

Carbon Dioxide Elimination in Semiclosed Systems

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SINCE large two chamber transparent reversible carbon dioxide absorbers have come into use, considerable reduction in soda lime consumption has been effected. While a longer soda lime life was expected, careful records of the time one chamber lasted showed an unbelievable performance. Instead of lasting the 16 to 20 hours expected for a semiclosed system where inflow equals minute volume, 60 to 90 hours per chamber was recorded in clinical use.*

These results were confirmed in anesthetized patients for an inflow rate of 5 l./min., and in addition, occasional checks were made of P_{CO_2} levels and CO_2 production. The alveolar P_{CO_2} levels were found to range between 30 and 44 mm. in patients whose respiration was controlled or assisted vigorously. Their CO_2 production rates were slightly reduced from the basal rate but corresponded well with previous data, ranging from 200 to 300 ml. per minute.¹ It was apparent that relatively more alveolar gas than fresh inflow was being preferentially discarded through the overflow valve. To further check our results in a variety of breathing circuits, we returned to our laboratory "patient."²

Preliminary Observations

An improved design of mechanical ventilation analogue provided standardized test conditions: *viz.*, 500 ml. tidal volume, 150 ml. dead space, 16 respirations per minute, 284 ml. per minute carbon dioxide production, 90 per cent relative humidity at 30° C. in "expired air" at the "mouth." For comparison and reference, a Heidbrink Model 20 absorber with a Swivel "Y" valve system was used which had the spring-loaded overflow valve at

the expiratory side of the canister directly over the reservoir bag. The inflow was into the top of the absorber between the inspiratory valve and the absorbent bed. Soda Sorb with a moisture content of approximately 19 per cent (moist basis) was used throughout. The moisture content of the used lime was measured to compare the closed and semiclosed systems. Each run was continued until the indicator change had reached the bottom of the upper canister. At eight hours a day, several days were required for most runs, and in each case results are reported on canisters previously used as the lower canister in the previous run.

Gas inflow was zero in tests of the closed system. The upper canister of the Heidbrink Model 20 required changing after about 14 hours. At this time, the lime had absorbed 20 liters of CO_2 per 100 g. of lime. The moisture content of lime in the top of the exhausted canister was 30–35 per cent.

With a 4 liter per minute inflow as in a semiclosed circuit, the upper canister required changing after about 65 hours. At this time 90 liters of CO_2 per 100 g. of lime had been produced by the "patient." The moisture content of the top of the upper canister was 18–20 per cent and the bottom 28–30 per cent. The lower canister had a moisture content of 30–35 per cent.

In the closed circuit at the same test conditions, the absorption was only 20 liters of CO_2 /100 g. of lime. An inflow only half the minute volume should extend this value to 30 liters of CO_2 /100 g. of lime. The value of 90 liters confirmed that fresh gas inflow was being conserved in the circuit while expired CO_2 was being preferentially discarded through the overflow valve.

To determine where the excess CO_2 was being eliminated, samples of gas were collected at the overflow valve and found to be

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* Terry, R. N.: Personal communication, 1959.

