A NEW AND HIGHLY EFFICIENT CIRCUIT FOR PAEDIATRIC ANAESTHESIA

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IT IS THE INTENT of this paper to present some work carried out in an attempt to make a simple paediatric anaesthesia circuit by carrying out modifications to a Magill Circuit.¹

The Magill Circuit shown in Figure 1 is a commonly used circuit in British anaesthesia. It is primarily designed for giving anaesthesia to patients breathing spontaneously and cannot be used to deliver positive pressure ventilation to patients without a very high fresh gas flow being fed into the circuit. However, the Magill Circuit does have a very interesting property, in that fresh gas flows averaging 70 per cent of the predicted normal minute volume^{2,3} can be fed into the circuit without the patient building up CO₂ in the arterial blood, providing that the patient is breathing spontaneously.

If reference is made to Figure 2, one can see what happens to the gas flows in the circuit during spontaneous ventilation. At the end of expiration, the first gas to be inhaled by the patient will be the alveolar gas occupying the apparatus

FIGURE 1. Magill Circuit showing: A. Connection to anaesthetic machine, B. Reservoir bag, C. Corrugated tubing, D. Heidbrink valve.

FIGURE 2. Diagrammatic representation showing distribution of gas during spontaneous ventilation in a Magill Circuit with a fresh gas flow of more than 70 per cent predicted minute volume.

In the top figure the situation at the end of inspiration is shown. The circuit is full of fresh gas.

In the middle figure, in early expiration the reservoir bag is just full again. Anatomical dead space gas is seen in the circuit tubing with some alveolar gas behind it.

In the bottom figure the flow of fresh gas is pushing the column of anatomical dead space gas toward and out of the Heidbrink valve.

dead space, which comprises the face mask and the space between the face mask and the exhalation valve. This is present in all circuits and so it will not be considered further. The next gas to be inhaled would be the patient dead-space gas, the amount of which in the circuit is related to the amount of fresh gas flow to the circuit.

By correct adjustment of the fresh gas flow, a situation can be obtained by which the whole of the patient dead-space gas is inhaled with each inspiration. If, for example, one assumes that a particular patient has a minute volume of 4.5 liters and breathes 10 times a minute, a tidal volume of 450 cc will result. Assuming further that the dead space is 150 cc, the patient will be rebreathing 150 cc of dead-space gas plus 300 cc of fresh gas with each breath, if the fresh gas flow to the circuit has been correctly adjusted. Therefore, a fresh gas flow of 300×10 or three liters should be used, which is only two-thirds of the actual minute volume of the patient. In other words if the alveolar minute volume is delivered to the circuit, no CO_2 build-up will occur.

FIGURE 3. Showing diagrammatic representation of gas flows occurring during positive pressure ventilation with a Magill Circuit. The top figure shows the start of lung inflation. The bag is being squeezed, and some gas is going to the patient and some out of the Heidbrink valve.

The bottom figure shows the end of expiration. As can be seen, the tubing of the circuit contains a mixture of fresh gas, alveolar gas and patient dead space gas, which would be blown into the patient's lungs with the next inflation.

These pictures would be seen with fresh gas flows approximating to the predicted minute volume for that patient.

Now we shall consider what happens when positive pressure ventilation is used with a Magill Circuit by compression of the bag. To accomplish this the expiratory valve of the circuit must be tightened to the point where, when the bag is compressed, some of the gas will go to the patient and some of it will leak from the circuit through the valve, while no gas will leak from the circuit during expiration. The gas flows occurring this time are seen in Figure 3. This demonstrates that during inspiration fresh gas, dead-space gas, and alveolar gas will be vented from the expiratory valve. During expiration all the expired gas will enter the anaesthetic circuit, which means that the circuit will be filled with dead-space gas plus alveolar gas and very little fresh gas. Therefore, CO_2 build-up will occur unless a very high fresh gas flow is used.

