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

	Preoperative	Intraoperative*	Recovery
Range			
*p*H	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			
*p*H	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			
*p*H	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			
*p*H	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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Anesthesiology
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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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TABLE 1. Tube and Cuff Types, Intracuff Pressures, and Incidences of Aspiration*

Endotracheal tube	Cuff	Intracuff pressure (cm H_2O)	Tracheal Aspiration of Dye: Controlled Ventilation		Tracheal Aspiration of Dye: Spontaneous Ventilation	
			Yes	No	Yes	No
A. Lanz	Large	20	4	6	4	6
B. American/National Catheter Corporation Hi-Lo	Large	20	4	6	3	6
C. Lanz	Large	25	0	10	0	10
D. American/National Catheter Corporation Hi-Lo	Large	25	0	11	0	10
E. Lanz	Large	27–34 New Lanz valve	0	6	0	6
F. American/National Catheter Corporation Hi-Lo	Large	Minimal occluding volume (25–27)	0	6	0	6
G. Portex Blue Line	Large	Minimal occluding volume (25–27)	3	6	3	5
H. Rusch red rubber	Small	Minimal occluding volume (approximately 250)	0	8	0	4

* Tracheal aspiration of dye does not occur past large-diameter, thin cuffs (American/National Catheter Corporation and Lanz) during spontaneous or controlled ventilation when intracuff pressure is regulated at or above 25 cm H_2O.

tients whose tracheas are intubated with "high-volume, low-pressure" cuffed tracheal tubes.[4] Pavlin *et al.* reported tracheal aspiration past an endotracheal tube fitted with a large-diameter polyvinylchloride cuff with intracuff pressure controlled at 20 cm H_2O.[5] This study was done to determine the minimal intra-cuff pressure needed to prevent tracheal aspiration of dye in anesthetized surgical patients whose tracheas are intubated.

MATERIALS AND METHODS

Subjects of the study were 133 randomly selected consenting adult patients. General anesthesia was induced with thiopental and oxygen. After administration of succinylcholine (1–1.5 mg/kg, iv) tracheal intubation was accomplished orally with a 9.0-mm ID Lanz®, American/National Catheter Corporation (AM/NCC) Hi-Lo®, Portex Blue Line®, or resterilized 36-French red rubber Rusch® endotracheal tube. Anesthesia was maintained with N_2O, O_2, and halothane or narcotics with or without nondepolarizing neuromuscular blocking agents. Ventilation was sponaneous in 63 patients and mechanically controlled in 70 patients. Cuffs were inflated with room air to minimal occluding volume or to an intracuff pressure of 20 cm H_2O, 25 cm H_2O, or 27–34 cm H_2O. Intracuff pressure was regulated with:

1) Dead weight 20 cm H_2O valve**
2) Dead weight 25 cm H_2O valve**
3) Two-way external pressure-regulating valve and control balloon with limits of 27–34 cm H_2O††

Minimal occluding volume was determined by listening with a stethoscope for "blow-by" of anesthetic gases around the cuff during positive-pressure ventilation. Initial intracuff pressures at minimal occluding volumes were measured in large-diameter cuffs with a low-pressure aneroid manometer connected to a stopcock, as described by Cox and Schatz[6] and by Lewis *et al.*,[7] and in small-diameter cuffs with a transducer, because intracuff pressure was high.

After cuff inflation, 10 ml of 10 per cent Evans blue dye was placed in the posterior oropharynx under direct vision. At the conclusion of the surgical procedure, the operating table was tilted 30 degrees head-up and a fiberoptic bronchoscope was passed through the endotracheal tube to inspect for visible evidence of dye distal to the cuff.

Cuff diameters and wall thicknesses of three selected cuffs of each design were measured twice each. A Mitutoyo® micrometer, with friction thimble for standardization of force, measured cuff wall thickness to an accuracy of 0.005 mm. Cuff diameter at residual volume was measured with a Vernier caliper.

