ter were again connected in series and attached to the exhaust tubing of a Bennett MA-1 mechanical ventilator. Six measurements of $\dot{V}_E$ were made with this system at four different delivered volumes. The output of the ventilator was calibrated before, during, and after each series of measurements using a Collins spirometer.

Results

Vital Capacity Measurements. Regression equations and correlation coefficients for the disposable spirometer V_c data (one observer) and Wright respirometer V_c data *vs.* the delivered giant-syringe volumes are presented in table 1. Figure 4 is a plot of the disposable spirometer data. There was good agreement between the two independent observers who measured the volumes of gas in the disposable spirometer (correlation coefficient = 0.998). The accuracy of the disposable spirometer compared quite favorably with that of the Wright respirometer at all delivered volumes and flow rates. Moreover, the Wright respirometer was notably flow-dependent, while the disposable spirometer was not.

Minute Ventilation Measurements. Regression equations and correlation coefficients for the disposable spirometer $\dot{V}_E$ data and the Wright respirometer $\dot{V}_E$ data *vs.* Collins spirometer measurements are presented in table 2. Figure 5 is a plot of the disposable spirometer data. Again, the results were at least as accurate with the disposable device as with the Wright respirometer.

Discussion

On the basis of the above data, it is apparent that accuracy of the disposable Boehringer spirometer is more than adequate for clinical needs. The new device has the durability to be used over the entire hospital course of any given patient. The only obvious disadvantages of the disposable spirometer are: 1) a nonrebreathing valve is needed for $\dot{V}_E$ determinations in a patient who is breathing spontaneously; 2) $\dot{V}_E$ is not read directly but must be calculated via nomogram from three tidal volumes plus the respiratory rate. (A nomogram for calculating $\dot{V}_E$ from ten tidal volumes is also available for pediatric use.) However, the cost advantages of the new device, its independence of flow rate, and its elimination of cross-contamination hazards make it an attractive clinical tool for patients who need intensive respiratory care.

Comparison of the Ventilating and Injection Bronchoscopes

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This study compares mechanical ventilation with the ventilating bronchoscope and with the injection bronchoscope during operative bronchoscopy in anesthetized, fully-relaxed patients with regard to: 1) adequacy of pulmonary ventilation; 2) pulse and blood-pressure changes; 3) time necessary for bronchoscopy; 4) acceptance by the surgeon and anesthesiologist.

Methods

Forty-two adult patients were selected for the study after having given permission for

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arterial puncture. They were given premedication in accordance with psychologic need and physical condition. Most patients received meperidine, promethazine, and atropine one to two hours prior to induction of anesthesia. Cannulae were placed in a forearm vein and a radial artery. Heparinized samples were withdrawn anaerobically from a radial-artery cannula prior to the induction of anesthesia (control), and 5, 10, 15, and 20 minutes after insertion of the bronschoscope or until the end of bronchoscopy. Anesthesia was induced with a thiobarbiturate in all cases. Relaxation was achieved with a bolus dose of succinylcholine and maintained with intravenous infusion of 0.2 per cent succinylcholine. Patients were alternately assigned to two groups.

The "ventilating" group consisted of 21 patients whose ventilation was assisted with a 400 × 8 mm Storz ventilating bronchoscope similar to that described by Mundnich and Hoflehner[1] and by Safar[2] (fig. 1). The 17 men and four women in this group had a mean age of 58 ± 14 years and a mean weight of 68 ± 13 kg. Suspected or known bronchogenic carcinoma was the most common indication for bronchoscopy, being present in 14

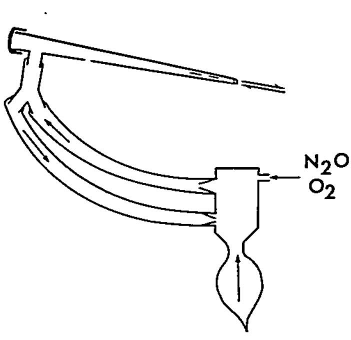

FIG. 1. The ventilating bronchoscope. The sidearm ventilation port is connected by a rubber tube to the Y piece. The optical end of the bronchoscope is occluded by a removable glass eyepiece. Ventilation is accomplished by intermittent compression of the reservoir bag. (Reproduced by permission of Safar[2] and ANESTHESIOLOGY.)

