ANESTHESIA FOR PATIENTS WITH PULMONARY EMPHYSEMA: USE OF POSITIVE-NEGATIVE PRESSURE RESPIRATOR DURING PULMONARY SURGERY

Karl L. Siebecker, M.D., and John K. Curtis, M.D.

Anesthesia for patients who have varying degrees of pulmonary emphysema is a frequent problem confronting the anesthesiologist. Some anesthesiology texts do not mention pulmonary emphysema and others discuss it briefly as a problem without proposing a definite solution. There are relatively few reports in the literature of studies concerning the anesthetic management of such patients.

Interest in this problem developed after administering an anesthetic to a patient for lung resection in whom the operation was impossible because of severe bullous emphysema. When the chest was opened, the lungs were found to be totally inelastic. An expiratory phase of respiration could be achieved with manual compression of the lungs by the surgeon or an assistant. Inspiration was accomplished by compression of the anesthetic reservoir bag. The lungs so filled the chest cavity that it was believed too hazardous to proceed with the operation. Seven months later this same patient was again scheduled for operation. In the meantime we had become interested in intermittent positive pressure and positive-negative pressure respirators and were using them routinely for open thoracic procedures. A positive-negative phase respirator was used for this second operation—the anesthetic administration was essentially uneventful. Ventilation proved relatively easy. Unfortunately, we were not prepared to analyze arterial blood samples at that time, and no proof exists that the acid-base balance was undisturbed. The operation was successful and the patient's recovery, relatively uneventful.

The present study was undertaken to determine the results of administering anesthesia to patients who had varying degrees of pulmonary emphysema and were to have pulmonary resection for tuberculosis. There were 8 segmental resections, 3 lobectomies, and 2 pneumonectomies performed. The 12 patients were all studied in the pulmonary function laboratory prior to anesthetization and operation. The vital capacity, timed vital capacity, maximum breathing capacity, residual air, index of intrapulmonary mixing, and the single breath oxygen tests were used. In 3 patients the pulmonary emphysema was classified as severe, 6 as moderate, and 3 as early (table 1).

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TABLE 1

PULMONARY FUNCTION STUDIES AND CLASSIFICATION OF EMPHYSEMA IN PATIENTS UNDERGOING PULMONARY RESECTION

Patient Number	Pulmonary Function Studies						Degree of Emphysema
	Total Vital Capacity (per cent)	Maximum Breathing Capacity (per cent)	Timed Vital Capacity (per cent)	Nitrogen Washout		Single Breath Oxygen (per cent)	
				Per Cent $\left[\frac{\text{Respiratory Capacity}}{\text{Tidal Volume}} \times 100\right]$	Mixing Index		
Normal Values	>90	>90 (elevation of curve considered evidence of emphysema*	>90	<35	<2.5	<2	
1	99	85 (elevated curve)	51 62 72	35	5.7	3 (post surgical, 9)	Moderate
2	102	75 (elevated curve)	62 71 78	32	4.2	6	Moderate
3	73	55 (elevated curve)	50 73 83	44	6	4 (at end, 8)	Moderate
4	135	98 (elevated curve)	57 73 78	24	5.5	3	Early
5	91	95 (elevated curve)	—	—	—	3 (at end, 8)	Moderate
6	90	42 (elevated curve)	40 59 69	15	3	5 (at end, 8)	Moderate

* Elevation of the maximum breathing curve is indicative of incomplete emptying of the lung during rapid forced respiration.

