SPONTANEOUS RESPIRATION WITH THE BAIN BREATHING CIRCUIT*

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TO QUALIFY as a universal breathing system,[4,10] the Bain modification of the Mapleson D circuit[3] should be useable in all patients including those breathing spontaneously under anaesthesia. In a theoretical assessment of the four partial rebreathing systems classified by Mapleson,[11] Sykes[12] and also Conway[5] assigned an order of merit for spontaneous respiration, considering circuit A (Magill) as the most efficient, followed by circuits D, C, and B; for controlled ventilation circuit D was classified as the most suitable and circuit A the least efficient. This rating has given rise to the assumption that the Mapleson D system was not suitable for spontaneously breathing patients and also that the use of the Mapleson D system with flow rates below the respiratory minute volume required a marked passive hyperventilation for the adequate elimination of carbon dioxide.[6]

It is the purpose of this presentation to show, through a comparison with the Magill attachment (Mapleson A) and the circle breathing system with absorber, that the Bain breathing system can be used safely for spontaneous breathing and to determine the fresh gas flow (FGF) required to maintain a normal arterial carbon dioxide tension (Pa_{CO_2}) without undue respiratory effort.

METHODS

One hundred and one healthy young adults undergoing dental surgery for the removal of impacted molars were admitted as out-patients and received no premedication. They were randomly assigned to the following types of management:

1. In 22 and 21 patients respectively, after induction with a sleeping dose of thiopentone and nasotracheal intubation with the aid of 40 to 60 mg of succinylcholine, anaesthesia with spontaneous respiration was maintained on nitrous oxide-oxygen and one per cent halothane with a FGF of 70 ml/kg/min, using either a Magill circuit or a Bain circuit.

2. Thirteen patients each received the same anaesthetic, but breathed either through a circle breathing system with soda lime absorption and a FGF of 70 ml/kg/min or a Bain circuit with a FGF of either 100 ml/kg/min or 140 ml/kg/min.

3. In nine and ten patients respectively the same anaesthetic management was used with a Bain circuit and a FGF of 70 or 100 ml/kg/min, except the halothane was replaced by 1.5 per cent enflurane.

Respiratory rate and expiratory minute volume (RMV) were measured at five-minute intervals with a Wright respirometer at the tracheal tube beginning 20 minutes after induction. The five determinations of respiratory rate and RMV were averaged in each patient to obtain a representative figure. Arterial blood for blood gas determination was drawn from the dorsalis pedis artery between the 35th and 40th minute of anaesthesia; that is, after at least 30 minutes of spontaneous respiration.

In addition, we reviewed 113 patients who had craniotomies for aneurysms of the basilar artery system conducted under nitrous oxide-halothane anaesthesia and controlled hypotension induced with Arfonad or nitroprusside. For these operations we prefer to maintain spontaneous respiration as the most sensitive monitor of functional disturbances of the brain stem.[1] Arterial blood gases had been done routinely within 15 to 30 minutes before the start of the induced hypotension to confirm adequacy of respiration. The patients had been breathing spontaneously for at least one hour with a FGF arbitrarily set between 6 l/min and 9 l/min, guided by the patient's size and weight, aiming approximately at a flow rate of not less than 90 ml/kg/min.

RESULTS

1. Craniotomies: The mean arterial P_{CO_2} in 113 cases breathing spontaneously with a Bain circuit and a FGF between 90 and 150 ml/kg/min was 39 ± 6 mm Hg. Since the flow rates had been set somewhat arbitrarily a comparison was made between the 15 patients each with the highest and

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the lowest FGF in an attempt to detect any association between FGF and Pa_{CO_2}. Fifteen patients with a mean FGF of 143 ± 11 ml/kg/min and a mean Pa_{CO_2} of 39 ± 5 mm Hg and another 15 patients with a mean FGF of 93 ± 4 ml/kg/min had a Pa_{CO_2} of 40 ± 6 mm Hg, not different from the group with the higher FGF.

