PULMONARY VENTILATION AND ARTERIAL OXYGEN SATURATION DURING ETHER–AIR ANESTHESIA

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The advantages of ether-air anesthesia in emergency circumstances, particularly during wartime, have been recognized, and attempts to develop apparatus for administering ether with air have been reported by Neff [1, 2] and Beecher.[3] Although these authors described satisfactory clinical anesthesia and presumed that oxygenation was adequate, quantitative determinations of oxygen saturation were not obtained. This is of importance in view of the work of Faulconer and Latrell [4] who found a reduction in oxygen saturation occurred frequently during semiopen, ether-air anesthesia. The purpose of the present study was to re-evaluate ether-air anesthesia and to determine whether adequate arterial oxygen saturation can be obtained without the use of supplemental oxygen.

Procedure

The Epstein-Macintosh-Oxford Ether Inhaler (E.M.O.) [5] and the Oxford Inflating Bellows [6] were used for induction and maintenance of anesthesia. This apparatus has the advantage of metering uniform, known concentrations of ether in a nonrebreathing system. In addition, it is possible to assist or control respiration whenever necessary. For patients whose tracheae are intubated, the distal valve of the bellows is elevated with the magnet provided for this purpose, and a nonrebreathing valve, such as the Fink or Ruben valve, is interposed between endotracheal tube and bellows. Control or assistance to respiration is then an easy maneuver.

Thirty-one unselected patients, age 20 to 83 were studied. Thirty patients were subjected to abdominal operative procedures and one to a radical mastectomy. The procedures varied in time from one to eight hours.

Preanesthetic medication consisted of atropine sulfate or scopolamine hydrobomide combined with meperidine or morphine usually given 30 to 60 minutes prior to anesthesia. In some patients, these drugs were given intravenously in the operating room five to ten minutes before induction of anesthesia.

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In 24 patients, ether-air was administered without ancillary agents. In seven patients, induction of anesthesia was performed with the aid of succinylcholine. Ether was then administered with the E.M.O. apparatus and anesthesia was maintained by ether alone throughout the remainder of the operation. Whenever respiration became depressed assistance or control of respiration was achieved by manual compression of the bellows. Concentrations of ether between 7 and 10 per cent, as metered by the machine, were necessary to produce satisfactory conditions during operation.

Arterial oxygen saturation was determined spectrophotometrically using hemolyzed whole blood and measuring optical density at wave lengths of 805 mu and 650 mu.[7] Two-milliliter blood samples were obtained from an indwelling 20 gauge spinal needle placed in the brachial artery. Samples were obtained before anesthesia in all patients. In 12 patients blood samples were taken prior to the administration of preanesthetic medication. Routinely, several arterial specimens were obtained during induction and then every 20 to 30 minutes during the operative procedure. In addition, samples of blood were taken whenever a decrease in oxygen saturation was suspected, such as might occur during bouts of coughing, breathholding, and hypotension. Whenever controlled respiration was employed, additional samples were obtained upon resumption of spontaneous respiration. Approximately 10 samples of blood were drawn from each patient.

In 25 of 31 patients respiratory minute volume was determined using an Emerson Breathometer. Inspired oxygen tension was then measured between the nonrebreathing valve and the bellows using the Beckman-Pauling Analyzer, as described by Faulconer and Latrell [4] for measurements of oxygen under the mask.

Results

The ease and speed with which surgical anesthesia could be achieved using ether-air alone with this apparatus is emphasized by the fact that patients were ready for laparotomy and tracheal intubation could be performed in six to twenty minutes, with an average of ten minutes. Measurement of the inspired oxygen tension revealed 140–145 mm. of mercury when 7–15 per cent (50–114 mm. of mercury) ether was administered with the E.M.O.

Table 1 summarizes the relationship between the oxygen saturation obtained and the type of respiratory management during maintenance of ether-air anesthesia. In 21 of 31 patients oxygen saturations of 95 per cent or greater were obtained. It is of interest that all nine patients whose respirations were controlled maintained an oxygen saturation above 95 per cent. Eight patients whose respirations were assisted had an oxygen saturation above 90 per cent, and in four of these the saturations were greater than 95 per cent. In the 14 patients with spontaneous respiration, eight had arterial oxygen saturations above 95 per cent, four between 90 to 95 per cent and in two patients the oxygen saturations remained between 85 to 90 per cent. Thus in only 6 per cent of the 31 patients did the oxygen saturation fall below 90 per cent.

