Controlled Normocarbia during IPPV with the Emerson Anesthetic Ventilator

ANIS BARAKA, M.D.,* CEDRIC O'M. S. SMITH, M.D.,
PHYLLIS F. SHROFF, M.D.

The Emerson postoperative ventilator † is a constant-volume, piston-driven appliance. It has been modified recently to provide a semi-open anesthesia circuit (fig. 1). The valved Y piece near the patient must be in phase with the corresponding unidirectional valves of the ventilator.

During IPP hyperventilation with a semi-open circuit, in both adults and children, P_{CO_2} is determined by the volume of fresh gas inflow delivered to the circuit.[1,2] The present study was undertaken to determine the fresh gas inflow and minute ventilation volumes necessary for maintenance of normocarbia in adults anesthetized by the Emerson anesthetic circuit.

* Present address: Department of Anesthesiology, American University of Beirut, Beirut, Lebanon.

Received from the Department of Anesthesiology, Wadsworth Hospital, Veterans Administration Center, and the Departments of Surgery and Anesthesiology, U.C.L.A. School of Medicine, Los Angeles, California.

METHOD

The subjects of the experiment were 14 anesthetized adults undergoing abdominal surgery. Their ages ranged from 22 to 63 years; weights, from 52 to 90 kg. All were free of cardiopulmonary disease. Morphine, 10 mg, and atropine, 0.5 mg, were injected intramuscularly 60 minutes before the start of anesthesia. Sleep was induced with thiopental, 250 mg, followed by suxamethonium, 100 mg, after which a cuffed endotracheal tube was inserted. Anesthesia was maintained with a mixture of nitrous oxide, 3 l/min, and oxygen, 2 l/min, supplemented with tubocurarine, 30–50 mg.

† J. H. Emerson Co., Cambridge, Massachusetts.

TABLE 1. Pa_{CO_2} and Pa_{O_2} Measured at Different Ventilation Volumes, with Total Fresh-gas Inflow Maintained at 5 l/min (N_2O 3 l/min and O_2 2 l/min)

Patient	Age (years)	Weight (kg)	Ventilation							
			16 l/min		12 l/min		8 l/min		4 l/min	
			Pa_{CO_2} (mm Hg)	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)	Pa_{O_2} (mm Hg)	Pa_{CO_2} (mm Hg)	Pa_{O_2} (mm Hg)
1	22	80	34.0	224	37.0	220	40.0	200	48.5	200
2	63	63	36.5	200	40.5	140	37.0	140	44.0	88
3	28	70	40.5	185			40.5	175	44.0	114
4	60	52	37.5	190	37.5	220	37.5	200	48.0	150
5	41	81	42.5	175			45.0	146	52.0	148
6	38	78	39.0	210	39.0	320	40.5	200	46.5	190
7	62	62	38.5	150			41.5	200	48.0	148
8	43	65	47.0	175			37.0	160	47.0	156
9	44	52	36.0	250			36.0	220	35.5	210
10	46	73	49.5	165	42.0	190	40.0	190	54.5	114
11	25	80	40.5	180	39.0	138	36.0	180	44.5	150
12	49	54	35.0	190	38.0	210	39.0	200	47.0	200
13	60	67	36.5	190	36.0	220	39.0	150	54.0	190
14	31	90	43.0	148	42.0	142	43.0	144	48.0	154
MEAN			40.0	187	39.0	188	39.0	179	47.0	158
SD			4.4	26	2.2	40	2.8	26	4.7	36.5

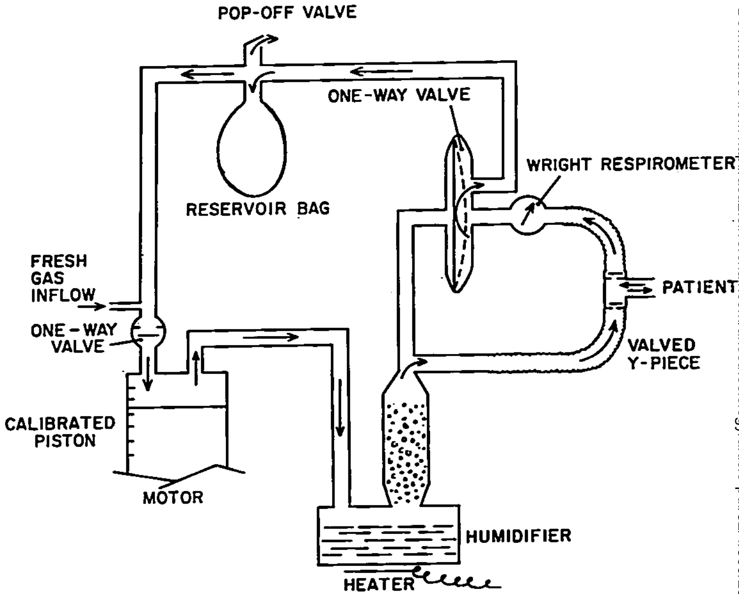

FIG. 1. Diagram of Emerson anesthetic ventilator. The valved Y piece near the patient must be in phase with the corresponding unidirectional valves of the ventilator. A Wright respirometer is placed at the expiratory side of the circuit to measure exhaled gases.