RESULTS

Aspiration of Evans blue dye around large-diameter, thin-walled polyvinylchloride cuffs (AM/NCC and Lanz) was seen in 15 of 39 patients (38.5 per cent)

** Boehringer Laboratories, Inc., P.O. Box 337, Wynnewood, Pa. 19096.

†† Lanz Pressure Regulating Valve, Extracorporeal Medical Specialties, Inc., Royal and Ross Rds., King of Prussia, Pa. 19406.

TABLE 2. Cuff Physical Characteristics, Intracuff Pressures, and Incidences of Aspiration*

Endotracheal Tube	Cuff Diameter (mm) ±1 SD	Cuff Thickness (mm) ±1 SD	Intracuff Pressure (cm H_2O)	Aspiration
American/National Catheter Corporation, 9.0 mm ID	33.28 ± .76	.044 ± .005	25	No
Lanz, 9.0 mm ID	30.07 ± .63	.104 ± .007	(27–34)	No
Portex, 9.0 mm ID	28.75 ± 1.63	.250 ± .029	Minimal occluding volume (25–27)	Yes
Rusch, 36-French	14.52 ± .44	.537 ± .029	Minimal occluding volume (±250)	No

* Aspiration of dye occurs at minimal occluding volume (ICP = 25–27 cm H_2O) when cuff thickness is 0.250 mm (Portex).

when intracuff pressure was controlled at 20 cm H_2O (table 1, A and B). None of 41 patients whose tracheas were intubated with AM/NCC or Lanz endotracheal tubes aspirated when intracuff pressure was controlled at 25 cm H_2O (table 1, C and D), and 0 of 12 patients aspirated around Lanz cuffs inflated and maintained at 27–34 cm H_2O with a pressure-regulating valve (table 1, E). Aspiration did not occur in any of 12 patients intubated with AM/NCC endotracheal tubes fitted with large-diameter, thin-walled (0.044 mm) polyvinylchloride cuffs initially air-filled to minimal occluding volume (table 1, F). Intracuff pressures in these large-diameter cuffs at minimal occluding volume measured 25 to 27 cm H_2O.

Aspiration occurred in six of 17 patients (35.3 per cent) whose tracheas were intubated with Portex tubes fitted with large-diameter, moderately thick-walled (.250 mm) polyvinylchloride cuffs initially air-filled to minimal occluding volume (table 1, G).

Aspiration of dye did not occur in any of 12 patients intubated with red rubber Rusch endotracheal tubes fitted with small-diameter, thick-walled (0.537 mm) latex cuffs inflated with air to minimal occluding volume (table 1, H). Intracuff pressure at minimal occluding volume in the latex cuffs was approximately 250 cm H_2O.

Aspiration occurred in 14 of 93 patients (15.1 per cent) paralyzed with nondepolarizing muscle relaxants, and in seven of 40 patients (17.5 per cent) anesthetized without nondepolarizing neuromuscular blocking agents. Ten of 63 (15.9 per cent) spontaneously breathing and 11 of 70 (15.7 per cent) mechanically ventilated patients aspirated dye. Mean (±SD) durations for dye above the cuffs for patients intubated with AM/NCC and Lanz tubes were 205.8 ± 97.9 min with intracuff pressure controlled at 20 cm H_2O and 153.4 ± 89.4 minutes with intracuff pressure regulated at 25 cm H_2O. Mean dye durations for cuffs filled to minimal occluding volume were: AM/NCC, 157.1 ± 71.7 min; Portex, 192.7 ± 132.8 min; Rusch, 112.9 ± 77.7 min.

Table 2 relates cuff diameter, wall thickness, and intracuff pressure to aspiration.

DISCUSSION

The minimal intracuff pressure necessary to prevent aspiration of dye past large-diameter, thin-walled cuffs during spontaneous or controlled ventilation appears to be 25 cm H_2O (table 1). Cuff diameter and wall thickness and intracuff pressure determine the number and size of folds lying against the tracheal mucosa through which liquids may travel down the trachea.[5] Our data confirm the role cuff-wall thickness plays in preventing aspiration, because at minimal occluding volume (intracuff pressure 25–27 cm H_2O), dye was seen distal to large-diameter cuffs when cuff-wall thickness was 0.250 mm (Portex), but not when it was 0.044 mm (AM/NCC) or 0.104 mm (Lanz) (table 2). Therefore, to minimize channeling of liquids through cuff folds when intracuff pressure is low, cuffs must be thin-walled.

