A METHOD FOR STUDYING RESPIRATORY FUNCTIONS IN AWAKE OR ANESTHETIZED PATIENTS

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The anesthesiologist often experiences the desire to study in man the effect of anesthetic agents on respiration, or to investigate the response of this body system to drugs administered during anesthesia. Such desires frequently go unfulfilled because of the lack of a readily available, reliable method of study, or because the cost of equipment ordinarily employed is prohibitive. This report will describe a method of studying respiration in conscious as well as anesthetized subjects It permits estimation of respiratory rate, tidal and minute volume, and "alveolar" carbon dioxide concentration. Most of the equipment utilized is available to a department of anesthesiology. Component parts of the method can be included or excluded, depending on the nature of the studies planned.

Method. The essential features in this method (fig. 1A) consist of a closed circuit including a spirometer, infrared carbon dioxide analyzer, and carbon dioxide absorption canisters. The spirometer utilized is the size (6 liters) commonly employed for measuring basal metabolic rate. If a spirometer originally designed for this purpose is to be used, certain changes are desirable. The motor for circulating respired gases is an explosive hazard and must be removed; the gear shift for operating the recording drum is unneeded; and the soda lime canister is impractical and inaccessible during the course of an anesthetic, so it should be removed. For recording, an ink writer can be attached to the counterbalance of the impression writer normally used on this type of spirometer. A continuous tracing for many hours can be obtained by wrapping a suitable length of 8- to 10-inch wide kymograph paper around the recording drum and attaching it to a small electric-driven kymograph drum placed at a safe distance (for example 3 feet) from the spirometer. The paper is thus drawn from the spirometer drum onto the kymograph drum.

A closed-circuit system between spirometer and patient is prepared, utilizing corrugated rubber tubing. The inspiratory tubing is connected directly to the patient via a unidirectional respiratory valve [for example, Stephen-Slater valve (1)]. On the expiratory side, an

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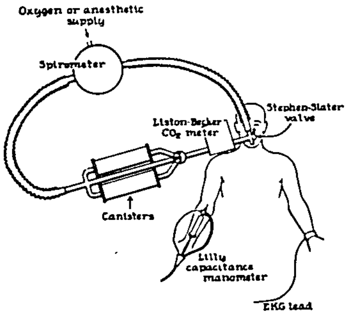


FIG. 1A. Closed circuit including a spirometer, infrared CO_2 analyzer, and CO_2 absorption canisters.

infrared absorption carbon dioxide meter * and soda lime canisters for absorption of expired carbon dioxide are interposed between valve and spirometer. The connection between the valve and the patient can be either by mouthpiece or by endotracheal tube (fig. 1B). The carbon dioxide meter must be as close to the patient and the respiratory valve as possible, to minimize dead space. For soda lime canisters, we have utilized a double canister circle filter head, since a bypass system is available. The bypass allows the canisters to be in, out, or partially out of the system.

Anesthetic gases or oxygen can be introduced from an anesthetic machine into the closed circuit through a lead tube attached to the

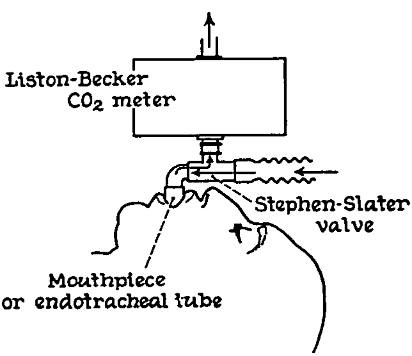
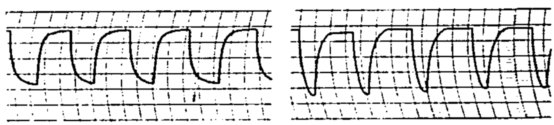


FIG. 1B. Detail of connection to patient.

* Liston-Becker, Stamford, Connecticut.

oxygen port of the spirometer. If the effect of explosive gases is to be studied, the carbon dioxide detector cell must be pressurized (2).

