Studies of Respiratory Gas Flows
A Comparison Using Different Anesthetic Agents

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NUMEROUS reports have been made of air flow resistance in anesthetic equipment and effects of resistance breathing.[1-6] Respiratory air flow patterns in normal and diseased states have also been reported.[7-10] Exact knowledge of respiratory flow rates is necessary to determine the resistance encountered in anesthetic equipment. The previously-gathered information is not completely usable unless the actual range of respiratory gas flow rates encountered during clinical anesthesia is known.

In this investigation respiratory flow rates and patterns in anesthetized patients were measured in order to make qualitative analyses of responses to various anesthetic agents with and without narcotic premedication.

Method

Respiratory air flows were measured by a pneumotachograph having a linear response between 5 and 50 liters/minute. The pneumotachograph was placed in the open end of an anesthetic face mask. This eliminated effects of the anesthesia machine and gas flow rates as possible artifacts. Tidal volumes were measured throughout the recording procedure by a Wright anemometer.[11] Meticulous attention was given to the maintenance of an unobstructed airway. To insure uniformity of awake and anesthetized states, endotracheal catheters were not used.

Respiratory rates, peak inspiratory and expiratory flow rates, duration of inspiration and expiration, and the initial slopes of inspiration were measured and analyzed. Miscellaneous observations, including gasps and sighs, respiratory pauses and arrhythmias, and peak flow rates and volumes of gases moved by cardiac contractions, were also noted and recorded.

Pneumotachogram tracings were collected on 66 patients ranging in age from two months to 79 years. Forty-eight per cent received narcotic premedication, the usual adult dose being 10 mg. morphine sulfate or 75–100 mg. meperidine combined with atropine or scopolamine (0.2–0.4 mg.). The remaining patients received either atropine or scopolamine alone or with an additional small dose of pentobarbital (50–100 mg.). Diethyl ether, halothane, cyclopropane, and intrathecal tetracaine were the anesthetics used. The distribution of 68 cases according to anesthetic and premedication studied is shown in figure 1. Four infants less than one year of age are not included. Recordings were taken with patients in the awake state and at three intervals in a progressive depression from light to deep anesthesia. Estimation of "depth of anesthesia" was based on usual clinical signs and was made always by the same individual. With a few exceptions, recordings were all taken following induction of anesthesia and prior to onset of surgical stimulation. Six patients were studied twice. In these cases halothane or cyclopropane anesthesia was studied and following appropriate elimination, anesthesia was reinduced using diethyl ether.

Results

Seventy-two tracings were collected and analyzed. Three infants less than one year were anesthetized with diethyl ether and one with halothane. In two infants awake peak inspiratory flow rates were 10 liters/minute. The peak flow rates in light anesthetic levels ranged from 7 to 19 liters/minute.

With the exception of infants the induced changes in flow rate relative to age appeared so small that further breakdown was not done.

Mean peak inspiratory flow rates for diethyl ether, halothane, and cyclopropane with and
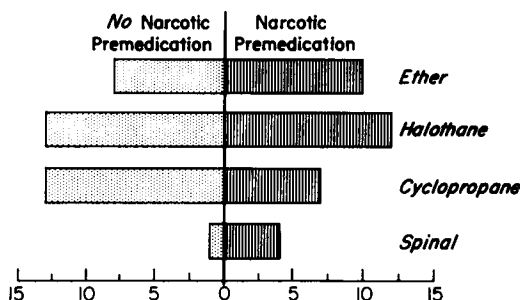
FIG. 1. Number of cases according to anesthetic and premedication studied.

without narcotic premedication are shown in figure 2.

Awake. Individual peak inspiratory flow rates ranged from 9 to 39 liters/minute in the awake state with a mean value of 21 liters/minute.

Light. Peak inspiratory flow rates increased during light anesthesia with all agents. Mean values ranged from 28 to 43 liters/minute. This increase was statistically significant ($P >$ 0.05) in every instance. Although mean values were different for each agent, distribution of individual flow rates within each agent group was similar.

Moderate and Deep. During moderate and deep anesthesia mean peak inspiratory flow rates varied from 16 to 37 liters/minute. This represents a decrease as compared to values during light anesthesia and represents a significant variation from the awake state only with diethyl ether.

Premedication. There were no significant differences in peak inspiratory flow rates during the awake state or at any anesthetic level between patients with and without narcotic premedication.

