CLOSED CIRCUIT ANAESTHESIA
A new approach

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SUMMARY
A logical development of the closed circuit is described, from a basic resuscitation device, through various modifications, to a circle system incorporating an oxygen demand valve, adsorbers for both carbon dioxide and halothane, and some specific safety features. The behaviour of the circuits has been investigated in relation to elimination of nitrogen, concentrations of halothane and circuit leaks.

When using a circle system the majority of anaesthetists use a fresh gas flow in excess of the patient's basal requirements, and the circuit behaves as if it were semi-closed (Mapleson, 1960).

With increasing concern about pollution in theatres, the totally closed circuit has much to commend it. Most of the anaesthetic systems so far proposed to reduce pollution require the connection of two lengths of hose to the patient. One of these carries gases to the patient and the other carries the expired gas, either to a halothane adsorber or out of the operating room. These systems have disadvantages and are no more convenient to use than a closed-circuit system. For a circle system to be completely closed it is necessary to balance exactly the flow of gases into the circuit against the patient's uptake. To do this by adjusting the valve on a Rotameter may require constant attention which could lead to insufficient care for other aspects of the patient's safety. This problem may be overcome by using a demand valve which will admit gas to the circuit whenever the pressure in the circuit becomes subatmospheric. In a circuit using only halothane and oxygen, this will occur as a result of carbon dioxide being removed by the soda-lime or oxygen being removed by the patient. Therefore, the rate at which oxygen is allowed into the circuit will balance exactly the metabolic requirement of the patient.

Low flow or closed techniques have particular problems. These may be summarized as follows:
(1) Nitrogen from the patient accumulates in the circuit, resulting in dilution of the inspired oxygen.
(2) Inspired gas concentrations are unpredictable as a result of nitrogen washout when using nitrous oxide with oxygen, and there is the additional problem of uncalibrated vaporizers in this application. The Goldman vaporizer has been used in these circuits and assessed under differing conditions.
(3) $P_{aCO_2}$ may increase abnormally as a result of ventilatory depression.
(4) High $F_{1O_2}$ especially in the presence of low tidal and minute volumes may have deleterious effects.
(5) There may be difficulty in producing rapid emergence following prolonged halothane/oxygen anaesthesia without pollution of the atmosphere.

Nitrogen washout
The importance of nitrogen washout will depend on the relative volumes of nitrogen in the patient and in the anaesthetic circuit. A 70-kg man will contain approximately 1300 ml of nitrogen dissolved in the body, made up as follows: (i) 450 ml in the blood, plasma and tissue water (volume 40 litre; nitrogen solubility in body fluids 0.017 at 37 °C) and (ii) 850 ml in the fat (20% by weight, fat solubility of nitrogen 0.09 at 37 °C). Immediately following induction of anaesthesia, a subject (70 kg) will have approximately 2 litre of air (FRC) in the lungs—1.6 litre of nitrogen. It follows that the total volume of nitrogen will be 450+850+1600 ml, which is approximately 3 litre. If this volume of nitrogen is mixed with an equal volume of 100% oxygen in the anaesthetic circuit, the inspired concentration of oxygen cannot
decrease to less than 50%. As the conventional reservoir bag is 2 litre capacity and anaesthetic tubing nominally 480 ml per metre length, it will be seen that it is most unlikely that any circuit will contain less than 3 litre. Most closed circuits have a capacity in excess of 4 litre as a result of the volume of the carbon dioxide adsorber.

Since the fresh gas flow in a closed system, to which oxygen is delivered from a demand valve, is very low, it is necessary to use a vaporizer inside rather than outside the circuit although under certain conditions a vaporizer outside the circuit can supply sufficient halothane. In order that the concentration of halothane may be altered rapidly if required, it is possible to have a halothane adsorber which can be switched in and out of the circuit. Thus the patient can wash out dissolved vapour without causing contamination of the operating room atmosphere.

Using a demand valve to supply oxygen to a circle system which included a carbon dioxide adsorber and a halothane adsorber, it has been shown that the circuit can be used safely totally closed, and the concentration of the halothane vapour in the circuit may be altered both rapidly and easily. Oxygen concentrations in the circuit depend on whether preoxygenation of the patient has been used, provided the circuit has no leaks.