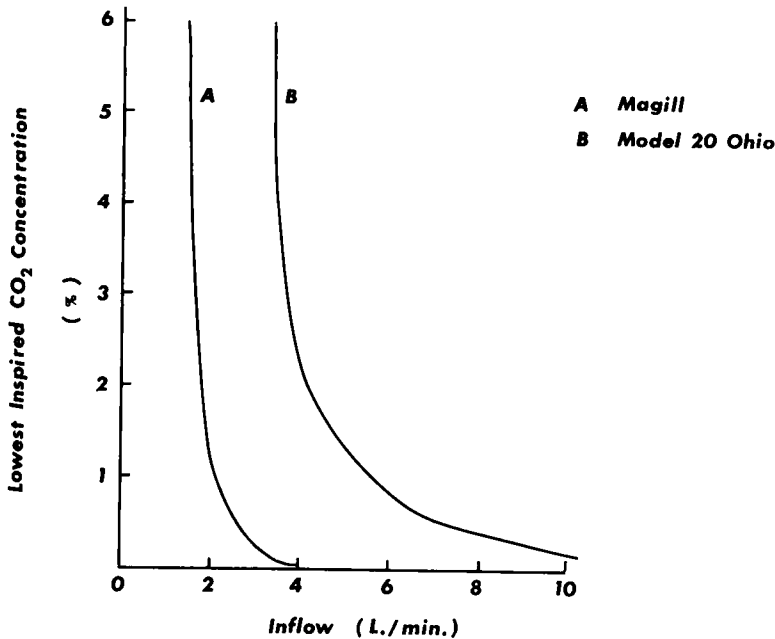


FIG. 1. Minimum concentrations of CO_2 inspired from semiclosed systems containing no soda lime when breathing was spontaneous. The Magill system was most efficient for the least fresh gas inflow rate.

3–4 per cent CO_2 . As a further check, the overflow valve was transferred to the inhalation side of the canister. The canister then lasted only 15 hours and absorbed 20 liters per 100 g. of lime.

Finally, the absorber system was run without soda lime at varying inflow rates. Popcorn

was employed to insure proper distribution of gas flow in the canisters. At inflow rates of 8 liters per minute, the inspired CO_2 concentration did not exceed 0.5 per cent in any of the absorbers tested (fig. 1). With an inflow equal to minute volume no soda lime would be needed during spontaneous breath-

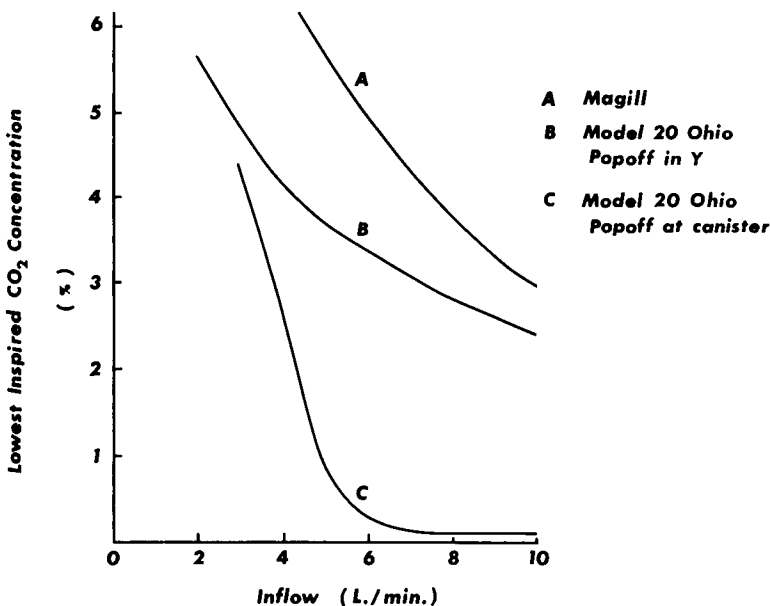


FIG. 2. Minimum concentration of CO_2 inspired from semiclosed systems containing no soda lime when breathing was controlled. The Magill system was least efficient of the systems tested.

ing. These results were compared to the Magill attachment with inflow into the bag and a single breathing tube connecting the bag to the patient where the overflow is located. This system has been analyzed by Molyneau and Pask³ and by Mapleson.⁴ The curve obtained is essentially identically with that obtained by Wolmer and Lind.⁵

However, these excellent results with "spontaneous breathing" in the Magill circuit did not obtain when controlled or assisted ventilation was used as Sykes pointed out,⁶ nor were the results quite as good in circle absorbers (fig. 2). Therefore, a systematic study was begun to investigate the most efficient placement of the components of the circle system for both controlled and spontaneous ventilation.