2. The results of the study on 101 dental outpatients are summarized in Table I. The groups of patients are approximately comparable in age, size and sex distribution. All patients anaesthetized with halothane had a markedly elevated respiratory rate irrespective of the breathing system or the FGF. If the patients on the circle absorber system were taken as controls, patients on the Mapleson A system had a 17 per cent higher RMV and a mean Pa_{CO_2} of 39 ± 6 mm Hg. This was not different from patients on a Bain circuit with a FGF of 100 ml/kg/min whose RMV was 20 per cent greater with a Pa_{CO_2} of 40 ± 4 mm Hg. However, the reduction of the FGF to 70 ml/kg/min in the Bain circuit caused a significant increase in RMV (57 per cent) with a mean Pa_{CO_2} of 42 ± 4 mm Hg. The slight rise in Pa_{CO_2} may be an indication that the patients' respiratory efforts are no longer adequate to maintain a normal Pa_{CO_2}, although the values are still within a range considered normal (35 to 45 mm Hg). With a FGF of 140 ml/kg/min into the Bain circuit, the Pa_{CO_2} of 36 ± 3 mm Hg was not different from the circle absorber group (35 ± 5 mm Hg), but a 13 per cent higher RMV was observed.

Patients on enflurane had a significantly lower respiratory rate (21 ± 2/min) when compared to halothane (36 ± 6/min). Again, a reduction of the FGF to 70 ml/kg in the Bain circuit produced an increased RMV of the same magnitude as with halothane.

It should be noted that the patients on the circle absorber system and on the Bain circuit with an FGF of 140 ml/kg/min were hyperventilating and had a Pa_{CO_2} below normal (Table I). It was assumed that this increase in ventilation was common to all patients and probably due to the painful stimuli of the surgery.

The inspired oxygen concentrations ranged from 25 to 45 per cent and the Pa_{O_2} in all patients was above 100 mm Hg.

Discussion

It is evident from Table I that patients in light halothane or enflurane anaesthesia undergoing surgery have a good carbon dioxide response (Figure 1). It is our impression that the anaesthetized patient with concomitant surgery reacts differently from the patient under anaesthesia only; the hyperventilation observed in the patients on the circle breathing system and on the Bain system with the highest FGF can be considered as evidence of the stimulating effect of the operation on the respiration.

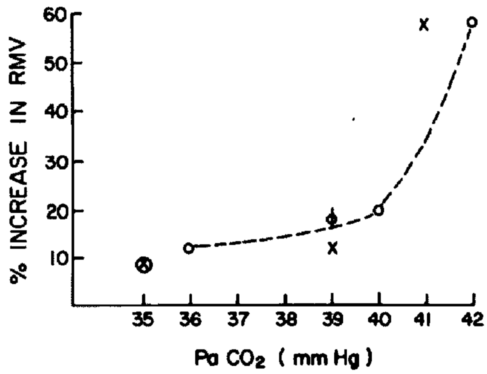

FIGURE 1. Change in respiratory minute volume (RMV) in relation to arterial CO_2 tension (Pa_{CO_2}). (Means from Tables 1 and 2).
o Circle absorber system. Φ Magill circuit. o---o "Bain" circuit (Halothane with FGF of 140, 100 and 70 ml/kg/min (left to right). X Bain circuit (Enflurane) with FGF of 100 and 70 ml/kg/min (left to right).

The degree of rebreathing in a breathing circuit is determined by the FGF in relation to the patient's carbon dioxide output. A FGF sufficient to provide only fresh gas with each breath causes the circuit to function as a non-rebreathing system. In conscious volunteers [5,13,14] it has been shown that a FGF greater than twice the RMV at rest will cause no change in breathing with the Mapleson D circuit. If the FGF is reduced to below the volume of alveolar ventilation, that is, to about two-thirds of the RMV, compensation is no longer possible and the Pa_{CO_2} must rise above normal. The functional range of a rebreathing system is therefore between twice the RMV and approximately two-thirds of RMV; within this range the inspired carbon dioxide concentration will increase as the FGF is reduced toward the volume of alveolar ventilation and the patient must compensate with an increased RMV to maintain normocarbia.