An intergroup comparison was also made of peak inspiratory flow rates of all agents during light anesthesia. Peak flow rates with diethyl ether were significantly increased when compared with all other agents during light anesthesia. Differences of peak flow rates of all other agents during light anesthesia were not significant.

Respiratory tidal volumes remained the same or were greater than awake values during light anesthesia and were decreased proportionately in deeper levels.
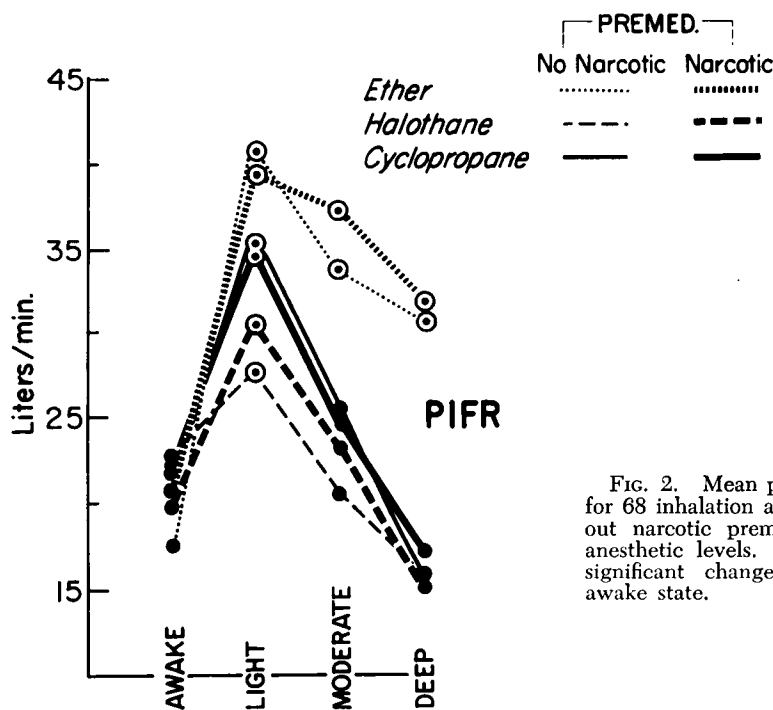

FIG. 2. Mean peak inspiratory flow rates for 68 inhalation anesthetics with and without narcotic premedication at awake and anesthetic levels. Circled values represent significant changes ($P < 0.05$) from the awake state.

Analgesic levels as high as the fourth thoracic dermatome were encountered with spinal anesthesia. No differences in peak flow rates or pneumotachogram patterns were seen when compared to control tracings.

Mean respiratory rates for all patients including infants are shown in figure 3. Patients with narcotic premedication showed lower values during anesthesia than patients without narcotic premedication. The highest rates were seen with diethyl ether and halothane without narcotic premedication and the lowest were with cyclopropane with narcotic premedication.

Time of inspiration was shorter than time of expiration in awake patients. Values for this ratio (T_I/T_E) ranged from 0.37 to 1.74 with a mean of 0.86. During anesthesia no definite and consistent changes were noted in the T_I/T_E ratio.

Initial inspiratory slopes were measured at all anesthetic levels for each agent and showed no consistent variation.

Peak flow rates during inspiration and expiration tended to be equal in awake patients, but peak expiratory flow rates diminished proportionately with increasing anesthetic depth.

Miscellaneous observations are shown in figure 4. Sighs and coupled respirations were noted in about half of all cyclopropane and non-narcotic premedicated diethyl-ether tracings. Postinspiratory and postexpiratory pauses were characteristic of cyclopropane and halothane tracings. Small "tidal" volumes of low flow rate synchronous with cardiac contractions were seen superimposed on half of diethyl ether and halothane tracings in patients given narcotic premedication. This cardiopneumotachogram shows cardiac contractions producing a peak flow rate of 6 liters/minute. The volume of these "beats" was 50 ml. In another patient, shown in figure 5, similar "beats" were seen to disappear with addition of nitrous oxide to the inspired atmosphere. The pattern reappeared after elimination of nitrous oxide.

