A Carbon Dioxide-mixing Chamber—a Simple Device for Continuous Measurement of Mean Expired Carbon Dioxide

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Continuous analysis of expired carbon dioxide is important in monitoring respiration. Mean expired CO_2 provides the data necessary for estimation of wasted ventilation, tidal volume-to-deadspace ratios, and CO_2 excretion. Furthermore, continuous measurement of mixed expired CO_2 serves as a valuable guide for the assessment of alveolar ventilation.[1,2] Presently available methods for collection and mixing of expired gas use bags, meteorologic balloons,[1] or large containers placed within the expiratory line[3,4] to collect expired gases. They either are too impractical for monitoring mechanically ventilated patients or are subject to large errors arising from contamination of the expired gases by the compressible volumes of the ventilators, particularly when high inflation pressures are used for mechanical ventilation. The following report describes a simple device for the collection and mixing of expired gases and a method for continuous measurement of the fractional mean expired CO_2 using a CO_2-mixing chamber, a CO_2 analyzer, and a pneumotachograph.

Methods, Materials and Results

A pneumotachograph ‡ which operates on the principle of ionization of gases[5,6] was used to trigger the sampling pump of an infrared CO_2 analyzer (Godart Capnograph). The pneumotachograph activates the sampling pump at the beginning of expiration and stops the pump when the expired flow reaches zero (fig. 1). Gas sampled during expiration is drawn into a CO_2-mixing chamber at a constant rate of 1 l/min via a 6-foot-long plastic catheter with a diameter of 2 mm, which is attached to a Rovenstine connector. The gas sampled, after passing through the CO_2 analyzer, is returned to the breathing circuit (fig. 2). The CO_2-mixing chamber is made of plexiglass. It is 9.5 × 5.5 × 4.5 cm and has an internal volume of 130 ml (measured by water displacement). The chamber is divided into several semi-compartments for efficient gas mixing (fig. 3).

The present methods of measuring mean expired CO_2 was compared with conventional use of a Douglas bag. Twelve adult patients were studied postoperatively during mechanical ventilation. The ventilator used was an Engström series 150 with a fixed inspiratory-to-expiratory ratio of 1:2. Respiratory frequency was set at 20/min. A 120-liter Douglas bag was attached to the expiratory port of the ventilator. A correction factor of 5.5 ml/cm H_2O inflation pressure was applied in the computation of the compressible volume of the ventilator.[7] With the CO_2-mixing chamber no correction factor for compressible volume was necessary, because the expired gas was sampled from the trachea. The capnograph was calibrated with 3 per cent and 6 per cent CO_2 in air prior to each study. Fractional mean expired CO_2, flow, and integrated volume were continuously recorded on an eight-channel San-

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‡ Manufactured by Institut Josef Stefan, Jamova UL 39, Ljubljana, Jugoslavia.

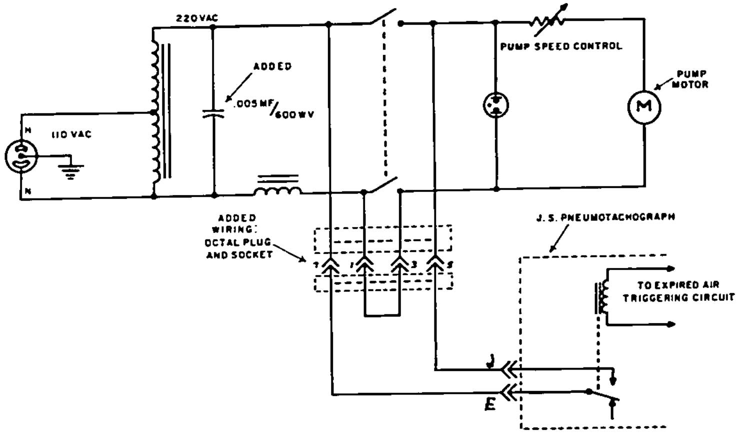

FIG. 1. Schematic diagram of the pneumotachograph triggering the CO_2 analyzer sampling pump. Additional wiring was provided so that the Capnograph sampling pump could be turned on during expiration. The pneumotachograph contains a detector which energizes a relay when the patient inhales. Thus, on expiration the normally closed contacts of the relay are closed. As indicated in the diagram, wiring was added to each terminal of the Capnograph "pump-on" switch and was brought to a socket which was installed on the Capnograph. A plug and interconnecting cable were constructed to (a) place a jumper across the switch terminals in the low side of the pump AC line and (b) connect the switch terminals in the high side of the pump line to pins J and E on the pneumotachograph connector. These, in turn, are connected to the common and normally closed relay terminals, respectively. Thus, when the patient exhales, the terminals of the switch are bypassed by the relay and the pump is turned on. During inspiration, the relay opens and the sampling pump turns off. (The 0.005 μF capacitor was added to bypass a relay switching transient.)

born recorder, series 958-100, provided with a 350-2700 preamplifier.

The results given by the two methods for mean fractional CO_2 values in the 12 patients are shown in table 1.