Methods

To stimulate a passive patient, a 5-liter reservoir bag was enclosed in a 5-gallon glass bottle. A small tube carried CO₂ to the bottom of the bag from a rotameter which metered in 300 ml. per minute. A Mörch surgical respirator replaced the reservoir bag. When semiclosed technique was employed, a

Wright respiration meter was employed to confirm adjustment of the tidal volume to 500 ml. despite the outflow from the overflow valve. The same Heidbrink Model 20 absorber was used with several other fittings added to allow altering the location of the valves, reservoir bag, overflow valve, and the point of inflow of fresh gas. The Georgia valve was compared with the spring-loaded overflow valve and the overflow characteristics of the ventimeter/ventilator were also tested. A spring-loaded overflow valve discards gas during the inflation phase of controlled breathing. Both the Georgia valve and v/v are designed to phase the overflow at the end of the passive expiratory phase of controlled breathing.

Results

With two exceptions, values of the apparent capacity of soda lime were within ± 2 per cent for successive runs. The average of these runs for the various arrangements are reported in table 1. Some arrangements such as placing the overflow valve on the inspiratory side of the absorber were not tested since no advantage over the closed system could be expected

TABLE 1. Apparent Capacity of Soda Lime with Semiclosed Circle Technique and 4-Liter Inflow

Location in the Circuit					Apparent Capacity (Liters CO ₂ /100 g.)	
Valves	Bag	Inflow	Overflow Valve	Diagram	Spontaneous Breathing	Controlled Breathing
Absorber	Exp.	Absorber	Exp. spring-loaded	A	86	48
Absorber	Exp.	Absorber	Exp. Georgia valve		—	36
Absorber	Exp.	Absorber	Exp. ventimeter/ventilator		—	51
Absorber	Exp.	Tube	Expiratory	B	45	36
Absorber	Exp.	Tube	"Y" piece		49	26
"Y" piece	Exp.	Absorber	Exp. spring-loaded	C	86	64†
"Y" piece	Exp.	Absorber	Exp. Georgia valve		—	51
"Y" piece	Exp.	Absorber	Exp. ventimeter/ventilator		—	68
"Y" piece	Exp.	Absorber	"Y" piece		99*	25
"Y" piece	Insp.	Absorber	Exp. spring-loaded	D	86	52
"Y" piece	Insp.	Absorber	Exp. Georgia valve		—	64

The bag or ventilator was placed on either expiratory (Exp.) or inspiratory (Insp.) side of the absorber. The overflow valve was always on the expiratory side of the absorber or in the "Y" piece. The inflow of fresh gas was either on the *absorber* side or the *breathing tube* side of the inspiratory valve. The valves were either in the "Y" piece or at the absorber. These arrangements are illustrated in figure 3 in diagrams A-D.

* Range 70 to 314 liters; † Range 47 to 79 liters.

