Oxygen therapy for acute respiratory infections in young children in developing countries

Programme for the Control of Acute Respiratory Infections

World Health Organization
Geneva
OXYGEN THERAPY FOR ACUTE RESPIRATORY INFECTIONS IN YOUNG CHILDREN IN DEVELOPING COUNTRIES

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1. REVIEW OF THE USE OF OXYGEN THERAPY

Anoxaemia not only stops the machine but wrecks the machinery.
JS Haldane, 1919

Oxygen was first isolated by Priestley in 1744 and used therapeutically by Beddoes in 1798. However, for many years oxygen was not given properly and most doctors thought it was ineffective; it was administered to patients who were not hypoxaemic, and who would therefore not benefit from it; it was delivered by ineffective means, usually at a very low flow rate through a funnel held near the patient's face, but also by nasogastric tube, subcutaneously and even intravenously; and it was given only intermittently, for example, for 10 minutes every four hours.

Oxygen therapy was first used in a logical way by JS Haldane, who treated soldiers affected by toxic chlorine gas during the First World War. Haldane stressed that the body has practically no stores of oxygen, so that therapy needs to be continuous, and he developed equipment that delivered oxygen cheaply and effectively.

1.1 DOES OXYGEN THERAPY REDUCE MORTALITY IN PNEUMONIA?

For a patient with severe or very severe pneumonia who is dying from lack of oxygen, it seems logical to give oxygen to keep the patient alive until the body defences and antibiotics have had time to kill the pathogens causing the infection. Unfortunately, no randomized controlled trials were conducted when oxygen therapy was first introduced into clinical practice in about 1920; however, there is indirect evidence of its effectiveness.

1.1.1 An animal study (pre-antibiotics), 1928

Binger and associates at the Mayo Clinic anaesthetized guinea-pigs with ether, and then injected into their lungs streptococci cultured from the throats of healthy humans. Of 70 guinea-pigs kept in air, 66 (94%) died within 2 weeks, while of 45 guinea-pigs kept in 50% oxygen for 24 to 48 hours only 22 (49%) died within this period; the mortality was 45% lower with oxygen (95% confidence limit 30% to 61%).
1.1.2 Retrospective controls in humans (pre-antibiotics), 1919-1929

The case-fatality rate for pneumonia varies greatly from year to year, so retrospective controls can be used only if details are available about the severity of the disease. Mortality from pneumonia has been shown to be related to the oxygen saturation of arterial blood,\(^5,6\) the presence of bacteraemia, the serotype of the organism (in pneumococcal pneumonia) and the age of the patient.\(^7\)

Measurement of the oxygen saturation of arterial blood became possible at just about the time when oxygen therapy began to be used routinely, so few patients with pneumonia had oxygen saturation measured without receiving oxygen therapy. Stadie reported such measurement in 33 adults who did not receive oxygen;\(^5\) however, since he did not report the age of his subjects, age could not be included in the analysis. The mortality in Stadie’s patients can be compared with the mortality in five early studies of oxygen therapy in which oxygen saturation was measured\(^9,10,11,13\) and one large series of patients for which oxygen saturation can be estimated because the degree of cyanosis was carefully recorded.\(^5\) All these reports were from the Rockefeller Institute Hospital\(^8,10,11,13\) and the Presbyterian Hospital\(^5,12\) in New York, or the Massachusetts General Hospital\(^9\) in Boston. The results of the analysis are shown in Table 1. Adjusted for the severity of illness, mortality was 39% with oxygen and 74% without oxygen. No effective chemotherapeutic treatment was then available.

Table 1

<table>
<thead>
<tr>
<th>Died/total (%) died</th>
<th>Without oxygen</th>
<th>With oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation(^a) &lt; 80%, bacteraemia:</td>
<td>2/2 (100)</td>
<td>15/21 (71)</td>
</tr>
<tr>
<td>Saturation &lt; 80%, no bacteraemia:</td>
<td>12/13 (92)</td>
<td>19/52 (37)</td>
</tr>
<tr>
<td>Saturation &gt; = 80%, bacteraemia:</td>
<td>2/4 (50)</td>
<td>3/8 (38)</td>
</tr>
<tr>
<td>Saturation &gt; = 80%, no bacteraemia:</td>
<td>2/15 (13)</td>
<td>2/12 (17)</td>
</tr>
<tr>
<td>Total, adjusted for severity of illness:</td>
<td>74% died</td>
<td>39% died</td>
</tr>
</tbody>
</table>

\(^a\) Saturation represents oxygen saturation of arterial blood.
1.1.3 Concurrent controls in humans (with antibiotics, 1966-1967)

It is expensive and difficult to transport oxygen cylinders to rural areas. In Papua New Guinea, from mid-1976 to mid-1977 at Tari in the Southern Highlands, oxygen was available for only about two out of every four weeks. Treatment was given according to a standard protocol. When oxygen was available, it was given at 0.5 l/min via nasopharyngeal catheter to any child who was cyanosed or restless. For eight children, oxygen therapy was begun but supplies of oxygen ran out before clinical cyanosis or restlessness had resolved. The outcome of treatment was recorded by Dr David Smith (unpublished data), and the results are presented in Table 2. A clear trend towards a reduction in mortality with oxygen therapy is seen, but the number of children studied was small and the effect does not reach statistical significance.

Table 2

<table>
<thead>
<tr>
<th>Oxygen therapy and mortality from pneumonia</th>
<th>No oxygen</th>
<th>Some oxygen</th>
<th>Ample oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>in children with cyanosis or restlessness, Tari, Papua New Guinea, 1976-1977</td>
<td>(n=32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number who survived</td>
<td>9</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Number who died (%)</td>
<td>6 (40.0)</td>
<td>2 (25.0)</td>
<td>1 (11.1)</td>
</tr>
</tbody>
</table>

Conclusion

The evidence presented here has to be interpreted cautiously. The results of the guinea-pig study may not apply to humans, and few details were given in the report. There are two problems with the analysis of mortality from pneumonia in humans just before and just after the introduction of oxygen therapy: we do not know what differences there were in treatment other than oxygen therapy, and we cannot be certain that the two groups of patients were comparable, although it was possible to adjust for known risk factors, with the exception of age. Interpretation of the study of the effect of oxygen therapy on mortality from pneumonia in children in Papua New Guinea is hampered by the small number of patients in each group; the trend towards a lower mortality with oxygen therapy does not reach statistical significance. However, despite these shortcomings, the evidence presented here suggests that there is a substantial reduction in mortality when oxygen is given to
patients with very severe pneumonia who are hypoxaemic. It must also be borne in mind that considerable morbidity, including brain damage, may result from prolonged hypoxaemia in children who survive.

It is clear that the above-mentioned studies and analyses have serious methodological inadequacies. They represent, however, the best information which can be found in the literature. What is relevant is the consensus among scientists and clinicians about the life-saving benefits of oxygen therapy for pneumonia patients with signs of decreased oxygen saturation. On the basis of the general consensus it is therefore important to develop inexpensive and reliable ways of providing oxygen to children with very severe pneumonia or severe pneumonia with cyanosis, and to advise health workers at small hospitals in developing countries on the minimum set of signs that can be reliably used to institute oxygen therapy.

1.2 INDICATIONS FOR THE USE OF OXYGEN

There are relatively few published studies that have explored the relationship between individual clinical signs and hypoxaemia. The strength of the published evidence for each of the clinical signs recommended in 1990 by WHO is summarized below.

1.2.1 Central cyanosis

There is no doubt that central cyanosis is the best clinical sign of hypoxaemia. However, cyanosis is a late and therefore relatively insensitive sign (particularly in the presence of anaemia), it may be difficult to detect in pigmented races or in poor lighting, and observers often disagree about whether cyanosis is present. Of six studies that measured pO₂ (partial pressure of oxygen) or oxygen saturation in children with cyanosis caused by an acute respiratory infection (almost all the patients studied had bronchiolitis), all but one concluded that cyanosis was the best sign of hypoxaemia. The exception was a small study of 18 children with bronchiolitis which measured pO₂ in "arterialized" capillary blood; this technique is inaccurate. Two recent studies confirmed that cyanosis is a very specific but insensitive sign of hypoxaemia, measured by pulse oximetry, in children. Both studies were, however, conducted at high altitudes, in the Peruvian Andes (3750 m) and in Nairobi, Kenya, (1670 m); in these situations, where children have an increased risk of hypoxaemia and may be less able to compensate, many more children than those presenting with central cyanosis would require oxygen therapy. In the Kenyan study, Onyango et al. found that a mother's report of cyanosis ("blueness") was the best
single predictor of hypoxaemia in young infants less than 3 months of age.

### 1.2.2 Inability to drink

None of the studies referred to above\textsuperscript{6,18,24} provided data relating inability to drink (or to feed in young infants) when caused by an acute respiratory infection, to hypoxaemia. Mulholland et al. (unpublished) collected data about inability to feed and oxygen saturation: they found no difference between the saturation levels of children who fed poorly and children who fed well. However, the study involved children with bronchiolitis rather than pneumonia\textsuperscript{28} and only 2 of 48 children were unable to feed (26 of the 48 fed poorly). Two studies in Papua New Guinea\textsuperscript{16,25} found a relationship between inability to feed and mortality from pneumonia, but pO\textsubscript{2} and oxygen saturation were not measured in these studies.

