NITROUS OXIDE ADMINISTRATION USING COMMONLY AVAILABLE OXYGEN THERAPY DEVICES

P. JOSHI, R. OOI AND N. SONI

SUMMARY

Administration of nitrous oxide is useful for providing sedation and analgesia. The therapeutic range for nitrous oxide is 20-30%. Several oxygen treatment devices have been used for administering nitrous oxide, but little is known about the concentrations of nitrous oxide and oxygen delivered to the trachea. We have studied this, using an analogue lung model, with several oxygen therapy devices. With a 1:1 nitrous oxide-oxygen mixture in the primary flow for all systems, end-expired nitrous oxide concentrations varied between 6.5% and 34.3%. Therapeutic concentrations were produced using the Hudson (nominal oxygen concentration 60%) fixed-performance mask, the variable performance Hudson mask at 4 litre min⁻¹, the MC masks at 4 and 6 litre min⁻¹ and the nasal prongs at 6 and 8 litre min⁻¹. Simultaneous end-expired oxygen concentrations for all devices tested were within a safe range.

KEY WORDS

Nitrous oxide is used frequently as an analgesic and sedative agent during operation during regional anaesthesia. It has a history of apparent safety and effective use, but it may depress ventilation [1-3] and circulation [4,5], particularly in patients with initially compromised function. Parbrook reviewed the concentrations of nitrous oxide required for anaesthesia and analgesia [6]; he concluded that 20-30% nitrous oxide (zones 1-2) provided optimum analgesic and sedative effects.

This study was designed to determine if appropriate concentrations of nitrous oxide and oxygen could be delivered, when oxygen delivery systems were supplied with a 1:1 mixture of nitrous oxide and oxygen. We chose a 1:1 mixture because this is used commonly to supplement regional techniques. Because it is difficult to obtain representative inspired gas concentrations non-invasively in humans, we have used a lung model for spontaneous ventilation.

METHODS

The lung model used [7] produced a sinusoidal ventilatory flow pattern, with a tidal volume of 400 ml, tracheal volume equivalent to the deadspace (130 ml) and minute ventilation of 6 litre min⁻¹. The peak inspiratory flow rate (PIFR) was measured with a Fleisch pneumotachograph and found to be 20 litre min⁻¹. A Laerdal face shield was used to simulate a patient-mask interface.

The lung model is not involved in gas exchange and therefore equilibrates eventually with the mixed-inspired concentration, which in the model is equivalent to the alveolar concentration; the lung model acts as a volume-weighted averager of the inspiratory concentration. In a patient, at the end of expiration the deadspace is filled with end-tidal gas which contains a different concentration of nitrous oxide and forms part of the mixture that enters the alveoli on the next inspiration. However, this effect is small when equilibrium is approached with the inspired nitrous oxide concentration. Therefore, end-expired concentrations of gases were measured as a reflection of the alveolar gas concentration and hence, in the lung model, of the mixed-inspired concentration.

Gas concentrations were measured at the "subglottic" level via a catheter attached to a mass spectrometer (Centronics 200 MGA). The mass spectrometer was calibrated with a British Oxygen Company certified gas mixture; zero for each gas was established using a 100% concentration of another gas. A computer with a multi-channel chart program was used to record the signals from the mass spectrometer. The end-expiratory concentrations of nitrous oxide and oxygen were noted. At each stage of the study, equilibration of gases in the mechanical lung model was permitted for 20 min. Duplicate measurements were performed on each breathing system.

The oxygen delivery devices used included Ventimask and Hudson mask (nominal oxygen concentrations 40% and 60% at gas flows of 10 litre min⁻¹ and 15 litre min⁻¹, respectively), Mary Catterall mask (gas flows of 4 litre min⁻¹ and 6 litre min⁻¹) and nasal prongs (gas flows of 2, 4, 6 and 8 litre min⁻¹). In addition, the Hudson mask was used as a variable performance device at flow rates of 4 litre min⁻¹ and 6 litre min⁻¹.

The 50% nitrous oxide in oxygen driving gases were delivered from a Boyle's anaesthetic machine. The gas flow rates were checked using a rotating...