It is possible, however, to modify the circuit so that the distribution of the various types of gas is the same as that occurring during spontaneous ventilation. This can be accomplished by closing the expiratory valve completely during the inspiration phase of positive pressure ventilation and allowing gas to escape during

FIGURE 4. Showing the steps used to modify the Magill Circuit. (A) Heidbrink valve from its normal position (1) moved to the end of the limb (2). (B) Heidbrink valve changed for valve of flattened Penrose drain (3). (C) Penrose drain moved to side of bag.

the expiratory phase. Thus, positive pressure ventilation could be delivered to a patient under anaesthesia without high gas flows.

Figure 4 is a schematic representation of the way in which this has been solved. First the valve has been moved from its position proximal to the patient to the end of a side-limb, connected at the site where the valve had been located originally (4a). Next, the valve at the end of this limb has been changed to a different type, consisting of a flattened piece of penrose drain (4b). Furthermore, the reservoir bag has been placed directly at the end of the inspiratory limb, with the fresh gas flow fed into the tail of the bag in such a way that no venturi effect would be created in the inspiratory limb. To achieve this, the end of this tube has been blanked off and the gas allowed to escape into a reservoir bag through holes on the side. Finally, the respiratory valve has been moved to lie alongside the reservoir bag in such a way that, when the bag is compressed with the hand, the thumb can be placed on the valve and so close it (4c). This thus creates a circuit, with which positive pressure ventilation can be delivered with fresh gas flows similar to those appropriate during spontaneous breathing. The parts necessary to assemble this circuit are seen in Figure 5. It should be noted

FIGURE 5. The parts needed to make the circuit. Shown are: (A) .75 liter reservoir bag (MIE). (B) 2 paediatric size 34-cm long Foregger tubings. (C) Paediatric Dupaco Y-piece. (D) 2 Plastic clips. (E) Bag mount (MIE). (F) Short connecting corrugated tube (BOC). (G) 30 inch long fresh gas tubing. (H) Special adaptor to connect the pieces of tubing. (I) 3 inch piece of Penrose drain.

FIGURE 6. The assembled circuit. Showing: (A) Patient connection. (B) Expiratory valve. (C) Fresh gas tubing. (D) Reservoir bag.

FIGURE 6. continued from page previous.

that all but one of the parts are commercially available and all are of paediatric size. Figure 6 shows the circuit fully assembled and ready for use.

CLINICAL STUDY

The circuit was given a clinical trial by the members of the Department of Anaesthesia, The Children's Hospital, Akron, Ohio in the following manner:

It was used by six attending staff, two nurse anaesthetists, one nurse anaesthetist-in-training, and two residents on a random basis and on thirty-one patients undergoing operations for a variety of conditions. The children were premedicated either orally or intramuscularly. The oral premedication was chloral hydrate 88 mg/cc and scopolamine 0.1 mg/cc, the dosage being 1 cc/four pounds, given 1½ hours preoperatively. The intramuscular premedication was meperidine (Demerol®) 1 mg/pound with atropine 0.1 to 0.4 mg, depending on the age, given 1½ hours before operation. Induction was carried out with 2.0 per cent thiopentone in a dose of 2 mg/pound and D-tubocurarine 0.3 mg/pound, or methohexital 1 per cent, 1 mg/pound with D-tubocurarine 0.3 mg/pound. The children's lungs were gently ventilated with oxygen by mask until they were ready for intubation, and the trachea having been intubated with non-cuffed tubes and connected to the circuit, the lungs were ventilated by hand with the circuit for the whole procedure (see Figure 7). The predicted minute volume for each child was calculated from the Radford Nomogram and this total flow was fed to the circuit. (This volume was corrected for temperature but not for the fact that an endotracheal tube was used.) The concentration of nitrous oxide varied between

FIGURE 7. The circuit seen in use on a four-year-old undergoing leg operation while in the prone position. NOTE: The anaesthetist's thumb is over the exhalation valve.