### 1.2.3 Severe chest indrawing

Hall et al.\textsuperscript{18} found no relationship between hypoxaemia and chest indrawing in children with bronchiolitis. Mulholland et al.\textsuperscript{28} reported that chest indrawing was present in 7 (58\%) of 12 children with bronchiolitis and less than 90\% saturation, compared with only 13 (30\%) of 44 with saturation of 90\% or more; although this difference is not statistically significant, there was a significant difference between the oxygen saturation levels of children with and without severe chest indrawing (unpublished data). The relationship between chest indrawing and saturation disappears when cyanosis is included in the model; that is, once cyanosis has been taken into account, chest indrawing does not help in the prediction of hypoxaemia. Reynolds\textsuperscript{32} studied 10 infants with bronchiolitis. Analysis of his data shows a statistically significant relationship between hypoxaemia and chest indrawing but, as in the previous study,\textsuperscript{70} this relationship disappears when cyanosis is included in the model. Berman et al.\textsuperscript{26} measured oxygen saturation in 30 children with an acute respiratory infection in Denver, Colorado, and found a statistically significant relationship between chest indrawing and hypoxaemia. None of these children had cyanosis. Contrasting results were provided by Reuland et al.\textsuperscript{24} from Peru (3750 m above sea level) and Onyango et al.\textsuperscript{6} from Nairobi (1670 m): chest retractions had a low sensitivity (35\%) and a high specificity (94\%) as a predictor of hypoxaemia (measured by pulse oximetry) in the former study, and a high sensitivity (88\% to 97\% depending on age group) and a low specificity (20\% to 30\%) in the latter. A study conducted in Bogotá, Colombia (2640 m), gave conclusions similar to those reported from Nairobi (Lozano et al., unpublished data).
1.2.4 Over 70 breaths/minute (in children 2 months up to 5 years old)

Hall et al.\textsuperscript{18} and Reynolds\textsuperscript{21} both found a correlation between hypoxaemia and respiratory rate in children with an acute respiratory infection, mainly bronchiolitis. However, since both studies failed to distinguish between multiple observations on the same individual and observations on different individuals, their conclusions are open to question. Two recent studies\textsuperscript{10,26} have found no relationship between respiratory rate and hypoxaemia (most of the subjects had bronchiolitis). In contrast, Reuland et al.\textsuperscript{24} reported that fast breathing, as defined by WHO (40 or more breaths per minute), had a 68% accuracy in predicting oxygen saturation status in children 12 to 60 months old, at an altitude of 3750 m, when combined with a history of rapid breathing and chest retractions in a logistic regression model; each of the three variables had an adjusted odds ratio of about 3.5. In the same study, fast breathing was not a predictor of hypoxaemia in infants. Onyango et al.\textsuperscript{8} found, using a logistic regression model, that a respiratory rate of 70 breaths/minute or more in infants 3 to 11 months old and of 60 or more in children 12 months and older were the best predictors of hypoxaemia measured by pulse oximetry at an altitude of 1670 m. Lozano et al. (unpublished data) reported that a threshold of 50 breaths/minute or more in infants had 76% sensitivity and 71% specificity as a sign of hypoxaemia at an altitude of 2640 m. In older children the best cut-off point was 40 breaths/minute or more (sensitivity 73%, specificity 61%), while 70 or more had 100% specificity but a very low sensitivity. In a large prospective study of children with pneumonia in Goroka, Papua New Guinea,\textsuperscript{25} the proportion of children taking more than 60 breaths/minute was similar for severe pneumonia (73% of 278) and fatal pneumonia (63% of 59), and there was no difference in the proportion of children taking more than 60 breaths/minute among those with bacteraemia (58% of 60) and those without bacteraemia (58% of 180). Shann et al.\textsuperscript{10} found no relationship between a respiratory rate greater than 70 breaths/minute and mortality in children with severe pneumonia. Further studies, in which altitude will have to be taken into account, are required to resolve these inconsistencies.

1.2.5 Grunting (in young infants less than 2 months old)

Harrison et al.\textsuperscript{27} showed that grunting is a protective mechanism in hypoxaemic babies with hyaline membrane disease. However, the evidence for identifying grunting as a clinical sign of hypoxaemia and an indication for oxygen administration in infants less than 2 months old is conflicting. In Papua New Guinea, Spooner et al.\textsuperscript{25}
found that grunting was more common in children who died than in children with moderate pneumonia. However, both Shann et al.\textsuperscript{16} and Spooner et al.\textsuperscript{25} found no difference between fatal pneumonia and severe pneumonia in the proportion of children with grunting. In Gambia, Campbell et al.\textsuperscript{28} found that children with lobar pneumonia were more likely to be grunting than children who did not have lobar pneumonia, but grunting was present in only 6 of the 216 children studied, and the sensitivity was only 12%. In Kenya,\textsuperscript{4} grunting was not significantly associated with hypoxaemia in young infants less than 3 months of age, but had a sensitivity of 64% and 56% and a specificity of 56% and 76% in infants 3 to 11 months and in children older than 12 months, respectively.

1.2.6 Restlessness (if improved by the administration of oxygen)

Morrison\textsuperscript{19} studied children with acute respiratory infections admitted to St Mary's Hospital, London, and concluded that restlessness was the best guide to the presence of hypoxaemia. However, she studied only 18 children (and only half of them were hypoxaemic), the nature of their illness was poorly defined (they most probably had bronchiolitis), and she used an unreliable measure of hypoxaemia ("arterialized" capillary blood). Three subsequent studies\textsuperscript{18,21,23} have found no relationship between restlessness and hypoxaemia.

Conclusion

Table 3 summarizes the evidence for a relationship between these individual clinical signs and hypoxaemia or mortality associated with severe pneumonia. In addition to the published evidence, other factors have to be taken into account when deciding the indications for oxygen therapy in young children with severe pneumonia. In a situation in which hypoxaemia cannot be measured, such as in most small hospitals in developing countries, the indications for oxygen therapy have to be based on clinical signs that are not only associated with hypoxaemia and increased mortality, but also practical and for which the consequences of a wrong result are unlikely to be dangerous. Despite the conflicting evidence, the clinical signs recommended by WHO\textsuperscript{14} meet these requirements: they are safe and they can be applied in most situations.
### Table 3
Strength of the evidence for a relationship between individual clinical signs and hypoxaemia or mortality associated with severe pneumonia

<table>
<thead>
<tr>
<th>Clinical sign</th>
<th>Evidence of relationship to hypoxaemia</th>
<th>Evidence of relationship to mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central cyanosis</td>
<td>Strongly related(^6,8,15,18-24)</td>
<td>Strongly related(^16,25)</td>
</tr>
<tr>
<td>Inability to drink or feed</td>
<td>Little data</td>
<td>Related(^16,25)</td>
</tr>
<tr>
<td>Severe chest indrawing</td>
<td>Weakly related(^6,18,20,22,24,28)</td>
<td>Weakly related(^16)</td>
</tr>
<tr>
<td>Over 70 breaths/minute (in children 2 months up to 5 years old)</td>
<td>Possibly related(^6,18,21,24)</td>
<td>Not related(^16,25)</td>
</tr>
<tr>
<td>Grunting (in young infants less than 2 months old)</td>
<td>Weakly related(^6,27,28)</td>
<td>Not related in children(^16,25)</td>
</tr>
<tr>
<td>Restlessness (if improved by oxygen)</td>
<td>Not related(^14,21,23)</td>
<td>No data</td>
</tr>
</tbody>
</table>
2. THE OXYGEN DELIVERY SYSTEM

It is important to recognize that in making oxygen therapy continuously available to patients, the choice of equipment and ways to use it must be influenced by the personnel and infrastructure that are available. The equipment cannot stand alone; it always needs people to understand, operate and repair it, and supplies and spare parts to keep it working. What is described next are the systems (i.e., the sources of oxygen and the equipment needed to administer it) and the methods of administering oxygen. In each section, the conclusions and recommendations reflect the opinion of the majority of expert paediatricians, and take into account the personnel and infrastructure available in the "average" small hospital in developing countries. Different levels of personnel and infrastructure may entail a different choice of systems and methods of administering oxygen.

2.1 SOURCES OF OXYGEN

Oxygen supplies need to be available at all times. The two main sources of oxygen for developing countries are cylinders and oxygen concentrators.

2.1.1 Oxygen cylinders

Oxygen for cylinders is produced by cooling air until it liquifies, and then distilling the liquid to separate pure oxygen from it. Because of the very low temperatures required, below -180°C, this process has a high energy consumption and can only be done in large manufacturing plants. It is an expensive process.

Oxygen cylinders are heavy and difficult to transport. The cylinders have to be transported back to the bulk supply depot to be refilled, as well as from the depot out to the point of use. Transport is often unreliable in developing countries, and expensive, so there are often long periods when small hospitals in developing countries have no supplies of oxygen.