The respiratory demand valve is incorporated into the system in order that only the expired breath will pass through the carbon dioxide analyzer for a maximal period of time (that is, during inspiration). Data from the carbon dioxide analyzer are more accurate if recorded on paper by an oscillographic recorder.† Figure 2 depicts recordings from an infrared carbon dioxide analyzer—"A" is a tracing obtained from a patient whose inspired and expired air passed through the detector cell; "B" is the type of recording obtained when a unidirectional respiratory valve was employed and only the expired gas passed through the detector cell. Obviously, the incorporation of the respiratory valve improves the accuracy of the calculations from the recordings. It is apparent that the employment of a more sensitive recording device would increase the accuracy of the method if greater accuracy is required.



A B

FIG. 2. (A) Inspired and expired air through detector cell.
(B) Expired gas only through detector cell.

With the system utilized in the above fashion, respiratory tidal volume may influence the accuracy of the recordings. Whenever the tidal volume decreases to a point where it equals or is less than the dead space (respiratory dead space and that between detector cell and the patient's mouth), obviously the recordings are inaccurate. In our experience, tidal exchanges of less than 300 cc. may not permit accurate analysis of "alveolar" pCO_2. The response time of the instrument itself has not been a factor in accuracy, since it is of the order of 0.1 second. Neither anesthetic agents nor water vapor appears to significantly influence the accuracy of carbon dioxide determination. This is, however, being investigated further. The response time of the ink writer we have employed is so small as to be negligible.

The limitation of small tidal volumes can be overcome by using a Rahn sampler (3), wherein a sample of the expired air only is drawn through the meter. However, this converts the closed system into a semiclosed one, and, in our experience, increases the technical difficulties of measuring the effect of anesthetic agents or endogenously accumulated carbon dioxide upon respiration.

† Brush Electronics Company, Cleveland, Ohio.

In order to keep the accuracy of the measurements by the carbon dioxide meter at a maximum, we have found certain other precautions to be necessary. These include: (1) Equipment must be turned on for at least 2 hours prior to the start of the investigation to minimize "drift" of the analyzer. (2) Drafts in the operating room or in the investigational room must be avoided to minimize instrument "drift." (3) For maximum accuracy, the instrument must be calibrated frequently. Our procedure has been to calibrate the machine with 5 gases of known carbon dioxide concentration after the patient has been breathing into the system for at least five minutes, and then immediately before and after any given test run. In our experience, failure to calibrate frequently has led to serious errors.

To verify the fact that we were analyzing "alveolar" gas samples with the system arranged as described, on 63 occasions utilizing 12 subjects, end expiratory carbon dioxide tensions were compared with maximal expiratory carbon dioxide tensions. Analysis of these 63

TABLE 1

CORRELATION BETWEEN ALVEOLAR pCO_2 DETERMINED FROM LISTON METER AND ARTERIAL BLOOD pCO_2

Experiment	Alveolar pCO_2	Arterial pCO_2
I	43	43
II	43	45
III	42	43
VI	51	50
VIII	48	52
XIV	49	47
XV	43	40
XVI	54	57

comparisons revealed that, with maximal expiration, there was an average increase of 1.4 ± 1.3 mm. Hg carbon dioxide tension. This was believed to be within the experimental error of the method.

In order to test the validity of the carbon dioxide meter recordings, the figures obtained at the end of a normal respiration were compared with the carbon dioxide tension obtained during the same period from arterial blood samples. The comparison is listed in table 1. We believe the comparison showing only a 2 mm. average difference between arterial blood and expiratory pCO_2 indicates that the method is accurately recording arterial blood carbon dioxide tensions.

