

slightly, but has little effect on cardiac index, mean blood pressure, or left ventricular systolic ejection time.⁷ Recently, the drug has been shown to prolong conduction time through the A-V node.⁸ It has been used successfully in the diagnosis and treatment of atrial flutter, atrial fibrillation, sinus tachycardia, and paroxysmal atrial tachycardia.²⁻⁴ Various initial iv doses of edrophonium ranging from 1 to 10 mg have been used to treat supraventricular tachyarrhythmia.^{1,7} A 1-2-mg dose has been recommended for the elderly patient who has a history of cardiac disease.⁹ Since edrophonium produces results similar to those of stimulation of the carotid sinus, it would follow that patients taking digitalis may be more sensitive to edrophonium. Conversely, studies in which all patients received an initial dose of 10 mg edrophonium without any serious side effect have been reported.^{3,4,8} As mentioned, every patient thus far reported to have experienced a serious side effect of edrophonium either had a history of cardiac disease or had been taking digitalis.^{2,5,6} Indeed, one of the patients reported to have had ventricular asystole following administration of edrophonium was found to have been digitalis-toxic at the time.

The patient reported here neither had a history of cardiac disease nor was she taking digitalis. This would seem to reinforce the concept that all elderly patients, if not every patient, should be given an initial test dose of 1-2 mg edrophonium to grade their individual responses.

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Severe Stridor after Prolonged Endotracheal Intubation Using High-volume Cuffs

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The pressure exerted on the trachea by inflatable cuffs of endotracheal tubes has been found to be one

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In summary, edrophonium should be used with caution for the elderly or for patients who have histories of cardiac disease or are taking digitalis. It would seem mandatory to give a test dose of 1-2 mg edrophonium to all elderly patients, and possibly all patients, regardless of age or health, to avoid ominous side effects.

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of the major avoidable factors in the etiology of damage during prolonged tracheal intubation.¹⁻³ To overcome this problem, Lomholt introduced the high-volume, low-pressure (high-compliance) cuff in 1967,⁴ and Geffin and Pontoppidan, in 1969, suggested prestretching standard cuffs.⁵ Since high-compliance cuffs became widely used, several reports of complications have appeared in the literature.⁶⁻⁸

One of these high-volume, high-compliance cuffed orotracheal tubes was introduced into use in a 12-bed critical care recovery unit (CCRU) on January 1, 1975. In the two years until December 31, 1976, there has been a sudden increase in the number of patients experiencing stridor after tracheal extubation of sufficient severity to necessitate reintubation and tracheostomy for management. These cases were re-

TABLE 1. Details of Airway Management

	Age (Years), Sex	Orotracheal Intubation		Duration of Intubation in Days		Duration of Ventilation (Days)	Pre-existing Pulmonary Disease	Results of Culture of Endotracheal Secretions	Time Interval before Stridor Developed
		Total Number	Number Emergency Cases	Orotracheal	Tracheostomy				
Patient 1	41, M	4	1	4	32	6	Had tracheostomy at age 8	Streptococci in sputum and blood	5 min
Patient 2	19, F	1		4	Still has stent	10		<i>Klebsiella</i> in sputum	5 min
Patient 3	32, M	2	1	2.5	13	4.5	Asthma since age 18	Hemolytic streptococci in sputum	4 hours
Patient 4	24, F	3	1	3	7	4	Asthma		15 min
Patient 5	33, M	4	2	5	19	19	History of morning cough before injury	<i>Haemophilus influenzae</i> in sputum	30 min
Patient 6	20, F	3	1	5	7	4.5	Upper respiratory tract infection prior to admission	Hemolytic staphylococci, coagulase-positive, in sputum	1 hour

viewed and are discussed in comparison with the experience during the two-year period before 1975, when low-volume high-pressure (low-compliance) cuffed orotracheal tubes were in use. Patients with conservatively managed mild stridor or direct laryngeal trauma prior to intubation have not been included.

