AUTOMATIC FLOW INTERRUPTION BRONCHOSCOPE:  
A LABORATORY STUDY

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SUMMARY

A laboratory assessment of a ventilating bronchoscope incorporating automatic flow interruption suggests that it will safely provide adequate ventilation.

There are techniques designed to avoid inadequate pulmonary ventilation during bronchoscopy, but none is free from the risk of hypoxia and hypercarbia. The application of the venturi system by Sanders in 1967 provided a new approach, allowing simultaneous ventilation and bronchoscopy. Several authors (Pender et al., 1968; Spoerel, 1969; Grant, 1971; Giesecke et al., 1973) have shown that adequate ventilation and oxygenation can be achieved in clinical practice, using instruments incorporating this principle. However, despite Spoerel's suggestion (1969) in favour of automatic interruption of the ventilating gas flow, manual operation is still used invariably. This study reports the assessment of a bronchoscope incorporating the venturi principle and time cycled automatic flow interruption of the ventilating gases. Tests have been performed to determine the effects of the time cycled interruption on the tidal volume, the oxygen concentration and the volume of air entrained.

EQUIPMENT

The bronchoscope incorporates distal side vents and has been modified proximally to accept a detachable venturi pattern injector (fig. 1) with a needle diameter 0.8/1.0 mm. Unlike most venturi systems (fig. 2), the injector does not pass to a point distal from its point of entry into the bronchoscope. Furthermore, encroachment by the injector into the bronchoscope lumen is minimal. The injector is connected by a plastic pressure hose to the outlet of a ventilator. The ventilator allows gas pressure, flow and cycling time to be varied. The gas supply pressure used (4.2 kg/cm$^2$, 60 Lb./sq. in.) corresponds with current United Kingdom piped gas practice although the ventilator will function with pressures up to 6.0 kg/cm$^2$, 85 Lb./sq. in.).

METHOD

An artificial lung (Manley lung ventilator performance analyser with improved calibration features) was connected to the distal (patient) end of the bronchoscope and the side vents were occluded to prevent gas loss. In clinical use, gas leakage between bronchoscope and trachea would be expected and therefore the variable leak incorporated in the artificial lung was set at its maximum value (fig. 3). The total delivered tidal volume and its component volumes were measured under different conditions. All measurements were repeated five times and the mean of the readings used to construct the graphs. The component volumes were driving gas, air or oxygen entrained by the venturi and air entrained at the proximal (operator) end of the bronchoscope. During measurements of...
injected gas volume an eye piece was used to occlude the operator end and prevent air entrainment at stage II (fig. 1) and in addition a rubber seal was used to occlude the venturi at stage I (fig. 1), during measurement of driving gas volume. All volumes were assessed at a driving gas pressure of 4, 3 and 2 kg/cm$^2$ for both good (0.05 litre/cm H$_2$O) and poor (0.02 litre/cm H$_2$O) simulated compliances, and with varying (5, 20, 50 and 200 cm H$_2$O/litre/sec) airway resistance. Inspiratory/expiratory times were restricted to 1.0/2.0 sec and 1.5/2.5 sec.

RESULTS

**Injector.** The entrainment ratio of the injector venturi at varying driving gas pressures was derived from the following formula:

Entrainment ratio = \[
\frac{\text{total injector volume} - \text{driving gas volume}}{\text{total injector volume}}
\]

The ratio increased from 0.46 to 0.54 with a decrease in driving gas pressure (over the range used).

**Tidal volume.** Tidal volume was reduced by a decrease in compliance and an increase in airway resistance (fig. 4). At a compliance of 0.05 litre/cm H$_2$O with a driving pressure of 4.0 kg/cm$^2$ and airway resistance of 5 cm H$_2$O/litre/sec, the tidal volume was 700 ml. At a compliance of 0.02 litre/cm H$_2$O with a driving pressure of 3 kg/cm$^2$ and airway resistance of 200 cm H$_2$O/litre/sec, the tidal volume was 175 ml. These volumes were obtained with an inspiratory/expiratory ratio of 1.0/2.0 sec. However, the tidal volume increased by less than 1%, when the inspiratory phase was increased to 1.5 sec. All the measurements were reproducible using this mechanical system.

**Oxygenation.** The concentration of oxygen in the gas mixture delivered to the artificial lung was calculated using the volumes measured with stage

![Diagram of experimental model](https://example.com/diagram)

**FIG. 3.** The experimental model.

I venturi entrainment of both air and 100% oxygen; in both cases oxygen was the driving gas and air was entrained at stage II. With stage I air entrainment (fig. 5), the minimum oxygen concentration in the mixture was 53%. A decrease in compliance and an increase in airway resistance resulted in an increase in the delivered oxygen concentration, when air or oxygen were entrained at stage I (figs. 5 and 6).

The oxygen concentrations at different driving pressures were derived using the following expression:

\[
\%O_2 = \frac{\text{DGV} + (V_1 \times F_O) + (V_3 \times 0.21)}{\text{Total delivered volume}} \times 100
\]

DGV=driving volume; $V_1$=stage I entrained volume; $F_O$=entrained O$_2$ concentration; $V_3$=stage II entrained volume.

