FACTORS INFLUENCING CARBON DIOXIDE ABSORPTION DURING ANESTHESIA

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Recent studies of pulmonary ventilation in patients under general anesthesia with a closed rebreathing circuit revealed concentrations of carbon doixide as high as 2 per cent in the inspired gas. Defective anesthetic machines and inadequate carbon dioxide absorbent material were shown to be responsible for this rebreathing of carbon dioxide. The possibility that these factors may be operating in other institutions prompts us to report our experience in detail.

Methods and Material

Observations were made upon 56 surgical patients under general anesthesia. The operations included a wide variety of abdominal and thoracic surgical procedures. Endotracheal anesthesia with a closed rebreathing circuit was used in all cases. In most operations ethyl ether was the anesthetic, and in the others nitrous oxide was used.

Our apparatus and sampling technique have been described in detail elsewhere (1). A dry test gas flowmeter was included in the expiratory line of the circuit to measure ventilatory minute volumes. The concentration of carbon dioxide in the inspired and end-expired gases was continuously measured by an infrared absorption carbon dioxide analyzer. The technique described by Collier (2) was used. Pulmonary ventilation was maintained by a positive and negative pressure ventilator * (3). The positive and negative pressures, the relative duration of inflation and deflation and the respiratory rate are independently adjustable in this apparatus. Using respiratory rates between 14 and 20 per minute and equal durations of inflation and deflation, the positive and negative pressures were adjusted to provide the desired ventilatory minute volume (4).

Apnea was produced by intravenous succinylcholine. The patient was hyperventilated and the succinylcholine discontinued. The minute volume of ventilation was then slowly decreased. The carbon dioxide content of the end-expired gas when the patient first made a respiratory effort was noted on the tracing of the carbon dioxide analyzer. There-

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* The Jefferson Ventilator manufactured by Air Shields, Inc., Hatboro, Pennsylvania.

after the minute volume of ventilation was adjusted to maintain the tension of carbon dioxide in the end-expired gas just below this level. Obviously, an increase in the concentration of carbon dioxide in the inspired gas required an increase in the ventilatory minute volume to maintain this constant value of carbon dioxide in the end-expired gas. The maximum minute volume required was 20 liters per minute in a patient rebreathing gas containing 1.5 per cent carbon dioxide. The smallest minute volume was 10 liters per minute in a patient rebreathing gas free of carbon dioxide.

Results

Anesthetic Machines.—Studies were carried out on two different types of anesthetic machines: a Heidbrink with a 9-B circle filter canister and a McKesson Model N. With the Heidbrink machines,

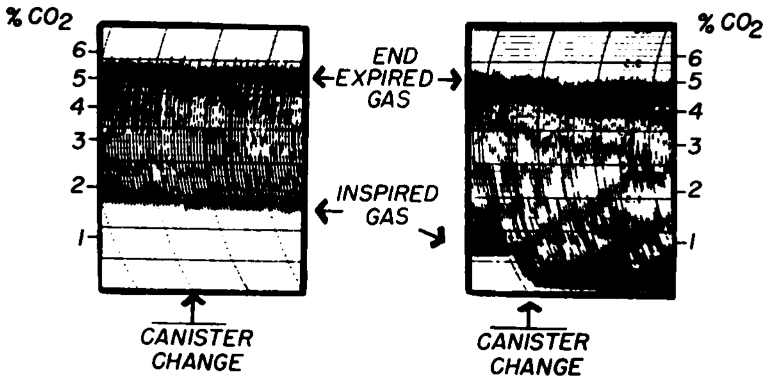

FIG. 1. Tracing of the concentration of carbon dioxide in the gas in the endotracheal tube. Both tracings were made during the same operation. The tracing on the left was made while a defective machine was in use. Changing to a canister of fresh absorbent failed to eliminate carbon dioxide from the inspired gas. The tracing on the right was made using a properly functioning machine. In this instance changing the canister resulted in the removal of all the carbon dioxide from the inspired gas.

using an efficient absorbent material (U.S.P. soda lime) in the canister, no carbon dioxide appeared in the inspired gas. On the other hand when any one of 11 new McKesson Model N machines was used a high level of carbon dioxide promptly appeared and persisted in the inspired gas. Switching to a canister of fresh absorbent resulted in little or no improvement in carbon dioxide absorption (fig. 1). The presence of carbon dioxide in the inspired gas was found to be due to imperfect closure of a valve in the McKesson machine, which allowed part of the expired gas to by-pass the canister. After this defect had been repaired by the manufacturer, changing canisters immediately resulted in the complete absorption of carbon dioxide (fig. 1).

