REBREATHING IN A DOUBLE T-PIECE SYSTEM

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SUMMARY
A double T-piece paediatric system is described. During spontaneous respiration, the system will perform like a Magill system if the fresh gas flow is delivered via the distal T-piece; the proximal T-piece will provide an outlet. During controlled ventilation the set will perform like a Rees system if the fresh gas flow is delivered via the proximal T-piece; the distal T-piece will provide a control outlet. As judged by the degree of rebreathing, distal inflow is more efficient than proximal inflow during spontaneous respiration. Distal and proximal inflow are equally efficient during controlled hyper-ventilation.

The T-piece has found wide application in anaesthesia since Ayre's original description in 1937. His system had neither valves nor breathing bag, and resistance to respiration was minimal. In course of time many adaptations appeared, a popular one being that of Rees (1950), who attached a double-ended bag to the reservoir tube, so enabling pulmonary ventilation to be controlled.

In semi-open systems, rebreathing during intermittent positive pressure ventilation is different from that which occurs during spontaneous respiration. Mapleson (1954) published a theoretical examination which included a comparison of the Magill system, which has a gas outlet close to the patient while the reservoir bag and the fresh gas inflow are remote, with a system like that of Rees, in which the fresh gas inflow is close to the patient and the outlet is remote. To eliminate rebreathing during spontaneous respiration, the Magill system is considered to need a fresh gas flow at least equal to the patient's minute ventilation volume, while a system like that of Rees needs a fresh gas flow equal to at least twice the minute volume. If, on the other hand, controlled ventilation is used with these systems, their rebreathing properties change, and the Rees-like system is then to be preferred to the Magill (Waters and Mapleson, 1961).

The double T-piece system depicted in figure 1A permits an easy change in the relative positions of gas inflow and outflow. It performs like the Magill system if fresh gas enters via the distal T-piece near the reservoir bag; the proximal T-piece then provides an outlet which differs from the original Magill system in not having a valve (fig. 1B). It performs like the Rees system if the gas delivery tube is attached to the proximal T-piece; the distal T-piece then provides an outlet...

which is easily controlled by an occluding finger. The reservoir bag is not open-ended (fig. 1c).

When fresh gas is delivered via the distal T-piece the set performs like a Magill system. The proximal T-piece provides an overflow outlet which differs from the original Magill system in not having a valve. A soft small bag is recommended to avoid collapse of the bag at low gas flows.

The purpose of this investigation was to compare the degree of rebreathing that occurs in the two arrangements during spontaneous and controlled ventilation in anaesthetized children.

**METHOD**

This investigation was carried out on 12 anaesthetized children undergoing surgery. Their ages ranged between 1 month and 10 years, and their weights between 3.5 and 28 kg.

**Anaesthesia.**

Pentobarbitone 4 mg/kg and atropine 0.15–0.6 mg were injected intramuscularly 30 minutes before anaesthesia. Anaesthesia was induced with oxygen and halothane. All children were intubated orally and anaesthesia was maintained with 1–2 per cent halothane in oxygen using a Boyle apparatus. The Rotameter flowmeters were frequently checked for leakage and calibrated with a spirometer before use.

The double T-piece system was used during induction and maintenance. The capacity of the reservoir tube between the two T-pieces is approximately 60 ml. The proximal T-piece was connected to the endotracheal tube by a rubber connection 5 ml long, through which a sampling catheter was directed into the endotracheal tube. The carbon dioxide concentration in the airway was determined using a Beckman LB1 infra-red analyser, calibrated initially with three known mixtures of carbon dioxide in oxygen. The analyser output was continuously recorded on a Grass Polygraph. The upper limit of the recordings represents the end-expiratory carbon dioxide concentration while the base indicates the inspired concentration and the amount of rebreathing. Rebreathing was considered to be minimal or absent if a zero-level plateau was recorded during inspiration.

**Determination of fresh gas inflow.**

Carbon dioxide production is more closely related to the age or to body surface area than to body weight (Nightingale, Richards and Glass, 1965). For this reason the minute ventilation volume of average children can be approximately estimated according to age from the nomogram shown in figure 2. This nomogram was constructed from the average surface area at different ages in proportion to adult values (table I). It is a simple approximate clinical guide.

In our subjects the minute volume was read from the nomogram according to the age of the child. The fresh gas inflow was then determined as a multiple of this estimated minute volume.

**General procedure.**

All studies were carried out during maintenance of halothane anaesthesia. Each child acted as his own control. Spontaneous respiration was studied first and then controlled respiration.
REBREATHING IN A DOUBLE T-PIECE SYSTEM

A simple nomogram showing approximate minute volume of children at different ages. It is constructed from the average surface area of children at different ages in proportion to the adult valves.

