

New Appliances

Dry Method for Estimation of Mixed Venous CO₂ Concentration

Dr. O. BREY and Dr. R. HOLLOWAY, respiratory unit, department of medicine, King Edward VIII Hospital, Durban, South Africa, write: Since the introduction of the simplified Haldane apparatus for measuring CO₂ in respired gases¹ estimation of mixed venous PCO₂ has become possible for the clinician in hospital practice. Nevertheless, even the modified apparatus is fairly large and not portable enough to be carried into the patient's home by the visiting physician as it contains two liquid chemicals, mercury and potassium hydroxide, which may spill or mix in transport. The apparatus has therefore to be carried upright. There is a need for a rapid, simpler method using compact and inexpensive apparatus containing easily replaceable solid chemicals. The apparatus should fit easily in the doctor's bag and give reliable and accurate results within minutes. The Drager gas detector* used in industry satisfies the above-mentioned requisites. In this paper we present evidence that the accuracy is acceptable for clinical purposes and approaches that of the "half-Haldane."¹

Pump and Detector Tubes

The hand-actuated bellows pump (Drager No. DBP 100753 Mod. 31) (Fig. 1), when fully compressed and released, sucks 100 cm³ of unknown gas through a CO₂ sensitive tube. The flow of gas stops when the limiting chain is taut.

The CO₂ detector tubes (0.5% to 10% CO₂ measuring Drager tube No. CH. 31401) (Fig. 1) are made of glass. The seals are broken just before use. Correct positioning is ensured by an arrow at one end which indicates the direction of flow

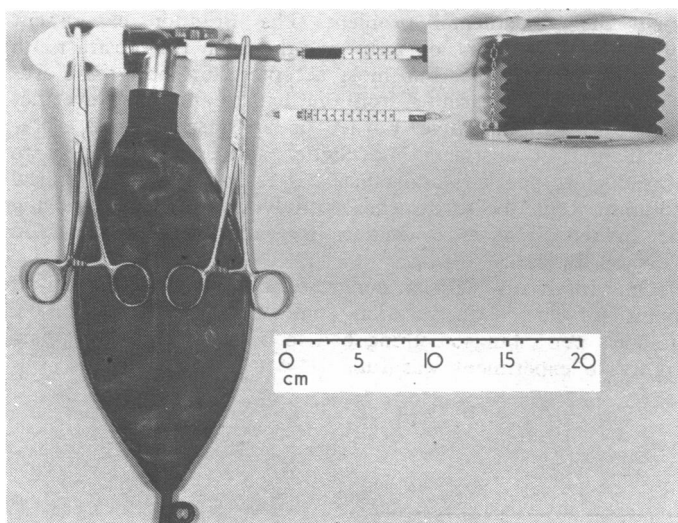
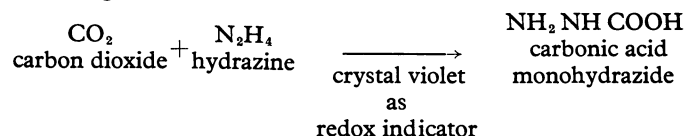


FIG. 1—Assembly of apparatus for CO₂ estimation. Artery forceps were used to clamp the mouthpiece and the tube connecting the tap to the CO₂ measuring glass tube. The Drager pump is shown at the top right of the picture. It consists of two plastic end-pieces into which are built appropriate valves and a bellows, the expansion of which is limited by a chain. The CO₂ sensitive tubes form a push fit when engaged with a perforated rubber seat mounted into the one plastic base-plate.

*Dragerwerk, Lübeck, Germany.

from the tube into the pump. The other end is connected to the unknown-gas container. The tube contains white material which turns blue on reacting with CO₂. The reaction principle according to Beilstein² is



The length of discoloration can be read off as a percentage of CO₂, the range being 0.5 to 10%. The time taken to release the compressed bellows is important and should be controlled to take 15-30 seconds. Gases other than CO₂ do not affect the indicator system.³

Collection of Sample

A standard 1-2 litre anaesthetic rebreathing bag was used for adults and a smaller one for children. The bag (Fig. 1) is connected to a mouthpiece which has a side-arm with a tap. This is used for filling the bag with oxygen and also for sampling. The rebreathing method for collecting gas in CO₂ equilibrium with mixed venous blood was used^{4,5} (see below).