TABLE 1—(*Continued*)

Patient Number	Pulmonary Function Studies: Total Vital Capacity (per cent)	Maximum Breathing Capacity (per cent)	Timed Vital Capacity (per cent)	Nitrogen Washout: Per Cent $\left[\frac{\text{Respiratory Capacity}}{\text{Tidal Volume}} \times 100\right]$	Nitrogen Washout: Mixing Index	Single Breath Oxygen (per cent)	Degree of Emphysema
7	143	128 (elevated curve)	—	—	—	3 (at end, 9)	Moderate
8	100	117 (elevated curve)	68 (first second) 86 (second second) 90 (third second)	—	—	2.5 (at end, 7.5)	Early
9	96	50 (elevated curve)	58 75 83	40	3.5	2.5 (at end, 7.5)	Moderate
10	66	63 (elevated curve)	69 82 90	47	5.5	6 (at end, 15)	Advanced
11	93	54 (elevated curve)	44 64 74	38	2.5	9	Advanced
12	85	80 (elevated curve)	56 71 75	—	—	3.25 (at end, 10.2)	Advanced

Method

The patients received only scopolamine as preanesthetic medication. An arterial blood sample was taken in the morning before induction of anesthesia. The arterial blood *p*H was determined immediately by means of a Cambridge glass electrode *p*H meter in which the electrode and buffers were kept at 37 C. as described by Wilson (1). The hematocrit reading was determined in Wintrobe tubes, and the carbon dioxide and oxygen content, by the manometric method of Van Slyke and Neill (2). The pCO_2 was then calculated from the nomogram of Singer and Hastings (3).

Anesthesia was begun with a thiobarbiturate and succinylcholine for intubation with a Carlens, divided-lumen endotracheal tube (4). The anesthetic was then continued with nitrous oxide-oxygen, intermittent doses of thiobarbiturate and meperidine, and either a continu-

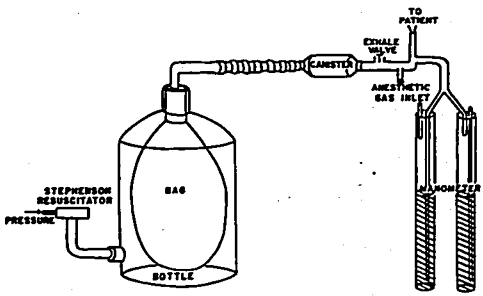

Fig. 1. Schematic diagram of positive-negative respirator.

ous drip of 0.2 per cent succinylcholine or intermittent doses of *d*-tubocurarine hydrochloride. A nonexplosive technique was required, since cautery was used for control of bleeding.

The method (5) employed for applying positive-negative pressure consisted of a Stephenson * "minuteman" field resuscitator, which was pressure regulated and operated from the oxygen supply source, either wall line or tank (fig. 1). The resuscitator was connected to the bottom outlet of an ordinary 8-liter laboratory bottle by a tube placed through a rubber cork for tight connection. A piece of "accordion" tubing was used to connect the breathing bag to the carbon dioxide absorption cannister, either to-and-fro or circle type. A pair of water manometers for measurement of positive and negative pressures were connected to a side tube of the endotracheal connector. These manometers acted as safety valves to prevent the application of too much positive or

* The Stephenson Corporation, Red Bank, New Jersey.