Carbon Dioxide Absorbents.—Several types of canisters were employed in the study. A 3,300 cc.-canister (fig. 2) was used in 24 operations ranging up to ten hours in duration. This large canister was once used during major operations almost daily for two weeks without renewing the absorbent, with complete absorption of carbon dioxide in the circuit. This large canister worked well with either U. S. P. soda lime or Baralyme.

Two conventional sized canisters, 750 cc. and 500 cc., were also employed. The former was more efficient than the latter when either soda lime or Baralyme was used as the absorbent. Since the absorbing power of the 500 cc.-canister was more rapidly exhausted, it was more frequently used in the present studies in order to make comparison of more absorbent materials on the same patient. A canister was allowed to function continuously; alternating canisters has been shown to have little effect on efficiency of absorption (5).

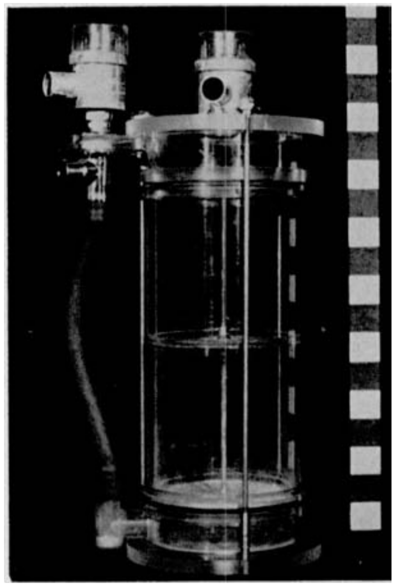

FIG. 2. Photograph of 3,300 cc.-canister designed by Drs. James O. Elam and Elwyn S. Brown. Each block on the measuring stick is one inch.

Two absorbent materials were studied: Baralyme and U. S. P. soda lime. In a properly functioning anesthetic apparatus, Baralyme pellets did not completely absorb carbon dioxide. Figure 3 is a scattergram of the concentrations of carbon dioxide in the inspired gas using Baralyme pellets in 500 cc.-canisters. The concentration of carbon dioxide in the inspired gas rose promptly and ranged between 0.6 and 1.3 per cent thirty minutes after the canister was put in use (fig. 3). We then tested a smaller and more porous Baralyme pellet with concave ends especially supplied to us by the manufacturers. This pellet in the 500 cc. canister again failed to absorb carbon dioxide adequately (fig. 3). Both types of Baralyme pellets functioned properly only when used in the 3,300 cc.-canister.

The absorptive power of U. S. P. soda lime granules was in striking contrast to that of Baralyme pellets. In all instances when soda lime was used in the 500 cc. canisters, the concentration of carbon dioxide in the inspired air remained below 0.5 per cent for at least two hours (fig. 4). When soda lime was used in the 750 cc.-canisters, the carbon dioxide in the rebreathed gas did not exceed 0.2 per cent for periods ranging up to four hours (fig. 5). Indeed, during one operation, soda lime in a 750 cc.-canister completely absorbed all the expired carbon dioxide for seven hours. Baralyme pellets in the same sized canister were inadequate within thirty minutes.