We attempted to separate pneumotachogram patterns by some mathematical basis for each agent. However, we were unable to do so. In spite of this failure we were frequently able to identify certain flow patterns with specific anesthetic agents. Such typical pat-
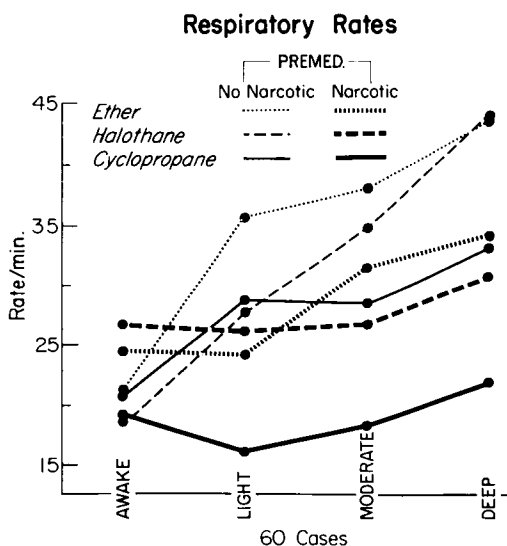

FIG. 3. Mean respiratory rates at awake and anesthetic levels for 60 inhalation anesthetics. Four infants are included.

terns are shown in figure 6. Characteristic differences to be noted are as follows: *Ether.* There is a rapid attainment of peak flow rate combined with a relatively short time of inspiration so a high peaked pattern is produced. *Halothane.* This agent characteristically produces a smoother more even pattern. The inspiratory slope is more gradual than with diethyl ether and inspiration and expiration are more symmetrical. *Cyclopropane.* Markedly diminished flow rates in deep anesthesia are characteristic of this agent. Cardiac "beats" are commonly seen during cyclopropane anesthesia which gives the pneumotachogram an irregular appearance. This phenomenon is also seen in some awake tracings and is exhibited in the awake portion of this tracing. Cardiac "beats" are more clearly demonstrated in the light cyclopropane tracing in figure 4.

Discussion

Awake peak inspiratory flow rates in our adult patients ranged from 9 to 39 liters/minute compared to previously reported values of 25 to 50 liters/minute.[3, 10, 12] Two infants aged two and eight months had awake peak inspiratory flow rates of 10 liters/minute. Peak inspiratory flow rate values of 5 to 10 liters/

minute in infants have been reported by several authors.[4,5] We agree with Proctor[4] that peak inspiratory flow rates encountered in children of four to five years of age fall within the adult range.

Proctor further reported that adult air flow patterns with spontaneous breathing during surgical anesthesia would be quite similar to those in the awake state and thought the same would apply for infants and children.[13] However, patients we studied showed significantly increased peak inspiratory flow rates during light levels of anesthesia with all agents and with diethyl ether anesthesia in deeper levels of anesthesia.

Figures 7 and 8 are patterned from Orkin's study of resistance in anesthetic apparatus.[3]

Resistance through various sized endotracheal catheters over a wide range of flow rates is represented. Our data allow specific localization of clinically encountered resistance on these graphs. For example, mean peak inspiratory flow rates of agents studied in our patients above one year ranged from 28 to 43 liters/minute. It is apparent in figure 7 that the difference in resistance encountered at 40 liters/minute comparing a 42 F catheter (10) at 'A' with a 32 F catheter (7) at 'B' is 1.0 cm. of water. Thus for a large difference in endotracheal catheter size the difference in resistance is only 1.0 cm. of water. We now have specific information upon which to choose endotracheal catheter size.