CLINICAL MATERIAL AND FINDINGS 1973-1974

From January 1, 1973 to December 31, 1974 (two years), 1,727 patients were admitted to a 12-bed CCRU situated at the Maryland Institute for Emergency Medical Services. The tracheas of approximately 61 per cent of the patients (1,050) were intubated with a low-compliance cuffed orotracheal tube (Portex Blue Line). After extubation, one patient, a 16-year-old male motorcycle-accident victim, had stridor that necessitated reintubation progressing to tracheostomy for management. On admission, after atraumatic intubation using an 8.0-mm (ID) orotracheal tube and muscle relaxants, he was mechanically hyperventilated for head injury and given corticosteroids. He was frequently decerebrate and out of phase with the ventilator, and stridor developed within half an hour of tracheal extubation on the third day. Laryngoscopy showed supraglottic edema, and tracheostomy was performed. Four days later, *Pseudomonas aeruginosa* grew from necrotic material in the trachea. Septicemia developed and the patient died 25 days after admission.

CLINICAL MATERIAL AND FINDINGS 1975-76

Between January 1, 1975, and December 31, 1976, 1,856 patients were admitted to the CCRU. The tracheas of 1,290 (69 per cent) were intubated with a high-compliance cuffed orotracheal tube (Portex Soft Seal®). After endotracheal extubation, six patients experienced stridor of sufficient severity to necessitate reintubation and subsequent management by tracheostomy. Five were traffic-accident victims, and one (Patient 3) had sustained a gunshot wound to the chest. Three patients were female and three male, with a mean age of 28 years (range 19-41 years).

Details of the airway management are listed in table 1. The mean duration of orotracheal intubation was 3.9 days (range 2.5-5 days), and the mean duration of ventilation (Engstrom 300) was 8 days (range 4.5-19 days). The intervals before stridor developed ranged from 5 min to four hours after extubation of the trachea. Patients 2 and 5 had had elective tracheostomy for long-term ventilation. In these, stridor was not seen until the removal of the tracheostomy tube and occlusion of the stoma. In either instance subglottic stenosis above the tracheostomy stoma was found. The remaining four patients had had tracheostomy because of stridor. Size 9.0 mm (ID) orotracheal tubes were used for male patients and size 8.0 mm (ID) for female patients. Three patients (Patients 2, 3, and 5) received corticosteroids following head or lung injuries.

Emergency Intubation. Five patients had had emer-

gency endotracheal intubation (table 1) before the development stridor. Patient 3 needed emergency endotracheal intubation at the heliport on his arrival by helicopter. The neurologic status of Patient 4 deteriorated rapidly after admission, and the trachea was intubated. Relaxants and sedation were not used for endotracheal intubation of Patients 3 and 4. Patients 1, 5, and 6 needed emergency reintubation of the trachea when stridor developed. The tracheas of all three were re-extubated the following day, and again stridor developed, necessitating reintubation. Repeated endotracheal intubation was common, with a mean of 2.9 per patient (range 1-4). Apart from the exceptions mentioned, endotracheal intubations were carried out with the use of muscle relaxants or sedation. Tube lubricants other than Surgilube® were not used.

Laryngoscopic Examination and Operation. The courses of all six patients who had stridor were followed by direct laryngoscopic or fiberoptic bronchoscopic examinations. Evidence of laryngeal trauma was found (table 2) around the glottis five times, and in the subglottic region five times; in patient 3, edema above glottis was also seen. Operative procedures on the air-

way other than tracheostomy were needed in three cases (Patients 1, 2, and 5). In Patients 2 and 5, who had subglottic stenosis, these procedures were extensive. Patient 2 had insertion of T-tube, then a stent, which is still in position two years later despite attempts to remove it permanently. Patient 5 had subglottic stenosis above the tracheostomy stoma that was associated with a second stenotic area beneath the tracheostomy cuff (also high-compliance), and a tracheal resection was performed. Follow-up examination of the airway was obtained in every case. With the exception of the two cases of subglottic stenosis, healing of the lesions was evident within five weeks.