APPARATUS AND METHODS

The circuits described were assessed comprehensively with respect to oxygen and halothane concentrations under a variety of conditions. In addition, the Goldman vaporizer was assessed separately. Oxygen concentrations were measured continuously with either a Harlake fuel cell (British Oxygen Company) or an IL412 oxygen monitor. These oxygen analysers were chosen for the following reasons:

(1) In independent tests, the Harlake has shown the least error of any tested in the presence of high humidity.
(2) The IL412 has a rapid response (time constant <3 s); therefore it is very suitable for detecting rapid changes.

Calibration of the oxygen monitors was with 100% oxygen and 100% nitrogen, and was then checked with room air. Concentrations of halothane were measured with either a Hook and Tucker ultraviolet halothane analyser (5% and 10% models), or a U.T.I. mass spectrometer. Calibration of the ultraviolet halothane analysers was verified with a Foregger halothane vaporizer which had been checked against weighed-in-air samples of halothane analysed by gas chromatography.

Calibration of the mass spectrometer for measurement of halothane was with either a saturated vapour of halothane producing 31.7% halothane at an atmospheric pressure of 766 mm Hg and 20 °C, or the same Foregger vaporizer. For measurements of oxygen and carbon dioxide, calibration was with a special gas mixture of 5% carbon dioxide in oxygen, room air (20.9% oxygen) and white spot nitrogen. Permanent records from the mass spectrometer were obtained using either a Devices or a Brush Clevite pen recorder.

DESCRIPTION OF CIRCUITS

Circuit 1. This was a circle system derived from a "to-and-fro" system which had been developed and tested successfully for mine rescue (fig. 1). This circuit was designed to allow a miner to remain in a poisonous atmosphere for the maximum available time when supplied with oxygen from a small portable cylinder. If it is assumed that the reservoir bag is empty and the subject inhales from the mouthpiece, the pressure within the circuit becomes subatmospheric, the demand valve opens and supplies the tidal volume demanded by the subject. On expiration the expired gas passes through the soda-lime and so the volume of gas reaching the reservoir bag equals the tidal volume minus the volume of carbon dioxide in the expired air. Assuming that the next tidal volume inspired is of the same size, gas comes from the reservoir bag until it is empty, at which time the demand valve opens to supply the volume lost by the removal of the carbon dioxide. Normally, the expiratory valve is closed so that gas escapes from the circuit only if the pressure becomes excessive.

Circuit 2. The addition of a vaporizer, either in or out of the circuit, produces an anaesthetic circuit (fig. 2).
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The dangers of assisting ventilation with the vaporizer inside these circuits are considerably greater than in the more conventional circuit using a fresh gas flow in excess of the patient's basal metabolic requirements, as a result of the very small fresh gas flow diluting the concentration of vapour in the circuit.

In practice it was found that the vaporizer in the circuit was necessary only for a short period at the beginning of the anaesthetic, and the required concentration could be maintained by the vaporizer situated outside the circle.

**Circuit 5.** The circuit was used also with ventilators powered independently from the fresh gas flow. Both the Cape ventilator and the Philips AVIII were used with the circuit shown in figure 5. With this arrangement it is necessary to ensure that if an air entrainment valve is fitted to the ventilator it does not open at a subatmospheric pressure less than that required to open the demand valve.

**Circuit 6.** The closed circuit has been used also with a charcoal adsorber in the circuit, as shown in figure 6. This is connected via two three-way taps on either side of the in-circuit vaporizer. This has the

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**FIG. 2.** Mine rescue circuit with vaporizers.

**FIG. 3.** Circle system with vaporizers and demand valve.

**FIG. 4.** Circle system with vaporizers, demand valve and bellows.

**FIG. 5.** Circle system with vaporizers, demand valve and ventilator.

**FIG. 6.** Circle system with vaporizers, demand valve, bellows and charcoal adsorber.
important advantage of permitting ventilatory assistance without the concomitant dangers of ventilating the patient with high concentrations of halothane.

In the investigations with anaesthetized subjects, anaesthesia was induced with thiopentone, an oropharyngeal airway was inserted, and a mask and head harness applied immediately to obtain a leak-free system. The appropriate circuit was then connected to the patient.