The effect of rebreathing can be demonstrated in general terms by introduction of inspired carbon dioxide (FI_{CO_2}) into the alveolar air equation:

$$FA_{CO_2} = FI_{CO_2} + (V_{CO_2}/V_A)$$

FA_{CO_2} represents the alveolar carbon dioxide concentration, FI_{CO_2} the carbon dioxide concen-

TABLE I

SPONTANEOUS BREATHING AND ANAESTHETIC CIRCUITS
Anaesthesia with halothane and enflurane

Breathing system + fresh gas flow ml/kg/min	No. of pat.	Male/Female	Age	Weight kg + SD	Surface area $m^2 \pm SD$	Pa_{CO_2} mm Hg ± SD	pH	RR breath/min	RMV $ml/m^2/min$	Percentage increase
Circle system + absorber FGF 70 ml/kg/min	13	3/10	27	59 ± 10	1.65 ±0.21	35 ± 5	7.37 ±0.02	30 ± 4	4740 ±640	0
Magill attachment (Mapleson A) FGF 70 ml/kg/min	22	8/14	26	61 ± 10	1.67 ±0.17	39 ± 6	7.34 ±0.04	32 ± 4	5540 ±1050	17
Bain circuit (Mapleson D) FGF 70 ml/kg/min	21	8/13	26	60 ± 16	1.67 ±0.28	42 ± 4	7.31 ±0.03	33 ± 4	7460 ±2010	57
Bain circuit FGF 100 ml/kg/min	13	5/8	22	67 ± 13	1.76 ±0.18	40 ± 4	7.33 ±0.02	34 ± 6	5680 ±1180	20
Bain circuit FGF 140 ml/kg/min	13	4/9	24	64 ± 11	1.72 ±0.16	36 ± 3	7.35 ±0.02	36 ± 3	5350 ±1010	13
Enflurane-Bain circuit FGF 70 ml/kg/min	9	2/7	21	62 ± 13	1.70 ±0.20	41 ± 2	7.34 ±0.02	24 ± 2	6290 ±1730	(55)
Enflurane-Bain circuit FGF 100 ml/kg/min	10	4/6	26	63 ± 12	1.73 ±0.19	39 ± 4	7.34 ±0.03	21 ± 2	4050 ±1010	(0)

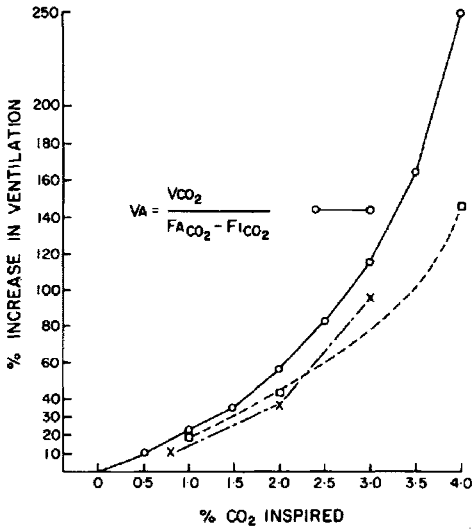

FIGURE 2 Change in volume of ventilation in response to a rising inspired CO_2 concentration.
o——o calculated from inserted fomula: VA = volume of alveolar ventilation, V_{CO_2} = volume of CO_2 output, $F_{A_{CO_2}}$ = alveolar CO_2 concentration, $F_{I_{CO_2}}$ = inspired CO_2 concentration.
Data from experiments on the effect of CO_2 inhalation in man by Haldane and Priestley (9) x---x and Dripps and Comroe (8) □---□ are presented for comparison.

