A MODIFICATION OF AYRE'S TECHNIQUE*

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MANY MODIFICATIONS⁴ have been described since Ayre published his "T-Piece" technique in 1937.¹ While Ayre emphasizes the use of tubing of varying length attached to the expiratory opening of the T-piece, modifications have been employed without such a sidearm or reservoir.^{3,8,9,11} The simplest of such modifications is in our opinion a piece of rubber tubing (connecting the gas machine with the endotracheal tube) in which, as close as possible to the endotracheal tube, a hole is cut in order to allow the escape of anaesthetic gases and expired air. In such a system, the flow of gases differs from that in Ayre's T-piece.

For the modified technique we have used a piece of tygon tubing with an internal diameter of 1 cm. and about 4 cm. long, with a side hole of 1-cm. in diameter; this tubing fits tightly the inside of a Foregger connector and can be slipped over a Bird plastic endotracheal adapter (Fig. 1). A piece of non-kinkable endotracheal tube is interposed between the tygon tube and the tubing coming from the anaesthetic machine in order to increase the flexibility. Used with a flexible endotracheal tube, this system can be adapted to any form of surgical drape and has the least bulk and weight possible. The anaesthetic machine can be moved any distance from the patient since the length and diameter of tubing between the expiratory opening and the gas machine is of no significance as long as a sufficient volume of gases can be delivered through it.

For the evaluation of such a system the following factors must be considered: that a concentration of anaesthetic adequate for the maintenance of anaesthesia can be administered; that the resistance is low enough to allow unobstructed breathing; that carbon dioxide is eliminated. In all T-pieces arrangements with a reservoir, the flow of gas must be adjusted to the size of reservoir⁷ in order to avoid accumulation of carbon dioxide.

From the above description it is obvious that without a side-arm or reservoir

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FIGURE 1

CO₂ accumulation is not possible since, in the absence of any flow of anaesthetic gases the patient will breathe room air through the expiratory opening with practically no added dead space. Thus, the limiting factors of the described modified technique are the resistance to breathing and the maintenance of a satisfactory level of anaesthesia. In order to confirm our clinical impression that this technique is satisfactory and in order to measure the volume of gas flow necessary to obtain an adequate anaesthetic concentration, the following investigations have been carried out.

METHOD

The resistance to flow of the expiratory opening was determined by occluding one end of the tube and connecting the other end to a source of compressed air. The pressure distal to the hole was measured with a strain gauge manometer at flows between 10 and 40 L per min.

In order to determine the factors influencing the concentration of anaesthetics, the tube was connected to a model lung consisting of a 10 cm length of corrugated tubing (representing the trachea) and an empty to and fro soda lime canister attached to a Starling pump (representing the lungs). The volume of the model was about 1 L. Ventilation at rates from 10–50 per minute and tidal volumes between 50 ml and 250 ml were used. Gas was constantly sampled through a fine plastic tubing placed inside the canister and analysed for its oxygen tension with a Pauling oxygen analyser (Beckman scale 0–160 mm). The anaesthetic mixture was represented by nitrogen. In the model the decrease in oxygen tension should be in proportion to the increase of nitrogen, that is, representative of the increase in anaesthetic concentration inside the lung. A

similar system was used by Eger⁵ for investigation of the circle system. In our results we shall refer to the percentage of nitrogen attained in the model lung, assuming that this concentration would be of the same order if an anaesthetic gas mixture had been used at the same rate of flow.

With this model, the effects of gas flow, pulmonary ventilation, variation of the diameter of the tube (8, 10, and 12 mm.), and the diameter of the expiratory opening (2–12 mm., tube 10 mm. in diameter) were studied.

RESULTS

If our technique is to be suitable for infants and children, the expiratory peak flow in addition to the inflowing gas mixture must pass through the expiratory opening without an undue increase in pressure inside the tube. Brooks *et al.*⁴ reported the resistance of an Ayre's tube of 1 cm. in diameter at a flow rate of 50 L. per min. to be less than 1 cm. of water. Our values including those of a "T-piece" of 7 mm. in diameter were considerably higher (Fig. 2); this could be partly due to different measuring techniques. With an expiratory opening 8 mm. in diameter the resistance appeared to be too high. It was felt that a 10 mm.