**EXPERIMENTS AND RESULTS**

**Circuit 1**

The basic circuit (fig. 1) which was developed for mine rescue has been tested comprehensively for more than 1 year. When the apparatus is worn by the conscious subject at rest, the demand valve can be heard to open to admit oxygen into the circuit about every five breaths. It does not open at the end of every inspiration since these are not all sufficiently deep to empty the reservoir bag to produce a subatmospheric pressure within the system. During exercise, such as performing “press-ups” or trotting, the valve can be heard to open at the end of most inspiratory efforts and remain open for a longer period. Subjectively, the user is not aware of increased respiratory effort while either resting or exercising, although the inspired gas feels both warm and moist during exercise. Users of this apparatus for mine rescue are instructed to breathe out maximally before inserting the mouth-piece and applying a nose-clip. If this is done the inspired concentration of oxygen remains between 40% and 60%, depending on the initial expiratory effort and the total lung volume.

If the user connects himself to the system after a maximum inspiratory effort, the subsequent inspired concentrations will depend on the size of the reservoir bag. If this is in excess of the vital capacity, the inspired concentration of oxygen may become significantly less than 20% before the pressure in the bag becomes subatmospheric and the demand valve opens. This assumes that the subsequent tidal volume is not equal to the vital capacity. If the volume of the reservoir bag is reduced to between 1 and 1.2 litre it is impossible to reduce the inspired concentration to less than 17% in a 70-kg subject with a tidal volume of 500 ml. This is because the greater part of the first expired volume will be discharged to atmosphere via the relief valve when the relatively small reservoir bag is full. The subsequent removal of carbon dioxide from the circuit ensures that the demand valve opens to admit more oxygen before the concentration decreases to less than 17%. If the circuit is flushed with oxygen while the subject takes three or four breaths from the system, the concentration of the inspired oxygen will remain between 40% and 60%.

The following experiments were performed to illustrate this point. Table I shows the oxygen percentages achieved using different sizes of reservoir bag in two subjects. We used a simulated mine rescue apparatus, as shown in figure 7. Oxygen was supplied from a cylinder through a modified Entonox (B.O.C.) demand valve. An AGA carbon dioxide adsorber, with the unidirectional valves removed to allow its

<table>
<thead>
<tr>
<th>Bag size (litre)</th>
<th>J B</th>
<th>D E</th>
<th>Lowest v/v % oxygen before demand valve opens</th>
<th>Time to demand valve opening (s) (number of breaths)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>14</td>
<td></td>
<td>14</td>
<td>70 (14)</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td></td>
<td>16</td>
<td>50 (10)</td>
</tr>
<tr>
<td>1.7</td>
<td>17.5</td>
<td></td>
<td>17.5</td>
<td>45 (9)</td>
</tr>
<tr>
<td>1.5</td>
<td>18.5</td>
<td>16.5</td>
<td>17.9</td>
<td>15 (3) 40 (8)</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td>17.0</td>
<td>17.0</td>
<td>50 (10) 42 (8)</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
<td>17.0</td>
<td>35 (7)</td>
</tr>
<tr>
<td>1.2</td>
<td>&gt; 20</td>
<td></td>
<td>17.5</td>
<td>25 (5) 20 (4)</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>17.0</td>
<td>17.3</td>
<td>15 (3) 18 (3-4)</td>
</tr>
<tr>
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<td>18.0</td>
<td></td>
<td>18.0</td>
<td>15 (3)</td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td>18.0</td>
<td>18.0</td>
<td>15 (3)</td>
</tr>
</tbody>
</table>
CLOSED CIRCUIT ANAESTHESIA

DEMAND VALVE

DXYCEN - CYLINDER

MOUTHPIECE

FIG. 7. Simulated mine rescue system for an assessment of the effect of reservoir bag size on inspired oxygen percentage.