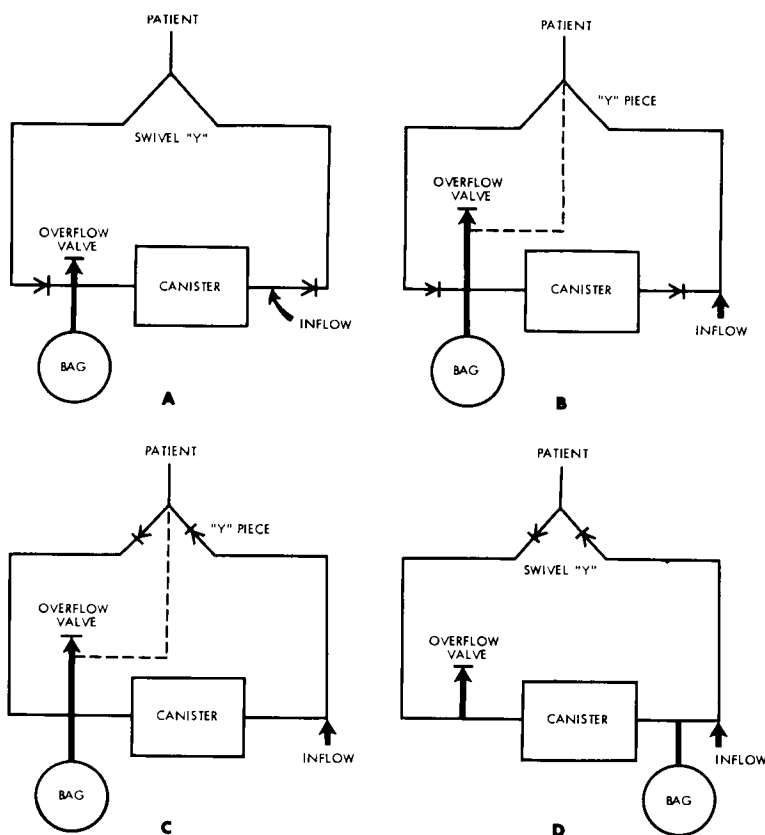


FIG. 3. Variations of placement of components of the semiclosed system. Data presented in table 1.

with this arrangement. Similarly, leading the inflow into the expiratory side of the absorber was not tried.

With spontaneous breathing, the most efficient use of lime was in an arrangement with the overflow valve in the "Y" piece (fig. 3C). Small changes in the inflow rate made large differences in the apparent capacity with this arrangement of components. The range was from 70 to 314 liters of CO_2 per 100 g. of lime with the mean value of 99 liters. However, the mean was only 10 per cent better than having the overflow valve on the expiratory side of the canister. The site of the reservoir bag or the location of the valves did not affect the life of the absorbent. When the inflow of gas was changed to the inspiratory tube between the patient and the valves (fig. 3B), the absorbent life was halved, 49 liters of CO_2 per 100 g. of lime.

During controlled breathing, locating the overflow valve at the patient gave the poorest

efficiency, 25 liters of CO_2 per 100 g. of lime. This apparent capacity is only slightly larger than that expected in a closed system, 20 liters of CO_2 per 100 g. of lime. Placing the bag on the expiratory side was better than on the inspiratory side, 64 liters versus 52 liters of CO_2 per 100 g. of lime. As with spontaneous ventilation, the inflow of gas to the absorber side of the inspiratory valve was preferable. The Georgia valve was less efficient than the spring-loaded valve with the bag or ventilator on the expiratory side of the canister. However, if the bag was on the inspiratory side of the absorber (fig. 3D), the Georgia valve was more efficient than the spring-loaded overflow valve and was as efficient as the best arrangement having the bag on the expiratory side of the canister. No difference in the absorber efficiency was found during spontaneous ventilation when the valves were at the "Y" instead of at the absorber. However, with controlled ventila-

tion, placing the valves at the patient was much better, 64 liters versus 48 liters of CO₂ per 100 g. of lime. This arrangement, the most efficient when a springloaded valve was employed, also showed a wide range of apparent capacities, 47 to 79 liters per 100 g. These variations were also dependent on small changes in inflow rate.

Discussion

The use of the high flow semiclosed technique with N₂O-O₂ mixtures was known to provide some measure of control of both CO₂ accumulation and O₂ concentration in the system. Both Hamilton and Eastwood⁷ and Miles, Martin and Adriani⁸ found that in the semiclosed circle, nitrogen is eliminated almost as rapidly with 5-liter inflow rates as with 10-liter inflow. The amount of re-breathing and the quantity of fresh gas inspired were seen directly in the nitrogen trace during inspiration. However, the degree to which the semiclosed circle system can approach the nonbreathing system was unsuspected. The success of this method of eliminating most of the exhaled CO₂ depends on optimal arrangement of the valves, absorber, overflow valve, reservoir bag, and inlet for fresh gases. During spontaneous breathing, the overflow valve in the expiratory line opens at the end of expiration. So long as the overflow valve is at the patient or on the expiratory side of the absorber, it is primarily alveolar air which is discarded from the system. Admixture with fresh gas is prevented by introducing the gas inflow into the system between the absorber and the inspiratory valve. Gas is displaced retrograde through the absorber and expired air is eliminated from the head of the absorber through the overflow valve. The position of the valves or bag is not critical.