Medical oxygen is very expensive in some developing countries and may have to be imported, therefore consuming scarce foreign currency. For instance, in Papua New Guinea, with bulk purchase of large (7600-litre) cylinders, a continuous flow of 1 l/min of oxygen costs approximately US$ 6 per day, or US$ 2190 per year; this price does not include the cost of transport, which is
considerable for rural areas, and it may be even greater if small orders are placed or small cylinders are used. For example, it costs US$ 14 per day or US$ 5110 per year for a continuous flow of 1 l/min from 440-litre cylinders purchased in bulk. A recent article compared the cost of oxygen from cylinders and from concentrators in Papua New Guinea and found significant cost savings with the latter, ranging from 25% in the smallest hospitals to 75% in large district hospitals. A further study showed a significant cost saving when 101 oxygen concentrators for anaesthesia were installed in all district hospitals in Malawi. These savings were estimated by comparing the costs of running the concentrators with those the Ministry of Health of Malawi would have incurred if the same amount of oxygen had been supplied with cylinders. The estimated annual savings for oxygen amounted to about £137,000, or 1.27% of the total health budget for the fiscal year 1987/88. These promising results need to be confirmed by further cost studies in other settings in developing countries.

Industrial oxygen is often much cheaper than medical oxygen and may be easier to obtain. As the principle of manufacture is identical to that of medical oxygen, chemical impurities are unlikely in either form. Industrial oxygen is therefore usually safe for medical use and can be used instead of medical oxygen. If oxygen is obtained from an industrial source however, hospital administrators or persons in charge of oxygen supplies must make certain with the manufacturer that the cylinders do indeed contain oxygen and have not previously been used for other gases. The means of cylinder identification must be agreed with the supplier before cylinders are purchased.

2.1.2 Oxygen concentrators

Oxygen concentrators were first produced in the 1960s to provide long-term home oxygen therapy for patients with chronic lung disease in developed countries. An oxygen concentrator separates the nitrogen from the oxygen in air. Most machines use an electrically powered compressor to force compressed air through synthetic aluminium silicate (zeolite), which reversibly binds nitrogen. They deliver approximately 2-4 l/min of gas containing over 90% oxygen; the concentration of oxygen is less at higher flow rates.

There have been recent improvements in the design and manufacture of oxygen concentrators, making them more reliable, smaller, lighter and cheaper. A working group established by WHO and the World Federation of Societies of Anaesthesiologists has drawn up requirements for concentrators to be used in adverse conditions, which are based on the international standard for oxygen concentrators. In order to meet the WHO specifications,
concentrators are required to operate at temperatures of up to 43°C, a relative humidity of 90-95% and altitudes of up to 4000 m. A vibration test, to simulate the hazards of transport over rough terrain, and a corrosion test are also specified. Machines meeting these specifications are now being field-tested to assure their suitability for use in developing countries. Their performance should be closely monitored since to date there is relatively little experience with their use in such settings.

Existing concentrators require a regular AC power supply of about 300 watts from mains or a back-up generator. It is recommended that an oxygen cylinder be kept in addition as a back-up in case of breakdown or power failure. Oxygen concentrators are much more reliable now than they used to be. Typically, all that is required for their regular maintenance is that the user wash a filter each day and replace two other filters every 3 to 6 months. Skilled mechanical maintenance is needed at intervals of about one year. Concentrators do malfunction occasionally, and their repair can require considerable expertise; worn parts on the compressor and valves may need replacement, so that adequate stocks of filters and spare parts must be included in the initial purchase. In Malawi, two technicians were trained abroad for 3 months, six more received 4 weeks' training locally, and filters and spare parts were provided for 5 years. The performance of the concentrators was monitored twice a year and found to match the specifications for 26 months.

Some malfunctions cause oxygen concentrators to pump out air rather than oxygen, so it is important to be able to test the oxygen concentrations delivered, and not just check for a gas flow. The models meeting the WHO specifications have a built-in device, called an OSD (Oxygen Sensing Device), which measures the oxygen concentration just before the outlet. A warning is given when the concentration is low, and the machines switch off if the concentration of oxygen falls below 70%. In models which are not fitted with such a device, the concentration of oxygen needs to be checked at regular intervals using a separate oxygen analyser. It is advisable to check the concentration of oxygen in the models fitted with an OSD as well, though less frequently (twice a year, for example). The measurement must be carried out about 10 minutes after switching the concentrator on, since this is the average time taken by the machine to build up the desired (90-95%) concentration of oxygen. Oxygen concentrators cost about US$ 1500-2000 each; because cylinders of oxygen are so expensive, concentrators can result in large savings in cost, but they should only be used where there is a reliable electricity supply and adequate maintenance and repair facilities. WHO recommends that only models meeting the technical specifications mentioned above be used in small hospitals in developing countries.
Conclusion

The advantages and disadvantages of oxygen cylinders and oxygen concentrators are compared in Table 4. Observations in many developing countries indicate that cylinder-based oxygen delivery systems fail to reach the majority of small hospitals, owing to lack of transport, infrastructure and funds. Concentrator-based systems have the potential to reach many more such hospitals at a lower cost. But hospitals may find it difficult to meet the essential requirements (regular maintenance and a reliable power supply). Small hospitals in developing countries in which the supply of oxygen cylinders is absent, unsatisfactory or too expensive, should consider the purchase and use of oxygen concentrators as a promising alternative.

Table 4

<table>
<thead>
<tr>
<th></th>
<th>Cylinders</th>
<th>Concentrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Running cost</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Reliability</td>
<td>Excellent</td>
<td>Good on selected models</td>
</tr>
<tr>
<td>Regular maintenance</td>
<td>Simple care only</td>
<td>Needed</td>
</tr>
<tr>
<td>Electricity</td>
<td>Not needed</td>
<td>Needed</td>
</tr>
<tr>
<td>Continuity of oxygen</td>
<td>Liable to run out</td>
<td>Good, unless they break down or</td>
</tr>
<tr>
<td>delivery</td>
<td></td>
<td>power fails</td>
</tr>
<tr>
<td>Supply system</td>
<td>Transport needed</td>
<td>Transport not needed</td>
</tr>
</tbody>
</table>

2.2 EQUIPMENT FOR THE ADMINISTRATION OF OXYGEN

In large hospitals, oxygen pipeline systems are often used to deliver oxygen to each bed. These are expensive, require complex and difficult engineering and are therefore impractical for small hospitals in developing countries. In these hospitals the traditional solution has been to wheel cylinders of oxygen to the beds of patients requiring treatment. The following sections describe and discuss the equipment available to convey oxygen from the source, a cylinder or a concentrator, to the patient.
2.2.1 Using cylinders with single patients

Oxygen cylinders are filled with gas at a very high pressure. A regulator, also known as a reducing valve, is needed to reduce this pressure to a constant lower working pressure and to allow the flow of gas to be controlled rather than determined by the pressure remaining in the cylinder.

There are a number of different cylinder connectors; the regulator must match the cylinder connector so as to be able to connect with it. The most commonly found connectors are the pin-index and the bull-nose, but others exist in different parts of the world: handwheel, air liquide and American olive. Before ordering a regulator, the user must check which type of connector is needed.

Regulators should include a high pressure gauge which indicates the amount of oxygen remaining in the cylinder. Full cylinders usually contain oxygen at a pressure of about 13,400 kPa (132 atmospheres or bars, or 2000 p.s.i.). When the pressure falls below 800 kPa (8 atmospheres or bars, or 120 p.s.i.), the cylinder is nearly empty.

A flow control device must be attached downstream from the regulator to allow the flow of oxygen to the patient to be precisely set. There are two sorts of flow control devices:

a. Variable orifice flowmeters, in which the flow is controlled by a knob which adjusts a needle valve. The flow is usually indicated by a ball in a tube. For paediatric use it is desirable to have a flowmeter with a range of 0-2 l/min, rather than the 0-16 l/min flowmeters used for adults.

b. Fixed-orifice flow controllers, in which the flow is controlled by a series of fixed-size openings using a control knob. Flows of 0.5, 1, 1.5, 2, 4 and 5 l/min are usually available. Fixed-orifice flow controllers are often sold already combined with a regulator in a single unit.

Variable orifice flowmeters are widely used and those for adults are readily available. Health workers are more likely to be familiar with this sort of flow control device. They allow any flow at all to be set that is within the range and limits of accuracy of the instrument. Low-flow paediatric versions, however, are often more expensive and difficult to obtain.

Fixed-orifice flow controllers are accurate at the flows for which they are designed. They are more robust than variable orifice flowmeters. For paediatric use they must be capable of delivering a flow of 0.5, 1 and 2 l/min. Usually they offer other flows and a range up to 5 l/min is desirable. They cannot give intermediate flows between their fixed settings, but intermediate flows (say
0.8 l/min) are rarely prescribed, and with flowmeters such small adjustments of flow are limited by the accuracy of the instrument and the skill of the user.

Either type of flow control device is adequate. Variable orifice flowmeters are more widely available, but new purchasers may choose fixed-orifice flow controllers because of their robustness, compactness and possible cost advantage. A regulator and a flow control device in a single unit are less likely to get lost or damaged.