Circuit 2

The addition of vaporizers to this circuit (fig. 2) did not affect any of the observed oxygen concentrations in circuit 1. With the two Goldman vaporizers the inspired concentration of halothane could be adjusted over a wide range. After about 5 min of anaesthesia it was found that the vaporizer in the circuit was not required, except very occasionally to boost the inspired concentration. This observation applied also to the other circuits which were examined, with the exception of circuit 5. This result was unexpected as, theoretically, the vaporizer outside the circuit would not normally supply sufficient anaesthetic vapour to the patient, because of the small flow passing through the vaporizer. The explanation would appear to be that, while the demand valve is closed, a volume of tubing on either side of the vaporizer becomes saturated with vapour. When the demand valve opens the whole of the volume is carried to the patient circuit. In this situation of intermittent flow the proportionating valve on the vaporizer does little to determine the inspired concentration during the period when a small quantity of fresh gas passes across it, but the setting of the valve determines the volume of gas outside the vaporizer which will approach saturation during a given period when no gas is passing through it. Another contributing factor is that during intermittent flow only, when a volume of gas of 100 ml or less passes across a Goldman vaporizer, at any setting beyond position 1, a considerably greater output concentration is seen as a result of the internal volume of the vaporizer becoming a significant proportion of the total tidal gas volume (tables IV and V).

Circuit 3

The conventional closed circuit (fig. 3) worked well when the basal oxygen requirement was supplied from a demand valve, as might have been expected. The observations made about the vaporizer in the previous system (fig. 2) apply in this system also except that the control was easier and remained more stable as a result of the increased circuit volume.
This circuit was used to assess the effects of nitrogen washout on $F_{1O_2}$ in patients who were pre-oxygenated and in those who were not. The circuit volume was measured carefully and found to be 4 litre. Anaesthesia was induced with thiopentone and maintained with oxygen and halothane using a leak-free mask.

The circuit was prefilled with oxygen. No fresh gas was admitted to the circuit during washout of nitrogen except halothane vaporized from a Goldman vaporizer in the circuit. The carbon dioxide adsorber was an AGA disposable canister containing the lightweight plastic valves for the circle. This carbon dioxide adsorber was assessed separately and demonstrated to be satisfactory for this purpose. The concentration of carbon dioxide issuing from this adsorber while being perfused with a constant 5-litre/min flow of 5% carbon dioxide was measured (fig. 8). It will be seen that in 1 h, less than 1% carbon dioxide was emitted, this being approximately equivalent to 3 h of intermittent flow with expired gas (spontaneous ventilation).

The decrease in $F_{1O_2}$ when a patient (weight 60 kg) who was not preoxygenated was connected to the circuit prefilled with oxygen is shown in figure 9. The initial decrease from 90% oxygen (the small decrease from 100% being inevitable from small leaks when connecting the patient to the circuit) to 55% represents nitrogen washout from the lungs (FRC), largely completed in 3 min. The slow decrease thereafter, from 52% to 48%, represents a slow washout from body stores (fat and water). The effect of preoxygenation of the patient on the eventual $F_{1O_2}$ is seen in figure 10. In this case the patient was ventilated with 10 litre/min of oxygen using this circuit for 10 min, during which time $F_{1O_2}$ increased from 90% to 100%. A subsequent decrease to 85%, completed in 3 min, represents a small volume of residual nitrogen in the FRC; the slow decrease from 85% to 80% over the next 25 min results from nitrogen emerging from the water and fat stores.

It is widely recognized that a high inspired oxygen concentration, especially in the presence of low tidal and minute volumes (as may be seen often during halothane anaesthesia), may predispose to peripheral collapse in the lungs. Our use of nitrogen to dilute the inspired oxygen to 50%, in the patients who were not preoxygenated, may be considered potentially beneficial.

Circuit 4

The major disadvantage of circuit 3 was the inability to ventilate the patient when the bag was nearly empty without first refilling with oxygen. This might be considered a safety feature in a closed system with a vaporizer in the circuit, but in view of certain
modifications described in circuit 6 we considered it a restriction of versatility. This problem was overcome by replacing the reservoir bag with a bellows (fig. 4). Providing the bellows could be distended with very little pressure, it did not matter whether it was self-inflating or not, though on balance it appeared that the light non-self-inflating bellows was preferable as it ensured that the pressure in the circuit, for most of the cycle, remained slightly positive and thus discouraged the leakage of air into the system. The important effect of leaks on these circuits is discussed in a later section. This modification worked well, and controlled ventilation could be performed easily if desired. The bellows also allowed the concentration of inspired oxygen to be increased rapidly, if desired, by ventilating the patient with either of the expiratory valves open. However, this procedure would result in contamination of the theatre atmosphere with halothane vapour; the solution to this particular problem is discussed in relation to circuit 6.