tration in inspired gas, V_{CO_2} the volume of carbon dioxide output and VA the volume of alveolar ventilation. This formula can be solved for the volume of alveolar air

$$V_A = (V_{CO_2}/F_{A_{CO_2}} - F_{I_{CO_2}}).$$

A plot of the solution for inspired carbon dioxide concentrations from one to four per cent shows that the volume of alveolar ventilation required to maintain a normal $F_{A_{CO_2}}$ in the formula rises only gradually up to two per cent inhaled CO_2 and very steeply with inspired CO_2 concentrations over three per cent. The classical experiments on the respiratory response to CO_2 inhalation by Haldane and Priestley[9] and Dripps and Comroe[8] yield similar curves which approximate the shape of the calculated curve (Figure 2). Willis and others[14] showed in conscious volunteers that the reduction of the FGF to 1.5 times the volume of normal ventilation increased the patients RMV by 10 to 20 per cent while a FGF equal to the patient's volume of normal ventilation caused the RMV to rise by 50 to 60 per cent. Since the CO_2 production is lower in the anaesthetized patient it can be assumed that the FGF required under anaesthesia should be lower than the FGF needed in conscious persons.[13,14] In our patients on the Bain circuit, a FGF of 100 ml/kg/min, approximately equal to the normal volume of ventilation under basal conditions, induced only a 20 per cent increase in ventilation while a normal CO_2 level was maintained. The same conditions were found with the Magill system but at a FGF of only 70 ml/kg/min, indicating the greater efficiency of that system to eliminate CO_2 (Table I). We conclude that the Bain circuit with a FGF of 100 ml/kg/min is as efficient as the Magill system with a FGF of 70 ml/kg/min in patients breathing spontaneously under anaesthesia. We believe that our experience with spontaneous breathing in surgery for cerebral aneurysms is a satisfactory demonstration of the efficacy of the Bain breathing circuit.

One could assume that the Mapleson D system might be more efficient at a slower rate of breathing. However, when compared with halothane there was no detectable improvement in CO_2 elimination with the significantly slower respiratory rate under anaesthesia with enflurane.

If the FGF in the Bain circuit was reduced to 70 ml/kg/min the patient's ventilation rose in accordance to the curve shown in Figure 2 and the blood gas values indicated that this increase in ventilation was not quite adequate to maintain the Pa_{CO_2} at 40 mm Hg. However, at an increase in ventilation of about 60 per cent, the Pa_{CO_2} was still well within generally recognized normal limits (35–45 mm Hg). It could be a matter of debate whether such a degree of hyperventilation is desirable under anaesthesia. For the patient with normal lungs hyperventilation should be rather beneficial, contributing to better oxygenation and the prevention of alveolar collapse; the same therapy is recommended in the post-operative period. Perhaps a recent paper by Dobkin and others[7] on anaesthesia with increased CO_2 levels gives an indication that our views on hypercarbia may change and that a case can be made for the desirability of moderate hyperventilation with normocarbia or slight hypercarbia under anaesthesia, particularly since the increase in RMV is due mainly to deeper breathing.

SUMMARY

Although the Mapleson A system (Magill attachment) is more efficient in spontaneously breathing patients under anaesthesia, our clinical experience has shown that the Mapleson D sys-

tem (Bain circuit) can be used safely for spontaneous respiration under suitable conditions. In 113 craniotomies under general anaesthesia with spontaneous breathing a mean Pa_{CO_2} of 39 ± 6 mm Hg was obtained with a fresh gas flow (FGF) ranging from 90 to 160 ml/kg; there was no difference between 15 patients with FGF of 93 ± 4 ml/kg/min and a Pa_{CO_2} of 40 ± 6 mm Hg and 15 patients maintained on the highest FGF of 143 ± 11 ml/kg/min with a Pa_{CO_2} of 39 ± 5 mm Hg.