TABLE 2

RESULTS OF ANALYSES OF ARTERIAL BLOOD SAMPLES TAKEN BEFORE, DURING AND AFTER OPERATION ON EMPHYSEMATOUS PATIENTS

Patient Number	Degree of Emphysema	Operation	Sampling Time and Status of Patient	Blood Analyses: Oxygen (Volumes per cent)	Blood Analyses: Hematocrit Reading	Blood Analyses: Carbon Dioxide (Volumes per cent)	Blood Analyses: pH	Blood Analyses: pCO_2 (mm. Hg)	Ear Oximeter Reading (per cent)
1	Moderate	Segmental resection, right upper lobe	7:45 a.m. (awake)	16.8	46	51.7	7.40	43	—
			8:20 a.m. (spontaneous respiration)	15.8	46	57.1	7.25	67	97
			9:10 a.m. (respirator, one lung)	16.7	44	51.6	7.31	53	97
			12:45 p.m. ((respirator, both lungs)	18.8	46	50.8	7.31	53	—
			2:15 p.m. (awake, nasal oxygen)	18.1	52	48.5	7.33	50	—
2	Moderate	Segmental resection, right upper and right lower lobe	7:40 a.m. (awake)	18.9	48	49.4	7.40	44	91
			8:50 a.m. (respirator, one lung)	18.3	47	50.5	7.23	63	—
			11:45 a.m. (respirator, both lungs)	20.2	51	45.4	7.26	52	—
			1:30 p.m. (awake, nasal oxygen 1 hour postoperative)	20.2	50	45.8	7.39	41	—
3	Moderate	Left pneumonectomy	7:50 a.m. (awake)	18.8	50	49.6	7.45	40	
			8:30 a.m. (respirator, both lungs)	16.9	47	50.6	7.33	52	
			10:15 a.m. (respirator, one lung)	17.9	48	57.5	7.20	76	
			11:03 a.m. (respirator, after ligation of pulmonary artery)	17.8	46	51.3	7.35	42.5	
			3:00 p.m. (awake, nasal oxygen 2½ hours postoperative)	18.8	45	51.1	7.41	41	
			8:00 a.m. (first postoperative day, off nasal oxygen)	14.0	34	58.0	7.44	42.5	
4	Early	Right upper lobectomy	7:45 a.m. (awake)	19.2	48	47.1	7.43	37	—
			8:30 a.m. (spontaneous respiration)	18.3	48	53.5	7.23	66	—
			9:00 a.m. (respirator, both lungs, pleura closed)	18.8	48	49.9	7.32	51	—
			9:20 a.m. (respirator, pleura open)	19.6	46	45.4	7.38	41	—
			11:00 a.m. (respirator, one lung)				7.36		
			1:40 p.m. (respirator, both lungs)				7.36		
			4:00 p.m. (awake, nasal oxygen 2 hours postoperative)	19.0	46	47.3	7.40	41	98

TABLE 2—(*Continued*)

Patient Number	Degree of Emphysema	Operation	Sampling Time and Status of Patient	Blood Analyses					Ear Oximeter Reading (per cent)
				Oxygen (Volumes per cent)	Hema-tocrit Reading	Carbon Dioxide (Volumes per cent)	pH	pCO_2 (mm. Hg)	
5	Early	Decortication and segmental resection right upper lobe	7:45 a.m. (awake)	19.4	48	44.5	7.44	35	—
			8:50 a.m. (respirator, both lungs)				7.32		
			9:00 a.m. (respirator, one lung)	19.4	48	43.9	7.33	44	
			12:00 noon (respirator, both lungs)	18.2	47	49.6	7.27	55	
			3:00 p.m. (awake, nasal oxygen 2 hours postoperative)	19.4	46	47.8	7.45	38	99
6	Moderate	Right upper lobectomy (marked emphysema noted grossly at surgery)	7:40 a.m. (awake)	16.2	42	41.8	7.41	35	
			8:30 a.m. (spontaneous respiration)	14.3	42	47.0	7.28	51	
			9:25 a.m. (respirator, both lungs)	14.1	41	47.9	7.20	61	
			10:40 a.m. (respirator, artery destroyed to right upper lobe, ligated)	15.6	42	49.6	7.26	53	90
			2:30 p.m. (awake, nasal oxygen)	17.7	40	44.0	7.30	40	—
7	Moderate	Segmental resection, left upper lobe	7:35 a.m. (awake)	21.4	51	41.6	7.46	33	
			8:45 a.m. (respirator)	19.1	51	39.5	7.49	20	98.5
			10:10 a.m. (one lung for past ten minutes)	18.6	50	39.4	7.49	20	97
			3:00 p.m. (awake)	19.6	50	43.9	7.41	37	101
								(nasal oxygen)	
8	Early	Segmental resection, right upper lobe	7:45 a.m. (awake)	15.6	40	46.5	7.46	40	97
			9:00 a.m. (respirator, one lung)	15.3	42	47.9	7.36	42	97
			9:55 a.m. (respirator, both lungs)	16.8	42	45.0	7.47	42	99.5
			3:00 p.m. (awake, 4 hours postoperative)	16.2	41	47.8	7.36	41	101
								(nasal oxygen)	
			9:00 a.m. (first postoperative day, oxygen stopped)	12.1	39	46.3	7.45	33.5	—