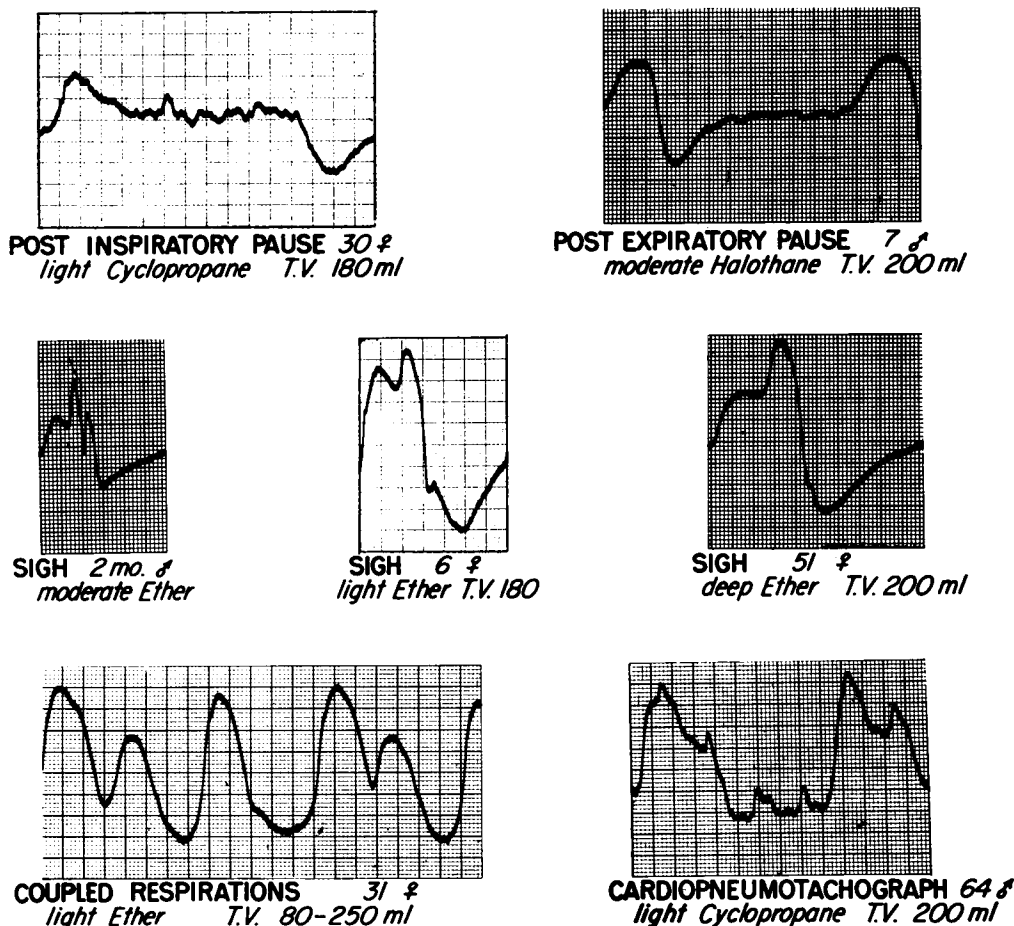The effect of size is of course more im-

POST INSPIRATORY PAUSE *30* ♀
light Cyclopropane   T.V. 180 ml

POST EXPIRATORY PAUSE   *7* ♂
moderate Halothane   T.V. 200 ml

SIGH   *2 mo.* ♂
moderate Ether

SIGH   *6* ♀
light Ether T.V. 180

SIGH   *51* ♀
deep Ether   T.V. 200 ml

COUPLED RESPIRATIONS   *31* ♀
light Ether   T.V. 80–250 ml

CARDIOPNEUMOTACHOGRAPH *64* ♂
light Cyclopropane   T.V. 200 ml

FIG. 4. Miscellaneous observations—sighs, coupled respirations, cardiac contractions, and postinspiratory and postexpiratory pauses.

C.R. 33 ♀
125 lbs.