Circuit 5
A demand valve was used to supply oxygen to both Cape and Philips AVIII ventilators (fig. 5). With the use of a ventilator, a notable difference in behaviour of the out-of-circuit vaporizer occurred compared with circuit 2. Because of the nature of the automatic ventilation only a fraction of the basal metabolic requirement of oxygen was admitted to the circuit with each individual breath, and it was not always possible, therefore, to maintain a satisfactory concentration of halothane with the vaporizer outside the circuit. For this reason the inclusion of a vaporizer inside the circuit was needed both for the initial 5 min following an i.v. induction and for the subsequent maintenance.

Circuit 6
This circuit (fig. 6) was a development of the circuit shown in figure 4. The inclusion of charcoal for the removal of halothane vapour during or at the end of anaesthesia, was a logical step in the rational use of charcoal, particularly in view of the current interest in the prevention of atmospheric pollution by anaesthetic waste gases.

The performance of the charcoal in removing halothane from the circuit is demonstrated in figure 11 which shows the decrease in concentration of halothane in a circuit when a charcoal adsorber is incorporated. This was a simulated patient system, using a 40-litre drum to simulate the lungs and a Philips AVIII ventilator in conjunction with the circuit, that is a combination of circuits 5 and 6. Halothane concentrations were measured with a U.T.I. mass spectrometer. “A” shows the calibration steps of 0.5, 1.0, 1.5 and 2.0% v/v halothane. “B” is zero. At “C”, a small surge of halothane concentration occurred as the Goldman vaporizer was turned on, and “D” shows the increase in concentration of halothane in the circuit to 2.0% v/v. At “E” the vaporizer was switched off, and “F” shows a near steady-state concentration of halothane (1.8% v/v). At “G” the charcoal was turned on, and an extremely rapid decrease occurred. After 30 s (five breaths only) the concentration decreased to 0.15% v/v, and to 0.03% v/v after 3 min (“H”).

This performance, when used in a circle system (circuit 6) while anaesthetizing patients, is demonstrated in figures 12 and 13.

The different rate of increase of halothane concentration which is shown in these two figures resulted from the different size of the patients—a slow increase in the large patient (80 kg) (fig. 12) and a faster increase in a small patient (55 kg) (fig. 13). At point “H off” in the figures, the Goldman vaporizer was turned off and at “C on”, the charcoal was switched on. The decrease in concentration seen on switching on the charcoal is similar to that in the model. However, because of continuing excretion from the patient, the concentration did not reach zero as in the model, but usually stabilized at less than 0.1%. The performance of this circuit, being of a volume similar to circuit 3 (4 litre), was similar with respect to nitrogen elimination and changes in inspired oxygen concentration. Figure 14 shows an inspired oxygen concentration of 45% being maintained by oxygen admitted intermittently from the demand valve. The spikes of higher oxygen concentrations were of brief duration (approx. 10-15 s) and
have been expanded in the figure for clarity. Only the large volume demands from the valve are audible; the arrows show the timing of the large demands only.

**Circuit leaks**

Leaks in this type of circuit are extremely important. With experience it is possible to obtain a completely leak-free fit with a face-mask in the majority of patients. This may be checked easily by closing the circuit completely, and ventilating the patient with the vaporizer off. Any leaks from the mask will be immediately apparent. In the very few in which a satisfactory fit is not possible, tracheal intubation could be used.

In a circuit in which a slight subatmospheric pressure is necessary for oxygen supply by a demand valve, circuit leaks may allow the dilution of oxygen to unsatisfactory or even dangerous concentrations.

The effect on $F_iO_2$ of a defective demand valve permitting the entrainment of room air is shown in figure 15. Continuously diminishing oxygen concentrations less than 30% necessitated intermittent manual refilling of the circuit with oxygen in order to maintain satisfactory oxygenation.