DISCUSSION

Bergstrom,⁹ in a series of 173 patients intubated endotracheally for barbiturate overdose, found one patient who needed tracheostomy following extubation because of laryngeal edema that obstructed breathing. Tonkin and Harrison¹⁰ reported that only one tracheostomy was necessary because of respiratory obstruction following prolonged translaryngeal intubation in 166 patients. In both these series, low-compliance, cuffed, red rubber tubes were used

TABLE 2. Laryngoscopic Findings and Operations Performed

	Age (Years), Sex	Glottic Findings	Subglottic Findings	Operation Performed
Patient 1	41, M	Cords edematous; immobile left cord with granulation tissue	Edema	Granulation tissue removed from postcommissure left cord; tracheostomy for stridor; direct laryngoscopy five weeks after admission; both cords mobile
Patient 2	19, F	Web in anterior commissure; left cord paralyzed; granulation tissue along left cord	Subglottic stenosis; granulation tissue above tracheostomy; stoma 1.5 cm below cords	Biopsy; removal of granulation tissue; T-tube inserted, then stent; stent still in position two years later; direct laryngoscopy four months after removal of granulation tissue; both cords moving
Patient 3	32, M	Cords edematous; left cord not abducting; necrosis of posterior commissure	Edema	Tracheostomy for stridor; direct laryngoscopy three weeks after admission showed complete healing
Patient 4	24, F	Both cords edematous		Tracheostomy for stridor; direct laryngoscopy eight days after operation showed complete healing
Patient 5	33, M		Sub-glottic stenosis above and below tracheostomy stoma	Tracheal resection with repair of stenosis; fiberoptic bronchoscopy four months after operation showed granulation tissue at the site of resection
Patient 6	20, F	Both cords edematous with ulceration and granulation tissue of right anterior commissure	Edema	Tracheostomy for stridor; fiberoptic bronchoscopy ten days after operation showed resolution of edema and healing right-cord granuloma

for intubation. The lower incidence of stridor of 0.1 per cent (1/1,050 cases) we report compared with the incidence of 0.6 per cent seen in the above-mentioned series may have been due to the use of inert plastic rather than red rubber orotracheal tubes.

Since the introduction of the high-compliance cuffed tubes, increase in the incidence of severe stridor following prolonged orotracheal intubation in our institution to 0.46 per cent (6/1,290) has been striking. A problem of documented laryngeal injury appears to have been created since the high-compliance cuffs were introduced. Increased incidences of sore throat following short periods of endotracheal intubation with high-volume high-compliance cuffs⁸ may be due not to the increased tracheal surface contact area of the cuffs, as is suggested, but rather to the direct trauma inflicted on the larynx by the bulky cuff during insertion and withdrawal.

Several features of the high-volume high-compliance cuff were thought to predispose to trauma compared with low-compliance cuffs. Residents instructors and staff anesthesiologists alike thought that it was more difficult to insert the high-volume cuffed tube into the larynx. The bulky cuff may obscure a view of the tip of the tube, making damage from misdirection more likely.

Because of the greater difficulty associated with endotracheal intubation, metal stylettes were routinely used during insertion of the Portex Soft Seal[®] orotracheal tubes. This increased the likelihood of damage to the larynx during insertion, especially in an emergency or when used by an inexperienced operator. The bulky cuff tends to fold on itself when fully deflated, and the double thickness of cuff material forms wedges that cause trauma during passage through the glottis, both on insertion and on withdrawal. All the orotracheal tubes were inserted with the right hand and thus tended to be directed toward the left side of the glottis. This may account for the three cases of left-cord immobility seen in these six patients, although other reasons for the known higher incidence of left-vocal-cord paralysis following endotracheal intubation have been reported.¹¹⁻¹³

The high-compliance cuff cannot be incriminated as the sole cause of laryngeal injury during prolonged endotracheal intubation. There will be continued aggravation by a translaryngeal tube of any damage inflicted during intubation. Repeated movement of an orotracheal tube within the larynx occurs during the respiratory excursion of mechanical ventilation, flexion and extension of the neck, chest physiotherapy, and suctioning, and when the patient is out of phase with the ventilator. Jackson¹⁴ has described the laryngeal injuries resulting from patients' attempts to

close the glottis during intratracheal intubation. All of these irritant factors are likely to be accentuated in the presence of infection, as occurred in five of these six patients. Removal of the tube inflicts further laryngeal damage.