If oxygen is to be given by nasopharyngeal catheter, a humidifier is required downstream after the flow control device. For oxygen delivered through nasal catheter or prongs, humidification is not needed, since sufficient humidity is added by the nose when the catheter or prongs are correctly placed. Humidifiers require care and supervision, and their connectors are a potential source of leaks. The water has to be boiled, needs to be replaced every day, and may become colonized by bacteria. Humidifiers must be periodically washed and dried.

A sufficient length, usually about two metres, of non-crush plastic oxygen delivery tubing must be used to link the oxygen outlet to the nasal or nasopharyngeal catheter. Nasal prongs are already supplied with a sufficient length of non-crush plastic oxygen delivery tubing. Non-crush oxygen tubing can be easily identified, because its cross-section is not a ring (the opening is usually star shaped).

2.2.2 Using concentrators with single patients

Oxygen concentrators operate at a low pressure. All the models meeting the WHO specifications have built-in flow control devices and can be fitted with humidifiers if desired. A suitable length, usually about two metres, of non-crush plastic oxygen delivery tubing is the only equipment needed to connect the oxygen outlet to the catheter or prongs (which are already fitted with a sufficient length of non-crush oxygen tubing).

2.2.3 Using one oxygen source for several patients

By far the best way of giving oxygen to several patients is to set aside a part of the health centre or hospital as the oxygen administration area. Patients who need oxygen are moved to this area. This arrangement is convenient for staff (the equipment is permanently set up), it protects the equipment, and it concentrates the sickest patients in one area. Either a concentrator, with a cylinder back-up, or a cylinder alone can be used as sources of oxygen for the treatment of more than one patient. The equipment
needed varies depending on the source and is described in Part 3 of this document.

2.3 METHODS OF OXYGEN ADMINISTRATION

There are many ways of giving oxygen. The best method depends on the needs of the patient receiving it and the resources of the place giving it.

2.3.1 Nasopharyngeal catheter

This is a thin flexible tube which is passed through the nose until its tip lies in the patient’s throat, just beyond the soft palate (Figure 1). A catheter passed for a distance equal to that from the side of the nostril to the front of the ear usually reaches that point in the oropharynx. The tip of the catheter should be visible just below the uvula when the mouth of the child is open. The nasopharyngeal catheter is also known, in some places, as oropharyngeal catheter, because its tip lies in the patient’s oropharynx.

Figure 1

Placement of a nasopharyngeal catheter

![Diagram of placement of a nasopharyngeal catheter]

TIP OF CATHETER
The advantages of this method are that the lowest flow rate of oxygen is required to achieve a given concentration in the airways, the concentration is not reduced if the patient's nostrils are blocked, the catheter can easily be secured in place so that it is unlikely to be dislodged, and there is no danger of hypercarbia (carbon dioxide accumulation) if the oxygen is turned off or the tubing disconnects. With a nasopharyngeal catheter, an oxygen flow of 1 l/min delivers between 45% and 60% of oxygen to a 5 kg child.\(^{36}\) When oxygen is supplied from a cylinder with a flowmeter, the use of a nasopharyngeal catheter can result in considerable savings over other methods of administration.

However, the gas should be humidified (to avoid drying of the pharyngeal mucosa and reduce the likelihood of ininspissated secretions which can block the catheter and cause airway obstruction),\(^{37}\) the catheter must not be pushed in too far (because gastric distension may result), the flow rate must not be greater than 2 l/min (because of the risk of gastric distension), and the catheter must be taken out and cleaned at least twice a day (so that mucus does not block the holes of the catheter). Some children will cough and gag, or even vomit, when a nasopharyngeal catheter is first put in. Some will keep on coughing and gagging, and the catheter should then be withdrawn slightly. Occasionally, a nasopharyngeal catheter will cause obstruction of the airways or even apnoea; continuous and skilled nursing care is needed to prevent or treat these rare but potentially fatal complications. If a nasogastric tube and a nasopharyngeal catheter are used at the same time, they should be placed in the same nostril.

2.3.2 Nasal catheter

This is a thin flexible tube which is passed through the nose and ends with its tip in the nasal cavity, or just within the nasopharynx (Figure 2). 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 that point in the nasal cavity. The tip of the catheter should not be visible when the mouth of the child is open.
Nasal catheters are not as economical as nasopharyngeal catheters, when oxygen is supplied from a cylinder: they require a higher flow to achieve a given concentration of oxygen in the airways. They are usually well tolerated and unlikely to be dislodged. Humidification of oxygen is not necessary (Klein, personal communication). Like nasopharyngeal catheters, they can become blocked with mucus; accumulation of mucus can also cause airway obstruction. The risk of displacement into the oesophagus, and as a consequence the potential risk of gastric distension, is smaller. If a nasogastric tube and a nasal catheter are used at the same time, they should be placed in the same nostril.
2.3.3 Nasal prongs

This is a device for oxygen therapy ending in two short tapered tubes (i.e., a fork or prong) designed to lie just within the nostrils (Figure 3). It is also called nasal cannula in some places and by some manufacturers. Nasal prongs are not as efficient as nasopharyngeal catheters for giving oxygen: the inspired oxygen concentration is limited to about 30-35%. The concentration delivered falls substantially if the child breathes through the mouth (for example, when the nose is blocked by mucus). Nasal prongs can be easily dislodged if they are not fixed to the upper lip with a piece of tape. On the other hand, nasal prongs are comfortable for the patient and there is no danger of gastric distension. Also, humidification is not required with nasal prongs. When used in combination with an oxygen concentrator and a flow splitter, nasal prongs are the cheapest method of oxygen administration.

Figure 3

Placement of nasal prongs

2.3.4 Headbox

Headboxes are widely used in industrialized countries because they are well tolerated by babies and do not need humidification. They
usually require much higher flows of oxygen, as well as a mixing device to ensure the correct oxygen concentration. They are not widely available in small hospitals in developing countries.

Hypercarbia (carbon dioxide accumulation) will occur if the oxygen tubing kinks or disconnects, or if the oxygen flow rate is too low (a gas flow of 2-3 l/kg/min is necessary to avoid rebreathing of carbon dioxide - Tibballs J. and Hochmann M., unpublished data).

The actual concentration inspired is often less than expected in a headbox because the child's mouth and nose are very close to the opening in the box, and because the concentration falls to nearly 21% (room air) every time the headbox is opened to give access to the child's face or head. A further drawback is that oxygen therapy has to be discontinued whilst the child is feeding.

2.3.5 Facemask

As with headbox administration, there is a danger of carbon dioxide accumulation if the flow of gas into the facemask is too low. High flows of oxygen (4 l/min or more) are needed to attain 40% or 50% oxygen with a mask, and small children will often refuse to keep a mask over their face. The mask also interferes with feeding.

2.3.6 Humidification

Oxygen from cylinders or concentrators is completely dry. It is important to humidify (add water to) oxygen being given by nasopharyngeal catheter. If this is not done, the child's pharynx will become dry, sore and inflamed, and there may be an increased risk of local infection. Humidification is not needed if oxygen is given by nasal catheter or prongs, since sufficient humidity is added by the nose when the catheter or prongs are correctly placed.

Heated humidifiers are expensive, difficult to operate, and need electricity. Unheated bubble humidifiers, though less efficient, are cheaper and much easier to use. They are not very efficient at high rates of flow of oxygen, or if the gas is being given by an endotracheal tube; however, they give acceptable results when low flow rates are used in the tropics, where ambient temperatures are high.

The use of a humidifier carries the potential risk of bacterial contamination and health workers need to be trained in methods of preventing this.
Conclusion

Table 5 summarizes the advantages and disadvantages of different methods of oxygen administration. The choice of the method, for each patient and in each hospital, will depend on the availability of equipment, the quality of nursing care, and institutional experience.
### Table 5
Comparison of different methods of oxygen administration to young children

<table>
<thead>
<tr>
<th>Method</th>
<th>Oxygen concentration from 1 l/min in 5 kg child (%)</th>
<th>Danger of carbon dioxide accumulation with low flow</th>
<th>Humidification</th>
<th>Delivery of exact concentration to patient</th>
<th>Change in concentration with mouth breathing</th>
<th>Obstruction of airways by mucus may increase hypoxaemia</th>
<th>Chance that device will dislodge, changing oxygen concentration</th>
<th>Risk of gastric distension with wrong position or high flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasopharyngeal catheter</td>
<td>45-60</td>
<td>No</td>
<td>Required</td>
<td>Not possible</td>
<td>+ a</td>
<td>+++</td>
<td>+ +</td>
<td>+ +</td>
</tr>
<tr>
<td>Nasal catheter</td>
<td>35-40</td>
<td>No</td>
<td>Not necessary</td>
<td>Not possible</td>
<td>+ +</td>
<td>+ +</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nasal prongs</td>
<td>30-35</td>
<td>No</td>
<td>Not necessary</td>
<td>Not possible</td>
<td>+ +</td>
<td>+ +</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Headbox</td>
<td>29 b</td>
<td>Yes</td>
<td>Not necessary</td>
<td>Possible</td>
<td>None</td>
<td>No</td>
<td>+ +</td>
<td>No</td>
</tr>
<tr>
<td>Facemask</td>
<td>Variable</td>
<td>Yes</td>
<td>Not necessary</td>
<td>Not possible</td>
<td>None</td>
<td>No</td>
<td>+ +</td>
<td>No</td>
</tr>
</tbody>
</table>

* a + represents the least danger, change, etc.; + + + the most.