Comparing the Bain circuit with the Magill attachment and the circle absorber in 101 unpremedicated young adults undergoing oral surgery under endotracheal anaesthesia with nitrous oxide and halothane or enflurane, we found the Bain circuit with 100 ml/kg/min (RMV 20 per cent higher than circle absorber, Pa_{CO_2} 40 ± 4 mm Hg) equally efficient than the Magill attachment with a FGF of 70 ml/kg/min (RMV 17 per cent higher than the circle absorber, Pa_{CO_2} 39 ± 6 mm Hg). In the Bain circuit greater rebreathing by a reduction of the FGF to 70 ml/kg/min produced a 57 per cent rise in RMV with a Pa_{CO_2} of 42 ± 4 mm Hg; a slower respiratory rate induced by substituting enflurane for halothane did not improve the efficiency of the Bain circuit. In all patients the surgical stimulation induced about a ten per cent increase in RMV, inducing mild hypocapnia with the circle absorber (Pa_{CO_2} 35 ± 5 mm Hg) and the Bain circuit with FGF of 140 ml/kg/min (Pa_{CO_2} 36 ± 3 mm Hg). It is concluded that suitable patients, anaesthetized to retain an adequate CO_2 response, can be allowed to breathe spontaneously with the Bain breathing circuit.

RÉSUMÉ

Bien qu'un système Mapleson A (montage de Magill) soit plus efficace chez des malades anesthésiés et en respiration spontanée, notre expérience clinique nous a montré que le système Mapleson D (circuit de Bain) peut être utilisé en toute sécurité en respiration spontanée, sous certaines conditions.

Au cours de 113 crâniotomies chez des malades anesthésiés et respirant spontanément dans un circuit de Bain, la Pa_{CO_2} moyenne était de 39 ± 6 mm Hg avec un débit de gaz frais de 90 à 160 ml/kilo. Il n'y avait pas de différences entre les Pa_{CO_2} de 15 malades recevant un débit de gaz frais de 93 ± 4 ml/kilo (Pa_{CO_2} moyenne = 40 ± 6 mm Hg) et celle de 15 malades recevant un débit élevé de gaz frais, soit 143 ± 11 ml/kilo (Pa_{CO_2} moyenne = 39 ± 5 mm Hg).

Nous avons comparé le circuit de Bain, le montage de Magill et le circuit avec absorption chez 101 jeunes adultes, non prémédiqués et soumis à une chirurgie buccale sous anesthésie générale (N_2O + halothane ou enflurane), en respiration spontanée. Le circuit de Bain utilisé avec un débit de gaz frais de 100 ml/kilo/mn s'est avéré aussi efficace (Pa_{CO_2} moyenne = 42 ± 4 mm Hg; volume respiratoire/minute de 20 pour cent supérieur à celui observé avec le circuit avec absorption), aussi efficace disonsnous, que le montage de Magill utilisé avec un débit de gaz frais de 70 ml/kilo/mn (Pa_{CO_2} moyenne = 39 ± 6 mm Hg; volume respiratoire/minute de 17 pour cent supérieur à celui observé avec le circuit avec absorption).

Avec un circuit de Bain, une augmentation du rebreathing secondair à une diminution de l'apport de gaz frais à 70 ml/kilo/mn, a amené une augmentation du volume respiratoire/minute de l'ordre de 57 pour cent, la Pa_{CO_2} moyenne se maintenant à 42 ± 4 mm Hg. Un ralentissement de la fréquence respiratoire obtenu en remplaçant l'halothane par l'enflurane, n'a pas augmenté l'efficacité du circuit de Bain.

Chez tous les patients, la stimulation chirurgicale amenait une augmentation de dix pour cent du volume respiratoire/minute, conduisant à une légère hypocapnée avec le circuit avec absorption (Pa_{CO_2} = 35 ± 5 mm Hg) et chez les patients reliés à un circuit de Bain avec débit de gaz frais de 140 ml/kilo/mn (Pa_{CO_2} = 36 ± 3 mm Hg).

Nous concluons que les patients peuvent être laissés en respiration spontanée avec le circuit de Bain lorsque la chose est désirable.

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