USE OF ENTONOX PLUS CARBON DIOXIDE IN THE DENTAL SURGERY

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SUMMARY

The introduction of Entonox has made it possible to guarantee full oxygenation of the inspired gas of outpatients having nitrous oxide anaesthesia. The addition of 1–2% halothane enables good conditions to be obtained for minor surgery such as dental extraction. The use of an Entonox mixture containing 7% carbon dioxide to stimulate ventilation in patients receiving anaesthesia with nitrous oxide, oxygen and halothane is described.

For a long time, nitrous oxide was regarded as the anaesthetic agent of choice for outpatients. There were many reasons for this, including speed of induction and recovery. Bourne (1954) drew attention to the shortcomings of the method, pointing out that hypoxia frequently resulted from attempts to achieve an adequate level of anaesthesia. He suggested a mixture of cyclopropane with oxygen as an alternative, to provide more potent anaesthesia with more generous oxygenation. Problems encountered with cyclopropane included salivation and nausea.

Latham and Parbrook (1966) described the use of Entonox (premixed 50% nitrous oxide in oxygen) together with either methohexitone or halothane. This technique guaranteed an adequate inspired oxygen concentration. The use of halothane with nitrous oxide and oxygen has been found by us to slow the induction of anaesthesia, presumably because of ventilatory depression. Intravenous drug administration, although satisfactory in certain centres, requires that one person injects the drug while another supervises the patient’s airway. Two of the advantages of inhalation anaesthesia for outpatients are that the anaesthetist can control the airway as he gives the anaesthetic, and recovery is at least as rapid as that following an intravenous technique. In the hope of overcoming the problem of slow induction with halothane, the British Oxygen Company was approached with a view to the addition of 7% carbon dioxide to the Entonox mixture. Cylinders containing 50% nitrous oxide, 43% oxygen and 7% carbon dioxide were produced and this mixture has proved extremely satisfactory.

The healthy patient can breathe up to 3% carbon dioxide in air for prolonged periods with no ill effects (Malikman, Polyakov and Stephanov, 1971), but opinions differ on the effects of carbon dioxide in the range 3–9%. Earlier workers postulated hazards from breathing 4% carbon dioxide but others later claimed that 8.8% carbon dioxide in air can be inhaled safely for up to 10 min (White et al., 1952). Malikman, Polyakov and Stephanov (1971) showed that 7% was the concentration at which man begins to be unable to effect adequate ventilatory compensation. We considered that this concentration would be safe for short exposures and that the increased ventilation and cerebral blood flow (Lees et al., 1972) would have the desired effect of shortening the anaesthesia induction time. In choosing 7% carbon dioxide, we were mindful that the mixture would contain 43% oxygen whereas previous workers, by using air as carrier gas, depleted the oxygen supply. Black and colleagues (1959) showed that arrhythmias associated with halothane and carbon dioxide did not appear when the PaCO₂ was less than 66 mm Hg. We have assumed that this value would not be reached by breathing 7% carbon dioxide for 5–10 min.

APPARATUS

The apparatus used was a Walton Mark 5, modified by having one of the nitrous oxide cylinder yokes replaced by one having no projecting pins. This enabled it to receive the standard flush non-pin-index valve fitted to the special cylinder. This was painted a lilac colour and stencilled with the


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legend "7% carbon dioxide, 43% oxygen, 50% nitrous oxide". For better identification, it carried a green band on the shoulder and the neck was painted green. When in use, the nitrous oxide cylinder on the second of the nitrous oxide yokes was turned off and the mixture indicator was turned to read “100% N₂O". Thus 100% of the mixture was delivered (i.e. 50% nitrous oxide, 43% oxygen and 7% carbon dioxide). The nitrous oxide pressure gauge had to be replaced because of the greater pressure in the new cylinder (see below). This system of gas safety in use conforms to present views that whilst pin-index valves contribute greatly to safety, their rigid use could prevent new mixtures from being tried. International authorities are considering the adoption of a regulation that yoke connections without pin indexing may be used for gases not yet assigned a pin index. If this new mixture should come into wide use, a pin index will be assigned to it to be in accordance with British and International Standards. An intermittent/continuous flow apparatus such as the Walton Mark 5 may then have both the nitrous oxide yokes replaced by yokes to accept the new mixture. Alternatively, a simple continuous flow apparatus such as the MiniBoyle, suitably pin indexed, may be used.

THE GAS MIXTURE

Preparation.

The mixture was prepared by procedures which are standard for experimental cylinders of this kind. The gas which was smallest in amount, carbon dioxide, was added first to the previously evacuated cylinder, to a pressure which was calculated to give 7% v/v when the final cylinder pressure was made up to 137 bar (1980 Lb./sq.in.). The calculated weight of nitrous oxide was added next to give a final concentration of 50% v/v of this gas. This quantity of nitrous oxide is present as a liquid in the cylinder. Finally, oxygen was added by causing it to pass through the liquid nitrous oxide/carbon dioxide in the cylinder to give 43% oxygen at full cylinder pressure. The cylinder was then allowed to stand for 24 hr to allow the contents to mix, and the mixture was analysed. In general the concentrations were within the tolerance specified of ±2% for oxygen and nitrous oxide and ±1% for carbon dioxide. If not, it was part of the mixing technique to ensure that the error would be for the cylinder oxygen content to be reduced. Then the high-pressure gas (oxygen) could be forced into the cylinder without the final composition falling outside the specified limits; the very small increase in cylinder pressure over 137 bar is acceptable. The above procedure is quite troublesome and would not necessarily be greatly improved in a production process.

