tilator settings that produce the lowest tracheal pressures and yet still allow adequate oxygenation and carbon dioxide removal will be the most advantageous in ventilating patients with bronchopleural fistulas.

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Assessing Tidal Volume and Detecting Hyperinflation during Venturi Jet Ventilation for Microlaryngeal Surgery

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Venturi jet ventilation has been used during microlaryngeal surgery for several years.[1,2] Advantages during laser microsurgery include an unobstructed full view of the larynx and the absence of a potentially combustible endotracheal tube. Uncertainty as to the delivered volume from this "open" system is a major disadvantage. Evaluation of ventilation has been limited to observation of chest expansion and random analysis of arterial blood gases. This report describes a technique for assessing tidal volume and for monitoring hyperinflation during jet ventilation in patients undergoing microlaryngeal surgery.

METHODS

Thirteen patients (ages 12–70 yr, weight 38–120 kg) undergoing suspension microlaryngeal surgery utilizing jet ventilation were monitored during 16 operations. The study was approved by our Institutional Review Board. Two patients had chronic obstructive lung disease; the remaining patients had clinically normal preoperative pulmonary function. Before induction of anesthesia, two aneroid chest bellows, hereafter referred to as pneumobelts (Coulborn Instruments, Lehigh Valley, Pennsylvania), were circumferentially attached to the patient: 1) "abdominal"—midway between the umbilicus and xiphoid process; 2) "thoracic"—midway between xiphoid process and intermammillary line (fig. 1). The pneumobelts were connected to pressure transducers (Statham Model P22S®) and output recorded on a multichannel

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recorder (General Scanner Company, Watertown, Massachusetts).

Anesthesia was induced with thiopental 4 mg · kg^{-1} iv, and tracheal intubation with a standard cuffed oral endotracheal tube was facilitated by succinylcholine 1.5 mg · kg^{-1} iv. Anesthesia was maintained by breathing N_2O with iv administered fentanyl and diazepam. Muscle relaxation, monitored by a peripheral nerve stimulator, was maintained by a continuous iv 0.2% succinylcholine infusion.

A 1,000-ml super-syringe was used to calibrate the pneumobelts and recording equipment for each patient. Known volumes of gas were delivered through the endotracheal tube by the super-syringe in 100-ml increments (100–1,000 ml). The millimeter displacement of the abdominal and chest pneumobelts at each volume increment were added. Total displacement was correlated with the known incremental delivered volume and a linear regression equation calculated.[3] The abdominal to thoracic pneumobelt displacement ratio was calculated in the calibration process and during jet ventilation. These ratios were compared by the paired t test. On ten occasions three randomly chosen "unknown" volumes also were delivered by the super-syringe, and a blinded observer compared them with the delivered volume as estimated by the pneumobelts.

An Abramson-Dedo® operating laryngoscope (Model #52-2229, Pilling Company, Fort Washington, Pennsylvania) was inserted into position and the endotracheal tube removed. A 14-gauge steel jet injector was inserted into one of the laryngoscope's four channels. A pressure regulator placed in-line was used to control jet driving pressure (0–50 psi). Ventilation was controlled by manually operating a spring-loaded valve. Ventilatory rate was maintained between 40 and 60 breaths/min. A sine-wave airway pressure waveform was maintained, although the I/E ratio of each cycle was not precisely controlled. In the last six patients, tracheal pressure 5 cm distal to the jet port was measured. A 14-g steel needle was inserted into one of the laryngoscope's four channels and connected to an airway pressure monitor (Novametrix Pneumogard 1200®, Wallingford, Connecticut) and output channeled to the multichannel recorder. Jet driving pressure was adjusted by observing the graphic pneumobelt displacements at various driving pressures and choosing a driving pressure that provided a satisfactory delivered volume. Analysis of arterial blood gases was determined in all patients using an IL 813 analyzer following at least 15 min of jet ventilation. Results are presented as the mean ± standard deviation.

RESULTS

The relationship between the super-syringe-delivered volume and total (thoracic plus abdominal) pneumobelt displacement was linear for each patient between 100 and 1,000 ml. Individual correlation coefficients were 0.99 or greater. Considerable variation existed between patients regarding regression lines. These slopes ranged from 9.8 to 36.2 ml/mm (table 1). The y-intercepts ranged from −34.8 to 36.5 ml. The abdominal to thoracic pneumobelt displacement ratio was 1.6 ± 0.7 during calibration and 1.6 ± 0.8 during jet ventilation. There was no difference in the abdominal to thoracic displacement ratio between high (1,000 ml) and low (100 or 200 ml) calibration volumes.