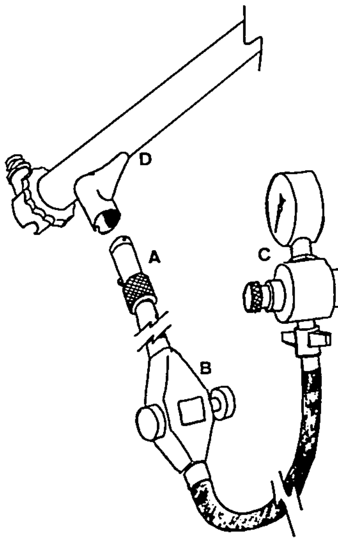

FIG. 2. The injection bronchoscope used in this study. The injector, *A*, is machined to fit the inner bore of the ventilation port of the bronchoscope, *D*. The injector is connected via an off–on switch, *B*, to a reducing valve, *C*, for tank oxygen or directly to the central oxygen supply. The optical end of the bronchoscope remains open. (Reproduced by permission of Gerbershagen[4] and *Der Anaesthesist*.)

of the 21 patients. After insertion of the bronchoscope, the ventilating port was attached to the anesthesia circuit by a short rubber tube, and ventilation was accomplished by intermittent compression of the reservoir bag on the anesthesia machine. All patients received oxygen. Some received nitrous oxide in amounts not exceeding 50 per cent of the inhaled mixture, and some patients received halothane, not exceeding 2 per cent. Respiratory rates and tidal volumes depended on the anesthesiologist's judgment of adequacy of ventilation. Flow rates of oxygen and nitrous oxide were always sufficient to keep the reservoir bag full. Periodic interruptions of ventilation were necessary when the surgeon removed the eyepiece to suction, irrigate, or take biopsies or washings. Each surgical operation was interrupted periodically when it became necessary to ventilate the patient again.

The "injection" group consisted of 21 patients whose ventilation was assisted with a modification of the injection system originally described by Sanders.[3] The injector consisted of hollow brass attachment, closed at one end, which exactly fitted the inner bore of the ventilation port of a 400 × 8 mm Storz bronchoscope. It was drilled with a 1-mm jet directed toward the tracheal end of the bronchoscope, the proper direction being assured by a key-lock device. The device, which did not interfere with the lumen of the bronchoscope, was connected over an off–on switch to a reducing valve adjusted to 3.5 atm (45 lb/sq in). Figure 2 is a diagrammatic view of the modified injection system.¶ After insertion of the bronchoscope, the injection attachment was inserted into the ventilation port of the bronchoscope. *The eyepiece was not used,* and the surgeon's end of the bronchoscope remained open at all times. The injector, which was activated by turning the switch on, was found to deliver 28 cm H_2O inspiratory pressure, an inspiratory flow rate of 140 l/min, and an oxygen concentration of 35–40 per cent under normal circumstances (thus, 3.5 to 4.5 liters of air were entrained for each liter of oxygen injected).[4] When adequate inspiratory excursion of the chest was judged to have occurred, the switch was turned off, the patient was allowed to exhale passively through the open optical end of the bronchoscope. The injector was activated 16–20 times per minute. No interruption of either ventilation or operative endoscopy was necessary, since the optical end of the scope was always open. As only oxygen and air were delivered to the patient by the injector system, intermittent intravenous injections of thiopental were necessary for maintenance of anesthesia. The 16 men and five women in this group had a mean age of 52 ± 8 years and a mean weight of 73 ± 12 kg. Known or suspected bronchogenic carcinoma was the most common indication for bronchoscopy in this group also.

¶ The injector described was made in the anesthesiology workshop, University Clinic, Mainz, Germany, although commercial injectors are now available from Storz and Pilling for almost all types of bronchoscopes.

The rise and fall of the chest during each respiratory excursion were observed. Pulse rates and mean arterial pressures (mean ± SD) were recorded for the various time periods. Arterial blood samples were iced and analyzed by the Astrup technique within two hours.

The ventilating group was compared with the injection group at the various time intervals after bronchoscope insertion, using Student's t test.[5] The groups were also compared with their respective controls at the various time intervals using the t test for paired data. Patients in the two groups whose bronchoscopies were not completed by the end of the 20-minute time interval were compared using the likelihood ratio and Pearson chi-square testing of row–column interdependence.[6] Confidence limits of 95 per cent ($P < 0.05$) and 99 per cent ($P < 0.01$) were used throughout.

Outpatients were followed until awake, and inpatients were visited on the following day. Surgeons and anesthesiologists were asked to express their opinions about the comparative value of the two systems.

