INVESTIGATIONS OF SOME ASPECTS OF ATMOSPHERIC POLLUTION BY ANAESTHETIC GASES. I: DIFFUSION OF HALOTHANE ACROSS PLASTIC AND RUBBER TUBES

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SUMMARY

Plastic and rubber tubing, of the types used frequently to convey anaesthetic gases to and from the patient, or anaesthetic waste gases out of the operating theatre, were assessed for their capacity to allow diffusion of halothane through the tube wall. The magnitude of this effect has been calculated in relation to pollution of the operating theatre atmosphere under different circumstances.

One important aspect of pollution of the operating theatre atmosphere is the effect of leaks of anaesthetic gases from circuit connections (Berner, 1973), faulty equipment and diffusion through circuit or exhaust duct tubing. The magnitude of this last effect has not been assessed. It is known that anaesthetic agents diffuse through plastic and rubber; some relevant coefficients are shown in tables I and II. The figures in table II were obtained as the result of investigations, using gas chromatography, into the cause of delayed uptake of anaesthetic gas from circle systems (Titel and Lowe, 1968).

We have studied the amount of anaesthetic gas diffusing through the tube wall, and diffusing back into the lumen. Both phenomena may produce environmental contamination.

A widely used method of anaesthetic gas scavenging employs a suitable expiratory valve connected via a length of tube to an exhaust port in the theatre wall (Enderby, 1972), or an air-conditioning extract duct. Several types of tube are in current use for this purpose, all of which, unless constructed of metal, will permit gas diffusion.

Halothane in air was used for these investigations, and three commonly used types of tube were assessed. Table III lists the physical characteristics of the tubes. The amount of halothane diffusion through the tube to the outside, and back into the tube lumen following a standardized exposure to halothane, was assessed quantitatively by mass spectrometry.

METHODS

The experimental arrangement is shown in figure 1.
Dry gas in the form of compressed air was delivered from a floating ball flowmeter (British Oxygen Company) which had been calibrated previously against an Aktiebolaget Nordgas dry gas meter. This was passed through a halothane vaporizer (Foregger) calibrated against weighed-in-air samples of halothane analysed on a Perkin Elmer gas chromatograph with a flame ionization detector.

The halothane vapour in air was introduced into 7.6 m of tube under investigation which was sealed into a thick glass tank of 25 litre capacity. This length of tube was chosen as being representative of the length usually needed to convey anaesthetic gases out of the operating theatre. The outlet from the tube was exhausted through an adjacent window. An analysis suction probe to a quadrupole mass spectrometer (UTI) was introduced through the gas-tight metal lid down to the bottom of the glass tank. A small air inlet (23-gauge needle) was provided to eliminate any possible vacuum caused by the suction from the mass spectrometer. The error in measurement, caused by this dilution of the halothane concentration resulting from room air admitted to the tank, can be calculated to produce an 8% under-estimation of the true magnitude of the values. This error was unavoidable when performing a continuous measurement of the halothane in the tank, and a correction in the results has been made for this.

Calibration of the mass spectrometer for measurements of this order (p.p.m. v/v) was performed by a serial dilution method (fig. 2). In this method, a low flow of a known concentration of halothane is diluted in a high flow of air, to produce concentrations between 10 and 10 000 p.p.m. (v/v). Halothane 1% from a calibrated Foregger vaporizer was delivered to a 0–250 ml “Sho-rate” floating ball flowmeter calibrated by a soap bubble in a burette method. In order to avoid inaccuracies resulting from low gas flows through the vaporizer, the flow of halothane vapour in oxygen to the 0–250 ml flowmeter was regulated by controlling the escape of vapour from a side arm with a clamp; fine control was effected by the adjustment of the flowmeter pin valve.

This low flow of 1% halothane was diluted with a high flow of air from a separate floating ball flow meter calibrated with a dry gas meter. For lesser concentrations, such as 10 p.p.m., 100 litre of air was obtained with a Venturi entrainment device (Bushman and Askill, 1971). For measurement of these high flows of air, a flow meter calibrated in the range 0–150 litre was used (fig. 2).

The gas was then led by a short length of tube (to avoid possible diffusion errors) to the mass spectrometer sampling probe for calibration purposes.

Four litre per min of gas (1% v/v halothane in dry air) was passed through the tubes for 3.5 h. The concentration and time period were chosen as being representative of conditions existing in an operating theatre. During the passage of gas through the tube, the amount of halothane accumulating in the glass
tank was measured continuously by the UTI mass spectrometer.

At the end of the period of gas flow, the tank and the tube were flushed for 10 min with a high flow of fresh air, the ends of the tube sealed and the tube left enclosed in the glass tank for a period of 14–19 h. This time was considered representative of an "overnight" period in an operating theatre. After this, the halothane concentrations in the container and the tube lumen were measured.

RESULTS
The first exposure of the thick p.v.c. tubing (table III) was to 4% halothane v/v in air for 3.5 h. This tubing continued to emit halothane in measurable quantities for more than 30 days after this single exposure. After 14 days, a value of 72 p.p.m. of halothane was measured, and after 30 days a value of 1 p.p.m. was measured from within the lumen. This tube was placed, with the ends open, in a wellventilated halothane-free environment throughout this period, except for one period of 66 h in an oven at 40 °C. This was not a satisfactory method of removing halothane from the tubes (see table V). The amount of halothane remaining in the wall of the tube after 30 days was reflected by a considerably different behaviour on exposure to 1% halothane 30 days after the first exposure, and 5 months later (table IV, c (ii) and c (iii)).