* b With venturi device in the tubing to entrain room air for a total flow of 10 l/min.
In making a recommendation as to which method is more appropriate for small hospitals in developing countries, the criteria listed in Table 6 should be considered.

### Table 6

Criteria for the selection of an appropriate method of oxygen administration to young children in small hospitals in developing countries

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Nasal prongs</th>
<th>Nasal catheter</th>
<th>Nasopharyngeal catheter</th>
<th>Headbox</th>
<th>Face-mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety*</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Simplicity</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Tolerability</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Availability</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Related to the risk of either serious complications or inadvertent hypoxaemia.

In view of these criteria, and particularly in the interest of safety, WHO recommends the use of nasal prongs for most children in most such hospitals. Nasal prongs cannot achieve the higher concentrations of oxygen in the airways that are achievable with a nasopharyngeal catheter. These concentrations, however, are rarely needed: almost all children with hypoxaemia due to lower respiratory tract infections can be well oxygenated using nasal prongs at flow rates of 1 L/min or less (Weber et al., unpublished data). Nasal prongs are less efficient than nasal and nasopharyngeal catheters, and a higher flow of oxygen is needed to achieve a given concentration in the airways. Efficiency, however, is important only when oxygen is scarce and expensive, as is often the case with cylinders; it is a less important concern with concentrators.

If nasal prongs are not available, a nasal catheter can be used. This is preferred to a nasopharyngeal catheter in unsupervised environments where safety is a major concern. Nasal catheters have been used for many years in a large hospital in South Africa without a single adverse effect being reported (Klein, personal communication).

If the use of nasal prongs or nasal catheter does not provide adequate oxygenation (i.e., if the clinical signs for which oxygen is indicated persist), or if the oxygen supply is very limited, a
nasopharyngeal catheter can be used. This is the most efficient method of oxygen administration, but owing to the risk of serious complications it should only be used in places where skilled staff are available for continuous monitoring of oxygen therapy. If the nasopharyngeal catheter is adopted as the usual method in a hospital, another method must be available for those children who cannot tolerate the catheter or who develop serious complications.
3. GUIDELINES FOR OXYGEN ADMINISTRATION

3.1 INDICATIONS

3.1.1 When oxygen is scarce

In situations in which the oxygen supply is very limited, give priority to children with central cyanosis or inability to drink, or to feed in the case of young infants less than 2 months old. In addition, always consider young infants less than 2 months of age with lower respiratory infections as a priority; they have a higher risk of apnoea and respiratory failure if they are not given oxygen when required.

To detect central cyanosis, examine the child’s tongue (not the lips) using daylight or the light from an ordinary light bulb (even normal people look slightly blue in the light from a fluorescent tube). If you have doubts about the presence of cyanosis, compare the colour of the child’s tongue with the colour of his or her mother’s tongue. A child who does not have central cyanosis (from hypoxaemia) may have blue fingers and lips if he or she has peripheral vasoconstriction (from cold stress or shock), and some pigmented races always have blue lips. Children with severe anaemia and hypoxaemia will have pallor rather than cyanosis. If the cyanosis does not improve with oxygen therapy, the child may have cyanotic congenital heart disease.

A child is not able to drink if he or she is not able to drink at all. This includes the child who is too weak to drink when offered fluids, who is unable to suck or swallow, or who repeatedly vomits and keeps nothing down. Breastfeeding children may have difficulty sucking when their noses are blocked. However, if they are not severely ill, they can still breastfeed if their nose is cleared. In the young infant less than 2 months of age, inability to feed means breastfeeding or bottle feeding less than half the amount that the young infant usually takes.

3.1.2 When oxygen is abundant

In situations in which there is an ample supply, in addition to the above, give oxygen to children with severe chest indrawing, with a respiratory rate of 70 breaths/minute or more, or with restlessness (if improved by oxygen). Give it also to young infants who are grunting. Severe chest indrawing is a very deep and easy-to-see
retraction of the lower chest wall when the child breathes in; it is significant only if it is present all the time and clearly visible. Grunting is a short gruff sound that a child makes at the beginning of expiration when he or she has difficulty breathing.

3.1.3 When to stop oxygen therapy

The aim of oxygen therapy is to try and correct severe hypoxaemia. However, in severely hypoxaemic children, correction may not be complete and clinical signs may remain. This does not mean that in such a situation oxygen therapy should be abandoned. Do not interrupt oxygen therapy in a child who is still very ill.

When a child receiving oxygen therapy is improving clinically, he or she should undergo a trial period without oxygen each day. Remove the nasal prongs or catheter (which can be cleaned at this time); alternatively, disconnect the oxygen, if this is less disturbing for the child. Then closely observe the child for about 10 minutes. If he or she is comfortable without oxygen and does not become cyanosed, oxygen therapy is no longer needed.

In the absence of cyanosis, the severity of chest indrawing provides some help in deciding when to stop oxygen therapy. A child who still has severe chest indrawing while on oxygen will probably need to continue oxygen therapy; an improvement in the depth of chest indrawing over a few days suggests that oxygen therapy may no longer be needed. The only way to be sure, however, is to stop oxygen therapy and observe the child. Chest X-ray appearance does not provide any guide to the need for oxygen therapy. There may be little abnormality in the chest X-ray in the first few days of severe pneumonia, and X-ray abnormality often persists long after a child with pneumonia is clinically well.

3.2 WARNINGS ON THE USE OF OXYGEN

Oxygen can cause a fire to spread rapidly. When you administer oxygen, make sure that nobody is smoking. Keep anything that might create a spark or flame, such as portable heaters, stoves and electrical appliances, well away from cylinders, concentrators and tubing; a distance of 1.5 metres is considered safe. Do not use oil or grease on cylinders and concentrators, because if these substances are combined with oxygen the fire risk is greatly increased. Do not use an oxygen concentrator if either the power supply cable or the plug is damaged; replace the cable and plugs if they are damaged. In case of fire, switch off the oxygen flow.
immediately. To avoid fire risk turn the oxygen source off when not in use.

Oxygen cylinders are large heavy objects which could kill a child if they fell over; consequently, install them securely using a strap or chain to fix them to the wall.

3.3 USING OXYGEN CONCENTRATORS

3.3.1 Installation

Oxygen concentrators meeting the WHO specifications are normally supplied with a user's and a maintenance manual which explain how the apparatus works and what the limits of performance are. Read the instructions on how to unpack and install the concentrator. Check in particular that the voltage shown on the packing list is correct for your power supply and that the plug fits the mains power socket. Very carefully read the instructions for using the concentrator and its accessories and the information on necessary regular maintenance.

Place the concentrator close to a mains power socket in a cool part of the building with a good air supply. The room or ward must be well ventilated and there must be good air circulation around the concentrator itself; clearance on all sides must be in accordance with the manufacturer's instructions to allow free circulation of air (Figure 4). Keep the concentrator in the shade and at least 1.5 metres away from any source of heat.

Figure 4

Typical clearance requirements for the placement of an oxygen concentrator
3.3.2 Equipment for the administration of oxygen

There are three ways in which you can use a concentrator to give oxygen:

a. Using a short non-crush oxygen delivery tube and wheeling the concentrator from place to place to individual patients. In this case, connect the tube directly to the tubing adapter at the oxygen outlet of the concentrator (Figure 5). If you use a humidifier, connect it to the oxygen outlet of the concentrator, before the tube. Follow the instructions in the user's manual to mount the humidifier in a vertical position; you may need an angle adapter, provided by the manufacturer, to connect the humidifier to the concentrator.

Figure 5

How to connect a short length of non-crush oxygen delivery tubing to a concentrator
b. Using a long plastic tube, up to 15 metres long, for a single patient, with the concentrator in a fixed position. Connect the tubing to the oxygen outlet of the concentrator and fix it to the wall with cable clips; route it carefully to avoid damage or kinking (Figure 6). If you use a humidifier, connect it to the patient’s end of the tubing to avoid condensation in it. Put the humidifier in a bracket and fix it to the wall in a convenient position (Figure 7). Finally, connect a sufficient length of non-crush oxygen delivery tubing to the end of the long plastic tube or to the outlet of the humidifier, to convey oxygen to the patient.

Figure 6

How to connect a long length of 5 mm internal diameter oxygen distribution tubing to a concentrator

Figure 7

A bubble oxygen humidifier mounted on a wall bracket
c. Using the concentrator to give oxygen to more than one and up to four patients. Specific instructions for using the concentrator in this way are given below.

There are two types of oxygen distribution tubing, both made of plastic, that you can use with a concentrator:

a. 5 mm internal diameter 8 mm external diameter plastic tubing. This can be up to 15 metres long and connects the oxygen source to each cot or bed. Use this type of tubing when you have the concentrator in a fixed position and you want to deliver oxygen to one or up to four patients in a room. You do not need this tube if you wheel the oxygen concentrator to the patient’s bed. Secure all the tubes with cable ties, at their connection with adapters. If necessary, join the tubes using in-line connectors secured on both sides with cable ties.

b. Non-crush oxygen delivery tubing. This is the only tubing required if you wheel the oxygen concentrator to the patient’s bed. It has usually a star shaped opening on cross section and is about 2 metres long. Use it to connect the oxygen outlet at the source or at the end of the fixed tubing to the catheter used for the administration of oxygen to the patient. Nasal prongs are already fitted with a sufficient length of non-crush oxygen tubing.