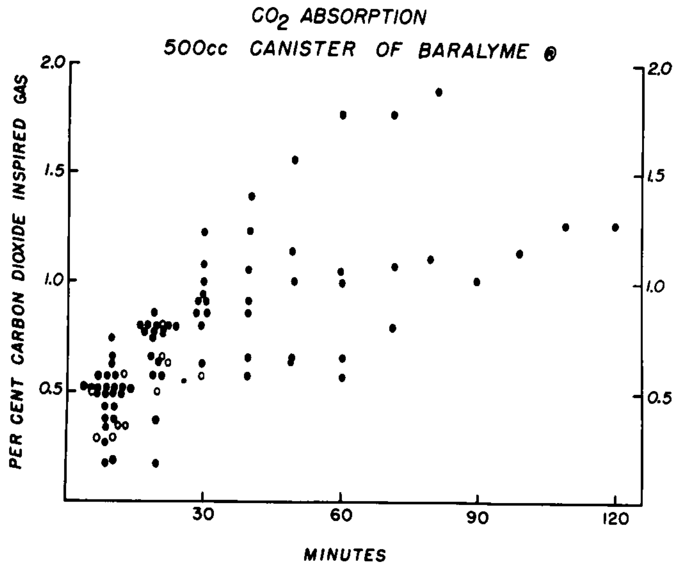

FIG. 3. Scattergram of the concentration of carbon dioxide in the inspired gas using a 500-cc. canister containing Baralyme pellets. The dots indicate the 25 instances in which the original pellets were used and the circles indicate the six instances when the new pellets were used. With either type of pellet, the carbon dioxide concentration was usually 0.5 per cent or above after 10 minutes. After 30 minutes the observed concentrations ranged between 0.6 and 1.3 per cent carbon dioxide.

It was possible to compare the two absorbents during the course of an operation on one patient. Five hundred cubic centimeters of the original Baralyme pellets allowed the carbon dioxide in the inspired gas to reach approximately 0.5 per cent within ten minutes (fig. 6), whereas 500 cc. of soda lime constantly removed all but 0.2 per cent of the carbon dioxide from the inspired gas during the 90 minute period of observation.

With both Baralyme and U. S. P. soda lime there was no correlation between the appearance of the indicator in the absorbent and the absorptive efficiency of the material when the conventional sized canisters were used. Both absorbents frequently appeared to be fresh when they were demonstrated to be exhausted.

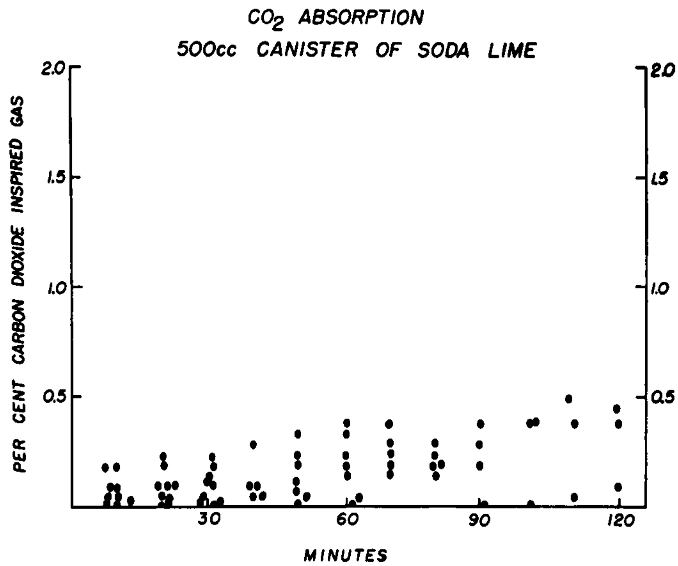

FIG. 4. Scattergram of the concentration of carbon dioxide in the inspired gas using a 500 cc.-canister containing soda lime. In the 9 patients studied the concentration of carbon dioxide did not go above 0.5 per cent in periods up to two hours.

DISCUSSION

An average pulmonary ventilation of 14 liters per minute was required to maintain a normal carbon dioxide tension in the end-expired gas in the patients studied. Adriani demonstrated that an absorbent

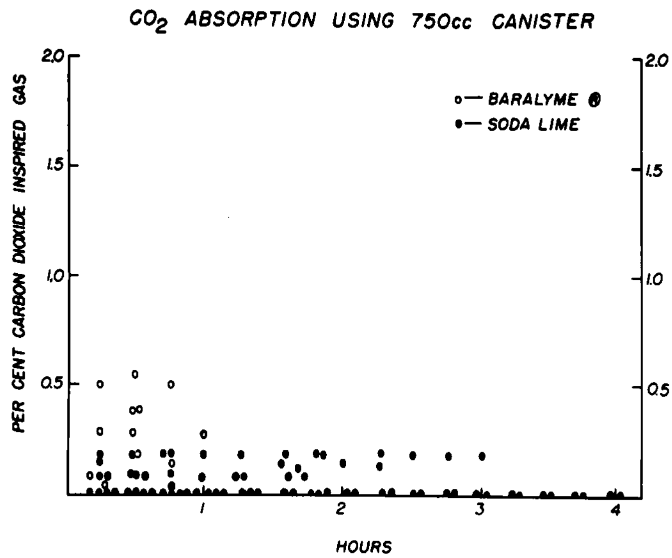

FIG. 5. Scattergram of the concentration of carbon dioxide in the inspired gas using a 750 cc.-canister. When Baralyme was used, the concentration rose rapidly during the first 30 minutes in the 4 patients studied (circles). When soda lime was used, the concentration of carbon dioxide was unchanged in periods up to four hours (dots).

has a longer useful life when the tidal volume is small (6, 7). As the tidal volumes during anesthesia in the patients in this series were large, the absorbents used had a shorter useful life than if pulmonary ventilation had been less. This, of course, does not invalidate the observations which we have reported.