The total fresh gas inflow was maintained continuously at 5 l/min. Ventilation was set successively at 16, 12, 8, 4 l/min as measured by a Wright respirometer placed at the expiratory side of the circuit (fig. 1). These ventilation volumes approximately correspond to 2, 1.5, 1, and 0.5 minute ventilation volumes in the average adult. In order to achieve a steady state, 30 minutes were allowed to elapse before changing the degree of ventilation. Arterial blood samples were taken from the radial artery at the end of each stage. Pa_{O_2} and Pa_{CO_2} were determined.

RESULTS

The effects of different rates of ventilation on Pa_{CO_2} and Pa_{O_2} are shown in table 1. Normocarbia (mean Pa_{CO_2} 40 mm Hg) is achieved by a fresh-gas inflow of 5 l/min when patients are ventilated with 16 l/min (2 minute ventilation volumes). Keeping fresh-gas inflow constant while changing the degree of ventilation showed that normocarbia is still maintained with ventilation volumes of 12 l (1.5 minute ventilation volumes), or 8 l (1 minute ventilation volume). Hypercarbia (mean Pa_{CO_2} 47 mm Hg) associated with some lowering of Pa_{O_2}, however, occurs when patients are ventilated with 4 l/min (½ minute ventilation volume).

DISCUSSION

Factors controlling Pa_{CO_2} differ depending on the anesthesia circuit used. During controlled ventilation with a carbon dioxide absorption circuit, Pa_{CO_2} is determined by alveolar ventilation according to the formula:

$$P_{CO_2} = (P_B - 47)\frac{\dot{V}_{CO_2}}{\dot{V}_A}$$

On the other hand, using a semiopen circuit, P_{CO_2} is determined by fresh gas flow rather than by alveolar ventilation[1-4]:

$$P_{CO_2} = (P_B - 47)\frac{\dot{V}_{CO_2}}{\dot{V}_{fresh\ gas}}$$

In the present investigation, normocarbia is achieved by a fresh-gas inflow of 5 l/min, which is approximately equal to the alveolar ventilation volume of the average adult. Normocarbia is maintained at different rates of ventilation. Hypercarbia occurs only when patients are hypoventilated. These findings may also apply to other semiopen circuits[1]; rebreathing in various semiopen systems differs less during controlled ventilation than it does during spontaneous ventilation.[2,5]

During IPPV with semiopen circuits normocarbia can be achieved in adults by a fresh-gas inflow of 5 l/min provided the patient is ventilated with not less than the minute ventilation volume. This technique provides a simple method of maintaining normocarbia during clinical anesthesia without repeated blood gas measurements, in adults over a wide range of age, weight and minute ventilation volumes. Pa_{CO_2} is controlled independent of ventilation. Normocarbia can be combined with relatively large tidal volumes and periodic hyperinflations which are required to prevent atelectasis during positive-pressure ventilation.[6-8] Carbon dioxide stores are not depleted during anesthesia, thus avoiding posthyperventilation hypoxemia during recovery.[9]

The authors are indebted to the surgical staff of Wadsworth Hospital, Veterans Administration Center, Los Angeles, for their kind cooperation, and to J. H. Emerson Co., Cambridge, Massachusetts, for providing the Emerson anesthetic ventilator.

References

1. Baraka, A.: P_{CO_2} control by fresh gas flow during controlled respiration with a semi-open circuit, Brit. J. Anaesth. 41: 527, 1969.
2. Baraka, A., Brandstater, B., Muallem, M., and Seraphim, C.: Rebreathing in a double T-piece system, Brit. J. Anaesth. 41: 47, 1969.
3. Mapleson, W. W.: Theoretical considerations of effects of rebreathing in two semi-closed anaesthetic systems, Brit. Med. Bull. 14: 64, 1958.
4. Kain, M., and Nunn, J.: Fresh gas economics of the Magill circuit, Anesthesiology 29: 964, 1968.
5. Waters, D. J., and Mapleson, W. W.: Rebreathing during controlled respiration with various semiclosed systems, Brit. J. Anaesth. 33: 374, 1961.
6. Bendixen, H., Hedley-Whyte, J., and Laver, M. B.: Impaired oxygenation in surgical patients during general anesthesia with controlled ventilation. A concept of atelectasis, New Eng. J. Med. 269: 991, 1963.
7. Hedley-Whyte, J., Laver, M. B., and Bendixen, H.: Effect of changes in tidal ventilation on physiologic shunting, Amer. J. Physiol. 206: 891, 1964.
8. Suwa, K., Geffin, B., Pontoppidan, H., and Bendixen, H.: A nomogram for deadspace requirement during prolonged artificial ventilation, Anesthesiology 29: 1206, 1968.
9. Sullivan, S., and Patterson, R.: Posthyperventilation hypoxia, Anesthesiology 29: 981, 1968.

Surgery

ABDOMINAL GAS VOLUME The average volume of abdominal gas at atmospheric pressure in healthy military personnel, as measured by body-volume plethysmography, was 111 ml. At a simulated pressure of 230 torr, abdominal gas volume increased to 500 ml, and 50 per cent of the subjects completed of abdominal discomfort and fullness. As ambient pressure was decreased further, abdominal gas volume continued to expand, and when a volume of about 1,090 ml was attained, abdominal pain was reported. *(Greenwald, A. J., Allen, T. H., and Bancroft, R. W.: Abdominal Gas Volume at Altitude and at Ground Level, J. Appl. Physiol. 26: 177 (Feb.) 1969.)*