Leaks of this nature may be overcome by:

1. A continuous flow of oxygen, necessitating a low flow Rotameter, as in conventional closed-circuit anaesthesia with higher than basal oxygen flow.
2. A continuous low flow suction.

Circuit 6, with the latter arrangement, is shown in figure 16. An air entrainment valve, set at a higher pressure than the demand valve is included also as an added safety feature; should the oxygen supply fail, air will be admitted. The effect of differing suction rates on the concentration of oxygen in a leaking circuit is shown in figure 17. In this particular
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FIG. 16. Circuit 6, modified with the addition of a suction pump and air entrainment valve.

instance, a suction rate of 600 ml/min overcame the reduction in oxygen concentration caused by the leak in a faulty demand valve.

This circuit (fig. 6) has a number of important advantages over a conventional closed circuit:

1) The patient's nitrogen is used to maintain $F_{I\alpha}O_2$ 0.50-0.60 rather than 1.0, with two benefits:
   (i) There is a decreased risk of absorption collapse in the lungs. (ii) There is no need for preoxygenation, or any high flow anaesthetic technique, before the use of the closed circuit. Therefore atmospheric pollution with anaesthetic gases during induction of anaesthesia may be avoided completely.

2) The use of Rotameters is avoided. With the Rotameters on anaesthetic machines currently in use it is difficult to measure flows of less than 300 ml/min with accuracy. The provision of a demand valve for the oxygen supply enables the conventional anaesthetic machine to be dispensed with. Thus, the whole circuit is portable, requiring only an oxygen cylinder for use anywhere.

3) The rapid removal of halothane vapour from the patient at the end of the desired period of anaesthesia accelerates recovery and diminishes atmospheric pollution both in the operating room and the recovery area.

4) A potential disadvantage of any closed system with a vaporizer in the circle is that, should IPPV be required, it is necessary either to dump the contents of the circle to atmosphere, or to subject the patient to potentially dangerous high concentrations of halothane. With this circuit, if the charcoal is incorporated, IPPV may be instituted with neither pollution of the atmosphere nor danger to the patient.

(5) This is a safe circuit (i) decreasing the hazards of V/C anaesthesia; (ii) using nitrogen to advantage; and (iii) with an air entrainment valve added (fig. 16) lessening the risks of serious consequences of an oxygen supply failure.

ASSESSMENT OF GOLDMAN VAPORIZERS

Since the Goldman vaporizer has been used in all these circuits both inside and outside the circle, it was necessary to know what concentrations of halothane might be delivered from it under these different circumstances. An assessment of its behaviour under constant and intermittent flow conditions was performed.

Constant flow characteristics

The percentages (v/v) of halothane obtained from a Goldman vaporizer at flow rates from 1 to 15 litre/min are shown in table II. Oxygen was used as the carrier gas and halothane was measured with an ultraviolet analyser.

With a constant flow of 15 litre/min the top three settings of the vaporizer (positions 3, 3½ and 4) gave a constant 1.8%, as a result of the decrease in temperature of the halothane. The figures in table II are of the same order as the original figures given for this vaporizer by Goldman (1962).

Intermittent flow

(a) Semiclosed system. A Philips AVIII ventilator providing a tidal volume of 700 ml and a minute volume of 10 litre (fig. 5) was used. Halothane concentrations were measured with a U.T.I. Mass Spectrometer. The results from this system gave results similar to those shown in table II, except that there were respiratory excursions of 0.25-0.35% (v/v) between inspiration and expiration at all settings except the first two (½ and 1), this presumably resulting from the critical orifice size of the proportionating valve of the vaporizer at these low settings.

(b) Closed circle. Fig. 16 was modified to form a closed circuit with the addition of a suction pump and air entrainment valve. The concentrations of halothane obtained under constant flow conditions (fig. 17) are compared with those obtained with the Goldman vaporizer under semiclosed conditions (table II) and with those obtained with the same machine used in open circuit (fig. 18).
(b) Closed circuit. In time, if there is no uptake by a patient, a closed-circuit model with a Goldman vaporizer in circuit will always produce a saturated vapour of the agent in use.

