dilator and introduction of the catheter into the sheath. There was no change in blood pressure or heart rate, nor were any of the other signs of air embolization detected, despite the presence of air within the heart for five cardiac cycles, as determined by the Doppler monitoring. We found that the relationship between flow through an 8-French introducer and the pressure drop across the introducer was curvilinear (fig. 1). At a pressure gradient of 4 torr, flow rate was 90 ml/sec.

Discussion

This study demonstrates that air can enter the heart during percutaneous placement of the Swan-Ganz catheter, and that the catheter introducer will accept potentially fatal air flow rates at clinically attainable pressures. It has been shown that a flow of 1 ml/kg/sec is sufficient to cause fatal air embolism.[4] Hence, a 4-torr gradient would be sufficient to induce a fatal air embolus in an adult patient.

There was no obvious cause of the air embolus detected in our patient. She had been tilted head down (20 degrees) and did not appear to attempt to breathe while the introducer hub was open.

The Seldinger technique for introducing Swan-Ganz catheters into the internal jugular vein has been used thousands of times worldwide without any report of air embolization. We scrupulously adhere to the common-sense maneuvers likely to decrease the chances of entry of air into the internal jugular vein. These include increasing the pressure within the internal jugular vein by head-down tilt (approximately 20 degrees), having the patient hold his breath in inspiration and perform a Valsalva maneuver during the critical moment, and minimizing the time the cannula is exposed to atmospheric pressure.†

Although this study has provided both laboratory and clinical evidence that air embolization can occur during Swan-Ganz catheter placement, we have not, in more than 400 applications of the technique, generated a clinically detectable air embolus, and we believe that the maneuvers outlined above have contributed to that record.

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† Since this study was performed, several manufacturers have introduced diaphragm-occluded catheter introducers designed to decrease the likelihood of entry of air. We have no data regarding their efficacy.

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A Simplified Endotracheal Tube for Microlaryngoscopy, Laryngoscopy, and Bronchoscopy

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In 1943, Mushin devised a self-inflating endotracheal tube cuff by puncturing two holes in the wall of a conventional-sized tube so that the lumen communicated with the interior of the cuff. The cuff automatically inflated when positive pressure was applied to the system, thereby effecting a seal, and deflated when the pressure was released. The expired gases escaped both around the tube and through the lumen.[1] We have applied this principle to endotracheal tubes of small caliber (5 mm ID) to facilitate administration of anesthesia for bronchoscopy, microlaryngoscopy, and allied procedures by use of standard anesthesia equipment in the conventional manner. This obviates the need for the more complex or the less safe apparatus requiring high insufflatory pres-

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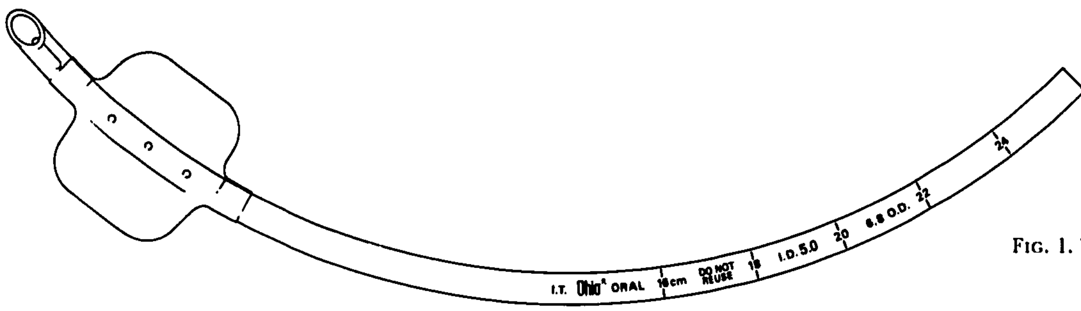

FIG. 1. The endotracheal tube.

sures to ventilate the patient satisfactorily.[2-4] Gases can be forced through a 5 mm-ID tube at flow rates as high as 103 l/min when the breathing bag is compressed with a pressure of 40 cm H_2O and 88 l/min when a 30 cm H_2O pressure is attained. When pressure is released the cuff collapses and the lungs deflate. Blood gases remain at normal levels using these flow rates.

Materials and Methods

One hundred fifty one patients, ASA I to IV, undergoing microlaryngoscopy, bronchoscopy, and related procedures, were anesthetized by use of this type of endotracheal tube. Ages of the patients ranged from 10 to 79 years. Durations of the procedures ranged from 20 to 105 min. Diazepam or thiopental was used for induction, followed by a nitrous oxide, oxygen, enflurane sequence at flow rates of 3–6 l/min. Ventilation was controlled manually or by use of Monahan® ventilator. Tidal volume and minute volume exchange were monitored using a Wright® spirometer.