Samples were obtained from patients and normal subjects. Patients on controlled ventilation were connected through an endotracheal or tracheostomy tube to the rebreathing bag and ventilated manually. Mixtures of CO₂ in O₂ and N₂ contained in gas cylinders were also analysed. Concentration of CO₂ was estimated by Campbell's modification of the Haldane apparatus¹ and also by the dry method described here.

PROCEDURE

- (1) Fill a bag with 1.5-2.0 litres of oxygen.
- (2) Rebreathe for one and a half minutes. During the first few breaths partially empty the bag if tidal volume is less than half the bag's volume.
- (3) Wait for two minutes.
- (4) Rebreathe for 20 seconds or five breaths (whichever is longer).
- (5) Break off the end seals of the CO₂ sensitive tube.
- (6) Expel a about a quarter of the bag's volume through the tap to flush out any oxygen remaining in it and its connexions. Immediately connect the CO₂ sensitive tube to avoid contamination of the sample with air. The arrow on the CO₂ tube indicates the direction of flow into the pump.
- (7) Squeeze all air from the pump by manually compressing the bellows—if possible, against a hard surface. (We suspect that one large difference between the Haldane and dry methods (Table I) resulted from incomplete emptying of the bellows.) Connect CO₂ tube to pump.
- (8) Allow the bellows to re-expand taking 15-30 seconds. When sampling is complete the attached chain will be tight. Read off the length of discoloration on the scale of the tube as volume % of CO₂.
- (9) Calculate the mixed venous PCO₂ from the equation

$$\text{PCO}_2 = \% \text{CO}_2 \times \frac{\text{BP}}{100}$$

where BP is the atmospheric pressure (760 mm Hg at sea level) minus the water vapour pressure (47 mm Hg at body temperature). Hence

$$\text{PCO}_2 = \frac{713 \times \% \text{CO}_2}{100} \quad \text{or} \quad 7.13 \times \text{CO}_2 \text{ volume } \%$$

Results

We compared the results using the new dry method with those obtained on the Haldane. The differences found were small, as shown in Table I (mean difference 0.06, S.D. 0.28 volume %). The mean was not statistically different from zero.

TABLE I—Differences found between the Two Methods used. Results given as Volume % of CO₂

Case No.	Haldane	Drager	Difference
1	4.7	4.8	+0.10
2	6.0	6.2	+0.20
3	4.2	2.8	-1.40
4	6.7	7.2	+0.50
5	4.8	5.0	+0.20
6	6.55	6.5	-0.05
7	6.3	6.6	+0.30
8	4.8	5.0	+0.20
9	5.0	4.9	-0.10
10	7.2	7.5	+0.30
11	6.0	6.3	+0.30
12	4.0	4.1	+0.10
13	5.75	5.1	-0.65
14	6.85	6.7	-0.15
15	5.8	6.4	+0.60
16	5.45	5.5	+0.05
17	5.35	5.3	-0.05
18	6.4	6.3	-0.10
19	6.6	6.8	+0.20
20	9.2	9.5	+0.30
21	9.32	9.5	+0.18
22	3.5	3.5	0
23	7.0	7.2	+0.20
24	8.2	8.7	+0.50
25	6.9	6.8	-0.10
26	4.45	4.5	+0.05
27	0.3	0.2	-0.10
28	7.15	7.2	+0.05
29	7.38	7.5	+0.12
Mean	5.92	5.98	0.0603
S.D.	1.78	1.94	0.2791

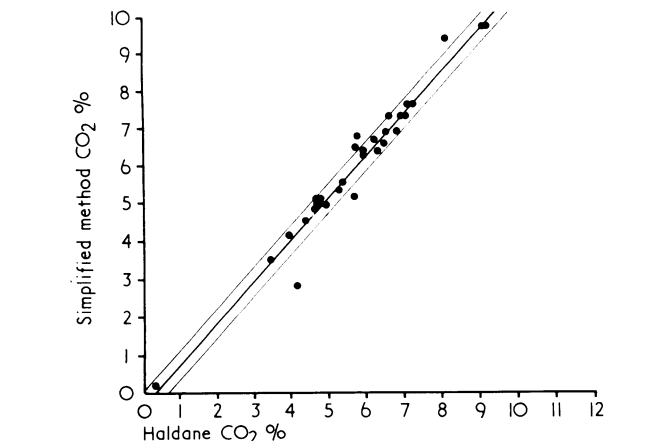


FIG. 2—Regression line showing correlation between CO₂ concentration of gases measured on the half-Haldane and by the method described.