FIGURE 2

hole should be adequate considering the flow rates encountered with quiet breathing; a larger hole is impractical in view of the diameter of the tube.

To evaluate the effect of the flow-rate on the concentration of anaesthetic required for maintenance with our tube, we have plotted the changes in oxygen tension within our lung model every 30 seconds at flow-rates of 3, 5, 7, and 10 L. of nitrogen. On the same scale we have calculated the nitrogen concentration (percentage) within the lung, representing the anaesthetic concentration obtained (Fig. 3). It can be seen that a steady state is reached within a few minutes,

FIGURE 3

indicating that the steady state concentration of nitrogen in the lung depends on the rate of flow and, furthermore, that with a flow of nitrogen of 7 L. per min. there is less than 10 per cent admixture with room air and with higher flows 100 per cent concentration can be reached. Obviously an equilibrium is obtained earlier with the higher flows.

The second factor influencing the concentration of nitrogen is the ventilation of the lung. To be certain that the respiratory minute volume provided a basis for comparison, we determined the steady state concentration attained with a 5-L. flow of nitrogen, changing the respiratory minute volume once by changing the rate and another time by changing the tidal volume (Fig. 4). The results are not significantly different up to 5 L.; as expected, there is a tendency for the nitrogen concentration to be slightly lower with higher tidal volumes. Thus, it can be demonstrated that for a given respiratory minute volume, the nitrogen concentration in the lung increases in a linear fashion with the increase of nitrogen flow into the tube (Fig. 5) and that for a given flow of nitrogen into the tube the nitrogen concentration at a steady state will be inversely proportional to the respiratory volume (Fig. 6). In addition, the effect of changes

FIGURE 4

of the volume of the tube and the diameter of the expiratory hole were investigated; neither the length of the 1-cm. tube (the expiratory openings in constant relationship to the endotracheal tube) nor the diameter of the expiratory hole within a range from 6 to 12 mm. appeared to have a significant influence on the nitrogen concentration in the lung.

If we assume that a concentration of 75 per cent anaesthetic mixture is adequate for the maintenance of anaesthesia (with potent agents it is no problem to overcome a dilution by 25 per cent room air), we can construct from Figure 5 a graph relating the flow of anaesthetic gases to the respiratory minute volume. When plotting the respiratory minute volume and the nitrogen flow for 75 per cent nitrogen concentration in the lung model, we obtain an almost linear relationship within the tested range (Fig. 7). From the graph we can predict the required flow of nitrogen (or anaesthetic mixture), if we know the respiratory minute volume of the patient.

When comparing the efficiency of a T-piece with our system, we found no difference when the reservoir was not used (Fig. 8); by adding a reservoir of 10 ml., the nitrogen concentration was significantly increased. This greater

FIGURE 5

efficiency does not, however, improve the economics, since the higher gas flow needed in our system to maintain an adequate concentration of the anaesthetic mixture will be required to remove carbon dioxide from the reservoir in Ayre's technique. A comparison of recommended flow rates will demonstrate this (Table I). Based on data from Smith¹⁰ the flow required according to Inkster's recommendation ($2 \times \text{RMV}$) has been calculated. In the next column are the figures recommended by Ayre² as based on Hall's respiratory data⁶ which differ considerably from those published by Smith.¹⁰ Aside from this discrepancy, the flow recommended by Ayre² is practically identical with ours; it can be assumed, however, that with a reservoir the concentration of the anaesthetic will be close to 100 per cent, while with our flow rates only 75 per cent is obtained.

CLINICAL EXPERIENCE

The described modification of Ayre's technique has been used in 119 cases for the following surgical procedures.

Types of surgery	No. of cases
Face	25
Cleft lip/cleft palate	19
Neck	11
Ophthalmology	47
Others	17

FIGURE 6

The age of these children ranged from one day to ten years; flows of 3–10 L. of a mixture of nitrous oxide and oxygen, supplemented by ether or fluothane, were used. In all cases satisfactory anaesthesia could be maintained and no difficulties or complications attributable to this technique were encountered.