**Table I. End-expiratory nitrous oxide \( (\% \text{NO}) \) and oxygen \( (\% \text{O}_2) \) concentrations obtained for the fixed-performance masks. \( \nu_f \) = fresh gas flow. Theoretical values for nitrous oxide based on calculation of the entrainment ratio (see Appendix) are given in parentheses**

<table>
<thead>
<tr>
<th>Delivery system</th>
<th>( \nu_f ) (litre ( \text{min}^{-1} ))</th>
<th>( % \text{NO} ) (%)</th>
<th>( % \text{O}_2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventimask 40%</td>
<td>10</td>
<td>13.6 (12)</td>
<td>30.8</td>
</tr>
<tr>
<td>Hudson 40%</td>
<td>10</td>
<td>6.5 (12)</td>
<td>25.9</td>
</tr>
<tr>
<td>Ventimask 60%</td>
<td>15</td>
<td>31.7 (24.7)</td>
<td>42.4</td>
</tr>
<tr>
<td>Hudson 60%</td>
<td>15</td>
<td>20.4 (24.7)</td>
<td>35.0</td>
</tr>
</tbody>
</table>

**Table II. End-expiratory nitrous oxide \( (\% \text{NO}) \) and oxygen \( (\% \text{O}_2) \) concentrations obtained for the variable-performance masks. \( \nu_f \) = fresh gas flow**

<table>
<thead>
<tr>
<th>Delivery system</th>
<th>( \nu_f ) (litre ( \text{min}^{-1} ))</th>
<th>( % \text{NO} ) (%)</th>
<th>( % \text{O}_2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hudson</td>
<td>4</td>
<td>28.0</td>
<td>40.1</td>
</tr>
<tr>
<td>MC</td>
<td>4</td>
<td>25.3</td>
<td>31.3</td>
</tr>
<tr>
<td>Hudson</td>
<td>6</td>
<td>34.5</td>
<td>44.4</td>
</tr>
<tr>
<td>MC</td>
<td>6</td>
<td>28.5</td>
<td>40.4</td>
</tr>
</tbody>
</table>

**Table III. End-expiratory nitrous oxide \( (\% \text{NO}) \) and oxygen \( (\% \text{O}_2) \) obtained for the nasal prongs. \( \nu_f \) = fresh gas flow**

<table>
<thead>
<tr>
<th>( \nu_f ) (litre ( \text{min}^{-1} ))</th>
<th>( % \text{NO} ) (%)</th>
<th>( % \text{O}_2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7.8</td>
<td>26.4</td>
</tr>
<tr>
<td>4</td>
<td>14.1</td>
<td>29.8</td>
</tr>
<tr>
<td>6</td>
<td>20.0</td>
<td>33.4</td>
</tr>
<tr>
<td>8</td>
<td>23.1</td>
<td>35.5</td>
</tr>
</tbody>
</table>

bobbin flowmeter (Gap-Meter A10 and A6) calibrated previously against a dry spirometer of known accuracy (Ohio 840). The ratio of nitrous oxide to oxygen delivered was maintained at 1:1. The design performances of the fixed-performance masks were tested also with 100% oxygen, to validate the manufacturer's stated oxygen delivery.

**RESULTS**

When the fixed-performance Ventimask was supplied with 100% oxygen, the delivered concentrations of oxygen were 40.2% and 62.4% with the 40% and 60% nominal concentration masks, respectively. For the Hudson masks, the corresponding concentrations were 40.4% and 59.7%. Therefore, at a PIFR of 20 litre \( \text{min}^{-1} \), these results are in close agreement with the oxygen delivery as stated by the manufacturers.

The mean end-expiratory concentrations of nitrous oxide and oxygen and the gas flows used for each of the three different types of devices tested (fixed-performance masks, variable-performance masks and nasal prongs), are summarized in tables I, II and III. The maximum difference in gas concentrations between duplicate measurements was less than 1%.

**DISCUSSION**

Previous in \( \text{vivo} \) studies of gas concentrations delivered by oxygen masks supplied with nitrous oxide and oxygen mixtures were affected by variations in inspiratory flow rate, tidal volume and end-expiratory pause, with varying nitrous oxide and oxygen entrainment. Leigh showed that variations were reflected by changes in end-tidal carbon dioxide [8]. The use of the mechanical lung model overcomes some of these problems.

