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A METHOD FOR THE MEASUREMENT OF PULMONARY VENTILATION DURING ANESTHESIA * †

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FROM the physiologic point of view, the most important duty of the anesthesiologist during the conduct of a case is to ensure that the patient's pulmonary ventilation is adequate to maintain normal partial pressures of oxygen and carbon dioxide in the blood. Until simplified methods are available for measuring alveolar or blood gas tensions accurately and continuously, ventilatory volumes must serve as the most convenient index of the adequacy of respiration. Although anesthesia machines have been improved by the addition of manometers to measure airway pressure and of rotameters to indicate flow of gas from the tanks to the breathing bag system, there is not available a simple device for measuring a much more important quantity—the movement of gas into and out of the patient's lungs.

The ventilatory volume of a patient may be measured in several ways without interrupting the administration of the anesthetic gas. The breathing bag may be surrounded by a chamber and the air displaced by movements of the bag recorded on a Benedict-Roth type spirometer (1) or measured in a valved collection system. The pneumotachograph (2), a device which measures air flow by the pressure drop across a low resistance screen inserted in the airway, may also be used. These methods require the timing of intervals by stop watch, the measurement of gas volumes, or the analysis of pen-written or

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photographic records, and are thus inconvenient for operating room use. The application of a previously described principle (3) to the standard anesthesia machine gives the anesthesiologist a continuous measurement of respiratory minute volume without these disadvantages.

The lucite modified venturi tube which is made a part of the standard fitting used to attach the breathing bag to the soda lime canister is illustrated in figure 1. As air moves in either direction through

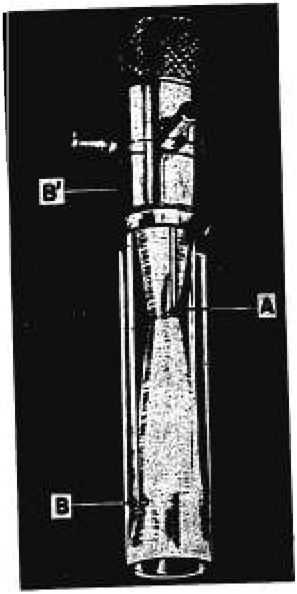

FIG. 1. The transparent lucite venturi tube slips into the breathing bag. The metal fitting at the top is the standard piece which attaches breathing bag to soda lime canister.

this tube, the pressure at the side tap A becomes negative in relation to the pressure at the interconnected taps B and B′ (in fig. 1, B′ is hidden by the metal fitting). The difference in pressure between A and BB′ is a function of the rate of air flow through the tube. The pressures at A and BB′ are transmitted through two separate rubber tubes to a differential draft gauge (a relatively inexpensive aneroid manometer widely used in industry for measuring air pressure in ventilating systems) located within the anesthesiologist's view (fig. 2).

A damping constriction is placed in the tube leading from side tap A to minimize fluctuations caused by individual respirations and produce a steady reading. The tube leading from BB′ is differentially damped so that the gauge responds only to air flow and is unaffected by pressure in the anesthesia system. It is thus possible to measure air flow with spontaneous, assisted or controlled respiration. The draft gauge needle indicates on a scale the average rate of air flow through the venturi tube during the preceding several breaths. Since the instrument measures *rate of flow* rather than *volume,* ventilation is automatically indicated in *volume per unit time.* The gauge can thus be

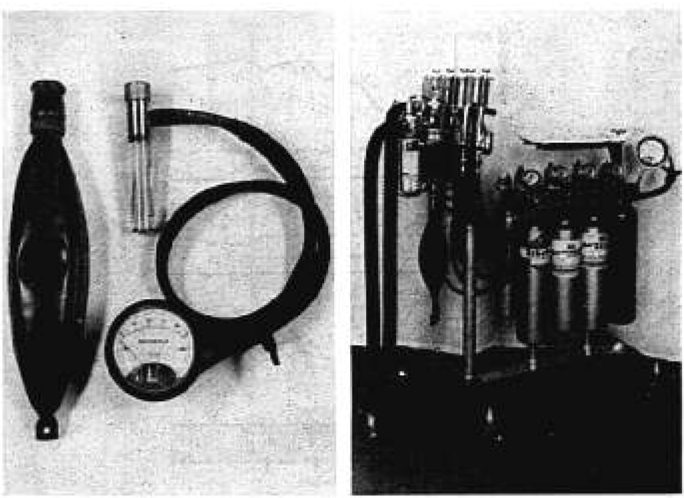

FIG. 2. Left, component parts of the ventilation meter. Right, assembled in use with anesthesia machine.

calibrated directly in liters per minute, and no stop watch or timing is necessary. When checked against a Benedict-Roth spirometer, the device was found to give a standard deviation of ± 2.6 per cent (3).