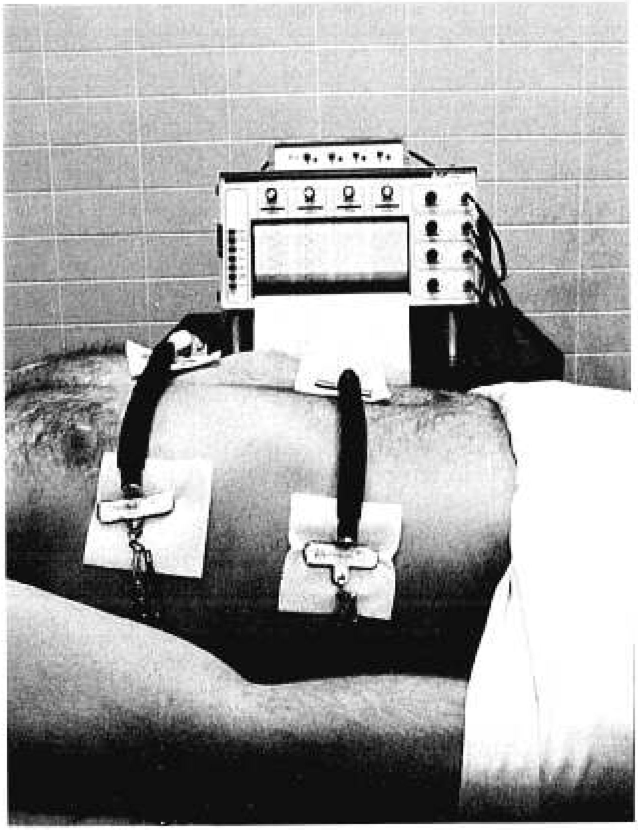

FIG. 1. Abdominal and thoracic pneumobelts in position.

Estimated delivered volume significantly correlated with jet driving pressure in each patient. The correlation coefficients ranged between 0.95 and 0.99. The driving pressure ranged from 30 to 50 psi (mean 39 ± 6 psi).

The mean estimated volume delivered during jet ventilation was 255 ± 73 ml or 3.4 ± 0.8 ml · kg^{-1}. Mean frequency was 50 ± 12 cycles · min^{-1}. Arterial carbon dioxide tension (Pa_{CO_2}) during jet ventilation ranged from 23–48 mmHg (mean 35 ± 6 mmHg). All six patients with estimated delivered volumes greater than 3.5 ml · kg^{-1} had a Pa_{CO_2} less than 35 mmHg. All patients with estimated delivered volumes of 2–3.5 ml · kg^{-1} had a Pa_{CO_2} between 35 and 45 mmHg, except for one patient with

TABLE 1. Summary Data

Patient	Delivered Volume Estimated by Pneumobelt		Pa_{CO_2} (mmHg)	Regression Line Data		Accuracy of Pneumobelt in Estimating "Unknown" Volume
	ml	ml/kg		Slope (ml/mm)	Y-Intercept (ml)	
1	231	1.9	39	15.5	36.5	8.7%
	358	3.0	43	9.8	21.7	6.5%
2	280	3.4	33	19.8	10.5	—
3	269	4.1	23	13.7	12.3	—
4	129	3.4	36	11.5	−34.8	—
5	217	3.2	40	12.3	0.4	—
6*	345	5.1	31	17.4	7.9	—
7	287	3.6	34	24.1	−26.0	—
	240	3.0	39	15.2	18.2	1.2%
8*	293	3.2	48	15.6	−23.9	1.9%
9	162	3.2	32	11.2	−9.7	2.0%
10	381	4.6	29	22.0	34.1	0.9%
11	232	3.6	30	13.3	28.1	2.0%
	135	2.1	36	12.8	−30.1	2.3%
12	281	4.1	32	22.2	−7.2	0.8%
13	246	2.6	39	35.0	0.6	5.4%

* Patient with chronic obstructive pulmonary disease.

chronic obstructive pulmonary disease whose Pa_{CO_2} was 48 mmHg.

The accuracy of the pneumobelt in estimating super-syringe-delivered "unknown" volumes was within 8.6%. The range of accuracy between patients is seen in table 1.

The pneumobelts produced a consistent pattern of progressive stepwise increases in combined rib cage and abdominal circumferences during episodes of intraoperative laryngeal airway obstruction (fig. 2). This pneumobelt pattern paralleled a stair-stepping in airway pressure in the two patients in whom tracheal pressure was monitored distal to the obstruction (fig. 3).

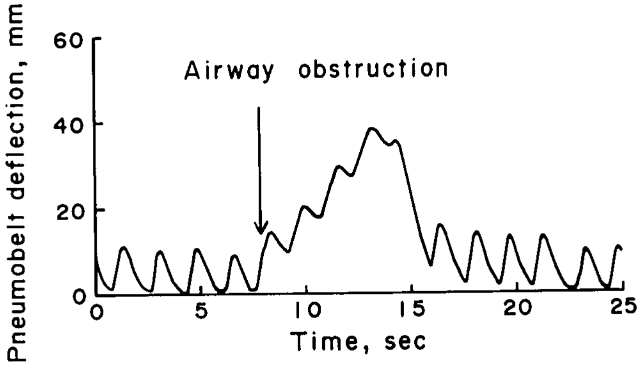

FIG. 2. Abdominal pneumobelt tracing during an episode of airway obstruction that occurred at the level of the larynx due to the existing pathology and surgical manipulation. The obstruction was proximal to the jet injector port, therefore, inhalation could occur but exhalation was prevented. A stair-step pattern was observed with each additional jet cycle, suggesting air trapping and hyperinflation.