TABLE 2—(*Continued*)

Patient Number	Degree of Emphysema	Operation	Sampling Time and Status of Patient	Blood Analyses: Oxygen (Volumes per cent)	Hematocrit Reading	Carbon Dioxide (Volumes per cent)	pH	pCO_2 (mm. Hg)	Ear Oximeter Reading (per cent)
9	Moderate	Segmental resection, left lower lobe	7:40 a.m. (awake)	17.9	46	42.3	7.42	46	—
			9:30 a.m. (respirator, both lungs)	17.9	46	48.9	7.37	49	97.5
			10:55 a.m. (manual assist)	18.5	49	48.7	7.40	46	98
			11:10 a.m. (respirator, both lungs)	17.9	47	49.4	7.43	44	96
			3:00 p.m. (awake, nasal oxygen 3½ hours postoperative)	19.4	49	42.9	7.54	30	100
10	Advanced	Segmental resection, left upper and left lower lobes	7:45 a.m. (awake)	17.0	49	49.5	7.40	44	90
			10:15 a.m. (respirator, one lung 20 minutes)	17.0	46	48.0	7.45	38	98.5
			1:40 p.m. (respirator, both lungs)	17.8	47	47.4	7.42	40.5	99
			3:50 p.m. (awake, nasal oxygen)	19.5	48	51.9	7.45	42	100
11	Advanced	Segmental reseaction, right upper lobe	7:45 a.m. (awake)	16.6	41	49.6	7.42	44	—
			9:20 a.m. (respirator, both lungs)	17.1	40	45.9	7.46	36	99
			2:00 p.m. (awake, nasal oxygen)	19.4	42	46.8	7.40	43	101
12	Advanced	Pneumonectomy	7:40 a.m. (awake)	16.4	50	46.7	7.46	38	97
			8:50 a.m. (respirator, one lung)	17.1	50	47.7	7.38	45	95
			11:10 a.m. (respirator, right lung out)	17.5	48	43.7	7.40	40	100.5
			2:30 p.m. (awake, nasal oxygen 2 hours postoperative)	17.6	48	45.5	7.42	40.5	100
12	Second operative procedure Advanced	Left upper lobectomy	7:30 a.m. (awake)	17.9	43	45.3	7.37	41	93
			9:50 a.m. (respirator, both lungs)	18.4	45	42.3	7.34	41	101
			12:40 p.m. (respirator, both lungs)	18.6	45	43.6	7.36	40	100
			2:40 p.m. (awake, nasal oxygen 1 hour postoperative)	19.9	45	47.6	7.39	39	101

negative pressure to the patient's respiratory tract. The anesthetic gases were introduced at the point indicated in figure 1, and a "blow-off" valve was inserted near the endotracheal tube. The pressures used varied from 5 inches of water pressure, negative, to 11 inches of water pressure, positive.

Arterial blood samples were taken during the administration of the anesthetic, while the patient was breathing spontaneously, and while the positive-negative respirator was in use with one lung and both lungs. (Respiration with one lung was made possible by clamping one side of the double lumen tube.) An arterial blood sample was also taken about two hours after the patient was returned to his room.

Results

The results of the analyses of the 61 arterial blood samples taken before, during, and after the administration of anesthesia in 13 operations on emphysematous patients are presented in table 2. It is of interest that the efficiency of ventilation increased during the three-year period of this study. This is demonstrated particularly by the improvement in pCO_2 levels.

TABLE 3

Average Results of Analyses of Arterial Blood Samples Taken Before, During and After 13 Operations on 12 Emphysematous Patients

Sampling Conditions	Oxygen (volumes per cent)	pH	Carbon Dioxide (volumes per cent)	pCO_2 (mm. Hg)
Preanesthetic (13 samples)	17.90	7.42	46.56	40.00
Spontaneous respirations in lateral position (3 samples)	16.17	7.25	52.58	61.30
Both lungs* (21 samples)	17.93	7.36	47.00	45.5
One lung* (9 samples)	17.57	7.35	48.36	48.7
One to three hours postoperatively (13 samples)	18.96	7.41	47.04	40.2
First postoperative day (2 samples)	13.09	7.45	52.19	38.0

* Respirator in use.

