THE T-PIECE TECHNIQUE IN ANAESTHESIA

An Investigation into the Inspired Gas Concentrations

BY

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Since its introduction in 1937 (Ayre) there have been few detailed investigations of practical value, apart from the mathematical analysis of Mapleson (1954), into the concentrations of carbon dioxide and nitrous oxide occurring in the inspired atmosphere when the T-piece technique is used.

The difficulties of such an investigation, especially when the subject is an infant or child, become less if we accept a mechanical “patient”. The reconstruction, with reasonable accuracy, of the conditions which prevail in a subject of a certain age is possible only with fairly comprehensive data; this data has only recently become available. Figures for respiratory rate, tidal volume and dead space have been provided by the work of Hall (1955) and are reproduced in table I. Additional information in respect of carbon dioxide production has been obtained from the work of Lewis et al. (1937).

The arrangement of the apparatus used in this investigation is shown diagrammatically in figure 1, and consists of a pump, the rate and stroke of which is inde-
pendently variable. A reservoir bottle, the capacity of which can be altered by the addition or removal of acidulated water, was interposed between the pump and tubing of bore and capacity such as to represent the dead space. Alteration of the capacity of the reservoir bottle permitted the correct value for the lung volume of a particular "patient" to be reproduced, and carbon dioxide was conveniently introduced at the appropriate rate into it.

Samples of gas were aspirated from the distal end of the "trachea" and the carbon dioxide and nitrous oxide concentrations determined by passing the sample through an infrared gas analyser. The sampling was performed automatically. Electromagnetic valves were opened at any desired phase of the respiratory cycle by means of a cam placed on the axle of the motor driving the respiratory pump. This allowed suction from a small suction pump to be applied through the infrared analyser to the sampling point.

In this system the factors operating which influence the carbon dioxide content of the inspired gases and the extent to which they are diluted with atmospheric air are: (1) the rate of fresh gas inflow; (2) the carbon dioxide production; (3) the minute volume of the patient; (4) the capacity of the limb on the T-piece.

It is to be expected, as shown theoretically by Mapleson, that no rebreathing will occur, nor will there be dilution of the anaesthetic mixture, if the fresh gas inflow equals or exceeds twice the minute volume.

The interval between the end of one expiration and the commencement of the next inspiration, considered in relation to the rate of fresh gas flow, is another factor of importance, since upon this relationship depends the extent to which the T-piece limb is cleared of expired gas. Where this interval is very short, however, for example, in infants and children, this clearance effect is minimal. In this investigation, dealing generally with rapid rates of respiration, it has been assumed that this minimal clearance state has prevailed and investigations of the effects of alteration of this factor have not been pursued. It is to be expected that, at a particular inflow rate, the inspired CO₂ percentages will be less with a longer respiratory pause.

When the fresh gas inflow is equivalent to less than twice the minute volume the carbon dioxide content of the inspired gas and the extent to which the anaesthetic mixture is diluted is dependent on the capacity of the limb on the T-piece and minute volume of the patient.

The comparative importance of these variables may be demonstrated if we compare the effect on the inspired carbon dioxide percentage of altering the minute volume, firstly by changing the rate and secondly by changing the tidal volume. These effects are demonstrated in figures 2 and 3. It is easily seen that a much more
EFFECT OF VARIED TUBE CAPACITY ON "EFFECTIVE" DEAD SPACE.
FRESH GAS INFLOW CONSTANT = 150% MINUTE VOLUME.
TIDAL VOLUME 204
RATE 26/MIN.
DEAD SPACE (ANATOMICAL) 43 MLS.

Fig. 4

TIDAL VOL. 204 ml.
CO₂ OUTPUT 156 ml./min.
ANATOMICAL DEAD SPACE 43 ml.
CAPACITY OF T-PIECE 77 ml. & 60 ml.
RATE 26/min.

--- = EFFECTIVE DEAD SPACE
--- = CO₂ CONCENTRATIONS

Fig. 5

DEAD SPACE IN MILLILITRE (CO₂ ESTIMATED)

ANATOMICAL DEAD SPACE

FRESH GAS INFLOW EXPRESSED AS A PERCENTAGE OF MINUTE VOLUME

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significant alteration in the inspired carbon dioxide concentration results when the minute volume is altered by changing the depth of respiration than when the alteration results from an alteration in the rate.

The relative importance of the capacity of the limb was investigated. An arbitrary point for fresh gas inflow equivalent to 150 per cent of the minute volume was chosen and the capacity of the T-piece increased in twenty millilitre increments. On each of these occasions the "effective" dead space was measured. "Alveolar" gas samples were obtained by altering the size and position of the cam, and since the tidal volume and carbon dioxide output were known the effective dead space could be calculated. Figure 4 demonstrates the result of such an investigation. In the particular circumstances detailed, at a fresh gas inflow equivalent to 150 per cent of the minute volume, no increase in the effective dead space above the anatomical value resulted until the capacity of the limb exceeded a value of 30 per cent of the tidal volume.

Alterations in the effective dead space, measured as described above, result in corresponding alterations in the inspired

![Graph](https://example.com/graph.png)

**Fig. 6**
carbon dioxide concentrations in the manner demonstrated in figure 5. The effective dead space in any particular circumstance is dependent upon the fresh gas inflow, and with a fresh gas inflow equal to twice the minute volume the effective dead space is equivalent to the anatomical value only and the inspired carbon dioxide concentrations are negligible.

Because of the multiple variables and their possible combinations, certain typical situations had to be selected for test. The results of estimations of carbon dioxide and nitrous oxide concentrations in the inspired air under circumstances which might prevail in a six-month-old, three-year-old and seven-year-old child are shown in figures 6, 7 and 8. In these cases the fresh gas inflow consisted of
70 per cent $N_2O$ and 30 per cent $O_2$ and was varied over a range of 0–10 litres per minute. The latter value is expressed in the graphs as a percentage of the minute volume.

Knowing from the figures reported by Hall the likely tidal volume for the age of a certain child, the minute volume can be roughly estimated. Reference to these curves, choosing the most appropriate for the case and the length of the T-piece, will indicate the fresh gas inflow necessary to avoid rebreathing and dilution; or if a certain inflow is in use the curves will indicate the inspired percentages.

In abnormal states, as demonstrated in figure 9, even with the highest $CO_2$ production likely to be compatible with spontaneous respiration, a fresh gas inflow of $2\frac{1}{2}$ times the minute volume will guarantee that there is neither a significant degree of rebreathing nor dilution of the anaesthetic gases.

Investigations have been made into the inspired carbon dioxide concentrations occurring in the adult, using a 120-ml

<table>
<thead>
<tr>
<th>TIDAL VOL.</th>
<th>204 ml.</th>
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<tr>
<td>RATE</td>
<td>26/mln.</td>
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<tr>
<td>CO$_2$ OUTPUT</td>
<td>128 – 201 ml.</td>
</tr>
<tr>
<td>REPRESENT. AGE</td>
<td>7 yrs.</td>
</tr>
<tr>
<td>CAPACITY T-PIECE</td>
<td>77 ml. &amp; 60 ml.</td>
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capacity "reservoir" limb on the T-piece. By means of a tap in the circuit the patient's inspiration could be diverted to expand a bag into which the whole of the inspired gases were collected. The results show that, as expected from the preceding work, a fresh gas inflow equal to twice the minute volume resulted in an inspired \( \text{CO}_2 \) concentration of less than 0.05 per cent, or when equal to the minute volume the inspired gases contained an average of 0.8 per cent \( \text{CO}_2 \).

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REFERENCES