CONCLUSION

It is felt that the presented modification of Ayre's technique, for which we do not claim any originality, has all the advantages of the original technique described, including the possibility to provide artificial respiration by intermittent occlusion of the expiratory opening. In addition the following points can be listed in its favour.

1. The equipment is exceedingly simple and can be improvised readily.
2. The anaesthetic concentration is predictable; this makes it possible to produce a stable anaesthesia and avoid over-dosage.
3. There is no re-breathing and no accumulation of carbon dioxide within the equipment.
4. This modification has even less bulk and weight than Ayre's T-tube and can be readily incorporated in drapes and other devices in situations where the surgeon likes to have the anaesthetic equipment out of his way.

FIGURE 7

FIGURE 8

TABLE I
RESPIRATORY INDICES AT VARIOUS AGES AND FLOW REQUIREMENTS FOR AYRE'S TECHNIQUE AND FOR MODIFIED TECHNIQUE

Age*	Weight (lb.)	VT* (c.c.)	Frequency* (per min.)	RMV* (L./min.)	Ayre's technique			
					Reservoir capacity† (c.c.)	Flow required‡ (2×RMV) L/min.	Flow recommended by Ayre‡ L/min.	Flow required with modified technique§ L/min.
1 wk.	6.5	17	30	0.5	(0-5)	1.0	3.0	2.0
1 yr.	22	78	24	1.8	24	3.6	6.5	5.5
3 yr.	32	112	22	2.4	37	4.8	7.5	6.6
5 yr.	40	130	20	2.6	43	5.2	8.0	7.0
8 yr.	58	180	18	3.2	60	6.4	9.0	8.0

*From Smith.¹⁰

†Ayre.²

‡Calculation based on recommendation by Ayre² and Inkster.⁷

§From Figure 17.

Disadvantages may be that this anaesthetic system is slightly less efficient than Ayre's technique. The possibility of accidental distortion or occlusion of the expiratory opening was kept in mind, but was not observed in practice.

SUMMARY

A modification of Ayre's technique, consisting of a piece of tygon tubing 1 cm. in diameter with an expiratory opening of the same diameter, was used in 119 cases with clinically satisfactory results. Carbon dioxide accumulation in the anaesthetic system is not possible, since there is no reservoir. The limiting factors are the expiratory resistance and the production of an adequate anaesthetic concentration in the lung. These two factors have been investigated using a model lung with variable changes in respiratory rate and volume; nitrogen represented the anaesthetic agent. The resistance was found to be acceptable. The concentration of nitrogen (anaesthetic gas mixture) in the lung was calculated from the measured changes in oxygen tension. Typical curves are presented for the effect of different rates of inflow of nitrogen and the influence of changes in respiratory minute volume on the nitrogen concentration in model lung. From these a graph was constructed from which the rate of flow of anaesthetic gas can be determined for a given respiratory minute volume in order to obtain an anaesthetic concentration of 75 per cent in the lung (or 25 per cent dilution of the anaesthetic mixture with air). The flow rates so determined were compared with data published by Ayre. It was concluded that this modification is only slightly less efficient than Ayre's technique, but has less bulk and weight than any other system in children. The technique is particularly useful in surgery of the head and neck in small children, where the tube will occupy a minimum of space and can be readily incorporated into the surgical drapes.

RÉSUMÉ

Nous avons présenté une variation de la technique de Ayre, en employant un tube en Tygon de 1 cm. de diamètre avec un trou de 1 cm. de diamètre. Nous avons étudié expérimentalement la résistance expiratoire et les facteurs influençant la concentration de l'agent anesthésique dans le poumon.

Nous avons trouvé une relation étroite entre la vitesse de l'inspiration des anesthésiques et le volume minute respiratoire. Cela permet de prédire le débit de mélange anesthésique nécessaire pour un volume minute respiratoire donné.

Nous avons comparé la modification décrite et la technique décrite par Ayre et, à notre avis, la première présente des avantages dans son application clinique.

Nous avons donné un bref résumé de notre expérience avec cette technique.

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