Results

Significant progressive respiratory acidosis developed in the ventilating group beginning 5 minutes after insertion of the bronchoscope and continuing until the end of the procedure or until the last sample was taken at 20 minutes (table 1). Pa_{CO_2}'s of more than 50 torr appeared in 60 per cent of the ventilating group; the highest Pa_{CO_2} observed was 91 torr. These findings were in sharp contrast to the normal mean pH and Pa_{CO_2} values in the injection group, in which Pa_{CO_2}'s of more than 50 torr were observed in only 14 per cent and the highest value found was 57 torr.

Control Pa_{O_2}'s in the two groups of patients breathing room air were not significantly different. In subsequent samples, Pa_{O_2}'s were higher than those in the control samples, being highest at 5 minutes and decreasing progressively toward control during the next 15 minutes. The higher inspired oxygen concentration in the ventilating group (50 per cent)

TABLE 1. Blood–Gas Values with Ventilating and Injection Bronchoscopes (Mean ± SD)

	Control	Minutes after Insertion of the Bronchoscope			
		5	10	15	20
Ventilating	n = 21	n = 19	n = 18	n = 10	n = 8
pH	7.39 ± 0.05	7.32 ± 0.8†	7.31 ± 0.08†	7.27 ± 0.06†	7.25 ± 0.05†
Pa_{CO_2} (torr)	38 ± 6	49 ± 11†	48 ± 10†	55 ± 15†	60 ± 11†
Pa_{O_2} (torr)	84 ± 9	196 ± 75*	176 ± 67†	173 ± 63†	145 ± 57*
Injection	n = 21	n = 21	n = 20	n = 9	n = 2
pH	7.38 ± 0.06	7.36 ± 0.05	7.36 ± 0.06	7.37 ± 0.06	7.37 ± 0.08
Pa_{CO_2} (torr)	38 ± 8	38 ± 8	38 ± 10	38 ± 10	33 ± 14
Pa_{O_2} (torr)	81 ± 12	171 ± 41†	146 ± 36†	123 ± 29†	96 ± 4

* $P < 0.05$.
† $P < 0.01$.

TABLE 2. Mean Arterial Pressures (MAP) and Pulse Rates (P) (±SD) before Anesthesia and 5, 10, 15, and 20 Minutes after Insertion of the Bronchoscopes

	Control	5 min	10 min	15 min	20 min
Ventilating					
MAP (torr)	96 ± 8	106 ± 5	102 ± 4	103 ± 5	96 ± 3
P (/min)	81 ± 5	97 ± 5	103 ± 3	102 ± 3	103 ± 5
Injection					
MAP (torr)	89 ± 8	109 ± 9	105 ± 9	91 ± 1	—
P (/min)	81 ± 5	92 ± 3	91 ± 3	93 ± 6	—

TABLE 3. Comparison of Weighted Mean Blood–Gas Values with Ventilating and Injection Bronchoscopes*

	n	Control			During Bronchoscopy		
		pH	Pa_{CO_2}	Pa_{O_2}	pH	Pa_{CO_2}	Pa_{O_2}
Ventilating							
Morales[9]	11	7.39	40	78	7.25	80	300
Giesecke (present study)	21	7.40	38	84	7.31	48	176
Weighted mean	32	7.40	39	82	7.29	60	220
Injection							
Mette[5]	20	—	38	80	—	32	200
Morales[9]	14	7.39	40	98	7.35	42	200
Pender[10]	11	7.41	40	77	7.47	32	228
Giesecke (present study)	21	7.38	38	81	7.36	38	146
Weighted mean	66	7.39	39	84	7.38	36	187

* All values were rounded to the same decimal place to facilitate comparison. The values presented for "during bronchoscopy" are Morales' 8-minute figures and Giesecke's 10-minute figures. Pender's and Mette's "during" samples were taken at times ranging from 5 to 30 minutes.

than in the injection group (35 per cent) produced predictably higher Pa_{O_2} values in the ventilating group, although values in both groups were higher than those in control samples. These changes, although statistically significant, are not considered clinically significant, since no patient had a Pa_{O_2} below control levels during bronchoscopy.

Table 2 shows the mean arterial pressures and pulse rates in the two groups during the period of study. There were progressive increases in pulse rate and mean arterial pressure of patients in both groups. These elevations achieved statistical significance in the ventilating group but, in our opinion, are not clinically significant.

Reference to table 1 indicates the duration of the procedure by showing the number of patients in each group whose bronchoscopies were not yet completed at the end of the specified time interval (n); for example, in the ventilating group after 20 minutes, eight bronchoscopies had not yet been completed and 13 had been completed. The comparison shows a significant difference between the numbers of bronchoscopies completed in 20 minutes or less in the two groups: a significantly larger proportion in the ventilating group took longer than 20 minutes.