During spontaneous ventilation, the ultimate concentrations of halothane developed are determined by that concentration which is needed to produce apnoea in the patient in the particular circumstances. Typical values are shown in table III. These were obtained in a 70-kg male patient breathing spontaneously in a circle system (fig. 3), with a Goldman (A. C. King) vaporizer. The anaesthetic gases were nitrous oxide and oxygen with $F_{1O_2}$ maintained at 0.30. Halothane concentrations were measured with a 0-10% ultraviolet halothane analyser (Hook and Tucker).

Effects of low tidal volume and deliberate movement of the vaporizer on the output concentration of the Goldman vaporizer

We investigated the factors responsible for producing undesirably high or uncontrolled fluctuations in halothane concentration from the Goldman vaporizer.

**METHODS**

The equipment is shown schematically in figure 18. Gas (air) was supplied from the Rotameters on a Philips AVI ventilator, passing directly to the vaporizer which was filled to “30 cc” level with halothane. Distal to the vaporizer was a 2-litre reservoir bag and an analysis probe leading to a U.T.I. Mass Spectrometer. The reservoir bag was used only for tidal volumes of 50 ml to ensure sufficient gas for the mass spectrometer suction flow of 30 ml/min and to prevent retrograde sampling of room air. Time was allowed between experiments for the halothane to rewarm to room temperature, and the vaporizer was refilled as necessary.
Measurements of the halothane concentrations (v/v%) were made under three different conditions: (a) continuous flow at 500 ml/min, 1000 ml/min, 2000 ml/min and 5000 ml/min; (b) intermittent flow at these same volumes divided into 10 b.p.m. of 1 s inspiration and 5 s expiration by the AVI ventilator, delivering tidal volumes of 50 ml, 100 ml, 200 ml and 500 ml respectively; (c) both (a) and (b) were repeated while the vaporizer was subjected to movement such as might occur during use on an anaesthetic machine.

Two models of the Goldman halothane vaporizer are commonly in use. One, distributed by A. C. King until 1964 (the A. C. King Goldman Halothane Vaporizer or Goldman Mark II) (Goldman, 1962), has settings: “OFF, 1, 2, 3 and ON”. The other, produced by the British Oxygen Company after 1964, has settings: “OFF, 1, 2 and ON” (BOC Goldman Halothane Vaporizer). An example of each of these was tested.

### RESULTS

#### Low tidal volumes

The output concentrations of (v/v%) halothane vapour at continuous and intermittent flows for the B.O.C. Goldman Vaporizer (three-settings model) are shown in table IV. Table V shows the same analysis of the A. C. King Goldman Halothane Vaporizer (four-settings model).

Where two values are given in the tables at any setting, the high value is given first as this was the initial measured concentration, and the lower that of the steady state. Since movement of the vaporizer may have a marked effect on output concentrations under certain conditions (see below), these initial higher values are almost certainly a result of that cause alone; it is difficult to alter the valve setting without producing some movement of the vaporizer.

It can be seen (tables IV and V) that at a tidal volume of 500 ml the halothane concentrations...
TABLE VI. Concentration of halothane (v/v) during continuous and intermittent flow following deliberate movement of the vaporizer (Goldman (B.O.C.) vaporizer)

<table>
<thead>
<tr>
<th>Vaporizer setting</th>
<th>Gas flow (litre/min)</th>
<th>Tidal volume (ml)</th>
<th>Peak</th>
<th>Steady</th>
<th>Peak</th>
<th>Steady</th>
<th>Peak</th>
<th>Steady</th>
</tr>
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<td></td>
<td>Continuous</td>
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<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>0.5</td>
<td>—</td>
<td>—</td>
<td>0.51-0.38</td>
<td>1.27-0.63</td>
<td>3.87-1.90</td>
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<td></td>
</tr>
<tr>
<td>1.0</td>
<td>—</td>
<td>—</td>
<td>0.32-0.19</td>
<td>1.27-0.32</td>
<td>3.80-1.20</td>
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<tr>
<td>2.0</td>
<td>—</td>
<td>—</td>
<td>0.38-0.19</td>
<td>4.31-1.52</td>
<td>10.78-1.90</td>
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<td>5.0</td>
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<td>0.63-0.38</td>
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<td>7.48-1.90</td>
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<tr>
<td>0.5</td>
<td>50</td>
<td>1.11-0.41</td>
<td>7.20-6.18</td>
<td>18.00*-9.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>100</td>
<td>0.98-0.35</td>
<td>7.01-4.60</td>
<td>8.91-4.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>200</td>
<td>0.16-0.10</td>
<td>4.47-1.49</td>
<td>3.84-1.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>500</td>
<td>0.41-0.16</td>
<td>3.46-1.30</td>
<td>4.47-1.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Concentrations from 15.9% to 18.7% depending on the severity of the agitation.