Spontaneous respiration.
A fresh gas inflow equal to 1 minute volume was used. The degree of rebreathing with proximal outflow of gas (Magill) was compared with that during distal outflow (Rees). If rebreathing was observed, the fresh gas inflow was increased in steps until rebreathing was eliminated.

Controlled respiration.
Intermittent positive pressure hyperventilation was carried out manually at a rate of about 50 b.p.m., using both arrangements. The degree of rebreathing was compared. In order to maintain identical patterns of ventilation, intermittent positive pressure ventilation was also carried out using a Radcliffe ventilator and a bag-in-box system, as shown in figure 3. The rate of ventilation was set at 25 b.p.m. and the inflation pressure was 15–20 cm H₂O. Minute ventilation volume was always greater than 2 estimated minute volumes, as checked by a Wright anemometer incorporated in the ventilator.

![Diagram of the double T-piece arrangement during controlled ventilation by a Radcliffe ventilator. The fresh gas inflow is delivered via one T-piece. The second T-piece is replaced by a balloon occlusion valve. Ventilation was carried out at a rate of 25 b.p.m. and a pressure of 15–20 cm H₂O.](image)

**Table I**
Table showing the minute volume of children calculated from the average surface area at different ages in proportion to the adult value. To simplify calculation the average adult minute volume is taken as 8 l./min.

<table>
<thead>
<tr>
<th>Surface area of child</th>
<th>Surface area of adult</th>
<th>Minute volume (l./min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>1 yr</td>
<td>1/3</td>
<td>2.0</td>
</tr>
<tr>
<td>3 yr</td>
<td>1/3</td>
<td>2.7</td>
</tr>
<tr>
<td>7 yr</td>
<td>1/3</td>
<td>4.0</td>
</tr>
<tr>
<td>14 yr</td>
<td>1/3</td>
<td>6.0</td>
</tr>
<tr>
<td>Adult</td>
<td>1</td>
<td>8.0</td>
</tr>
</tbody>
</table>

![Graph showing the approximate minute volume of children at different ages.](image)
The end-expiratory carbon dioxide concentration during controlled hyperventilation was recorded while the fresh gas inflow was set at one or two times the estimated minute volume. After every change of flow or system a period of 10 minutes was allowed to establish a steady state.

RESULTS

Spontaneous respiration.

There was no rebreathing in any patient in the series when a fresh gas flow equal to 1 minute volume was delivered via the distal T-piece. On the other hand, the inspired carbon dioxide concentration in all patients ranged between 1 and 3 volumes per cent when the same gas flow was delivered to the proximal T-piece. Figure 4 is a typical recording which shows this comparison. In order to eliminate rebreathing in the latter arrangement at least twice the minute volume was required, as shown in figure 5. These results are summarized in table II.

Controlled respiration.

During controlled hyperventilation no difference was seen in the degree of rebreathing between the two arrangements in any of the 12 patients. In figure 6 is shown a comparison of the degree of rebreathing during manual ventilation at a rate of about 50 b.p.m. An example of the degree of rebreathing during mechanical ventilation at a rate of 25 b.p.m. is shown in figure 7. As expected, rebreathing was greater during rapid manual ventilation than during slow mechanical ventilation (fig. 8), but the end-expiratory carbon dioxide concentration did not change once a steady state was reached. With either manual or mechanical hyperventilation the end-expiratory carbon dioxide concentration changed with the volume of fresh gas inflow. Using a fresh gas inflow of 1 minute volume, the end-expiratory carbon dioxide concentration ranged from 3.8 to 6 volumes per cent. When twice the minute volume fresh gas inflow was

<table>
<thead>
<tr>
<th>Fresh gas inflow</th>
<th>Magill-like arrangement</th>
<th>Rees-like arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 EMV</td>
<td>No rebreathing</td>
<td>1-3% rebreathed carbon dioxide</td>
</tr>
<tr>
<td>2 EMV</td>
<td>No rebreathing</td>
<td>No rebreathing</td>
</tr>
</tbody>
</table>

1 EMV = fresh gas inflow equals 1 estimated minute volume.
2 EMV = fresh gas inflow equals twice the estimated minute volume.

Table II

Table showing the degree of rebreathing during spontaneous breathing using a fresh gas inflow which equals one or two times the estimated minute volume.

Fig. 4

Recordings of airway carbon dioxide concentration in a child of 4 years during spontaneous breathing.
1 & 3. A fresh gas inflow equal to 1 minute volume (3 l./min) was delivered via the proximal T-piece. The distal T-piece provides an expiratory outlet. Rebreathing was observed.
2. The same fresh gas inflow delivered via the distal T-piece. The proximal T-piece provides an expiratory outlet. No rebreathing was observed.

