high flows to achieve adequate concentrations of oxygen and avoid carbon dioxide accumulation. Carbon dioxide toxicity may occur with low flows of oxygen caused by kinking or disconnection of the oxygen tubing and inappropriate tight seal of the box around the infant’s neck. A gas flow of 2–3 litres/kg/min is necessary to avoid rebreathing of carbon dioxide (J Tibballs and M Hochmann, Royal Children’s Hospital, Melbourne, unpublished).

FACEMASK (FIG 1B)

As with headbox administration, there is a danger of carbon dioxide accumulation if the flow of gas into the facemask is too low. If spontaneous inspiratory flow rates exceed the delivered oxygen flow rate, then there is room air entrainment through the perforations of the mask. The oxygen concentration delivered varies, depending on the infant’s inspiratory flow rate and the oxygen flow into the system. The effective oxygen fraction (hypopharyngeal oxygen fraction, FIO2) is difficult to predict, but it is rarely above 40%.6 However, there are no data in newborns and infants. Small children will often refuse to keep a mask over their face. The mask also interferes with feeding.

OXYGEN ADMINISTRATION BY HOLDING AN OXYGEN SOURCE NEAR THE INFANT’S FACE (FIG 1C)

This kind of oxygen administration is widely used for short periods—for example, after extubation.

Abbreviations: FIO2, inspired oxygen fraction; FHO2, hypopharyngeal oxygen fraction; PaO2, arterial oxygen tension; PEEP, positive end expiratory pressure; CPAP, continuous positive airway pressure.

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or when breast feeding an infant who is on headbox oxygen. Owing to the dilutional effects of ambient air, the effective 
FIO2—that is, the hypopharyngeal FIO2—may be low and is 
unpredictable. Infants dependent on supplemental oxygen 
should be given oxygen by nasal catheter when they are fed; 
this allows a more predictable and stable oxygen delivery.

NASAL CANNULAE (FIG 1D)

Nasal cannulae, nasal catheters, and nasopharyngeal catheters are more invasive methods of giving oxygen, and 
questions arise about airway obstruction, gastric distension, 
the need for humidification, and changes in lung function.

Nasal cannulae are a device ending in two short tapered 
tubes (about 1 cm in length) that are designed to lie just 
within the nostrils. They are also called nasal prongs. This is 
the preferred method of home oxygen therapy in infants.6–8

Older infants with chronic lung conditions may find it difficult 
to keep nasal cannulae on, particularly at night. There is no risk of gastric distension, as it is not possible to 
push them in too far. Humidification is not required with 
nasal cannulae.9

The natural nasal mechanisms are heating 
and humidifying the inspired gases. There is only a slight risk 
of airway obstruction by mucus.2 Weber et al10 observed 
complete nasal obstruction in eight out of 62 children (age 
range seven days to five years) with nasal cannulae.11

The FIO2 reaching the patient’s airway is not easy to 
determine. Vain et al11 measured the Fio2, in the infant’s face; (D) nasal 
cannulae; (E) nasal catheter; (F) nasopharyngeal catheter.

Figure 1

these levels were measured with exceedingly high oxygen 
flows not mentioned in any other paper. Fan and Voyles15 used 
an indirect method to determine the “true” FIO2. They 
measured the transcutaneous Po2 for a given nasal cannula 
flow, and then placed the infants into a headbox to evaluate 
the Fio2 necessary to reach the same transcutaneous Po2 (table 
1). In infants > 3500 g, 1 litre/min 100% nasal cannula oxygen 
produced an actual Fio2 of 30%, which is considerably less than 
the value obtained by Vain et al. However, Fan and Voyles used 
a different nasal cannula system (a 10 F Hudson oxygen cath-
eter was secured under both nares) and the infants studied 
were larger. In fact, they found that smaller infants (< 3500 g) 
required lower flow rates to deliver a given Fio2 (table 1). 
Wilson et al16 measured Fio2 in very premature infants (table 1). 
The 0.5 litre/min value is comparable to the finding of Vain et 
al11 in larger infants. Wilson et al observed wide variation in the 
Fio2 readings for any given infant (however, no measure of 
distribution is given). Finer et al17 measured Fio2 in newborn 
infants receiving low flow nasal cannula oxygen (table 1). 
They found weight dependent values.