achieved are similar to the continuous flow conditions. However, at tidal volumes of 200 ml or less, the vaporizers produce increasing concentrations over their continuous flow characteristics at any setting higher than 1, that is the lower the tidal volume at high vaporizer settings, the higher the output concentration achieved. Therefore this is the undesirable positive feedback system which ensures apnoea at high vaporizer settings in a closed circuit.

A discrepancy between some values in table V and table II (two different methods of analysis of a similar model of vaporizer) can be explained as follows: (1) A different vaporizer was used in each experiment. (2) The measurements in table V were obtained with a mass spectrometer which resulted in a scale calibration of 0-31.7%. This resulted in some inaccuracy in readings below 1%. (3) Cooling of the halothane during the experiments may cause discrepancies at high gas flows with the higher vaporizer settings.

**Deliberate movement of the vaporizer**

The effect of deliberate movement of the vaporizer on the output concentration at each setting, for the B.O.C. Goldman Vaporizer (three-settings model) during continuous and intermittent flow, is shown in table VI. The vaporizer was given a controlled shake to simulate accidental movement of an anaesthetic machine or circle system during use. Results are shown at each setting as peak and steady values. These peak concentrations resulting from movement settle to a steady value in a mean of 2.9 breaths (17.2 s) (range 2-6 breaths) with intermittent flows, or a mean of 15 s (range 10-25 s) with continuous flow, the longest periods naturally following the highest peak concentrations.

The extremely high peak values of 16-18% at a tidal volume of 50 ml, and 8.9% at a tidal volume of 100 ml following movement with the vaporizer at its maximum setting, are an indication of the total volume of saturated halothane vapour available from the vaporizer per breath.

The high steady values (9.2% and 4.9%) following movement with these tidal volumes of 50 ml and 100 ml were maintained for more than 1 min following the movement. More than 5 min were needed for a decrease to the concentrations shown in table IV for intermittent flow in this vaporizer without movement.

It is apparent from these observations that, under certain conditions, the Goldman vaporizer, in circuit, may be a threat to patient safety, notably in association with low tidal volumes and movement of the vaporizer. Since an increasing use of low flow or closed-circuit anaesthesia may stimulate interest in this vaporizer, it is important that those who are unfamiliar with its characteristics are made aware of its potential dangers.

**REFERENCES**


CLOSED CIRCUIT ANAESTHESIA

ANESTHESIE EN CIRCUIT FERME
Une nouvelle méthode

RESUME
On décrit dans cet article un développement logique du circuit fermé obtenu à partir d'un dispositif de réanimation de base et au moyen de diverses modifications, de manière à former un circuit annulaire incorporant une soupape d'appel d'oxygène, des adsorbeurs de gaz carbonique et d'halothane ainsi que certaines caractéristiques spécifiques de sécurité. On a étudié le comportement des circuits du point de vue élimination de l'azote, concentrations d'halothane et fuites du circuit.

KREISLEITUNGS-ANÄSTHESIE
Eine neue Methode

ZUSAMMENFASSUNG

ANESTESIA DE CIRCUITO CERRADO
Un nuevo enfoque

SUMARIO
Se describe un desarrollo lógico del circuito cerrado, partiendo de un dispositivo básico de reanimación, a través de diversas modificaciones, hasta un sistema en circuito incorporando una válvula reguladora de demanda de oxígeno, recipientes para absorción de anhídrido carbónico y halotano, y algunas características específicas de seguridad. Se ha investigado el comportamiento de los circuitos en relación con la eliminación del nitrógeno, concentraciones de halotano y fugas en el circuito.