the change was not large enough to be important clinically.

In our study, the use of 60 per cent nitrous oxide was associated with clinically significant increases in halothane output from Fluotec Mark 2 vaporizers at concentration dial settings up to 1 per cent. This was reflected as increases in inspired and end-tidal halothane concentrations in several patients. If nitrous oxide were added without changing the Fluotec concentration setting, the alveolar halothane would increase, due to both the second-gas effect and the increased delivered halothane concentration. Our results showed that halothane concentrations delivered at 5 liters oxygen per minute and the 0.5 setting and at 60 per cent nitrous oxide at the 0.1 setting were the same (fig. 1). Thus, if the concentration setting were decreased from 0.5 to 0.1 and nitrous oxide added, the end-result could be no change in the halothane concentration delivered plus the added effect of 60 per cent nitrous oxide.

SUMMARY

Halothane output from Fluotec Mark 2 vaporizers was increased when the carrier gas contained 60 per cent nitrous oxide rather than pure oxygen. Above the 1 per cent setting nitrous oxide did not alter halothane output. Nitrous oxide increased carrier-gas density, augmenting flow through the vaporizing chamber with a subsequent increase in halothane output.

The author acknowledges the cooperation of Mr. Fraser Sweatman and associates in the preparation of this paper.

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# Pneumotachography by the Ionization Principle—A New Approach

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Interest in the changes in pulmonary mechanics in patients receiving intermittent positive-pressure ventilation led to evaluation of the Fleisch pneumotachograph.[1,2] Flow-measuring devices built on the principle of Poiseuille's law are associated with error of method due to the effects of humidity and temperature, composition of gases, and loss of linear response. Although the error may be minimized by following the suggestions made by the above authors, it was claimed that for quantitative flow measurement an acceptable degree of accuracy is probably not possible without a computer.[3] Recognition of the difficulties encountered in the use of Fleisch pneumotachograph stimulated us to search for a more practical gas-flow-measuring device for continuous respiratory monitoring. The instrument we devised is the JSI ‡ pneumotachograph, which operates on the principle of ionization of gases by radioactive material. The following is a report of some of its functional characteristics, with a description of the principle of pneumotachography by ionization of gases.

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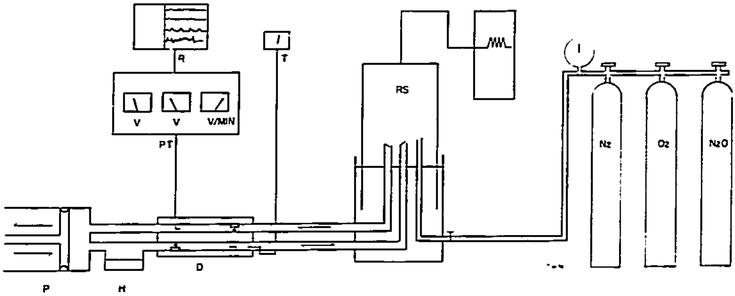


FIG. 1. Diagram of the experimental system. P = pump; H = humidifier; D = detector of the pneumotachograph; Pt = pneumotachograph; T = telethermometer; RS = recording spirometer; R = recorder.

METHODS

A 9-liter Harvard pump, Model 607 A, a Collins spirometer, and the pneumotachograph were arranged in a closed circuit. In order to study the effects of humidity and temperature on gas flows, either an ultrasonic nebulizer (E. H. N.) or a heated humidifier (Bennett Cascade) was incorporated in the circuit and the temperature of the gas passing through the detector was recorded by inserting a Yellow Springs telethermometer probe into the detector (fig. 1). Gases used were oxygen, nitrogen, 5 per cent $CO_2$ in oxygen, 100 per cent $N_2O$ and 50 per cent $N_2O$ in oxygen.

The Harvard pump was chosen for calibrating the pneumotachograph because this pump is constructed in such a way that its flow curve can be mathematically computed.[3] The com-

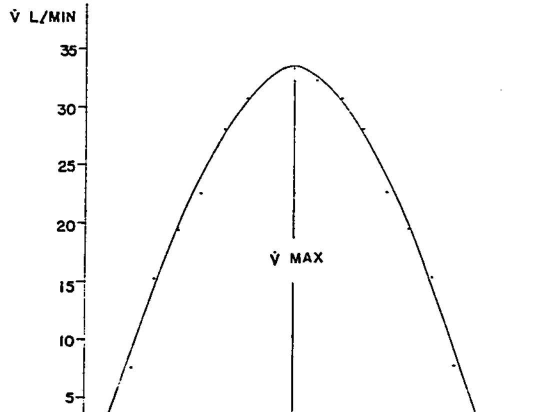


FIG. 2. Theoretical and measured flow curves. Heavy lines indicate computed flow delivered by pump, dots indicate measured flow.