TABLE II—Results Obtained with Dry and Haldane Methods in Patients and Normal Subjects

Case No.	Age (Years)	Diagnosis	Mode of Respiration	Mixed Venous CO ₂ Volume % by:	
				Modified Haldane	Drager Gas Detection
1	27	Asthma	Spontaneous	4.7	4.8
2	6	Tetanus with pneumonia	CR	6.0	6.2
3	59	Cardiac failure	Spontaneous	4.2	2.8
4	6	Tetanus in cardiac failure	CR	6.7	7.2
5	28	Tuberculosis	Spontaneous	4.8	5.0
6	37	Asthma	Spontaneous	6.55	6.5
7	13	Scoliosis old polio	Spontaneous	6.3	6.6
8	2	Measles bronchopneumonia	CR	4.8	5.0
9	2	Measles bronchopneumonia	CR	5.0	4.9
10	16	Tuberculosis	Spontaneous	7.2	7.5
11	24	Normal	"	6.0	6.3
12	31	"	"	4.0	4.1
13	30	"	"	5.75	5.1
14	33	"	"	6.85	6.7
15	36	"	"	5.8	6.4
16	36	"	"	5.45	5.5
17	25	"	"	5.35	5.3
18	22	"	"	6.4	6.3
19	30	"	"	6.6	6.8

CR = Intermittent positive-pressure ventilation plus curare. Mean difference = 0.042. S.D. = 0.3224.

The regression line \pm standard error is shown in Fig. 2. The regression equation is CO₂ %dry method \equiv 1.07; CO₂ % Haldane \equiv 0.329. The coefficient of correlation is 0.981 (P <0.001).

The results obtained with the two methods on patients and normal subjects are compared in Table II. The differences with one exception are small. We suspect that the exception was a result of the sampling error mentioned above.

Discussion

The importance of mixed venous CO₂ estimation in the diagnosis and assessment of ventilatory failure, acid-base status, and especially in the administration of oxygen is now well accepted.⁶ The following equation shows the relation between arterial CO₂ concentration and alveolar ventilation (\dot{V}_A):

$$\dot{V}_A = \frac{0.863 \times V_{CO_2}}{P_{aCO_2}}$$
 where P_{aCO_2} is the arterial CO₂ pressure in mm Hg and \dot{V}_{CO_2} is the volume of CO₂ produced in the body per minute in ml (about 200 ml). The equation could therefore be rewritten, $\dot{V}_A = \frac{0.863 \times 200}{P_{aCO_2}} = \frac{\text{constant}}{P_{aCO_2}}$

By using the rebreathing technique of Campbell and Howell⁴ and estimating the CO₂ concentration by the method described in this paper the general practitioner can rapidly and easily measure the mixed venous PCO₂ and assess ventilatory failure. (Note: mixed venous PCO₂ is about 6 mm Hg higher than arterial.)

We think that a simple method which gives the mixed venous carbon dioxide pressure with a mean error of 0.7 mm Hg \pm 2 mm Hg and never exceeds 10 mm Hg (even in the hands of a novice) is more useful than one based on the half-Haldane. Even though the half-Haldane is easier to use than the full-Haldane it calls for training and practice, for otherwise errors can easily exceed 10 mm Hg.

The apparatus described here is less expensive than the half-Haldane even though each estimation requires a new tube, and because of its simplicity a result can be obtained at the bedside within four minutes.

The margin of error is acceptable for clinical purposes and the correlation between the results obtained by using the half-Haldane and the equipment we employed is good. The simplicity of the technique and the fact that no maintenance is needed should make the dry method ideal for the busy practitioner. Where oxygen administration requires blood-gas monitoring this simple apparatus would be useful in preventing serious complications. Oxygen therapy to a patient with a high P_{aCO_2} is one clinical situation where a simple method for measuring CO₂ could provide vital information.

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