The average of samples taken from all patients prior to anesthetization show an oxygen content of 17.9 volumes per cent, a pH of 7.42, and a pCO_2 of 40.00 mm. of mercury which fall within the normal ranges (table 3). The samples taken after induction, with the patients in the lateral position and breathing spontaneously and unassisted, showed a reduction in pH to 7.25 and elevation of pCO_2 to 61.3 mm. of mercury. These values indicated inadequate ventilation even though the excursion of the anesthetic breathing bag appeared to be adequate. As soon as assisted respiration was instituted, these values approached normal levels. Blood samples taken while respiration was being accomplished with one lung only showed little decrease in pH (to 7.35) and only slight elevation of the pCO_2 (to 48.7). Analysis of blood samples taken postoperatively gave evidence of adequate respiration and gas exchange. The pH had returned to a level of 7.41 and the pCO_2 was 40.2 mm. of mercury.

Discussion

Chronic obstructive emphysema presents a complex problem to the anesthesiologist. The obstruction to ventilation of the alveoli is located in the bronchioles which tend to collapse because of lack of supporting elastic tissue. Inflation of the lung is achieved by raising the pressure of the anesthetic gas above atmospheric pressure, care being taken not to over distend the lung. In our experience, pressures up to 11 inches of water do not cause interstitial emphysema, pneumothorax, or arterial gas embolism. The volume and gas concentration of oxygen must be sufficient to provide adequate alveolar ventilation. This is doubly important because of the uneven mixing of gases within the emphysematous lung, the large residual volume, and the impaired ventilation perfusion ratio. High alveolar oxygen tension also improves the diffusion across the alveolar-capillary membrane which is frequently decreased in advanced emphysema.

The expiratory phase in the emphysematous lung is prolonged because of the obstruction in the bronchioles. The loss of elastic fibers also impairs the normal contractility of the lung, creating air trapping. These factors make it difficult for the anesthesiologist to obtain adequate expiratory volume to remove carbon dioxide. Slightly negative pressure of about 5 inches of water, applied over a somewhat longer phase than inspiration, has proved successful in providing sufficient ventilation to maintain pCO_2 within a normal range even in patients with advanced emphysema.

We agree with Nealon and his associates (6) who state in their conclusions that patients with pulmonary emphysema require a lower mean airway pressure than those with more elastic lungs. Nealon also concludes that negative pressure is of great value in assisting deflation of emphysematous lungs. He does not indicate which, if any, of the 20 patients on whom he analyzed blood samples had emphysema.

There have been numerous studies of pulmonary ventilation during anesthesia for "open" thoracic surgical procedures (7, 8). Martin and his associates (9), by means of differential bronchospirometry during anesthesia for thoracic surgical procedures, studied the actual ventilation and carbon dioxide output of each lung. Recently, Watson (10) also reported a series of thoracic operations controlled by repeated bronchospirometry measurements.

The use of mechanical respirators, both those with intermittent positive pressure and those with an alternating positive-negative pressure phase, has been described (11–15), and the results of their use during anesthesia determined by the analysis of arterial blood samples for pH, pCO_2, and oxygen saturation. Satisfactory results were reported by Nealon and associates (6) in 20 cases of open thoracotomy in which blood studies were done during the use of a positive-negative respirator; and also by our group (5) in 605 open thoracic procedures, using primarily a positive-negative phase respirator (blood studies were done in 151 of these cases).

SUMMARY

Twelve patients suffering from pulmonary emphysema, as well as tuberculosis, have been studied before, during, and after anesthetization for pulmonary resectional surgery. Arterial blood samples were analyzed to ascertain changes in acid-base balance. The method demonstrates that a positive-negative respirator provides adequate alveolar ventilation in such patients.

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