The role of steroids in the etiology of airway damage is controversial. They are thought by some to predispose to airway infection and exaggeration of tracheal injury.^{15,16} In our group, all three patients who received steroids also had pathologic organisms cultured from the trachea (table 1).

Improvements in high-compliance cuffs are needed. They must be made less bulky and of thinner material. The bulkiness of high-volume cuffs can be reduced by careful and complete evacuation of all the air from the cuff, assisted by gentle squeezing and twisting of the cuff. This makes the cuff conform to the tube more readily so that there is less trauma during insertion. Improvement of the cuff has been discussed with the manufacturer, and we are currently evaluating the new Portex Profile[®] cuff. Since the airway at the vocal cords is triangular, a tube with a translaryngeal cross-section shape conforming to the triangular passage through the vocal cords may further minimize posterior and lateral translaryngeal pressure.

Over comparable two-year periods, with similar patient populations, severe stridor occurred more frequently with a high-volume high-compliance cuff than with a low-compliance cuff. Laryngeal injury was the cause of the stridor, which appeared to result from trauma to the larynx during endotracheal intubation with the high-volume cuff and continued aggravation of the injury to the larynx during prolonged intubation.

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Intraoperative Hemodynamic Changes during Total Knee Replacement

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The physiologic consequences of intramedullary bone cement insertion during operations for total hip replacement have been subject to extensive study.¹⁻⁴ Total knee replacement differs from the hip operation in that during the former, the bone cement is inserted into two long medullary canals (tibial and femoral), and a tourniquet is generally used. Although complications such as hypotension, cardiac arrest, and fat embolism have been observed during the knee replacement operation,⁵⁻⁷ relevant hemodynamic data have not been available. The present investigation was undertaken to obtain hemodynamic data from five patients who did not have bone cement inserted at operation and five patients who did.

METHODS

Ten patients with no history or objective evidence of cardiopulmonary disease were studied. Six patients had osteoarthritis and four had rheumatoid arthritis. The patients were divided into two groups. Group I consisted of five patients with a mean age of 69 years (range 51-78 years) who underwent knee replacement without the use of bone cement. Group II consisted of five patients with a mean of 63 years

(range 49-80 years) who underwent knee replacement with use of bone cement.

Central venous pressure (CVP), pulmonary-artery wedge pressure (PWP), and pulmonary arterial pressure (PAP) were measured using a Swan-Ganz triple-lumen catheter, which was inserted from the antecubital fossa. Mean aortic pressure (MAP) was measured through a radial-artery catheter. Catheters were inserted 6-12 hours before operation. Heart rate (HR) was determined from a standard ECG lead. Cardiac output (CO) was measured in triplicate by the thermal dilution method with a computer (Edwards).

Derived variables were:

Cardiac index (CI)

$$= \text{CO/body surface area (l/min/m}^2\text{)}$$

Stroke volume index (SVI) = CI/HR (ml/m²)

Systemic vascular resistance (SVR)

$$= (\text{MAP} - \text{CVP})/\text{CI (torr/min/l} \times \text{m}^2\text{)}$$

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ABBREVIATIONS

CVP	= central venous pressure
PWP	= pulmonary wedge pressure
PAP	= pulmonary arterial pressure
MAP	= mean aortic pressure
HR	= heart rate
CO	= cardiac output
CI	= cardiac index
SVI	= stroke volume index
SVR	= systemic vascular resistance
PVR	= pulmonary vascular resistance
LVSWI	= left ventricular stroke work index
RVSWI	= right ventricular stroke work index