This prolonged period of emission of halothane following exposure to 4% halothane, in association with the desirability of reproducing actual conditions, prompted the subsequent use of halothane in concentrations of 1% only.

The emission of halothane by the different tubes over a 2-week period following a single exposure to halothane is shown in table V and the extent of halothane diffusion through the wall is shown in table IV. Column 2 of table IV is a measure of the ability of the different materials to prevent initial escape of halothane and is dependent on both the nature and thickness of the wall. Column 3 shows the concentrations of halothane in the tank immediately following the initial exposure, from which it may be possible to deduce the extent of environmental pollution during an operating session. Column 4 shows the "overnight" concentrations in the tank, from which one may calculate the contamination which may occur during the same period through a tube which is sealed at both ends. Column 5 shows the peak concentration of halothane in the lumen of the tube at this time, which may indicate the degree of pollution available from diffusion from within a contaminated tube.
TABLE IV. Halothane concentrations (p.p.m.) following single exposure to 1% halothane for 3.5 h

<table>
<thead>
<tr>
<th>Tubing type</th>
<th>Time (min) to 1 p.p.m. in tank</th>
<th>Halothane (p.p.m.) in tank after 3.5 h (corrected figures in second column)*</th>
<th>Halothane (p.p.m.) in tank “overnight”</th>
<th>Peak values of halothane (p.p.m.) from tube lumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Thin plastic</td>
<td>60</td>
<td>14 15</td>
<td>400</td>
<td>2200</td>
</tr>
<tr>
<td>(b) Rubber</td>
<td>150</td>
<td>1.9 2.0</td>
<td>200</td>
<td>1600</td>
</tr>
<tr>
<td>(c) Thick plastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) 4% halothane</td>
<td>15</td>
<td>5.5 6</td>
<td>6</td>
<td>7000</td>
</tr>
<tr>
<td>(ii) 1% halothane</td>
<td>15</td>
<td>15 16</td>
<td>25</td>
<td>2350</td>
</tr>
<tr>
<td>(iii) 1% halothane</td>
<td>30 days after (i)</td>
<td>150</td>
<td>2.2 2.4</td>
<td>4</td>
</tr>
</tbody>
</table>

*Correction for error as a result of mass spectrometer suction.

TABLE V. Peak values of halothane (p.p.m.) from tube lumen after a single exposure to 1% halothane for 3.5 h over a 15-day period

<table>
<thead>
<tr>
<th>Tubing type</th>
<th>Days after exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Thin plastic</td>
<td>1 2 3 4 5 6 7 13 14 15 30</td>
</tr>
<tr>
<td>(b) Rubber</td>
<td>2200 72 1* 1.2</td>
</tr>
<tr>
<td>(c) Thick plastic</td>
<td>1600 360 340* 2.5</td>
</tr>
<tr>
<td>(i) 4% halothane</td>
<td>7000 380 2400* 72 1</td>
</tr>
<tr>
<td>(ii) 1% halothane</td>
<td>4000 1100</td>
</tr>
<tr>
<td>(iii) 1% halothane</td>
<td>150 days after (i)</td>
</tr>
</tbody>
</table>

*Denotes values obtained after 66 h in an oven at 40 °C.

As the gas concentration along the tube decreases exponentially as a result of uptake, it is difficult to predict how different lengths of tube will behave under similar circumstances.

CONCLUSIONS

In a minimum-sized operating theatre of 4000 ft³ (112 000 litre) (DHSS, 1970), the atmospheric contamination as a result of diffusion of halothane through the wall of 7.6 metres of tube carrying 1% halothane in 4 litre for 3.5 h would be between 1/1120 (0.0009) and 1/11 (0.09) p.p.m. if the ends of the tube were plugged.

However, if the tube were not plugged the concentration present in the lumen volume (3.6 litre) distributed in the room volume (112 000 litre) would be a considerable underestimate of overnight contamination as a result of concentration gradient effects; that is, the egress of halothane from the tube wall into the lumen would decrease as the concentration in the lumen increased, rather than continuing if this were reduced to lower values by unhindered passage into the room. This hypothetical figure would be between 1/19 (0.05) and 1/8 (0.125) p.p.m. and with 4% halothane for 4 h this would increase to 1/4.4 (0.23) p.p.m. (assuming no air-conditioning). It is reasonable to assume that the actual value would be in excess of this, as diffusion through the wall in an outward direction as well as from within the lumen would occur simultaneously. Other contributions of this nature will be made from the tube in, for instance, an anaesthetic circle system (approx. 3 m plus a 2-litre bag) which frequently may contain more than 1% halothane.

The values above are obviously small when compared with other sources of contamination. However, when it is now considered desirable to ensure that contamination by halothane is less than 1 p.p.m. (D. L. Bruce, personal communication), it is apparent that contributions of this nature are not insignificant.
PRACTICAL CONSIDERATIONS

(1) Short lengths of plastic or rubber tubing are desirable in any situation in order to minimize contamination.

(2) Anaesthetic or scavenge tubing should be either capped or plugged when not in use, or stored outside the operating theatre in a well-ventilated area. The diffusion occurring through the wall of capped tubes is small compared with possible contamination from within the lumen.

(3) Any patient in whom it is considered desirable to avoid halothane should be anaesthetized using a circuit made up of either new tube or tube which has not been used to deliver halothane for at least 2 months. To illustrate this point, we have shown that after an exposure of 3½ h to 1% (v/v) halothane, a black rubber tube contained 1600 p.p.m. (0.16%) within its lumen 18 h later, and 2.5 p.p.m. after 13 days, which would be the concentration delivered initially to a patient.

REFERENCES