Durations of dye above AM/NCC and Lanz cuffs with intracuff pressures controlled at 20 and 25 cm H_2O were long enough (both more than 2.5 hours) to allow comparison of the incidences of aspiration at these intracuff pressures. Also, mean dye persistence times for Portex and AM/NCC cuffs filled to minimal occluding volumes were sufficiently similar (Portex, 3 hours, 13 min; AM/NCC, 2 hours, 37 min) to allow comparison of aspiration data obtained with different cuff-wall thicknesses. Mode of ventilation and use of nondepolarizing neuromuscular blocking agents did not markedly affect the percentage of patients aspirating.

Aspiration occurred in 87 per cent of patients with uncuffed metal tracheostomy tubes or "small-volume, high-pressure" cuffed tracheostomy tubes with deflated cuffs when breathing spontaneously, but in only 15–20 per cent of patients intubated with endotracheal or tracheostomy tubes with inflated large-diameter cuffs.[3,4] Since morbidity and mortality rates following documented aspiration are high,[8,9] aspiration of even small amounts of material should be prevented whenever possible. Pressure exerted against the tracheal wall by a cuff should be high enough to prevent significant aspiration yet low enough to allow adequate capillary mucosal blood flow. Nordin reports that large cuffs will not decrease mucosal blood flow until cuff-to-tracheal wall pressure exceeds 40.5 cm H_2O.[10]

Intracuff pressure in large-diameter cuffs approximates cuff-to-tracheal wall pressure until the cuff wall is stretched.[11] We assume that regulated pressures in the large-diameter cuffs studied approximated lateral tracheal wall pressures because cuff diameters were large and filling volumes small. However, large-diameter cuffs initially filled to minimal occluding volume with air may become "high-pressure" cuffs due to N_2O diffusion.[12]

Intracuff pressure at minimal occluding volume in the small-diameter Rusch latex cuff (approximately 250 cm H_2O in our study) is assumed to be higher than cuff-to-tracheal wall pressure because the cuff has to be stretched to seal the trachea. Wu *et al.* report that cuff-to-tracheal wall pressure at minimal occluding volume is above 243 cm H_2O for these small-diameter, thick-walled latex cuffs.[13] Since small-diameter (high-pressure) cuffs stop the microcirculation in the mucosa on top of tracheal cartilages at cuff-to-tracheal wall pressures exceeding 40.5 cm H_2O,[10] use of tracheal tubes with this type of cuff should probably be limited to special circumstances.

Endotracheal tubes with *large-diameter, thin-walled cuffs*, such as American/National Catheter Corporation or Lanz tubes, should be used whenever possible. When a reservoir-type inflation pressure-regulating valve is not used in the operating room, the cuff should be filled with anesthetic gases injected simultaneously into the cuff and a pressure manometer as described by Lewis *et al.*[7] Controlling intracuff pressures in large-diameter thin-walled cuffs between 25 and 34 cmH_2O should prevent significant aspiration and still allow adequate capillary mucosal blood flow. This can be done with a pressure-regulating valve or by periodically measuring intracuff pressure and adjusting intracuff volume and pressure through a three-way stopcock.

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Anesthesiology
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Innovar-induced Hypertensive Crises in Patients with Pheochromocytoma

David A. Bittar, M.D.

The butyrophenone compounds (droperidol and haloperidol) have many pharmacologic similarities to the piperazine-substitute phenothiazines. In normal man, these compounds induce a feeling of tiredness and reduce blood pressure, pulse rate, and body temperature.[1]

From 1972 to 1977, we encountered nine patients in whom sudden, severe hypertension developed after Innovar® had been administered iv. In some patients marked tachycardia occurred as well. Another patient had received fentanyl and droperidol separately. After the iv administration of droperidol, hypertension and tachycardia developed. Three of these pa-

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