Introducing the fresh gas into the inspiratory breathing tube between the inspiratory valve and the patient was originally advocated to reduce the external dead space by sweeping exhaled air out of the "Y" piece. This arrangement was admittedly wasteful of gas (45 liters of CO₂ versus 86 liters per 100 g. of lime). However, no retrograde flow occurred at the "Y" piece with competent valves at the absorber as evidenced by a comparison with valves at the "Y." With incompetent

valves, even a high inflow does not prevent re-breathing of expired air.

Controlled ventilation was much less efficient than spontaneous breathing in prolonging absorber life. Because the spring-loaded overflow valve vents gas during inflation, the vented gas is mixed expired air rather than alveolar air. The dead space air containing negligible CO₂ is about 25 per cent of the tidal volume, so efficiency should be 75 per cent of that obtained with spontaneous breathing. The spring-loaded overflow valve is less efficient when the bag is on the inspiratory side of the canister because the vented gas passes through the soda lime to the bag on expiration and then must return through the lime during inspiration to be vented through the overflow valve.

The Georgia valve or the ventimeter/ventilator vents gas only during expiration. At first glance, either should be more efficient than conventional overflow valves since the gas vented at the end of expiration should be alveolar air. However, neither was more efficient than the spring-loaded overflow valve, so they do not vent pure alveolar air. In both, the first part of the expiration must fill the bellows or bag. This mixed expired air is pushed through the absorber during inspiration and is pushed back out the head of the absorber and vented by the inflow gas during the postexpiratory pause. Thus, no improvement in efficiency over the spring-loaded overflow valves can be expected.

The Georgia valve gave a poor performance with the bag on the expiratory side of the absorber. When the bag was shifted to the inspiratory side of the absorber, performance improved apparently because the dead space air went through the lime, leaving alveolar air at the overflow valve to be vented.

Comparison of the plain "Y" with the valves at the absorber and the Swivel "Y" with valves in the "Y" revealed that although their efficiencies were equivalent with spontaneous breathing, locating the valves at the "Y" was superior with controlled ventilation. With the valves at the absorber, pressure expands the breathing tube with fresh gas so 200 ml. or more of fresh gas is admixed with the exhaled air.

The best arrangement of components for

both spontaneous and controlled ventilation placed valves at the "Y." The bag and the overflow valve were on the expiratory side of the absorber, and the inlet of fresh gas was on the inspiratory side.

Regardless of the particular arrangements of the components, the semiclosed system does not effect an economy in the use of lime in relation to the usage of gases. With the most extravagant use of absorbent, the cost is only five cents an hour. Increasing the inflow rate to spare lime costs about fifteen cents per liter per hour for N_2O-O_2 .

The most important advantage of the recommended arrangement of the semiclosed system is that by increasing the inflow to equal the minute volume, one obtains essentially a nonbreathing system. The more efficient the system in terms of absorbent life, the more fresh inflow gas reaches the patient's lungs. Therefore, the recommended circuit wastes less oxygen and anesthetic gas through the overflow valve before they reach the patient. In less efficient systems, an inflow gas rate larger than the minute volume would be needed to produce complete nonbreathing. Other arrangements or systems may require inflow rates two or more times the minute volume to rapidly flush out the lungs and the anesthetic system.^{5, 9}

Summary

Extremely long absorber life was found to result from a particular arrangement of the elements of the semiclosed system. The valves should be next to the patient; the bag and

overflow valve on the expiratory side and the fresh gas inlet on the inspiratory side of the absorber. When the inflow rate equals the minute volume, the system is essentially nonbreathing, both with spontaneous and controlled ventilation.

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CRUSHED CHEST A simple nonoperative apparatus known as the "Cape Town Limpet" was used to assist in controlling seven cases of crushed chest. It incorporates a rubber vacuum cup underneath elastoplast which is subsequently covered with plaster to achieve physiologic restoration of the integrity of the chest wall by making a temporarily intact exoskeleton. Ancillary methods of assisted respiration by tracheostomy and IPPB can be applied at leisure. (*Schrire, T.: Control of the Crushed Chest, Dis. Chest* **44**: 141 (Aug.) 1963.)