Stability.

Since this is a new gas mixture, it was considered essential to confirm its stability, especially under conditions of cooling. The molecules of both carbon dioxide and nitrous oxide are triatomic, their physical properties are similar and they have almost identical molecular weights (see table I). The mixture of 7% carbon dioxide and 50% nitrous oxide can be regarded as physically equivalent to 57% nitrous oxide, and the behaviour of the gas, especially the effects of low temperature storage, would be expected to be similar to those for this mixture, whose separation temperature would be about 0°C. This was confirmed in a series of experiments.

Cylinders were filled with a nominal mixture of 7% carbon dioxide, 43% oxygen and 50% nitrous oxide. Two were vented whilst they were maintained at 20°C at a flow rate of 10 litre/min. Others were placed vertically in an insulated box and cooled by sprays of liquid nitrogen until, after standing for 2 hr, the thermocouples fixed to the top and bottom of the cylinders showed the temperature to be the same and constant. Cylinders were cooled to 0°, -3°, -5° and -20°C, allowed to return to room temperature with the cylinder still in the vertical position and sampled.

| Table I. Some properties of carbon dioxide and nitrous oxide. |
|-------------|-------------|
| CO₂         | N₂O         |
| Molecular weight | 44.01 | 44.02 |
| Density, kg m⁻³ (15°C, 1013 m bar) | 1.874 | 1.875 |
| Density air=l | 1.529 | 1.53 |
| Boiling point °C | -78.5 | -89 |
| Critical temp. °C | 31 | 36.5 |
| Critical pressure (abs) bar | 73.8 | 72.5 |
| lbf/in² | 1070.1 | 1051.6 |
| kgf/cm² | 75.2 | 73.9 |
| Saturated vapour pressure (abs) at 15°C bar lbf/in² | 50.8 | 44.1 |
| kgf/cm² | 736.6 | 639.5 |
| at -5°C bar lbf/in² | 51.82 | 44.96 |
| kgf/cm² | 29.4 | 26.4 |
| Latent heat of vaporization at 15°C and 1013 m bar cal/g mol | 427.3 | 383 |
|  | 30.02 | 26.93 |
using a Godart Mijhardt Capnograph for carbon dioxide determinations and a Servomex oxygen analyser for oxygen. The balance was assumed to be nitrous oxide. Readings were taken at frequent intervals and a summary of the results is given in tables II and III.

These experiments showed that the mixture composition was constant on emptying the cylinder, that no separation takes place at 0°C and above, but that separation is serious at lower temperatures.

A point of considerable interest is how the carbon dioxide will distribute itself between the gas and liquid phases after separation when cooling has taken place. One experiment was carried out to explore this aspect. Two cylinders (one of them inverted) were cooled to —20°C for 2 hr then allowed to warm to room temperature. They were maintained in the same positions as during cooling and vented at the usual flow rate of 10 litre/min. The results are given in table III.

This last experiment confirmed the expected variations in composition of the mixture cooled to —20°C and discharged at room temperature. It also showed that the condensed nitrous oxide extracts carbon dioxide from the gas phase. In both cylinders the content of carbon dioxide in the gas phase was reduced whilst liquid nitrous oxide was present in the cylinder, and was correspondingly increased in the liquid phase. This was shown strikingly in the cylinder discharged in the normal position, where the final gas contained over 10% of carbon dioxide.

These experiments show that cylinders of 7% carbon dioxide, 43% oxygen, 50% nitrous oxide should not be allowed to cool to 0°C or below before use. If the same storage instructions are applied to the new mixture as are already well known for Entonox, there need be no fear of separation and consequent variations in composition.

**Combustion.**

One further safety aspect may be noted. Both nitrous oxide and oxygen, and therefore Entonox, vigorously support the combustion of substances which will burn in air, whereas carbon dioxide is a fire extinguisher. It is only a little more effective than nitrogen, however (Coward and Jones, 1952), so that a concentration even of 8% carbon dioxide in Entonox would not be expected to have any significant effect in rendering it less able to support combustion. No tests were carried out to support the above considerations but it would seem wise to assume that the fire precautions appropriate to Entonox should also be applied to its mixture with carbon dioxide.