50 per cent and 70 per cent, depending on the whim of the person giving the anaesthetic. At some time during the procedure, on a completely random basis, an arterial blood gas sample was taken into a heparinized syringe by radial artery puncture and this was analyzed for CO_2 and oxygen levels on an IL Model 113 blood gas analyzer. The results are seen in Tables I, II and III. During the surgical procedure, further increments of thiopentone, methohexitone and D-tubocurarine were given as needed. At the end of the procedure the paralysis was reversed with neostigmine, 0.035 mg/pound and atropine 0.008 mg/pound, both given intravenously. The patients were then transported to the recovery

TABLE I
UP TO 3 YEARS

Age in Years	Weight in Kg	PaCO_2 in mm Hg	PaO_2 in mm Hg	Fresh Gas Flow in cc/min	N_2O in cc/min	O_2 in cc/min
1	12.5	32	175	1800	1100	700
2	15	32	210	2100	1100	1000
2	10	34	158	1700	1000	700
1½	11	34	180	1700	1000	700
2	17	41	185	2300	1300	1000
3	9	28	119	1600	1000	600
1½	5.6	29.5	145	1000	600	400
1½	13	29.5	175	2100	1200	900
1½	11½	34	145	1900	1100	800
1½	11	30	245	2000	1000	1000
1	6	40	155	1100	600	500
1	12	36	136	1100	700	400

TABLE II
3-4 YEARS

Age in Years	Weight in Kg	PaCO ₂ in mm Hg	PaO ₂ in mm Hg	Fresh Gas Flow in cc/min	N ₂ O in cc/min	O ₂ in cc/min
4	17.5	35.5	250	2400	1400	1000
3	16	27	155	2300	1300	1000
4	17	35	94	2300	1400	900
4	17	27	190	2300	1300	1000
4	17	35	180	2300	1300	1000
4	19	35.5	175	2600	1600	1000
3	18	35	200	2400	1300	1100
3	15	40	132	1300	700	600
4	14	39	215	1300	700	600
4	17	32	165	2400	1400	1000
4	16	32	210	2300	1300	1000
4	20	35	200	2500	1300	1200

TABLE III
OVER 4 YEARS

Age in Years	Weight in Kg	PaCO ₂ in mm Hg	PaO ₂ in mm Hg	Fresh Gas Flow in cc/min	N ₂ O in cc/min	O ₂ in cc/min
10	25	36	180	2900	1600	1300
6	19	36	165	2600	1600	1000
5	22	34.5	170	2800	1800	1000
6	22	35.5	116.5	2800	1800	1000
9	22	27.5	170	2800	1700	1100
6	25	40	205	2900	1800	1100
6	29	32.5	200	3000	1700	1300

room and after a short stay were returned to their wards. During the time that they were in the recovery room their condition was compared to that of patients anaesthetized with the conventional Ayres T-Piece circuit normally used in this hospital. No difference was noted. The anaesthetists using this circuit were asked for their opinions and most found it very easy to use after one or two minutes acquaintance. No similar circuit had ever been used by these anaesthetists previously.

RESULTS

The age of patients varied from 3 months to 10 years and the fresh gas flow to the circuit varied from 1 to 3 liters. The lowest level of arterial CO₂ registered was 27 mm Hg; and the highest CO₂ level registered was 41 mm Hg. The lowest arterial oxygen level registered was 94 mm Hg and the highest was 245 mm Hg.

DISCUSSION

An attempt has been made to show that the Magill Circuit can be used as efficiently for controlled ventilation as for spontaneous ventilation, provided the expiratory valve is occluded during the inspiratory phase. We feel that the re-

sults presented here do prove that this is so. Secondly, we have attempted to show that even with low flows, there is sufficient fresh gas in reserve to compensate for the amount of gas that must inevitably leak around the noncuffed endotracheal tube customarily used in children. The results shown here seem to prove that this is the case also. All CO_2 levels were between 27 and 41 mm Hg, which means that ventilation was adequate in all patients; in fact, some were hyperventilated. Variations in CO_2 levels could be explained by the fact that some endotracheal tubes fitted the trachea better than others; therefore, gas leaks around them would vary. With a less close fit, less gas would go to the alveoli and the CO_2 levels would be expected to be higher. In theory at least, no matter how the patient is hyperventilated, the CO_2 level should not drop below a level which would depend on the amount of leak around the endotracheal tube. In fact, the more vigorously the patient is ventilated, the more gas would leak around the tube and consequently CO_2 might be presumed to rise. This is still a supposition, however, and has yet to be proven.