DISCUSSION

In this study the following equation was used to express the relationship between flow and expiratory flow[2,6]:

$$r_S^2 : r_E^2 = V_S : V_E,$$

where r_S is the radius of the catheter used for samplinga r_E, the radius of the Rovenstine connector, V_S, volume of the sample, and V_E the expiratory flow. The mixing of expired gases is mainly determined by the degree of turbulence, although diffusion becomes an important factor at low sampling flow rates and during the period of no flow into the CO_2-mixing chamber, which in this study occurred during inspiration. At constant sampling flow rates, the volume of gas entering the CO_2-mixing chamber is determined by the inspiratory-to-expiratory ratio and by the respiratory frequency. Thus, for example, at a respiratory frequency of 20/min with an inspiratory–expiratory ratio of 1:2, the amount of air sucked into the chamber was 33 ml/breath. At an inspiratory–expiratory ratio of 1:2 and a frequency of 20/min, the time constant of the mixing chamber, together with the six-foot plastic tubing, is 20 sec. Assuming that the sampling flow (1 l/min) and the inspiratory–

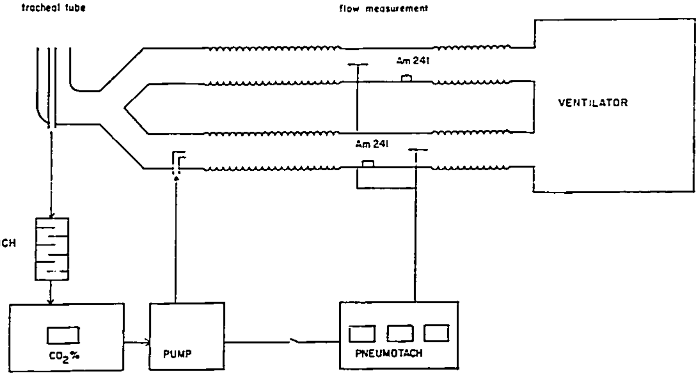

FIG. 2. Breathing circuit with the pneumotachograph and CO_2 analyzer. MCH = mixing chamber; Am 241 = americium 241.

expiratory ratio (1:2) remain constant, at different respiratory frequencies the numbers of samples drawn into the mixing chamber and the volumes sampled will vary. However, this will not change the concentration of the gas being measured in the mixture. Thus, for example, at respiratory rates of 40 and 10/min, the sample volumes will be 16.5 and 66 ml, respectively.

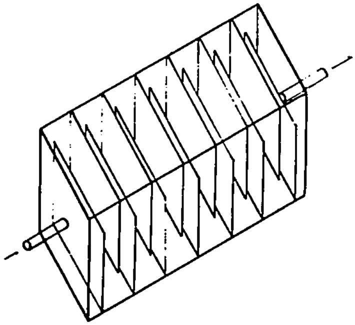

FIG. 3. Plexiglass carbon dioxide-mixing chamber.

SUMMARY

A triggered sampling pump and a mixing chamber were used with a CO_2 analyzer for continuous measurement of FE_{CO_2} of artificially ventilated patients. Simultaneously, measurements were made with a 120-l Douglas bag. The new method is accurate and useful for

TABLE 1. Comparison of Mean Expired CO_2 Values Measured by the Mixing Chamber and the Douglas Bag

	FE_{CO_2} Mixing Chamber (Per Cent)	FE_{CO_2} Douglas Bag (Per Cent)
Patient 1	2.82	2.81
Patient 2	3.12	3.11
Patient 3	2.91	2.93
Patient 4	2.81	2.82
Patient 5	3.02	3.03
Patient 6	3.12	3.12
Patient 7	3.11	3.12
Patient 8	3.51	3.52
Patient 9	3.22	3.21
Patient 10	1.82	1.82
Patient 11	2.50	2.50
Patient 12	2.60	2.59
MEAN	2.880	2.881

prolonged continuous monitoring of ventilated patients.

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A New Low-pressure Cuff for Endotracheal Tubes

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With the Technical Assistance of JACQUELINE BOON, R.N.

Direct pressure from a distended balloon on the tracheal wall is the major etiologic factor in tracheal injury. The length of time the pressure is maintained contributes to the severity of the injury.[1-3] To our knowledge, the safe pressure that the cuff may exert against the tracheal wall has not been determined, but it is likely to be a pressure that does not obliterate capillary blood flow (less than 20 mm Hg). The present study compares the pressures exerted on the tracheal wall by a newly designed endotracheal tube cuff and a standard commercial cuff.

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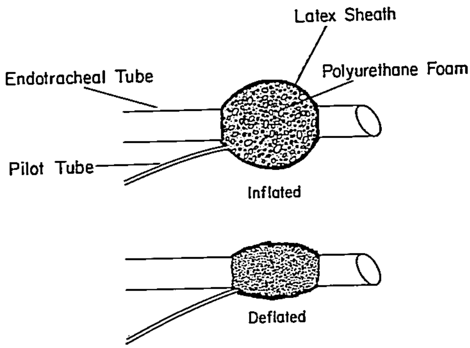

FIG. 1. Endotracheal tube with polyurethane cuff (inflated and deflated).