![Graph of delivered tidal volumes](https://example.com/graph)

**FIG. 4.** Delivered tidal volumes.

![Graph of oxygen delivered (%)](https://example.com/graph)

**FIG. 5.** Oxygen delivered (%)—venturi entraining air, stages I and II.
In patients undergoing bronchoscopy, hypoxia and hypercapnia will occur if ventilation is inadequate and if the concentration of oxygen in the inspired gas is low. Therefore, a mechanical ventilating system must be designed to maintain pulmonary ventilation and a high inspired oxygen concentration.

If oxygen is used as the driving gas in a venturi bronchoscope system, the concentration of oxygen in the ventilating gases depends on dilution by air entrainment. It appears from the results presented in this study that air entrainment is influenced by two factors: patient respiratory resistance and injector/venturi design. The relationship between the percentage of air entrained (stage II) and compliance at three different values for airway resistance is shown in figure 8. The percentage of air entrained at a fixed compliance decreases with increasing airway resistance and therefore if oxygen is used as the driving gas, reduced entrainment of air results in an increase in delivered oxygen concentration and this compensates to some extent for the reduced tidal volume.

The effect of patient respiratory resistance on air entrainment is confirmed (fig. 6), lower resistances having a relatively more marked influence on entrainment at lower driving gas pressures and resulting in higher delivered oxygen concentration.

The entrainment of air, assuming a value for patient resistance, is also dependent on the design of the injector. Analysis of the results obtained by Komesaroff and McKie (1972), using a modified cannula in their "bronchoflator" indicates stage II air entrainment values of between 22.5 and 45% of the tidal volume. Using an injector incorporating
a venturi entraining oxygen (stage I), we have reduced the maximum bronchoscope (stage II) entrainment to 28%. At the same time it can be seen (fig. 8) that an increase in airway resistance, or compliance, will reduce this value considerably. It is probable that these lower values are caused by reduction in the bronchoscope to injector pressure differential, decreasing the venturi effect at the injector tip. Careful attention to venturi design is also required if high delivered oxygen concentrations are to be achieved. To overcome the problem of low delivered oxygen concentration associated with many venturi bronchoscopes at present in use, a method of supplying oxygen as the driving gas, and to the venturi, is suggested (fig. 9). These findings confirm those of Bennetts (1973), who indicated that if Entonox is used as the driving gas for injector systems the delivered concentration of nitrous oxide may be reduced by 50%.

The bronchoscope and ventilator tested were found to be capable of maintaining good tidal flow (fig. 4). The maximum tidal volume delivered was 0.7 litre with a good compliance and low airway resistance. As expected, tidal volume decreased with increasing respiratory resistance; however the maximum pressure in the lung simulator did not exceed 17 cm of water. This autoregulation of the tidal volume by the injector would appear to be a safety factor when the bronchoscope is passed peripherally. This system is suitable for use in patients with obstructive airway disease and conversely with restrictive pulmonary lesions because tidal flow can be achieved and modified by changes in driving gas pressure in the presence of increased airway resistance and reduced compliance. Ventilation of the opposite lung occurs via the side vents even when the bronchoscope has been introduced into a main bronchus (fig. 10).

![Flow Diagram](https://example.com/flow-diagram.png)

**Fig. 9. Dual supply system for venturi bronchoscope.**

Although changes in the tidal volume were found to be minimal, when the inspiratory time was greater than 1 sec, injector gas continued to flow. This resulted in the delivered oxygen concentration increasing above that found with a shorter inspiratory time. It would seem therefore that to some extent previously distributed tidal gases were “washed out” by oxygen. The level of this wash out phase will of course be determined by the point at which rapid flow ceases in the bronchoscope. However, better distribution of gases within the lungs may be achieved by prolonging the inspiratory time and the advantage of this would probably outweigh the reduction in minute volume in patients with high respiratory resistance.

Analysis of function is somewhat complex as it would appear to be a mixture of three patterns. Firstly, the injector system behaves as a time cycled constant pressure generator. Second, the pattern of air entrainment at the bronchoscope may be considered analogous to the inspiratory phase of a pressure cycled constant pressure generator. Finally, an insufflation phase may be superimposed. It appears from the results obtained in this laboratory investigation that the automatic flow interruption venturi bronchoscope will enable bronchoscopy to be performed with more satisfactory pulmonary ventilation than has hitherto been obtained using other techniques.

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**REFERENCES**


**LA BRONCHOSCOPIE AVEC INTERRUPTION AUTOMATIQUE DE PASSAGE: ETUDE EN LABORATOIRE**

**RESUME**

Une évaluation en laboratoire d’un bronchoscope de ventilation incorporant un dispositif d’interruption automatique de passage suggère que ce dernier peut assurer la ventilation pulmonaire de manière sûre.

**BRONCHOSKOPIE MIT AUTOMATISCHER DURCHZUGSUNTERBRECHUNG—EINE LABORATORIUMSUNTERSUCHUNG**

**ZUSAMMENFASSUNG**

Eine laboratoriumsmäßige Untersuchung eines Belüftungs-Bronchoskops mit automatischer Durchzugsunterbrechung ergab, dass es eine sichere pulmonare Belüftung bietet.

**BRONCOSCOPIA CON INTERRUPCIÓN AUTOMÁTICA DE FLUJO: ESTUDIO DE LABORATORIO**

**SUMARIO**

La valoración de laboratorio de un broncoscopio ventilado con mecanismo para interrupción automática de flujo demostró que proporciona ventilación pulmonar segura.