Awake   T.V. 400 ml

moderate Cyclopropane T.V. 250 ml

*light Cyclopropane and
Nitrous Oxide T.V. 300 ml*

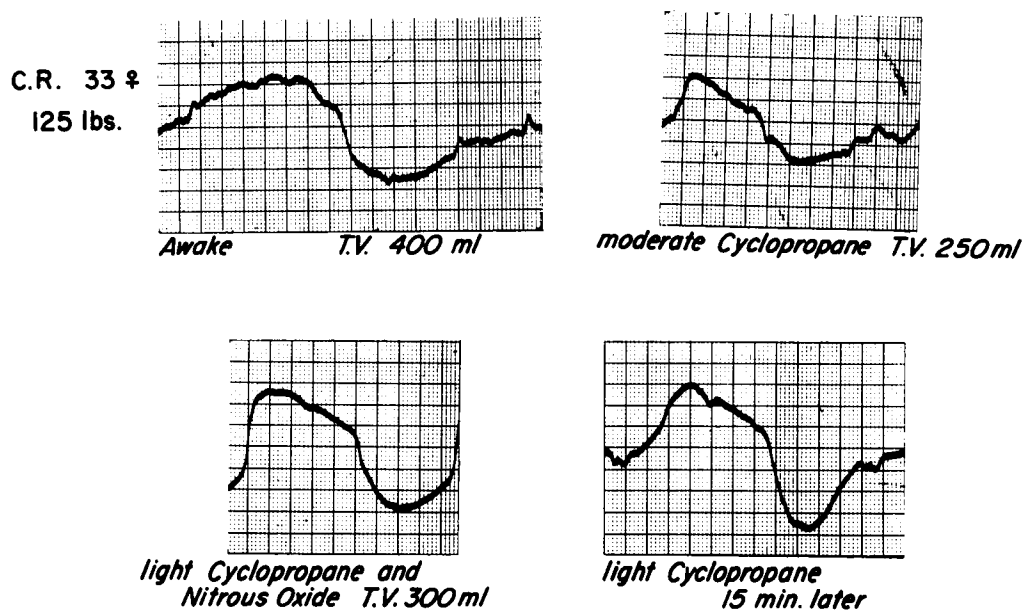*light Cyclopropane
15 min. later*

FIG. 5. Cardiopneumotachogram. The disappearance of cardiac "beats" with the addition of nitrous oxide to the inspired atmosphere is shown.

M.P.
23 ♀

Awake   T.V. 400 ml
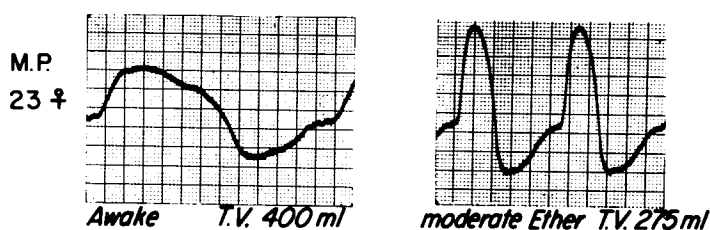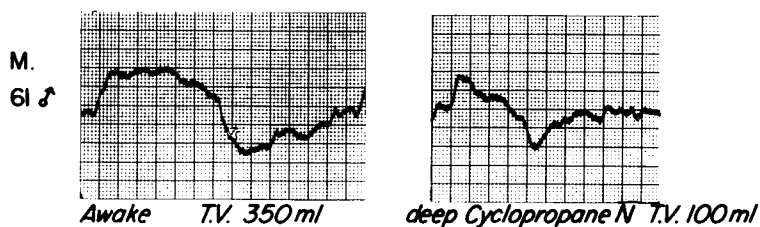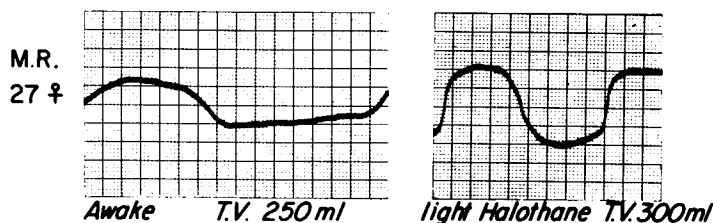
moderate Ether T.V. 275 ml

FIG. 6. Examples of typical flow patterns with specific anesthetic agents —diethyl ether, halothane and cyclopropane.

M.R.
27 ♀

Awake   T.V. 250 ml

light Halothane T.V. 300 ml

M.
61 ♂

Awake   T.V. 350 ml
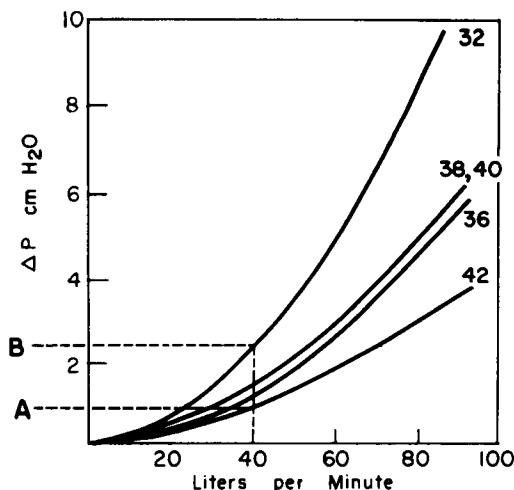
deep Cyclopropane N T.V. 100 ml

Fig. 7. Resistance through various sized endotracheal catheters (Magill) over a wide range of flow rates.

portant when one considers endotracheal catheters used in children. Figure 8 shows flow-resistance curves for catheters 12 F (0) to 22 F (3). Resistance in these catheters at the highest peak flow rate we recorded during anesthesia in infants ranges from 4 cm. of water at 'A' to 80 cm. of water at 'C.' Furthermore, at this same flow rate the difference in resistance of a 12 F catheter at 'C' compared to the next larger catheter at 'B' is still almost 60 cm. of water.