3.3.3 Initial procedures

With the system for the delivery of oxygen in place, uncoil the power supply cable, connect it to the concentrator, and plug it into the mains power socket. Do not use an extension cable. Switch the concentrator on. A continuous alarm will sound for up to one minute; this is normal. The concentrator should be allowed to run for 5 minutes before use. After this period the oxygen concentration will be up to the specified performance at 4 l/min. An alarm will sound, continuously or intermittently, if there is no power supply or other problems arise; refer to the user’s manual in these cases.

An OSD is fitted to the models meeting the WHO specifications (Figure 8). The OSD shows a green light to indicate normal operation and a concentration of oxygen greater than 85% by volume. A yellow light indicates that the oxygen concentration is between 70% and 85% by volume. A red light indicates that the oxygen concentration is below 70% by volume; a continuous alarm will sound in this case and the concentrator will automatically stop
running. Turn the power off and take remedial action if this happens; refer to the user's and maintenance manuals. The most usual causes of yellow and red lights and the appropriate remedies are:

<table>
<thead>
<tr>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dirty filters</td>
<td>Wash or change filters</td>
</tr>
<tr>
<td>Low voltage</td>
<td>Use a voltage regulator</td>
</tr>
<tr>
<td>Flow more than 4 l/min</td>
<td>Reduce flow</td>
</tr>
<tr>
<td>Hot and humid weather</td>
<td>Reduce flow</td>
</tr>
</tbody>
</table>

**Figure 8**

The Oxygen Sensing Device (OSD) of a concentrator

When the concentrator is on and running regularly, adjust the flow rate to the required value in the range 0-4 l/min by turning the control knob of the flowmeter anti-clockwise. Do not use concentrators at flow settings above 4 l/min. Read the markings at the centre of the ball (Figure 9).

**Figure 9**

The flowmeter fitted in an oxygen concentrator
3.3.4 Regular maintenance

Check each day that the concentrator is running by switching it on and waiting for 5 minutes. If an alarm continues to sound for more than one minute, or a warning light continues to show, or the green light of the OSD does not show, take action as indicated in the user’s and maintenance manuals.

Check the external coarse filter daily and clean it whenever it is dirty. Dirt or lint can easily be seen on this filter and must be removed. To clean the filter, remove it from the concentrator, wash it in soapy water, rinse it in clean water, squeeze out excess water and dry in air. Do not use heat to dry the filter as it may cause damage. Replace the filter on the concentrator, taking care to fasten it all around the edge. Do not operate the concentrator without the external coarse filter in place, or the performance of the concentrator will deteriorate.

Concentrators meeting the WHO specifications have two more filters, the pre-filter and the inlet filter, after the external coarse filter. Check the conditions of these two filters at regular intervals and change them in response to local conditions (dust, humidity) and the use of the concentrator. Typically, these two filters have to be changed every 3 to 6 months. Follow the manufacturer’s instructions on how to change these filters.

There is a fourth filter, called the bacterial filter, just before the oxygen outlet of the concentrator. Follow the instructions of the manufacturer on when and how to change it. Typically, it must be changed every 12 months or more, depending on use.

3.4 USING OXYGEN CYLINDERS

3.4.1 Identification

An international standard exists for the identification of oxygen cylinders, which specifies that they should be painted white. Unfortunately, the standard is widely ignored. Medical oxygen cylinders originating in the United States of America are normally green, while those originating in the United Kingdom and some other countries are usually black with white shoulders. Newly filled cylinders come with a plastic film seal; large cylinders have a protective metal dome.

Cylinders of industrial oxygen should also be identified clearly, but this is not always the case. If oxygen is obtained from an industrial
source, hospital administrators or persons in charge of oxygen supply must make certain with the manufacturer that the cylinders do indeed contain oxygen and have not previously been used for other gases. The means of cylinder identification must be agreed with the supplier before cylinders are purchased.

3.4.2 Installation

Two common types of oxygen cylinder are illustrated: those that accept a pin-indexed regulator (Figure 10), and those that accept a bull-nosed regulator (Figure 11).

**Figure 10**

Pin-indexed regulator

**Figure 11**

Bull-nosed regulator
The pin-indexed regulator has two metal pins which ensure that the regulator can be attached only to a cylinder of oxygen (which has two holes that the pins on the regulator must fit into). When changing pin-index cylinders be careful not to lose the small rubber seal, the Bodok seal, which is only loosely attached to the inlet of the regulator and cannot be replaced with an ordinary rubber seal. Use only a reasonable amount of force to tighten the regulator to the cylinder; do not overtighten the connection.

The bull-nosed regulator has a threaded, thumb-shaped "nose" which screws directly into the oxygen cylinder: this type of regulator can be attached not only to cylinders of medical or industrial oxygen, but also to cylinders containing other gases (the pin-index system is safer in this respect). Be careful not to cross-thread the nose, stripping the thread and ruining the cylinder and the regulator as you connect them. Use only a reasonable amount of force; do not overtighten the connection.

Most regulators include a pressure gauge which indicates the amount of oxygen remaining in the cylinder. The oxygen pressure in a cylinder is very high when the cylinder is full, and falls as the cylinder empties. The regulator ensures a constant low pressure of oxygen, to enable the flow control device to accurately deliver the desired flow of gas to the patient. Regulators for oxygen cylinders are typically calibrated at a delivery pressure of 400 kPa.

The amount of oxygen in the cylinder is directly proportional to the pressure shown on the gauge. When the gauge shows a high pressure, the cylinder is full; when the gauge shows a low pressure, the cylinder is empty or nearly empty. After you have opened the cylinder with the spanner or the keywheel, check the gauge to make sure there is enough oxygen in the cylinder. A full oxygen cylinder normally has a pressure of around 13 400 kPa (132 atmospheres or bars, or 2000 p.s.i.). If the pressure is less than 800 kPa (8 atmospheres or bars, or 120 p.s.i.), you must change the cylinder because it is nearly empty.

Before installing a new cylinder, turn off the cylinder in use by turning the spanner or keywheel fully clockwise. To discontinue the oxygen supply to the patients, which you may wish to do to observe them without oxygen once a day, you only need to turn the flow controller to 0 or to the "off" position. If a cylinder is not in use, turn it off with the spanner or keywheel, rather than just turning the flow controller to 0 or the "off" position.

3.4.3 Equipment for the administration of oxygen

In addition to an oxygen cylinder, you must have a cylinder spanner or keywheel, a regulator with a pressure gauge and a flow
controller. The flow controller may be either a flowmeter or a fixed-orifice device, and may be attached to the regulator or be separate from it. Also required are a 2-metre length of non-crush plastic oxygen delivery tubing to carry the oxygen to the patient, and catheters or prongs for final delivery. Nasal prongs are already fitted with non-crush oxygen tubing. If you use the cylinder to give oxygen to more than one patient, you should have in addition the equipment described in the next section. You need bubble humidifiers only if you administer oxygen using nasopharyngeal catheters. You need a spare bubble humidifier to ensure the continuity of oxygen therapy while the humidifier in use is washed and dried.

3.4.4 Initial procedures

To prepare the equipment, check that the cylinder is labelled "oxygen", remove the plastic seal or the metal dome, carefully screw on the regulator and the flow controller, and fit the non-crush oxygen delivery tubing firmly. Insert a humidifier between the flow controller and the tubing, if required. If your flow controller is a flowmeter with a ball in a tube, make sure that the tube is mounted vertically: the reading is accurate only if the tube is vertical (Figure 12). Check the make of the flowmeter; those manufactured in Europe are usually read at the top of the ball, while American flowmeters are usually read at the centre of the ball.

Figure 12

Low-range (0-2 l/min) flowmeter
Be sure that the connectors are free from dust and foreign bodies. Never apply grease or oil, as it could catch fire in pure oxygen, especially at high pressure.

Fully open the cylinder with the spanner or the keywheel by turning it anti-clockwise, then use the knob on the flow controller to adjust the oxygen flow. Make sure that the non-crush oxygen tubing is firmly attached to the oxygen outlet and that the tubing and catheter, if one is used, are all in place and are not kinked. Check that oxygen is coming out of the catheter or prongs by holding them under water.