The usefulness of minute volume measurements in a patient undergoing dilatation and curettage of the uterus under sodium pentothal anesthesia is illustrated in figure 3. The patient had received 0.4 gm. of pentothal during the thirty minute procedure and was lying quietly without any operative stimulation when the measurements were made. She was breathing a 50–50 mixture of oxygen and nitrous oxide in a semiclosed circle filter system. The respiratory rate was 26, and the "ventigrator" (ventilation integrator) showed the minute volume to be 5400 cc. By dividing the minute volume by the respiratory rate, it is seen that the volume of air taken into the respiratory tree on each inspiration was only 208 cc. Assuming the dead space of the respiratory system to be 180 cc. (exclusive of mask), and assuming the dead space —alveolar gas interface to be square, the amount of gas reaching the alveoli is calculated (208–180) to be only 28 cc. If 28 cc. of gas enters the alveoli twenty-six times a minute, the effective alveolar ventilation is 728 cc. (26 × 28) compared to the average normal effective alveolar ventilation of a resting adult of approximately 3000 cc. Such a patient obviously needs respiratory assistance. Approximately 2 cc. of ether

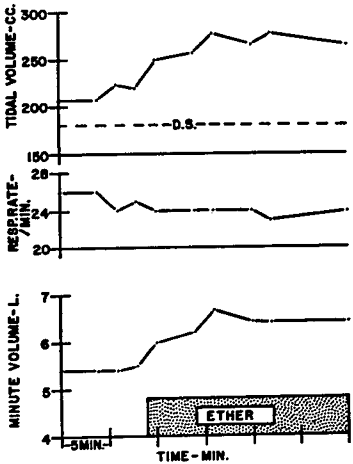

FIG. 3. Ventilation measurements showing stimulative effect of ether during pentothal anesthesia. "D. S," is an estimate of normal dead space.

was then added by the drop method to the system and the stimulating effect of this small amount of ether was immediately apparent. The tidal volume increased to 280 cc. with a respiratory rate of 24, giving the patient an effective alveolar ventilation of 2400 cc. (280 — 180 × 24).

The decrease in ventilation that occurs when the pleura is opened during intrathoracic operations may be profound. Figure 4 shows the fall in minute volume which occurred when the pleura of an adult male was opened preparatory to a left transthoracic sympathectomy. With the breathing bag overinflated to give positive pressure, minute volume was 4.0 liters compared to 9.8 liters before the thorax was opened. The pressure was then removed from the bag and inspiratory assistance begun with a special anesthesia machine producing regulated assisted respiration (4). The minute volume promptly returned to its previous level. With the aid of the ventigrator, the anesthesiologist maintained an adequate respiratory exchange for the two hours during which the chest was open.

COMMENT

The value of constant observation of the breathing bag cannot be overemphasized. However, it is beyond what can reasonably be expected of human judgment to be able always to distinguish between what may be an adequate tidal volume of 280 cc. and an inadequate one

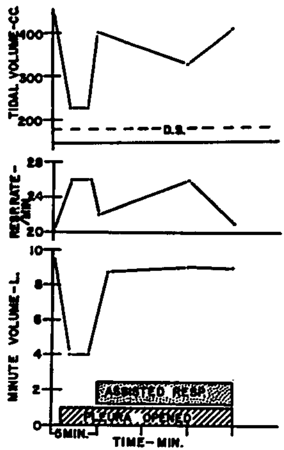

FIG. 4. Hypoventilation occurring during thoracic surgery as demonstrated by the direct reading ventilation meter. "D. S." as in Figure 3.

of 180 cc. This very important difference of 100 cc. represents only 2 per cent of the total gas volume in a 5 liter breathing bag—a difference hardly discernible by visual observation. This simple, direct reading ventilation meter is of considerable value in giving the anesthesiologist an objective measure of respiratory exchange.

The fact that the anesthetic mixture contains a high percentage of oxygen may allow adequate oxygenation of the blood to occur by diffusion even though the respiratory exchange is inadequate for excretion of carbon dioxide. The anesthesiologist may be lulled into a false sense of security by the good color of the patient's skin and blood while carbon dioxide continues to build up in the blood and tissues.

An indication of respiratory gas exchange should not be considered the ultimate measure of the adequacy of respiration. Depth of anesthesia, body temperature and many other factors may alter the ventilation requirements of the individual patient. Even in the presence of an apparently normal respiratory exchange, pulmonary disease and intracardiac shunts may produce a low oxygen saturation in arterial blood. Nevertheless, this method of following ventilation should prevent the severe hypoventilation which occurs much more frequently than is generally realized (5, 6, 7).

SUMMARY

The application of the ventigrator, a direct reading ventilation meter, to the standard anesthesia machine is described. Cases are presented to illustrate the desirability of having an accurate and continuous measure of respiratory exchange during anesthesia.

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