Fig. 5

Recording of airway carbon dioxide concentration in a child of 4 years during spontaneous breathing.
1. One minute volume fresh gas inflow (3 l./min) was delivered via the proximal T-piece. Rebreathing was observed.
2. Fresh gas inflow increased to 4 l./min.
3. Fresh gas inflow increased to 5 l./min.
4. Fresh gas inflow is increased to 6 l./min (double the estimated minute volume). Rebreathing was eliminated.
REBREATHING IN A DOUBLE T-PIECE SYSTEM

**Fig. 6**
Recording of airway carbon dioxide concentration in a child of 3 years during manually controlled ventilation at a rate of about 50 b.p.m.
1. One minute volume fresh gas inflow (2.75 l./min) was delivered via the proximal T-piece.
2. One minute volume fresh gas inflow (2.75 l./min) was delivered via the distal T-piece. Degree of rebreathing remained the same.

**Fig. 7**
Recording of airway carbon dioxide concentration in a child of 3 years. Ventilation was mechanically controlled using a Radcliffe ventilator at a rate of 25 b.p.m.
1. One minute volume fresh gas inflow (2.75 l./min) was delivered via the proximal T-piece.
2. One minute volume fresh gas inflow (2.75 l./min) was delivered via the distal T-piece.
Degree of rebreathing remained the same.

**Fig. 8**
Recording of airway carbon dioxide concentration in a child of 3 years during controlled ventilation. One minute volume fresh gas inflow was delivered via the proximal T-piece.
1 & 3. Ventilation controlled by a Radcliffe ventilator at a rate of 25 b.p.m.
2. Ventilation controlled manually at a rate of about 50 b.p.m. Marked rebreathing was observed.
Table III
Table showing the end-expiratory carbon dioxide concentration during controlled hyperventilation using a fresh gas inflow which equals one or two times the estimated minute volume.

<table>
<thead>
<tr>
<th>Age</th>
<th>Weight (kg)</th>
<th>Estimated minute vol. (l./min)</th>
<th>End-expiratory CO₂ concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 EMV (%)</td>
</tr>
<tr>
<td>1 m</td>
<td>3.5</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>4 m</td>
<td>5.4</td>
<td>1.25</td>
<td>5.0</td>
</tr>
<tr>
<td>7 m</td>
<td>8.0</td>
<td>1.75</td>
<td>5.0</td>
</tr>
<tr>
<td>1 yr 2 m</td>
<td>10.0</td>
<td>2.25</td>
<td>5.5</td>
</tr>
<tr>
<td>2.5 yr</td>
<td>15.0</td>
<td>2.5</td>
<td>6.0</td>
</tr>
<tr>
<td>2.5 yr</td>
<td>13.0</td>
<td>2.5</td>
<td>3.8</td>
</tr>
<tr>
<td>2.5 yr</td>
<td>13.0</td>
<td>2.5</td>
<td>5.0</td>
</tr>
<tr>
<td>3 yr</td>
<td>19.0</td>
<td>2.75</td>
<td>4.5</td>
</tr>
<tr>
<td>3.5 yr</td>
<td>15.0</td>
<td>3.0</td>
<td>5.8</td>
</tr>
<tr>
<td>4 yr</td>
<td>16.0</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>5 yr</td>
<td>15.0</td>
<td>3.5</td>
<td>6.0</td>
</tr>
<tr>
<td>10 yr</td>
<td>28.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

1 EMV=fresh gas inflow equals 1 estimated minute volume.
2 EMV=fresh gas inflow equals twice the estimated minute volume.

used, hyperventilation could lower the end-expiratory carbon dioxide concentration to 3–4 volumes per cent (table III).

**DISCUSSION**

This investigation shows that this paediatric double T-piece system can behave like a Magill system or a Rees system according to the site of fresh gas inflow. During spontaneous respiration rebreathing is negligible in the Magill-like arrangement if the fresh gas inflow equals the minute volume of the child, while at least double the minute volume is required to eliminate rebreathing in the Rees-like arrangement. During controlled hyperventilation rebreathing is approximately the same with both arrangements provided the fresh gas inflow and the pattern of ventilation are similar.

With semi-open systems such as the double T-piece, the concentration of carbon dioxide in the alveolar gas during controlled hyperventilation is determined according to the following equation (Nightingale, Richards and Glass, 1965):

\[
\text{Alveolar carbon dioxide concentration} = \frac{\text{carbon dioxide production}}{\text{fresh gas inflow}}
\]

Under stable conditions the carbon dioxide production remains fairly constant and the alveolar carbon dioxide tension is determined by fresh gas inflow, provided minute volume ventilation exceeds the fresh gas inflow. This has been confirmed with both our Magill- and Rees-like arrangements during intermittent positive pressure hyperventilation. A fresh gas inflow equal to 1 minute volume could maintain normocarbia, while 2 minute volumes could lower the alveolar carbon dioxide concentration to 3–4 volumes per cent.