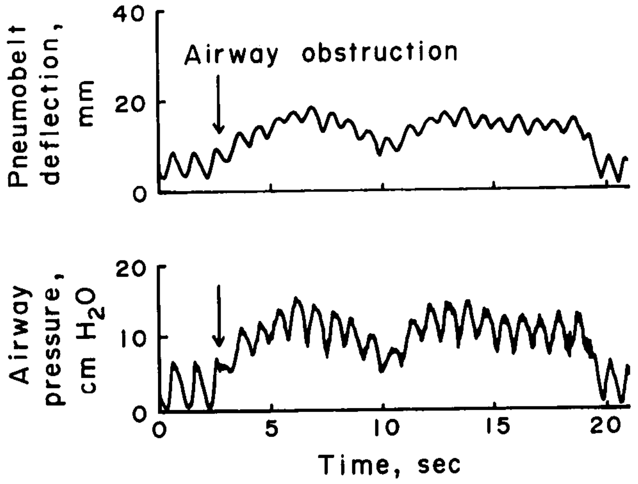

FIG. 3. Tracheal pressure and abdominal pneumobelt tracing during an episode of airway obstruction. The pneumobelt tracing paralleled the stair-stepping tracheal pressure.

DISCUSSION

Determination of pulmonary ventilation as measured from body surface movement using either impedance pneumography, respiratory inductance plethysmography, magnetometers, or strain-gauge pneumography has been previously described.[4–8] These techniques are not widely used clinically because of the difficulty in maintaining proper calibration during changes in posture or patient movement. This was not a problem in paralyzed patients maintained in constant position during surgery. Pneumobelts are the least expensive of these methods and are available in one size that will fit older children and adults. Although the positioning of the pneumobelts was accepted by the patients while awake, the pneumobelts easily could be applied after induction of anesthesia. The pneumobelt technique does add approximately 10 min to the operating room time, which includes recorder and pneumobelt calibration. We found the technique to be applicable to the clinical setting and are currently using it routinely during jet ventilation for microlaryngeal surgery.

The relative contributions of rib cage and abdomen to breathing are different between patients and are affected by several factors: body position, lung volume, and type of respiratory pattern.[5] For this reason, isovolume maneuvers often are used to determine the contribution of rib cage and abdominal motion to the total tidal volume. Optimal scaling of the thoracic and abdominal signals is based on the ratio of rib cage to abdominal motion and allows accuracy of calibration in the face of a change in breathing pattern. Ashutosh *et al.* showed optimal scaling of the thoracic and abdomen signals of a magnetometer failed to improve its performance.[4] For this reason we chose to give an equal contribution of abdominal and thoracic motion and eliminate the process of optimal scaling.

There was no difference between the abdominal to thoracic pneumobelt displacement ratio during the calibration procedure and jet ventilation.

Uncertainty as to delivered volume and adequacy of ventilation is a major disadvantage of any "open" ventilation system. The pneumobelts provided an indirect yet reasonably accurate estimate of delivered volume during jet ventilation. Satisfactory ventilation was achieved by maintaining estimated delivered volume between 2.0–3.5 ml · kg^{-1} at rates of 40–60 cycles/min.

Risk of barotrauma is a potential disadvantage of jet venturi ventilation. Pneumothorax secondary to ball-valve obstruction and subsequent overinflation during jet ventilation have been reported.[9,10,§] In this study, the pneumobelt system was helpful in detecting hyperinflation caused by airway obstruction and therefore may be useful in preventing barotrauma. Low jet driving pressures are less likely to produce mucosal tears and subsequent emphysema. By confirming the patient is receiving an adequate tidal volume, the use of pneumobelts prevents inadvertent application of excessively high jet driving pressures.

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Postural Stability after Oral Premedication with Diazepam

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The tendency of a patient to sway in a standing position after administration of a drug may be an index of patient safety. Because this index has not been used in studies of premedication regimens, we determined the postural stability of patients before and 90 min after oral administration of diazepam by use of a computer-assisted force plate. The applied method has been shown to be useful in the investigation of other drugs.[1–3]

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Methods

Twenty-one patients, 10 women and 11 men, scheduled for elective surgical procedures were tested. None took any medications or had any drugs the week before the study. All patients were ASA class I, ages ranging from 20 to 57 years. Informed consent was obtained from the patients after written and oral information. The study was approved by the staff of the involved departments.

The quantitative Romberg's test,[4] the indication of body sway, was used in this study. The Romberg's position is defined as a standing position with arms hanging aside and the feet parallel with 1 cm interspace. The fluctuations