The resistance within the system repeatedly has been measured at 2 to 4 mm. of water during inspiration, and 1 to 3 mm. of water during expiration at normal tidal exchange. This resistance gradually increases as tidal exchange and respiratory minute volume increases. When the minute volume is great, such as 40 to 50 liters per minute, which might occur under the stimulus of carbon dioxide, the resistance within the system may increase to 4 cm. of water with inspiration or

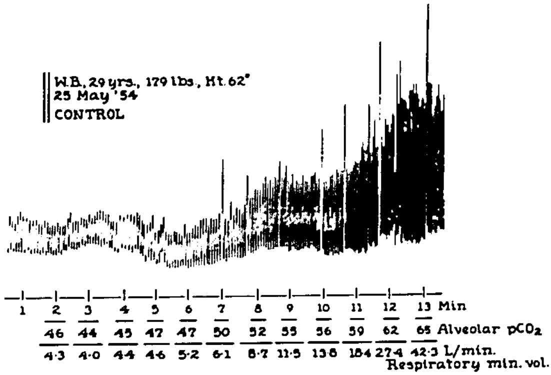


FIG. 3. Respiratory record and data obtained from a conscious subject whose respiration was stimulated by endogenously accumulated carbon dioxide.

expiration. This resistance can be minimized by carefully balancing the spirometer and making certain that all pulleys are functioning freely.

Figure 3 is a sample of the respiratory record and data obtained from a conscious subject whose respiration was stimulated by endogenously accumulated carbon dioxide. Figure 4 is a sample of a record from a patient anesthetized with cyclopropane and ether, and upon whom a hysterectomy was being performed. In this patient, respiration was also stimulated by endogenously accumulated carbon dioxide.

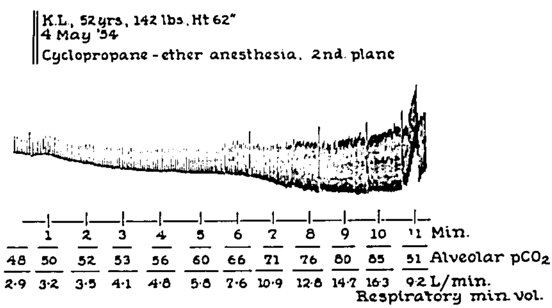


FIG. 4. Record from a patient anesthetized with cyclopropane and ether whose respiration was also stimulated by endogenously accumulated carbon dioxide.

Figure 5 demonstrates the reproducibility of the results obtained by this method. The subject's respiratory response to endogenously accumulated carbon dioxide was tested on 3 days, as indicated in the illustration.

Obviously, it is not difficult to incorporate into an investigation employing the method described, observations on blood pressure and pulse. In the majority of our patients, we have recorded intra-arterial blood pressure by means of the Lilly capacitance manometer (4). One also can incorporate electrocardiographic studies with this method.

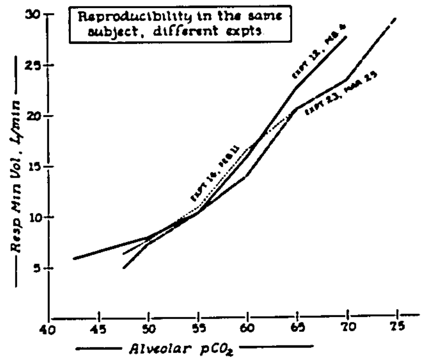


FIG. 5. Respiratory response to endogenously accumulated CO_2 in the same subject on 3 different days.

DISCUSSION

The system described for investigating the respiration of anesthetized patients is a relatively simple one, incorporating only one expensive item. By the use of this system, we have obtained results that are accurate so far as we can determine and reproducible in the same individuals under the same conditions. With usual tidal exchanges, the carbon dioxide meter, as utilized, apparently accurately measures "alveolar" carbon dioxide tension. We have utilized the method in a study of the effects of opiates in 40 conscious subjects and in 10 patients prior to and during anesthesia (5). As yet, we have found no serious objection to its use. The limitations in the recording system have been mentioned. It is obvious that the reduced tidal exchange often seen in deep anesthesia may invalidate data obtained under those conditions. However, our preliminary studies suggest that valuable observations can be made by the utilization of the method.

SUMMARY

A method of studying pulmonary ventilation in the anesthetized or unanesthetized patient is presented. A small respiratory spirometer, respiratory demand valve, infrared carbon dioxide analyzer and soda lime carbon dioxide absorption canisters are all incorporated into a closed system. Ink recordings of indefinite length can be made on kymograph paper. The validation of the method is presented.

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