The Fio2 studies show that the actual Fio2 depends on the 
cannula flow rate, the Fio2 in the cannula gas flow, the relation 
between prong and nasal diameters, and the patient’s body 
weight. Fio2 may further depend on minute ventilation and 
the relative duration of inspiration and expiration.18 14 Whether 
the amount of mouth breathing affects Fio2 is controversial.19 19 Sedated infants may have compromised 
upper airway patency with decreased minute ventilation.20 21 
Therefore, sedated infants on nasal cannula oxygen may have 
a lower Fio2 than unsedated infants. On the other hand, nasal 
cannula flow has been shown to produce positive distending 
airway pressure,20 21 and Hammer et al22 showed that the application 
of continuous positive airway pressure (CPAP) in 
seated infants improved minute ventilation. Thus, nasal can-
nula oxygen of sufficient flow may increase the actual Fio2 
even in sedated infants. The actual Fio2 may decrease with 
mouth breathing.2 Even neonates are not exclusive nose
breathers; they are preferential nose breathers. The high position of the larynx and consequent close apposition of the tongue to the palate contributes to the difficulty the newborn finds in breathing through the mouth.\textsuperscript{22} However, they may use the mouth for ventilation, both spontaneously and in response to complete nasal occlusion, and this ability increases with postconceptional age.\textsuperscript{22,23} In healthy, awake neonates, reducing the cross sectional area of nasal dimensions by 50% (by occlusion of one nostril) did not affect tidal flow loops or passive respiratory mechanics.\textsuperscript{24} How should the amount of oxygen applied be regulated: by changing the flow rate or the oxygen concentration, or both? Removing the need for an oxygen blender would definitely simplify oxygen delivery. Finer et al\textsuperscript{25} were able to deliver a wide range of FiO\textsubscript{2} values to premature and full term newborns using 100% oxygen and a low range flowmeter (25–200 ml/min). Benaron and Benitz\textsuperscript{26} analysed the theoretical impact of different weaning strategies on the stability of the actual inspired oxygen concentration. Variability in oxygen delivery is minimal when nasal cannula flow is reduced to the lowest possible flow by using undiluted (100%) oxygen; only then should the oxygen concentration be reduced below 100%. This strategy requires microcalibrated flowmeters. The data of Vain et al\textsuperscript{27} suggest that reducing the FiO\textsubscript{2} below 60% has little utility, and that reducing the FiO\textsubscript{2} below 35% does not significantly affect the FiO\textsubscript{2} in the box. However, Sreenan et al\textsuperscript{28} showed that high flows of oxygen administered through 1 mm cannulae generated PEEP: in 1000 g babies, the mean flow required to produce a PEEP of 4.5 cm H\textsubscript{2}O was 1.6 litres/min, and in 2000 g babies, the flow for the same PEEP was 2.3 litres/min (table 2). The same authors showed that high flow nasal cannulae were as effective as conventional nasal CPAP in the management of apnoea of prematurity.

**Table 1** Hypopharyngeal oxygen concentrations (FiO\textsubscript{2}) generated with different methods of oxygen administration