As compared to the conventional T-Piece a circuit of this sort can reduce the cost of gases such as nitrous oxide and oxygen by one-third, since most anaesthetists utilize three times⁴ the predicted minute volume of the child as the fresh gas flow for a T-Piece circuit and we are using only the predicted minute volume. While this may not be a large item in the budget of an anaesthetics department where only nitrous oxide and oxygen are concerned, when the cost of Halothane is considered, a decrease in the cost by a factor of 3 could amount to thousands of dollars per year in a large department.

In recent times anaesthetists have become increasingly aware of the hazards of operating room contamination with anaesthetic gases, and this circuit again will reduce that contamination by a factor of 3 as compared to a T-Piece circuit.

Circuits with non-rebreathing valves, of course, also can be run at just over the predicted minute volume for the child, but many have become disenchanted with circuits of this sort because the valves may stick or jam at the most inopportune moments; and there are not many non-rebreathing valves of suitable size to be used effectively on small children.

Closed circle systems and semi-closed circle systems or Waters' cannister systems can be used very effectively on children, either in the form of adult circuits modified in various ways, or in the form of the more sophisticated Bloomquist type circle, which is built especially for children. Disadvantages to systems of this sort are that they are more expensive, more complicated, and that they lack the ability to give the anaesthetist a good "feel" of the patient's lungs because of the compliance inherent in the circuit itself. They do, however, have the advantages that fresh gas flows of a very low order can be used, particularly if the circuit is closed completely, and that the inhaled gas is humidified to a large degree.

Humidification in closed circuit systems is good. There is little humidification in the T-Piece unless an in-line humidifier is available. Since the dead space gas which is partially humidified⁵ is being rebreathed in the circuit here described, it may be considered superior to the Ayre's T-Piece in this respect also.

FIGURE 8. A T-piece circuit. Showing: (a) T-piece. (b) Reservoir bag. (c) Bag tail blow off valve. (d) Fresh gas tubing.

The circuit does not have quite the simplicity of the T-Piece circuit, Figure 8. However, it is only slightly more complex and has one valve only. It is only slightly more cumbersome to use, but is far simpler than the closed circuit or the Waters' cannister.

An interesting fact is that flows in the order of 1 to 3 liters per minute were used on these children, and the concentration of anaesthetic agents may not be accurately controlled with flows as low as this. Oxygen and nitrous oxide concentrations usually create no problem, but the Mark 2 Fluotec vaporizers which are commonly used in Canada do not give accurate concentrations below flows of 2 liters per minute, and a more clinical approach to the delivered concentration will be needed. However, with Drager vaporizers, Mark 3 Fluotec vaporizers, or copper kettles this problem should not occur. During our clinical trials nitrous oxide and oxygen only were used.

CONCLUSION

A paediatric circuit is presented here which is relatively simple to construct, easy to use, and from the experimental evidence shown here can be effectively and safely used for controlled ventilation of children when fresh gas flows equaling the predicted minute volume for the child are fed to the circuit. In a series of thirty-one cases no arterial CO_2 levels were registered below 27 mm Hg, nor above 41 mm Hg.

RÉSUMÉ

Nous avons dessiné un circuit pédiatrique, qui est, en somme, un circuit Magill, mais, ce circuit a été modifié de façon à rendre possible une ventilation efficace à pression positive.

Un essai clinique de ce circuit démontre qu'il est simple, d'usage facile et assure une ventilation adéquate si le débit des gaz utilisés est égal au volume/minute prédit du malade.

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