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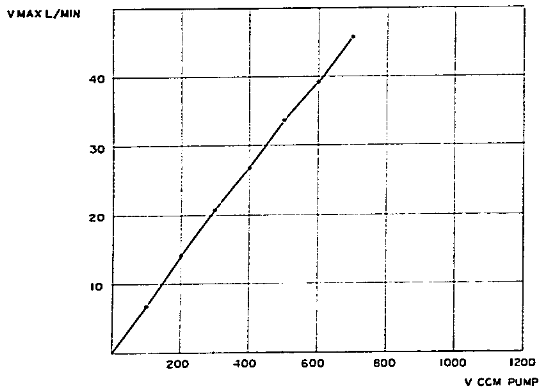


FIG. 3. $\dot{V}_{max}$ = maximal flow recorded at a given pump setting. $V_{ccm}$ = stroke volume of the pump at constant rate.

puted flow curve was compared with the flow actually measured (fig. 2). Room air at 24 C with a relative humidity of 48 per cent was used for calibration. The maximum flows ($\dot{V}_{max}$) of the flow curves at various volume settings between 100 and 700 ml, at a constant frequency of 20 c/min, were compared (fig. 3). In addition, the integrated volume of the pneumotachograph was plotted against the volume obtained from the Collins spirometer (fig. 4). The flow and volume output of the pneumotachograph were fed into a Sanborn preamplifier, Model 350-2700 C, and recorded on a Sanborn 8-channel recorder. $\dot{V}_{max}$ values of the test gases were compared with $\dot{V}_{max}$ for air and the difference was expressed as ± per cent $\dot{V}_{max}$ air.

## RESULTS

The effects of the various gases tested on measured flow are shown in figure 5. Flows for $N_2$, $O_2$, and 5 per cent $CO_2$ in $O_2$ are

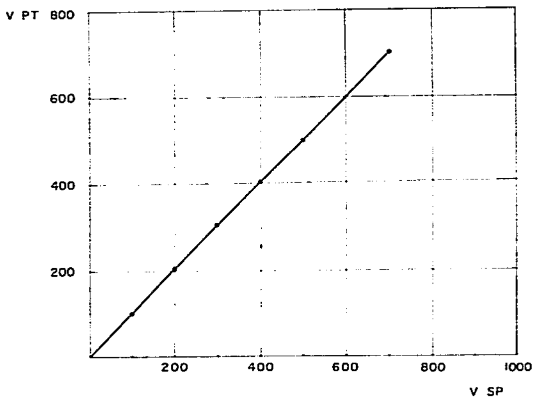


FIG. 4. $V_{pt}$ = integrated volume. $V_{sp}$ = volume recorded simultaneously on the recording spirometer.

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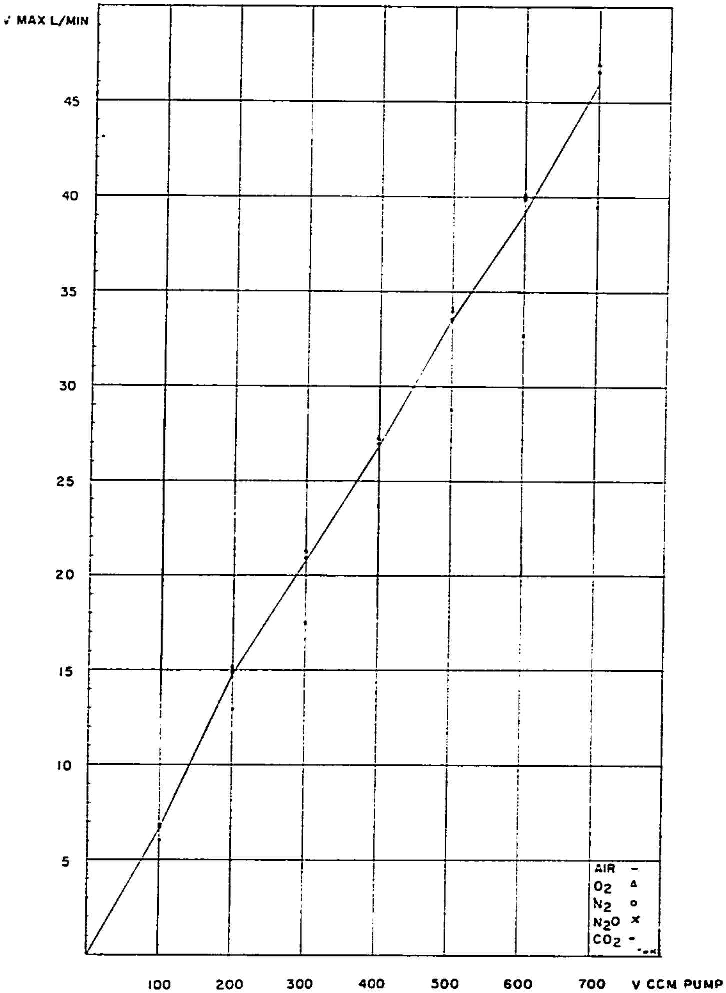


FIG. 5. Effects of various gases on flow measurements. $\dot{V}_{max}$ = maximal flow. $V_{cc}$ = stroke volume of pump at a frequency of 20 c/min. Each point of the diagram represents the mean of 12 measurements with SD ± 0.01.