<table>
<thead>
<tr>
<th>Method</th>
<th>Reference</th>
<th>Weight (g)</th>
<th>Cannula/catheter diameter*</th>
<th>Oxygen flow (litres/min)</th>
<th>Mean FiO\textsubscript{2} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headbox</td>
<td>Wilson et al\textsuperscript{29}</td>
<td>932 (mean)</td>
<td>1 mm</td>
<td>0.2</td>
<td>42</td>
</tr>
<tr>
<td>Face mask</td>
<td>Wilson et al\textsuperscript{29}</td>
<td>932 (mean)</td>
<td>1 mm</td>
<td>0.3</td>
<td>40</td>
</tr>
<tr>
<td>Oxygen line to face</td>
<td>Wilson et al\textsuperscript{29}</td>
<td>932 (mean)</td>
<td>1 mm</td>
<td>0.5</td>
<td>45</td>
</tr>
<tr>
<td>Nasal prongs</td>
<td>Finer et al\textsuperscript{17}</td>
<td>590–1315</td>
<td>1 mm</td>
<td>0.2</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Finer et al\textsuperscript{17}</td>
<td>1580–4020</td>
<td>1 mm</td>
<td>0.2</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Vain et al\textsuperscript{11}</td>
<td>1780–4090</td>
<td>1 mm</td>
<td>0.5</td>
<td>45 (SD 9)</td>
</tr>
<tr>
<td></td>
<td>Kuluz et al\textsuperscript{4}</td>
<td>3000–10000</td>
<td>1 mm</td>
<td>1</td>
<td>65 (SD 9)</td>
</tr>
<tr>
<td></td>
<td>Kuluz et al\textsuperscript{4}</td>
<td>3000–10000</td>
<td>1 mm</td>
<td>0</td>
<td>20 (SE 0.4)</td>
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<td>35 (SE 1.7)</td>
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<td>1</td>
<td>45 (SE 1.8)</td>
</tr>
<tr>
<td></td>
<td>Kuluz et al\textsuperscript{4}</td>
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<td>1 mm</td>
<td>2</td>
<td>57 (SE 3.7)</td>
</tr>
<tr>
<td></td>
<td>Kuluz et al\textsuperscript{4}</td>
<td>3000–10000</td>
<td>1 mm</td>
<td>3</td>
<td>70 (SE 2.5)</td>
</tr>
<tr>
<td></td>
<td>Kuluz et al\textsuperscript{4}</td>
<td>3000–10000</td>
<td>1 mm</td>
<td>4</td>
<td>73 (SE 2.7)</td>
</tr>
<tr>
<td>Fan &amp; Voyles\textsuperscript{15}</td>
<td>&lt;3500</td>
<td>10 F</td>
<td>0.5</td>
<td>35†</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fan &amp; Voyles\textsuperscript{15}</td>
<td>&gt;3500</td>
<td>10 F</td>
<td>0.5</td>
<td>28†</td>
</tr>
<tr>
<td></td>
<td>Fan &amp; Voyles\textsuperscript{15}</td>
<td>&gt;3500</td>
<td>10 F</td>
<td>1</td>
<td>31†</td>
</tr>
<tr>
<td></td>
<td>Fan &amp; Voyles\textsuperscript{15}</td>
<td>&gt;3500</td>
<td>10 F</td>
<td>2</td>
<td>35†</td>
</tr>
<tr>
<td>Nasal catheter</td>
<td>Shann et al\textsuperscript{1}</td>
<td>1400–1000</td>
<td>8 F</td>
<td>1.50 ml/kg</td>
<td></td>
</tr>
</tbody>
</table>

*Indirect measurement (owing to positive end expiratory pressure production, the measured value may be higher than the real FiO\textsubscript{2}; see text).

NASAL CATHETERS (FIG 1E)

A nasal catheter is a thin, flexible tube which is passed through the nose and ends with its tip in the nasal cavity. A catheter passed for a distance that is equal to the distance from the side of the nostril to the inner margin of the eyebrow usually reaches the posterior part of the nasal cavity. In infants, this distance is about 2.5 cm. Nasal catheters are usually well tolerated, and they are unlikely to be dislodged. Humidification of the oxygen is not necessary, because the tip of the catheter lies in the nasal cavity.\textsuperscript{7} They can become blocked with mucus, and accumulation of mucus can cause upper airway obstruction. The risk of displacement into the oesophagus, with a risk of gastric distension, is small. However, a nasogastric tube should be in place at the same time (in the same nostril).