Although no formalized technique was used to screen opinions, we feel that the advantages of the two techniques reported by the endoscopists and anesthesiologists can be of value to the clinician. The following advantages were listed for the ventilating system:

1) Exhaled air is returned to the anesthesia circuit and not released into the operating room or into the endoscopist's face, especially important in bronchoscopy of patients with active tuberculosis. Most endoscopists preferred to wear a plastic face shield when using the injection bronchoscope.

2) Approximation of the tidal volume and minute respiratory volume are possible with the usual in-circuit ventilation meter (Drager or Wright).

3) Estimation of lung compliance from the resistance encountered during manual compression of the reservoir bag is possible.

4) Maintenance of anesthesia with inhalation agents is possible.

5) The ventilating system is quiet. The jet of oxygen from the injector is noisy. Endoscopists complained of being distracted or startled by the noise on the first occasion of use. Fewer complaints were received as more experience was gained.

The following advantages were listed for the injection system.

1) The system is capable of providing continuous uninterrupted ventilation throughout the duration of the surgical procedure.

2) The endoscopist can work systematically and continuously without fear of ventilatory insufficiency. The overall time needed for bronchoscopy is thereby reduced.

3) Operation of the system is simple. It is easier to push the button than to squeeze the bag. Incorporation of a foot-switch or an automatic flow interruptor[7] has been proposed to simplify the procedure further.

4) Pulmonary ventilation as reflected by arterial *p*H and carbon dioxide tension is more efficient with the injection system.

Discussion

Anesthesia for bronchoscopy has been an actively discussed subject for many years. Although many techniques for ventilatory support have been used in the past, none has been consistently effective in preventing either hypoxia or respiratory acidosis. Adequate ventilation can be achieved with the ventilating bronchoscope *only* so long as the optical end of the bronchoscope is closed. Tidal volume, respiratory rate and flow rate must be adequate. Our data (table 2) confirm observations of Morales[9] that what the anesthesiologist thinks are appropriate tidal volumes and respiratory rates frequently are not adequate to prevent respiratory acidosis during use of the ventilating bronchoscope.

The development of the injection system for mechanical ventilation by Sanders in 1967 provided a new and valuable approach which allows simultaneous, uninterrupted conduct of both ventilation and endoscopy. Our data confirm the observations of Mette,[8] Morales,[9] and Pender[10] that *p*H, Pa_{CO_2} and Pa_{O_2} can be maintained in a physiologic range during therapeutic or diagnostic bronchoscopy. To facilitate comparison of ventilatory values during use of the ventilating and the injection systems, published data and our data are presented in table 3.

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Neonatology

HEMODYNAMIC EFFECTS OF MECHANICAL VENTILATION Using normal, spontaneously delivered or prematurely delivered lambs with respiratory distress, the authors studied the effects of positive- and negative-pressure ventilation on hemodynamic function. Determinations included cardiac output, shunt pattern through the foramen ovale and ductus arteriosus, and systemic and pulmonary arterial pressures. Seven lambs with "respiratory distress" were treated with periods of spontaneous breathing or mechanical ventilation using either a positive-pressure (Engstrom) or a negative-pressure (Air-Shields) ventilator. Lambs with respiratory distress had significantly lower cardiac outputs and higher pulmonary arterial pressures, with increased right-to-left shunts at the foramen ovale level, compared with the control, full-term animals. The effects of mechanical ventilation were similar in both groups and included significant decreases in cardiac output without significant change in shunt pattern or systemic arterial blood pressure. No difference between the effects of positive- and negative-pressure ventilation on cardiac output or vascular pressures at comparable levels of ventilation was demonstrable. There was no evidence of a progressive decrease in cardiac output as tidal volume was increased to as high as 108 ml/kg body weight.

No correlation between cardiac output and Pa_{CO_2}, as had been suggested in other experiments, was found. Similarly, no correlation between arterial *p*H and cardiac output could be shown to exist in either normal or distressed lambs.

A previous study in newborn humans in which the magnitude of right-to-left shunting during periods of spontaneous breathing and with mechanical ventilation were compared showed a marked reduction in right-to-left shunt when a negative-pressure phase was added to the ventilation pattern. The present study could not confirm this finding. The authors suggest that diminution of the right-to-left shunt through the ductus arteriosus and foramen ovale secondary to mechanical ventilation is caused by a change in hydrogen-ion concentration and oxygenation. (*Shepard, F. M., and others: Hemodynamic Effects of Mechanical Ventilation in Normal and Distressed Newborn Lambs—A Comparison of Negative Pressure and Positive Pressure Respirators, Biol. Neonate 19: 83–100, 1971.*)