Nunn has recently shown that tubular resistors corresponding to 24 F endotracheal catheters can be tolerated in anesthetized adults without producing significant changes in ventilation.[6] The effect of a flow dependent resistor is minimized by maintenance of a low peak flow rate.

The idea has been expressed in the past that one might gain advantage by using narcotic premedication to "slow down" respiration and thus diminish effects of resistance offered by anesthetic equipment. Our studies would not support this and suggest that narcotic premedication offers no advantage in this particular area. It is of interest to note that resistance to breathing in anesthetic apparatus would be less during deep anesthesia than at lighter levels.

With the possible exception of diethyl ether, the wide individual variability in peak flow

rates produced by different agents during anesthesia probably precludes selection of any anesthetic agent on the basis of providing a lower resistance pattern.

Failure to observe a decreased T_I/T_E ratio in deep anesthesia is in contradistinction to the classic Guedel description [14] of a shortening inspiration as anesthesia progresses. No explanation for this discrepancy is forthcoming.

Several authors [9, 15] have alluded to the variability of respiratory patterns in awake individuals, both from person to person, and from breath to breath. Silverman and Whittenberger [9] state that small undulations characteristic of normal respiratory air flow patterns are diminished and lost during resistance breathing, anesthesia, and with decreased lung elasticity. With a loss of elasticity stereotypy of successive breaths develops. Pneumotachogram tracings of our anesthetized patients were characterized by loss of undulations and stereotyped successive breaths.

Cardiac pneumotachogram patterns have been reported by Elam and Brown.[16] They recorded volumes of 4–35 ml. and postulated that portions of lung adjacent to the heart were massaged by the cardiac contraction. The disappearance of cardiac configurations with the addition of nitrous oxide to the inspired atmosphere is not well understood.
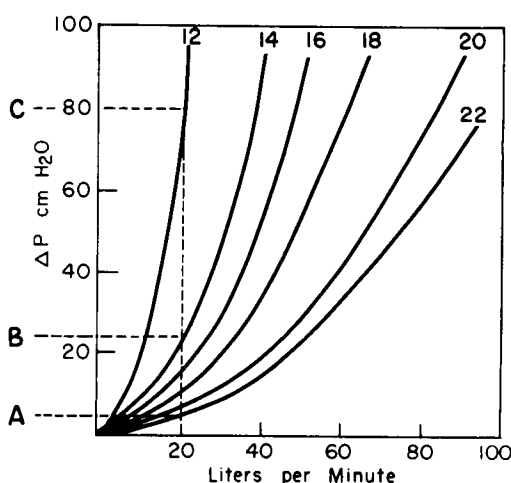
Fig. 8. Flow resistance curves for catheters 12F to 22F (Magill). Resistance at the highest peak flow rate from 4 cm. of water A to 80 cm. of water at C.

This may be related to differences in physical properties of the gases or their effect on respiratory tract musculature.

Intercostal and diaphragmatic components of pneumotachogram patterns have been described by Proctor [15] and Woods. [17] In this study, flow rates and pneumotachogram patterns in patients with high spinal anesthesia showed no changes when compared to control tracings.

Summary

Seventy-two pneumotachogram tracings have been analyzed on 66 patients anesthetized with diethyl ether, halothane, cyclopropane, or intrathecal tetracaine. Forty-eight per cent of the patients received narcotic premedication. No change from the awake state was seen during spinal anesthesia. During inhalation anesthesia peak inspiratory flow rate increases during light anesthesia were found for all agents when compared to awake values. Increases in peak inspiratory flow rates were found in deeper levels only during diethyl ether anesthesia. Peak flow rates with diethyl ether were also significantly increased when compared with halothane and cyclopropane during light anesthesia. No significant difference in flow rate was seen when each agent was compared with its narcotic premedicated counterpart during awake or comparable anesthetic levels. Peak inspiratory flow rates during anesthesia have been shown to be greater than previously reported. Some degree of agent specificity in the production of the pneumotachogram has also been described.

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