Clinical studies on the use of Baralyme as a carbon dioxide absorbent were first made by Kilborn (8) in 1941 who found it a more effective absorbent than low moisture soda lime. It was later shown that high moisture soda lime is more absorbent than low moisture soda lime (9). Adriani and Batten (10) found Baralyme superior to soda lime, as did Mousel, Weiss and Gillion (11). Much of this early work with Baralyme was done on mechanical laboratory models.

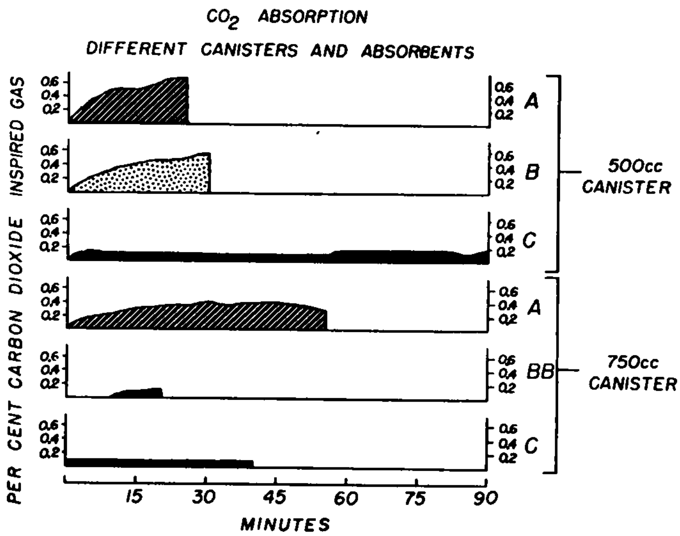

FIG. 6. Graph of carbon dioxide concentration in inspired gas during the course of an operation on one patient. The effects of carbon dioxide absorbents and canister size on the absorption of carbon dioxide are shown: A, original Baralyme pellets; B, smaller and more porous Baralyme pellets; BB, crushed Baralyme, and C, soda lime.

Possibly the Baralyme pellets used in our experiments differed in some way from the original material studied. The second type of pellet supplied to us by the manufacturers gave slightly better, but still poor, absorption of carbon dioxide. The poor absorption of carbon dioxide by Baralyme probably was due to the pellet form in which it was marketed since in a few trials the crushed material was as effective an absorbent as soda lime † (fig. 6). In the 500 cc.-canister apparently the pellet form of the absorbent material presented an insufficient surface in contact with the gas to absorb all the carbon dioxide. When the oversized canister was used the Baralyme pellets provided complete absorption for long periods of time. The Baralyme pellets tested were

† Since the preparation of this manuscript, the Thomas A. Edison Industries have marketed a new Baralyme in granular form. No studies were made of these granules which differ from the crushed material.

random samples from approximately two and one-half tons of the material which were purchased by the hospital over a period of more than a year. The material was used according to the instructions on the carton.

On the basis of our experience with a defective anesthetic machine and an inefficient carbon dioxide absorbent, it would seem desirable to test anesthetic machines and carbon dioxide absorbents by measuring the concentration of carbon dioxide in the inspired gas during surgical operations.

Summary

A structural fault was discovered in a commonly used make of anesthetic machine. The fault was corrected by the manufacturer, on request. The defect, while it existed, allowed part of the expired gas to by-pass the canister containing the carbon dioxide absorbent, resulting in significant concentrations of carbon dioxide in the gas inspired by the patient.

Baralyme in pellet form in conventional 500 cc.- and 750 cc.-canisters failed to absorb carbon dioxide completely in a properly functioning, closed, rebreathing circuit. It did perform efficiently, however, in a 3,300 cc.-canister. Crushed Baralyme, however, was as effective an absorbent as soda lime.

U. S. P. soda lime completely absorbed carbon dioxide when used in the conventional, as well as the large, canisters.

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