**Clinical use.**

Over 500 patients have been given this mixture for dental extractions in the sitting position in the dental chair. The age range was 3–65 years and the duration of operation was from 2 to 10 min. The depth of anaesthesia required for dental extractions was reached more quickly than had been observed previously when nitrous oxide, oxygen and halothane were used without carbon dioxide, and recovery was rapid. The two consul-

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**Table II. Cylinders containing 7% carbon dioxide, 43% oxygen and 50% nitrous oxide at 137 bar, held for 2 hr at stated temperature and allowed to reach room temperature before discharge at 10 litre/min. Cylinders held vertical throughout.**

<table>
<thead>
<tr>
<th>Cylinder temp. (°C)</th>
<th>Gas content</th>
<th>Initial composition (v/v)</th>
<th>After discharge of 400 litre</th>
<th>During discharge of final 100 litre</th>
</tr>
</thead>
<tbody>
<tr>
<td>+20</td>
<td>CO₂</td>
<td>7.1</td>
<td>7.1</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>42.2</td>
<td>42.2</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>50.7</td>
<td>50.7</td>
<td>*</td>
</tr>
<tr>
<td>+20</td>
<td>CO₂</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>39.8</td>
<td>39.8</td>
<td>39.8</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>53.2</td>
<td>53.2</td>
<td>53.2</td>
</tr>
<tr>
<td>0</td>
<td>CO₂</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>43.0</td>
<td>43.0</td>
<td>43.0</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>49.8</td>
<td>49.8</td>
<td>49.8</td>
</tr>
<tr>
<td>−3</td>
<td>CO₂</td>
<td>7.1</td>
<td>6.3</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>41.9</td>
<td>45.8</td>
<td>51.1</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>51.0</td>
<td>47.9</td>
<td>85.3</td>
</tr>
<tr>
<td>−5</td>
<td>CO₂</td>
<td>7.2</td>
<td>7.0</td>
<td>&gt;10.0</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>42.0</td>
<td>46.5</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>50.8</td>
<td>46.5</td>
<td>85−90</td>
</tr>
</tbody>
</table>

*Apparatus fault, but O₂ constancy shows mixture composition constant.

**Table III. Cylinders of 7% CO₂, 43% oxygen, 50% nitrous oxide at 137 bar held for 2 hr at —20°C and vented after being allowed to reach room temperature at a flow rate of 10 litre/min. Cylinders vertical throughout.**

<table>
<thead>
<tr>
<th>Cylinder position</th>
<th>Gas present</th>
<th>Initial</th>
<th>Composition v/v</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>First 300 litre</td>
</tr>
<tr>
<td>Normal vertical</td>
<td>CO₂</td>
<td>7.1</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>41.1</td>
<td>43.0</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>51.8</td>
<td>50.7</td>
</tr>
<tr>
<td>Inverted vertical</td>
<td>CO₂</td>
<td>7.1</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
<td>41.7</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>N₂O</td>
<td>51.2</td>
<td>75.0</td>
</tr>
</tbody>
</table>
tant dental surgeons commented on this and four
anaesthetists were very aware of a prolongation of
operating time when the mixture was not available.
The Entonox–carbon dioxide mixture was given
with halothane which was vaporized using a Gold-
man vaporizer. No premedication was given. The
nosepiece was gradually lowered over the nose with
the Goldman vaporizer set just below mark “2”
with the flow control on the Walton set between
“2” and “3” to give an acceptable concentration.
The patient was usually asleep in 15–30 sec, and
the vaporizer was then turned full “on” for a few
seconds. For a normal extraction of two or three
teeth, the halothane was turned “off” as soon as
the extraction began and the patient continued to
breathe the Entonox–carbon dioxide mixture. On
some occasions difficult extractions necessitated up
to 10 min of anaesthesia. In these cases the vapor-
izer was brought back into circuit between marks
“2” and “3” to maintain the concentration, and
then turned to “off” when the extraction was nearly
completed.

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VERWENDUNG VON ENTONOX UND
KOHLEDIOXYD IN DER ZAHNARZTLICHEN
PRAXIS
ZUSAMMENFASSUNG
Die Einführung von Entonox hat es ermöglicht, eine
vollständige Oxydation des eingeatmeten Gases bei
ambulanten Patienten zu garantieren, die eine Stickstoff-
ofxyd-Anästhesie erhalten. Der Zusatz von 1–2% Halo-
than ermöglicht gute Bedingungen für kleine Eingriffe
wie Zahnextraktionen. Die Verwendung einer Entonox-
Mischung mit 7% Kohlendioxid zur Belüftungs-
stimulierung in Patienten wird beschrieben, die eine
Stickstoffoxyd-, Sauerstoff- und Halothanästhesie
erhalten.

EMPLEO DE ENTONOX MAS BIOXIDO DE
CARBONO EN LA CIRUGIA DENTAL
SUMARIO
La introducción de Entonox ha hecho posible garantizar
la total oxigenación del gas inspirado por los pacientes
tratados con anestesia por óxido nitroso. En cirugía
menor, tal como extracción dental, se obtienen buenos
resultados añadiendo 1–2% de halotano. Se describe el
uso de una mezcla de Entonox que contiene 7% de
dióxido de carbono para estimular la ventilación en
pacientes que reciben anestesia con óxido nitroso, oxígeno
y halotano.