There is one physiological study of nasal catheters. In 12 infants, the transcutaneous oxygen tension was measured with 1 litre/min nasopharyngeal oxygen (with the tip of the catheter just visible below the soft palate), and again with the catheter withdrawn so that it was only 2.5 cm inside the nostril (nasal catheter).\textsuperscript{31} The mean transcutaneous oxygen tension was substantially lower when the tip of the catheter was placed in the nose rather than in the pharynx (mean difference 56 mm Hg, 95% confidence limits 34 to 78 mm Hg). Thus, nasal catheters require a higher oxygen flow to achieve a given transcutaneous oxygen tension.

NASOPHARYNGEAL CATHETERS (FIG 1F)

Nasopharyngeal catheters are inserted into the nose to a depth equal to the distance from the side of the nose to the front of the ear, so that the tip of the catheter is just visible in the pharynx below the soft palate when the mouth of the

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The level of the generated PEEP is positively associated with the oxygen flow, the cannula or catheter diameter, and the distance to which the catheter is inserted into the nasal cavity. There is a risk that the catheter will be displaced downward into the oesophagus and cause gastric distension. A nasogastric tube should therefore be passed to permit rapid decompression of the stomach. There is a risk that the infant is open. In infants, this distance is about 7 cm. Like nasal catheters, nasopharyngeal catheters can easily be secured in place so that they are unlikely to be dislodged, and there is no danger of hypercarbia if the oxygen is turned off or the tubing disconnects. Nasopharyngeal catheters can also become blocked with mucus, and accumulation of mucus can cause upper airway obstruction. In the study of Weber et al in the Gambia, in 24 out of 56 children with nasopharyngeal catheters, complete nasal obstruction was observed. For that reason, the catheter has to be taken out and cleaned or changed regularly. Oxygen given through a nasopharyngeal catheter is bypassing the humidifying and warming properties of the nose. Effective humidification is therefore essential to avoid drying of the pharyngeal mucosa and to reduce the likelihood of inspissated secretions.

However, it has been shown that a cheap, unheated bubble humidifier gives acceptable results when low flows of oxygen (0.5–1.0 litres/min) are given in warm climates. Removing and cleaning the catheter twice a day is also of importance. There is a risk that the catheter will be displaced downward into the oesophagus and cause gastric distension. A nasogastric tube should therefore be passed to permit rapid decompression of the stomach.

There are two studies evaluating the flow rates through nasopharyngeal catheters necessary to achieve adequate oxygenation. Shann et al indirectly measured the effective Fio2. They showed that, in children less than 2 years old, a flow of 150 ml/kg/min through an 8 F nasopharyngeal catheter resulted in the same transcutaneous oxygen tension as placing the child in a headbox containing 50% oxygen (table 1). Further, they found that the smaller 5 or 6 F catheters were much less effective than 8 F catheters. They recommended 0.5 litres/min oxygen through an 8 F nasopharyngeal catheter in newborn infants with pneumonia, and 1 litre/min in infants up to 12 months, in accordance with the WHO guidelines. Weber et al determined in a crossover design (nasopharyngeal catheters and nasal cannulae) the flow rates necessary to achieve a pulse oximeter oxygen saturation of 95% in 60 children with a lower respiratory tract infection. The cannulae needed, on average, 26% higher oxygen flow rates than the nasopharyngeal catheters (p = 0.003).