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very close to each other and are well in the range of +2 per cent $\dot{V}_{max}$ compared with air. The values obtained for 50 per cent $N_2O$ in $O_2$ and 100 per cent $N_2O$ were −6.59 per cent and −12.79 per cent $\dot{V}_{max}$, respectively. The effect of temperature changes on $\dot{V}_{max}$ amounted to 0.16 per cent/degree C in a temperature range of 29 to 88 C. $\dot{V}_{max}$ and integrated volume were not affected by water vapor in the range of 100 to 200 per cent relative humidity. Relative humidity readings were derived from the nomogram provided for the Bennett Cascade humidifier by the Bennett-Puritan Company.[9]

## Discussion

The JSI pneumotachograph consists of a detector tube, an amplifier, and an electrode.[4-6] The detector tube contains a radioactive material, americium-241, which emits alpha particles. Downstream the alpha source is the electrode, where ionized gas molecules are collected and the resulting collector current is fed into an amplifier. The collector current, which is proportional to gas flow, is expressed in liters per minute. In order to measure inspiratory and expiratory flows, two detector tubes are used. Each tube is placed in an aluminum cylinder which is heated to prevent condensation of water vapor inside the tube. The flow is integrated into inspiratory, expiratory and minute volume.

The principle involved in the continuous ionization of gases is: radiation from a radioactive source emitting $\alpha$ or $\beta$ rays ionizes gas molecules. The molecules hit by the $\alpha$ or $\beta$ radiation release one or more electrons and become positively-charged ions. The released electrons combine with neutral gas molecules, and these become negatively-charged ions or remain as free electrons. (Some gases, like $N_2$ and A, do not form negative ions.) Because of collision among ionized molecules or molecules and electrons, electrons are exchanged, and finally all molecules become electroneutral. This process is known as recombination of ions. The recombination of ions during their passage through the tube causes a decrease in the number of ions reaching the electrode. The higher the velocity of the gas passing through the tube, the more ions reach the electrode before recombination of ions occurs, resulting in a higher collector current.

Our results showed that the effects of changes in temperature on the measured gas flow are negligible. For gases such as $N_2$, $O_2$, and 5 per cent $CO_2$ in oxygen, the difference in measured flow is the range of +2 per cent when air is used to calibrate the pneumotachograph. The increase in temperature causes an increase in volume according to Gay-Lussac's law. At constant pressure and at the temperature used in our experiment this would result in a volume change of 0.18 per cent/degree C. The recombination coefficient of a gas is affected by temperature changes, and decreases with increase in temperature. A temperature change of 10 C causes a 2 per cent change in the recombination coefficient.[10] With increase in volume from $V_0$ to $V_t$ the number of ions per volume unit falls and the collector current is proportionally lower. Because of the volume increase at the same time, the flow is increased, which results in a higher collector current. These processes, which run in opposite directions, tend to compensate each other; thus, changes in temperature have little effect on the measurement of gas flow. The temperature in the detector is constantly set at 60 C, which is well above the temperature changes encountered in clinical practice.

In our study humidity did not affect the measurement of gas flows when water vapor was used to increase the humidity of the gases. However, when water in the liquid state enters the detector the $\alpha$ particles are absorbed, and no ionization occurs. This was also observed when water in the form of aerosols produced by ultrasonic nebulizers entered the detector. The small droplets of water absorb radiation and block the detector. When a nebulizer must be used during measurement, it is advisable to place the nebulizer proximal to the detector in order to avoid absorption of alpha particles by droplets of water.

In addition, we found that, unlike other methods, the method of continuous ionization for measuring gas flow offers both the accuracy and the versatility needed for clinical applications.[1,7,11] It is rugged, has low resistance and wide flow-range-measuring capability, responds rapidly to flow changes, and is

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free of pressure-induced artefacts.[7] After calibration, the apparatus stays stable and can be used continuously for at least six months.

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# Intravenous Regional Anesthesia for Sequential Operations on Two Extremities

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Most anesthesiologists limit the use of intravenous regional anesthesia to short procedures on the forearm and hand. Our experience, however, encouraged us to extend the applications of this technique, and one of us (E. M. B.) has described its use for prolonged procedures.[1, 2] The purpose of this communication is to present our experience with intravenous regional anesthesia in operations involving two extremities, both upper and lower.

## TECHNIQUE

For the upper extremities, the method is essentially that described by Holmes,[3] using lidocaine, 0.5 per cent. When the operation on the first extremity is nearing completion, anesthesia is induced in the second extremity. After anesthesia in the second extremity has been established, the tourniquet on the first extremity is released, provided that at least 40 minutes have elapsed from the time of initial injection of drug.

Originally, we used the same technique for procedures on the lower extremity, but we found this not completely satisfactory, since patients frequently experienced tourniquet pain despite the use of a double tourniquet. Consequently, we have modified our technique for procedures on the lower extremity. Regardless of the site of operation, the tourniquet is placed at midthigh. Instead of 40–50 ml of 0.5 per cent lidocaine, we use 75–100 ml of 0.35 per cent lidocaine. This concentration is prepared by adding 30 ml of saline solution to 70 ml of 0.5 per cent lidocaine to make 100 ml of 0.35 per cent lidocaine.

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