This study has revealed wide variations in the mixtures delivered by different systems: 6.5-34.3% for nitrous oxide and 25.9-44.4% for oxygen. Amongst the fixed-performance masks, only the Hudson 60% gave a nitrous oxide concentration within the 20-30% range, although the Ventimask 60% was only marginally increased, at 31.7%. All the variable-performance masks, with the exception of the Hudson at 6 litre \( \text{min}^{-1} \), produced nitrous oxide within the range 20-30%. Using nasal prongs, a minimum gas flow of 6 litre \( \text{min}^{-1} \) was required to achieve end-expired nitrous oxide concentrations of 20.0%; at 8 litre \( \text{min}^{-1} \) the concentration was 23.1%.

A check of the internal consistency of the measured concentrations was obtained theoretically on the basis that the delivered gas must be a mixture of the 1:1 nitrous oxide-oxygen with air. For each condition in tables I–III, a theoretical oxygen concentration was calculated from the measured nitrous oxide concentration (see Appendix). The calculated concentrations of oxygen were all a little less than the measured values (mean difference 1.9%, range 0.6-3.5%).

For the fixed-performance masks it was also possible to calculate the theoretical concentration of both oxygen and nitrous oxide, on the assumption that the fraction of the gas used as the driving gas in the delivered mixture is the same when the driving gas is nitrous oxide + 50% oxygen as when it is 100% oxygen (see Appendix). It was found that the expected concentrations of nitrous oxide were 12.0% and 24.7% for the 40% and 60% masks, respectively; the Hudson masks supplied less nitrous oxide than expected (6.5% and 20.4%, respectively), while the Ventimasks gave more (13.6% and 31.7%). This suggests that the differences were not the result of a systematic difference between the entrainment properties of our mixture and those of oxygen, but were features of the design of the two masks.

Hill [9] has shown that fixed-performance (low and high volume) masks are accurate up to a PIFR of 12 litre \( \text{min}^{-1} \), but he found that they may be variable at greater PIFR. Our measurements using 100% oxygen as the driving gas showed predictable results at PIFR 20 litre \( \text{min}^{-1} \). This apparent discrepancy may reflect the use of a lung model which cannot reproduce fully the interactions between masks and subjects.

In clinical practice, even during quiet breathing the PIFR may be as great as 30 litre \( \text{min}^{-1} \) [10]. Therefore the performance of the masks may be different in clinical use because the gas mixing and entrainment characteristics vary with flow rate [8].

**APPENDIX A**

To check the general validity of the measurements, the mutual consistency of measured nitrous oxide and oxygen concentrations for any given mask can be determined theoretically. Only a
fraction \((Fe)\) of the gas entering the lungs is the nitrous oxide-oxygen mixture, the remainder being air \((1-Fe)\). Therefore, if \(F_{N2}O\) is the fraction of nitrous oxide in the gas and \(F_O\) the fraction of oxygen, then:

\[ F_O = 0.5Fe + 0.21(1-Fe) \]

but

\[ F_{N2}O = 0.5Fe; \]

therefore, \(Fe = 2F_{N2}O\)

and hence

\[ F_O = F_{N2}O + 0.21(1-2F_{N2}O) \]

\[ = 0.58F_{N2}O + 0.21 \]

For the fixed-performance masks, it is also possible to calculate the expected concentrations of nitrous oxide. Let \(F_d\) be the fraction of driving gas in the mixture and \((1-F_d)\) be the fraction of entrained gas. Then, for an \(x\%\) mask, driven with oxygen and entraining air:

\[ (F_d \times x) + (1-F_d)0.21 = x \times 100 \]

therefore,

\[ F_d = (x \times 100 - 0.21)/0.79 \]

Hence, for a 40\% mask, \(F_d\) is 0.241 and for a 60\% mask \(F_d\) is 0.494. The mask, however, driven by 50\% nitrous oxide+50\% oxygen, entrains air; if we neglect any difference in the entrainment ratio which might arise from a change in the driving gas, the concentration of nitrous oxide delivered will be 0.5\(F_d\)—12\% for the 40\% mask and 24.7\% for the 60\% mask.

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REFERENCES