3.5 GIVING OXYGEN TO MORE THAN ONE PATIENT

3.5.1 From a concentrator

Fasten the concentrator and a back-up cylinder to the wall with a strap or a chain, in a corner (Figure 13). Use a flow splitter to divide the flow of oxygen to up to four patients (Figure 14). Connect the flow splitter to the oxygen outlet on the concentrator. Carefully screw four nozzles, or a combination of nozzles and blanking plugs, onto the flow splitter ports. Make sure that all the four ports have either a nozzle or a blanking plug; if you leave a port open, the oxygen will escape through it and will not be routed through the other nozzles. If you treat only two or three patients using a concentrator, you do not need to replace the unused nozzles with blanking plugs; the quantity of oxygen lost through unused nozzles does not affect the flow through the used nozzles and does not increase the running cost. It is important, however, that you put a blanking plug on the unused port of the flow splitter when you use a back-up cylinder as a source, to avoid wasting expensive oxygen. Make sure, in addition, that the delivery pressure of the regulator fitted to the back-up cylinder matches the pressure for which the flow splitter has been designed (i.e., the delivery pressure of the concentrator). You may need to procure a special low pressure regulator to use your cylinder as a back-up for a concentrator combined with a flow splitter.
Figure 13

Using a concentrator with a back-up cylinder for four patients

Figure 14

Flow splitter, nozzles and blanking plugs
The nozzles allow only a fixed flow of oxygen to go through fixed-size orifices. Colour coded nozzles for flows of 0.5 and 1 l/min are available for paediatric use. The nozzles allow accurate distribution to patients even when the oxygen distribution tubing to different patients is of different length. Make sure that the total flow shown on the flow controller of the concentrator does not exceed 4 l/min when all the four nozzles are in place. Use 1 l/min nozzles for oxygen therapy in young children 2 months to 5 years old. If you treat young infants less than two months of age, screw onto the flow splitter one or more 0.5 l/min nozzles to replace one or more of the 1 l/min nozzles. If you need to give oxygen at flow rates higher than 1 l/min, combine the output from two nozzles using Y-connectors; for example, combine a 0.5 and a 1 l/min nozzle to give 1.5 l/min.

Connect four lengths of 5 mm internal diameters 8 mm external diameters oxygen distribution tubing to the nozzles and fix them with simple cable clips to the wall at about eye level (Figure 15). Be careful to avoid damaging or kinking the tube. Each of the four tubes can be up to 15 metres long and will end beside a bed or cot. Secure a bubble humidifier on a bracket in the wall at this point, if required.

**Figure 15**

*Oxygen distribution tubing attached to a flow splitter and fixed to the wall*
Attach a flow indicator to the end of the oxygen distribution tubing, or to the outlet of the bubble humidifier, as needed. This device (Figure 16) confirms that the oxygen flowing to the individual patient exceeds 0.35 l/min by showing a green band or a rotating vane. A red band appears, or the vane stops rotating, if the flow falls below this level. Connect the non-crush oxygen delivery tubing of the nasal prongs or a 2-metre length of non-crush oxygen delivery tubing to the flow indicator. Finally, connect the catheter to this non-crush plastic delivery tubing, if you use nasal or nasopharyngeal catheters for the administration of oxygen.

**Figure 16**

*An example of a flow indicator*

In case of power failure, use the flow splitter to divide the flow of oxygen from the back-up cylinder in the same way, connecting it to the outlet of the flow control device. In this situation, the flow from the cylinder must never be allowed to exceed the total flow set on the flow splitter (for instance, a flow of 4 l/min if you use four 1 l/min nozzles). Fix a printed warning to this effect on the wall near the cylinder.

The equipment needed to administer oxygen to up to four patients from an oxygen concentrator is summarized in Table 7. All the materials, with the exception of the oxygen cylinders and the nasal catheters, can be supplied by the manufacturers of the oxygen concentrators meeting the WHO specifications.
Table 7
Equipment for the administration of oxygen
to up to four children from an oxygen concentrator

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen concentrator</td>
<td>1</td>
</tr>
<tr>
<td>Back-up cylinder with regulator(^a) and flow controller</td>
<td>1</td>
</tr>
<tr>
<td>Flow splitter</td>
<td>1</td>
</tr>
<tr>
<td>Nozzles 0.5 and 1 l/min</td>
<td>4 each</td>
</tr>
<tr>
<td>Blanking plugs</td>
<td>2</td>
</tr>
<tr>
<td>Plastic tubing 5 mm internal diameter</td>
<td>up to 60 m</td>
</tr>
<tr>
<td>Cable clips</td>
<td>100</td>
</tr>
<tr>
<td>(Bubble humidifiers with wall brackets)</td>
<td>(5)</td>
</tr>
<tr>
<td>Flow indicators</td>
<td>4</td>
</tr>
<tr>
<td>(Non-crush plastic oxygen delivery tubing)</td>
<td>(8 m)</td>
</tr>
<tr>
<td>Prongs (or catheters)(^b)</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^a\) The regulator must have a delivery pressure that matches the pressure for which the flow splitter has been designed (i.e., the outlet pressure of the oxygen concentrator).

\(^b\) Prongs and catheters are usually supplied in boxes of 100. Nasal prongs are already fitted with a sufficient length of non-crush oxygen delivery tubing.

### 3.5.2 From a cylinder

If your source of oxygen is a cylinder but you are planning to purchase a concentrator, you should procure, for the treatment of up to four patients, the same equipment as described above. If your hospital has a satisfactory supply of oxygen cylinders and is not planning to change to concentrators, you can use the method described below. The equipment needed is slightly more expensive than that recommended for concentrators, but has the advantage of being more widely available and familiar to clinical users.

Place a large oxygen cylinder (oxygen is least expensive in large cylinders) in a corner and fasten it to the wall with a strap or a chain. Connect a 4-way adaptor (not a flow splitter) to the
regulator. Carefully screw three flowmeters, preferably of the paediatric type (0-2 l/min), onto each of the adaptor's ports (Figure 17). Attach a length of non-crush plastic oxygen delivery tubing to each flowmeter, inserting a bubble humidifier if required. Finally connect each length of tubing with a catheter or nasal prongs (prongs are already fitted with non-crush oxygen tubing).

Figure 17

Cylinder and regulator, 4-way adaptor, flowmeters, and bubble humidifiers for the treatment of up to three patients

This system allows you to treat up to three patients simultaneously; you can treat up to five patients by adding a second 4-way adaptor after the first and increasing the number of flowmeters accordingly. The equipment needed to administer oxygen to up to three patients from an oxygen cylinder is summarized in Table 8.
Table 8
Equipment for the administration of oxygen
to up to three children from an oxygen cylinder

<table>
<thead>
<tr>
<th>Description</th>
<th>Number required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen cylinder with regulator</td>
<td>1</td>
</tr>
<tr>
<td>4-way adaptor</td>
<td>1</td>
</tr>
<tr>
<td>Flowmeters (0-2 l/min)</td>
<td>3</td>
</tr>
<tr>
<td>(Bubble humidifiers)</td>
<td>(4)</td>
</tr>
<tr>
<td>(Non-crush plastic oxygen delivery tubing)</td>
<td>(8 m)</td>
</tr>
<tr>
<td>Prongs (or catheters)*</td>
<td>3</td>
</tr>
</tbody>
</table>

* Prongs and catheters are usually supplied in boxes of 100. Nasal prongs are already fitted with a sufficient length of non-crush oxygen delivery tubing.

3.5.3 Warning

You must use a purpose-designed flow splitter, or a 4-way adaptor and a flowmeter for each patient, to give oxygen to more than one patient from a single source (either a concentrator or a cylinder). You must never use simple Y-connectors, because they will not allow the flow of oxygen to be distributed equally and/or accurately between patients. Wherever possible, make efforts to obtain the recommended equipment. The costs involved are not large compared with the overall cost of providing oxygen therapy.

3.6 ADMINISTRATION OF OXYGEN

WHO recommends giving oxygen to young children in small hospitals in developing countries using nasal prongs. This method is safe and delivers sufficiently high concentrations of oxygen with relatively low flow rates to most hypoxaemic children. It does not require humidification of oxygen. Nasal catheters are an alternative where prongs are not available. Nasopharyngeal catheters can be used when adequate oxygenation is not achieved with nasal prongs or catheters, or where the supply of oxygen is very limited. They require, however, trained skilled staff who can ensure continuous monitoring of oxygen therapy.
3.6.1 Using nasal prongs

Gently suck all the mucus from the child's nose and pharynx. Take infant (prongs 7 mm apart) or paediatric (prongs 12 mm apart) nasal oxygen prongs and tape them to the child's face so that the two prongs are just inside the nostrils. If only adult nasal prongs are available, first cut off the ends of the prongs leaving two short barrels to be inserted into the child's nostrils. Run the tubing over the shoulder and down under the back of the child's shirt so that the child cannot reach it.

If the child is less than 2 months old (or less than 5 kg), give 0.5 l/min of oxygen through the prongs. If the child is more than 2 months old (or more than 5 kg), give 1 l/min of oxygen. These flow rates will deliver about 30-35% of oxygen in the airways, provided that the child's nose is not blocked and the child is not breathing through the mouth (in which case the concentrations may be lower).

This method is adequate for the treatment of most hypoxaemic children with acute lower respiratory tract infections. If a child with cyanosis treated in this way does not turn pink, you can either try to switch to another method of administration (nasal or nasopharyngeal catheter), or increase the flow rate. If you use an oxygen concentrator with a flow splitter, use the nozzle or the combination of nozzles required for the increased flow rate. The flow from two nozzles can be combined using a Y-connector.

It is most important to keep the child's nose clean and free of mucus (if it is full of mucus, the oxygen cannot reach the lungs). Dip a wick of soft cloth in a salt-water solution, then use this wick to clear the mucus out of each nostril. Be very gentle when cleaning the child's nose, to avoid causing irritation and swelling of the nasal mucosa.