On the basis of these results, the double T-piece set has been used as a routine in children up to the age of 7 years. During spontaneous respiration, fresh gas was delivered via the distal T-piece while the proximal T-piece provided an expiratory outlet. During controlled ventilation, fresh gas was delivered via the proximal T-piece while the distal T-piece near the reservoir bag provided a conveniently controlled outlet. In either case a fresh gas flow was used equal to the patient’s minute volume, as approximated from the nomogram, and in these children it ranged from 1 to 4 l./min. The end-expiratory carbon dioxide levels were frequently spot-checked by infra-red analysis, and were found to be within the normal range.

The double T-piece system has the virtues of existing T-piece systems, together with a flexibility which permits use of gas flow rates within the limits of reasonable economy.
REFERENCES

REININSPIRATION AVEC UN SYSTEME A PIECE EN DOUBLE T

SOMMAIRE
Un système pédiatrique avec pièce en double T est décrit. Au cours de la respiration spontanée, le système agit comme un système Magill, sauf que le flux de gaz frais arrive par la partie distale du T; la partie proximale servira à l'échappement. Au cours de la ventilation contrôlée, l'appareil agit comme un système Rees, sit'arrivée du gaz frais se fait par la pièce proximale du T; la pièce distale sert alors comme échappement de contrôle. Évalué suivant le degré de réinspiration, le flux à 'arrivée distale est plus efficace que l'arrivée proximale durant la respiration spontanée. L'efficacité du flux à 'arrivée distale est égale à celle du flux à 'arrivée proximale au cours de l'hyperventilation contrôlée.

NARKOSE IN EINEM "DOPPELTEN T-STÜCK-SYSTEM"

ZUSAMMENFASSUNG

BOOK REVIEW—continued from p. 46

hepatic injury; this is lucid and of direct and immediate import to all clinicians, even if every anaesthetist might not agree with the stringent recommendations for the use of halothane. Interesting it is, also, to ponder that slow desensitization may be responsible for the rarity (or is it only apparent?) of liver damage among anaesthetists, dentists, and surgeons exposed to halothane over long periods.

The next two chapters, on the isolated calf liver perfused with anaesthetics, and on spermidine levels as a response to liver injury, have a few rough edges and less than certain conclusions; but there is the pertinent comment that no-one has yet produced a drug sensitivity (liver) reaction in any animal, including primates. When the term "Indirect periodicity analysis" appears the reader should not be deterred from discovering that mortality from halothane in mice depends on the time of day at which they are exposed (the cause of death is not specified, and is presumably circulatory arrest).

The effect of cyclopropane on catecholamine transformation is next discussed and related to its pharmacological action, but quite unconvincingly to this reviewer. It is then shown that the uptake of glucose by red cells, which is stimulated by carbon dioxide and is not insulin-dependent, is depressed by halothane. It is difficult to assess the claims of the next paper, that radiosensitivity of tumours is increased by locally-injected hydrogen peroxide; but it is of interest that intra-carotid injection causes temporary hemiparesis not infrequently. The final chapter in Section 3 describes "anaesthetic" actions of helium, nitrogen, and hydrogen at high pressure, findings of relevance more to under-sea exploration than to anaesthesia.

Section 4, "Teratogenic effects", starts with problems of testing drugs, and there is the sinister deduction that the major sensitivity to foetal abnormalities may occur 15–30 days after conception (i.e. sometimes before pregnancy is detected in the human). The chick embryo is the preparation used in the next three studies. First, diethyl ether, acting perhaps to cause cell death in a population whose individual susceptibility varies, causes peak teratogenesis at a dose level near the LD50. Then, over periods of 20 days, cyclopropane reduces the mitotic index (the fraction of cells in division in a homogeneous population at a given time), and produces an increased number of abnormal embryos; less dramatic effects are caused by nitrous oxide and halothane. Finally, foetal lesions become common when pregnant rats are exposed to nitrous oxide for periods exceeding 24 hours.

The above is but a brief summary of many notes taken during study of this impressive publication. As the reader will judge, the studies are "far out"; the editor, whose name appears on three papers, writes that the participants found this symposium exhilarating; so is this book, in which research endeavour is shown at full stretch toward goals mostly far removed from everyday activity in the operating-room—in fact, the kind of effort which should proceed in parallel with clinical research in an academic department. To forecast the future in a many-faceted specialty like anaesthesia is probably impossible, but it is a safe wager that this book contains a core of findings of critical importance to future research. Paralysedness (which disregards the inherently sterile, and often frankly malicious, accusation of "lack of immediate clinical relevance") has characterized the work of many contributors to this most important publication, and particularly that of the editor. This is an outstanding book which deserves wide reading and study.

R. A. Millar