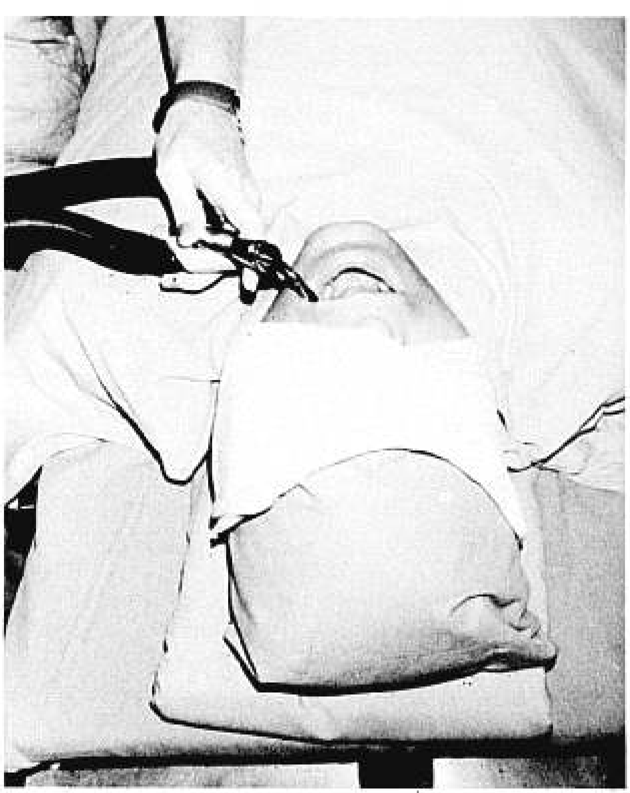

FIG. 2. Apparatus in use.

An endotracheal tube 5 mm ID and 22 cm long with a cuff that could be distended to a maximum diameter of 32 mm was used. Six perforations approximately 1.5 mm in diameter were made in the tube beneath the cuff. These tubes (fig. 1) can be self-made, but one must be absolutely certain that the cuff is securely fixed to the tube.

The vocal cords and trachea were sprayed with 4 per cent lidocaine and the tube with a curved 15-mm adaptor attached was introduced until the cuff rested beyond the vocal cords. The apparatus and the anesthetist were located on the left side of the patient, out of the operative field, thus permitting the anesthetist to maintain complete respiratory control of the patient (fig. 2) and still allow the surgeon easy access to the operative field. Trickling of blood and secretions into the trachea did not present a problem.

In several large men, however, the cuff could be introduced no further than 0.5–1 cm beyond the vocal cords. Although both the tube and the cuff functioned properly, the proximity of the cuff to the cords caused complaints. Therefore, it is recommended that a 24-cm endotracheal tube be used for large patients or those with long necks.

Results

Serial blood-gas studies of 51 patients were performed pre-, intra-, and postoperatively. Data obtained for microlaryngoscopic procedures are listed in table 1 and those obtained for bronchoscopic procedures, in table 2.

When bronchoscopy was performed the bronchoscope was passed along the side of the tube and advanced beyond the cuff while deflated. Both rigid and flexible bronchoscopes were used. The cuff produced an effective seal around both types of instruments as

TABLE 1. Blood Gases in 17 Microlaryngoscopic Procedures with 5 mm-ID Endotracheal Tubes

	Preoperative	Intraoperative*	Recovery
Range			
pH	7.30–7.45	7.30–7.56	7.24–7.41
P_{CO_2} (torr)	32–50	26–51	35–66
P_{O_2} (torr)	58–103	92–300	52–212
Mean			
pH	7.40	7.38	7.34
P_{CO_2} (torr)	40.5	39	45
P_{O_2} (torr)	76	212	118

* Intraoperative blood-gas values were obtained from samples drawn 10–69 min after induction of anesthesia (mean 27 min).

TABLE 2. Blood Gases in 30 Laryngoscopies and Bronchoscopies (Rigid and Flexible) with 5 mm-ID Endotracheal Tubes

	Preoperative	Intraoperative*	Recovery
Range			
pH	7.32–7.50	7.25–7.57	7.27–7.46
P_{CO_2} (torr)	30–50	27–58	32–50
P_{O_2} (torr)	50–90	52–340	60–175
Mean			
pH	7.43	7.38	7.37
P_{CO_2} (torr)	40	43	41
P_{O_2} (torr)	67	170	89

* Intraoperative blood-gas values were obtained from samples drawn 15–55 min after induction of anesthesia (mean 27 min).

well as the tube. A glass cover was placed over the end of rigid bronchoscopes to prevent gases from escaping from the system. When this was not done, values for Pa_{O_2} were below normal and those for Pa_{CO_2} were elevated.

Discussion

Five patients were hyperventilated to determine the maximum ventilatory capacity of the tube. Intraoperative P_{CO_2} values were reduced from a mean value of 40 torr to 22, 26, 27, 28, and 29 torr, respectively.

When a ventilator was used it was adjusted to create negative pressure during the exhalation cycle to assure that collapse of the cuff was complete and deflation of the lungs was rapid. When manual ventilation was used, the hand was kept off the bag to allow complete deflation of the cuff and lungs. Some anesthetists tend to "ride the bag" during the exhalation cycle. The resulting positive pressure, slight as it may be, prevents complete collapse of the cuff and interferes with deflation of the lung.

Additional studies, still in progress, indicate that respiratory endoscopic procedures can be performed successfully by use of smaller tubes. One microlaryngeal and three bronchoscopic procedures have been performed on four patients without difficulty with an endotracheal tube 4 mm in diameter.

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Adjustment of Intracuff Pressure to Prevent Aspiration

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Regurgitation or vomiting and subsequent tracheobronchial aspiration, atelectasis and hypoxia are recognized complications occurring in the perioperative period.[1] "Silent" regurgitation occurs in 14.5 per cent of surgical patients during general endotracheal anesthesia.[2] Aspiration of dye placed on the tongue occurs in 20 per cent of ICU patients with endotracheal tubes fitted with "high-volume, low-pressure" cuffs.[3] Aspiration occurs in 15–17 per cent of tracheostomized pa-

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