Table 2 Positive end expiratory pressure (PEEP) generated with different methods of oxygen administration

<table>
<thead>
<tr>
<th>Method</th>
<th>Reference</th>
<th>Weight (g)</th>
<th>Cannulae/catheter diameter*</th>
<th>Oxygen flow (litres/min)</th>
<th>PEEP (cm H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headbox</td>
<td>No data</td>
<td>0</td>
<td>1 mm</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Facemask</td>
<td>No data</td>
<td>0</td>
<td>1 mm</td>
<td>1.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Oxygen line to face</td>
<td>No data</td>
<td>0</td>
<td>2 mm</td>
<td>2.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Nasal cannulae</td>
<td>Locke et al1</td>
<td>1600 (mean)</td>
<td>1 mm</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 mm</td>
<td>1</td>
<td>0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1 mm</td>
<td>2</td>
<td>0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3 mm</td>
<td>0.5</td>
<td>1.4 (SE 0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 mm</td>
<td>1</td>
<td>4.2 (SE 0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 mm</td>
<td>2</td>
<td>9.8 (SE 1.0)</td>
</tr>
<tr>
<td></td>
<td>Sreenan et al20</td>
<td>1000</td>
<td>1 mm</td>
<td>1.6</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000</td>
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<td>2.3</td>
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<tr>
<td></td>
<td></td>
<td>2 mm</td>
<td>1</td>
<td>2.4 (SD 3.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frey et al21</td>
<td>5900–11800</td>
<td>6 F</td>
<td>1</td>
<td>0.8 (SE 0.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3900–11800</td>
<td>8 F</td>
<td>0.5</td>
<td>1.6 (SD 1.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 F</td>
<td>1</td>
<td>2.8 (SD 2.7)</td>
<td></td>
</tr>
<tr>
<td>Nasal catheter</td>
<td>No data</td>
<td>0</td>
<td>2</td>
<td>4.0 (SD 2.9)</td>
<td></td>
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<td>Frey et al21</td>
<td>5900–11800</td>
<td>6 F</td>
<td>1</td>
<td>0.8 (SD 0.3)</td>
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<td></td>
<td></td>
<td>8 F</td>
<td>1</td>
<td>2.8 (SD 2.7)</td>
<td></td>
</tr>
</tbody>
</table>

*1 mm cannula: Infant Nasal Cannula, Salter Labs, Arvin, California, USA; 2 mm cannula: Pediatric Nasal Cannula, Salter Labs; 3 mm cannula: no 3331, Hospitalk, Inc, Lindenhurst, New York, USA.

CONCLUSION

There are non-invasive means of oxygen administration (headbox oxygen, holding an oxygen line to the infant’s face, and facemask oxygen) and methods involving the insertion of cannulae or catheters for a defined distance into the upper airways (“semi-invasive”). In the latter methods, the impact on lung function has to be taken into account. There is uncontrolled PEEP production, which may be beneficial up to a moderate degree of about 5 cm H2O by altering the viscoelastic properties of the lung, but may be detrimental if higher. The level of the generated PEEP is positively associated with the oxygen flow, the cannula or catheter diameter, and the distance to which the catheter is inserted into the nasopharyngeal airway, and negatively with the infant’s weight. In premature infants (1000 g), up to 1 litre/min given through 1 mm nasal cannulae is safe, and in infants (4–12 kg) up to 1 litre/min given through 2 mm nasal cannulae or 8 F nasopharyngeal catheters is safe with regard to the risk of excessive PEEP production.

“Oxygen treatment is often life saving, but medical oxygen is very expensive for developing countries and therefore methods involving low oxygen flow are economically advantageous.”
Oxygen treatment is often life saving, but medical oxygen is very expensive for developing countries and therefore methods involving low oxygen flow are economically advantageous. Headboxes and facemasks need high flows to achieve adequate oxygenation. The “semi-invasive” methods (cannulae and nasopharyngeal catheters) need less oxygen, with nasopharyngeal catheters being the most economic method. The use of uniluted oxygen is advantageous: there is no need for a blender, and weaning can be achieved by simply decreasing the oxygen flow.

All methods of oxygen administration need supervision by trained personnel to detect and manage complications appropriately. The main complications are hypercarbia with headbox and facemask oxygen, dislodgement with nasal cannulae, and obstruction of the catheter or upper airway, as well as gastric distension, with nasopharyngeal catheters.

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