3.6.2 Using a nasal catheter

Gently suck all the mucus from the child's nose and pharynx. Use preferably an 8FG catheter; use a smaller catheter, such as 6FG model, if an 8FG is not available. 6FG catheters cause less nasal obstruction in small babies and can be used at flow rates lower than 1 l/min; higher flow rates tend to disengage the connections and produce higher velocity gas flows which are more likely to cause local damage. Use preferably oxygen catheters with multiple side and end exit holes. Measure the distance from the side of the nostril to the inner margin of the eyebrow with the catheter and mark the catheter at this point with adhesive tape. Insert the catheter into one nostril and push it straight backwards along the
floor of the nose until the edge of the tape reaches the nostril; do not angle it upwards to hit the roof of the nose. Do not push the catheter in too far: you may place the tip of the catheter inadvertently into the oesophagus, with a consequent risk of gastric distension. If the child coughs or gags when the catheter goes in, pull the catheter back 1-2 cm until the child stops coughing or gagging. Fix the catheter to the upper lip with another piece of tape to prevent it from going in too far. In this way you can easily check for any displacement. You should not be able to see the tip of the catheter when the mouth of the child is open. Run the tubing over the shoulder and tape it down the child's back so that it is safely out of the child's reach.

If the child is less than 2 months old (or less than 5 kg), give 0.5 l/min of oxygen through the catheter. If the child is more than 2 months old (or more than 5 kg), give 1 l/min of oxygen. These flow rates will deliver about 35-40% of oxygen in the airways. To avoid the risk of gastric distension, it is important not to push the nasal catheter in too far and to use the recommended low flow rates of oxygen. If the child is fed through a nasogastric tube, use the same nostril for both the nasal catheter and the nasogastric tube.

Remove the catheter twice a day, clean it or replace it with a new catheter if necessary. Gently clean out the child's nostrils, look at the child to see if he or she still needs oxygen and, if oxygen is still needed, put the catheter back into the other nostril. Inspect the catheter also if you have any reason to think it is blocked, for example if a red band shows or the vane stops rotating in the flow indicator or if the child, having responded initially to oxygen therapy, becomes cyanosed again. Before putting the catheter back, check the flow by holding the end of the catheter under water. Humidification of oxygen is not necessary using a nasal catheter.

3.6.3 Using a nasopharyngeal catheter

This is the most efficient way to give oxygen to young children. Efficiency is important when oxygen is scarce and expensive, usually when it is supplied in cylinders. Efficiency is less important when the oxygen is produced by a concentrator, which has a constant running cost irrespective of the flow of oxygen delivered. The use of a nasopharyngeal catheter is not as safe as the use of nasal prongs. Hospital staff must be adequately trained in the correct procedures and must thoroughly monitor the child under oxygen therapy.

Gently suck all the mucus from the child's nose and pharynx. Use preferably an 8FG catheter; use a smaller catheter, such as 6FG model, if an 8FG is not available. 6FG catheters cause less nasal obstruction in small babies and can be used at flow rates lower than
1 l/min; higher flow rates tend to disengage the connections and produce higher velocity gas flows which are more likely to cause local damage. Use preferably oxygen catheters with multiple side and end exit holes. Measure the distance from the side of the nostril to the front of the ear with the catheter and mark the catheter at this point with adhesive tape. Insert the catheter into one nostril and push it straight backwards along the floor of the nose until the edge of the tape reaches the nostril; do not angle it upwards to hit the roof of the nose. Do not push the catheter in too far: you may place the tip of the catheter inadvertently into the oesophagus, with a consequent risk of gastric distension. If the child coughs or gags when the catheter goes in, pull the catheter back 1-2 cm until the child stops coughing or gagging. If the child keeps on coughing and gagging, withdraw the catheter 1-2 cm more; the tip of the catheter will then be placed in the nasal cavity and you will be giving oxygen as with a nasal catheter. Fix the catheter to the upper lip with another piece of tape to prevent it from going in too far. In this way you can easily check for any displacement. You should be able to see the tip of the catheter just below the uvula when the mouth of the child is open. Run the tubing over the shoulder and tape it down the child's back so that it is safely out of the child's reach.

If the child is less than 2 months old (or less than 5 kg), give 0.5 l/min of oxygen through the catheter. If the child is more than 2 months old (or more than 5 kg), give 1 l/min of oxygen. These flow rates will deliver about 45-60% of oxygen in the airways, depending on the child's weight. The concentration is not greatly reduced if the child breathes through the mouth because of a blocked nose. To avoid the risk of gastric distension, it is important not to push the nasopharyngeal catheter in too far and to use the recommended low flow rates of oxygen. You should monitor the child continuously to act promptly in case of airway obstruction or apnoea. If the child is fed through a nasogastric tube, use the same nostril for both the nasopharyngeal catheter and the nasogastric tube.

Remove the catheter twice a day, clean it or replace it with a new catheter if necessary. Gently clean out the child's nostrils, look at the child to see if he or she still needs oxygen and, if oxygen is still needed, put the catheter back into the other nostril. Inspect the catheter also if you have any reason to think it is blocked, for example if a red band shows or the vane stops rotating in the flow indicator, or if the child, having responded initially to oxygen therapy, becomes cyanosed again. Before putting the catheter back, check the flow by holding the end of the catheter under water. Finally, check the level of the water in the humidifier (see below for more instructions on humidifiers).
3.6.4 Using humidifiers

You do not need a humidifier when you give oxygen by nasal catheter or prongs, but you need one to give it through a nasopharyngeal catheter. Bubble humidifiers reduce the dryness of the oxygen supplied from a concentrator or a cylinder by adding water. If you use a bubble humidifier, fill it with clean water (distilled water, or tap water that has been boiled and cooled) to the level marked on the jar. Then attach the humidifier firmly but not too tightly to the oxygen outlet. Take care doing this since oxygen leaks often occur at the point where the humidifier is connected. Check the bubbling of the humidifier regularly. Some humidifiers have a high-pressure alarm in the lid, in the form of a whistle that sounds if the tubing blocks or kinks between the humidifier and the patient. Do not put tape over the whistle, because this will stop it working. If the whistle sounds, inspect the tubing for a blockage; if you do not find any block in the tubing, remove the catheter and clean it.

Check twice a day that the water level in the humidifier is at the level marked on the jar. If necessary, unscrew the jar and top up the water level with clean water; screw the jar back tightly. Change the water daily. To do this, unscrew the jar from the humidifier and wash the humidifier, jar and catheter in a mild kitchen detergent or soapy water; rinse with clean water and dry in air before re-use. It is important to have a spare clean humidifier already filled with clean water, to replace the dirty one while it is cleaned and avoid interrupting the oxygen therapy for a long time. At least once a week, or when you stop giving oxygen to a patient, soak all the components of the humidifier in a mild antiseptic solution for 15 minutes, then rinse them well with clean water and dry them in air. It is important to allow the humidifier to dry completely if bacterial colonization is to be discouraged. You must have a spare humidifier to permit the regular maintenance of the one in use.

Humidifiers contain many connections and seals and may be the source of leaks in your oxygen system. The disadvantages of humidifiers include leaks, possible infections, and need for daily attention. Nasal catheters and prongs do not require humidifiers and this is a great advantage.

3.6.5 Oxygen therapy in newborn and premature babies

Young infants less than 2 months old with pneumonia are much more likely to die than older children, and it is particularly important to be able to give them oxygen. Give them oxygen
exactly as described above for older children, but at a flow rate of 0.5 l/min.

Take great care with premature babies to avoid giving them too much oxygen. Excess oxygen may cause retrolental fibroplasia (blindness) in a premature baby; the risk is greatest in very small babies (less than 34 weeks' gestation), and becomes less with each week after birth.

If you give oxygen to a premature baby, use the lowest flow rate needed to make the baby pink; you need a low reading flowmeter for this purpose. Whether you use nasal prongs, nasal or nasopharyngeal catheter, start with a flow rate of 0.5 l/min. If the baby turns pink, reduce the flow rate to 0.4 l/min and wait one minute. If the baby turns blue again, turn the flow back to 0.5 l/min; if the baby stays pink, turn the flow down to 0.3 l/min and wait another minute. Continue in the same way until you find the flow that just makes the baby pink. Do this twice every day to see that the lowest flow needed to make the baby pink is being given. Use only flowmeters capable of accurate reading below 0.5 l/min with oxygen cylinders, or use the flowmeter of the oxygen concentrator. Do not use fixed-orifice flow controllers, such as the nozzles of the flow splitter; oxygen concentrators can only be used for single patients when giving oxygen to premature babies. In hospitals with the available equipment and skilled nursing staff continuously monitoring oxygen therapy, a headbox with a flow rate of 2 l/min is a good alternative.

Newborn and premature babies must be kept at the right temperature, especially when they have pneumonia. Both cold stress and heat stress are very dangerous, because they greatly increase oxygen consumption and carbon dioxide production in babies.³¹ Appropriate temperatures are about 33°C for a naked newborn baby in a draught-free environment, and 26°C for a baby that is clothed and well wrapped up in a cot.⁴²
REFERENCES