Occasionally transient falls in oxygen saturation occurred, examples of which are shown in table 2. Three patients had oxygen saturations of less than 95 per cent which could be attributed to preanesthetic medication. Other decreases in saturation were related to coughing and breathholding during induction, or after endotracheal intubation. Oxygen desaturation was also associated with inadequate ventilation during maintenance of anesthesia or when spontaneous respiration was resumed following a period of controlled respiration

TABLE 1

Oxygen Saturation During the Maintenance of Ether-Air Anesthesia

O_2 Saturation (Per Cent)	Number of Patients			
	Type of Respiration			Total
	Spontaneous	Assisted	Controlled	
95 or greater	8	4	9	21
90–95	4	4	0	8
85–90	2	0	0	2
	14	8	9	31

TABLE 2

Oxygen Desaturation During Ether-Air Anesthesia

	Number of Patients	Range of O_2 Saturation (Per Cent)
1. Control period prior to anesthesia	3	91–95
2. Coughing, breathholding during induction	8	70–90
3. Immediately after intubation		
Apneic technique	5	43–90
Non-apneic technique	3	59–88
4. Inadequate ventilation during maintenance	7	76–90
5. Inadequate ventilation at the end of anesthesia	5	90–95

such as at the termination of anesthesia. All falls in oxygen saturation were brief and easily corrected by manual ventilation with air. Apnea during tracheal intubation induced by the thiopental and succinylcholine sequence, was accompanied by diminution in oxygen saturation. These patients' lungs were ventilated by air alone before instrumentation was attempted. This problem appears to be related to the small oxygen reservoir existing in the lungs. Further studies of this phenomenon and its clinical implication are the subject of another report.[8]

The data from patients in whom measurement of respiratory minute volume was made are presented in table 3. These figures represent the averages of data obtained during maintenance of anesthesia. The alveolar ventilation was calculated by considering a respiratory dead space of 150 ml. for males and 125 ml. for females. The average calculated alveolar ventilation was highest (7.2 l./minute) in the patients whose respirations were controlled. In this group oxygen saturation remained above 95 per cent. Four patients whose respirations were assisted and whose oxygen saturation remained above 95 per cent had alveolar ventilation of 6.4 l./minute and another four patients whose saturation remained 90–95 per cent had alveolar ventilation of 4.5 l./minute. In patients with spontaneous, unassisted respirations, whose oxygen saturation was above 95 per cent, the alveolar ventilation was only 3.4 l./minute, lower than that of those whose saturation was less. This phenomenon can be explained from the fact that patients 20 and 25 had moderate emphysema, and patient 24 had only 93 per cent oxygen saturation without anesthesia.

TABLE 3

DATA FROM PATIENTS OBTAINED DURING MAINTENANCE OF ANESTHESIA (AVERAGES)

		Pt. no.	Sex	Age	Ether Per Cent	Minute Volume	Resp. Rate	Tidal Volume	Alveolar Ventilation	Oxygen Saturation
Control		1	M	53	7	10.0	20	500	7.0	95
		2	M	61	10	11.5	25	460	7.8	95.5
		3	F	33	7	8.0	25	320	4.9	96.4
		4	F	36	7	12.0	25	480	8.9	95
		Mean		46	7.7	10.4	24	440	7.2	95.5
Assisted	Group I	5	M	79	8	9.8	25	392	5.6	95
		6	M	72	9	9.7	25	388	5.9	95.2
		7	F	37	9	10.0	25	400	6.9	96.5
		8	F	29	10	10.0	25	434	7.1	99.5
		Mean		54	9	9.9	25	404	6.4	96.5
	Group II	9	M	69	7	6.9	25	276	3.1	90.8
		10	F	37	8	8.0	25	320	4.9	91.9
		11	F	76	9	8.6	30	286	4.8	92.8
		12	F	45	13	8.5	25	340	5.3	92.9
		Mean		57	9.3	8.0	26	306	4.5	92.1
Spontaneous	Group I	13	M	78	9	8.5	27	314	4.4	98.1
		14	F	28	6	6.3	30	210	2.6	95.0
		15	F	72	7	6.6	25	264	3.5	95.7
		16	F	35	10	6.9	25	270	3.8	96.3
		17	F	21	8	6.4	30	214	2.7	97.0
		18	F	31	10	5.9	25	236	2.8	96.5
		19	F	31	13	7.3	25	292	4.2	96.5
		Mean		42	9	6.8	27	257	3.4	96.4
	Group II	20	M	60	8	11.6	25	466	7.9	92.2
		21	M	83	9	7.8	30	260	3.3	92.0
		22	M	46	9	8.1	25	324	4.4	92.5
		23	F	39	9	6.0	25	240	2.9	94.7
		Mean		57	9	8.4	26	323	4.6	92.9
	Group III	24	M	30	9	9.3	27	344	5.2	88.3
		25	F	68	7	8.4	28	300	4.9	87.5
		Mean		49	8	8.9	28	322	5.1	87.9

Oxygen tensions (measured at sea level) between the nonrebreathing valve and bellows before and after ether are shown in table 4 where they are contrasted with the data of Faulconer and Latrell corrected from 730 mm. of mercury at 1,000 feet to sea level (760 mm. of mercury).

DISCUSSION

Whenever air is used as the principle diluent in anesthesia, the possibility of oxygen desaturation is present. In the study by Faulconer and Latrell[4] saturations as low as 70 per cent were recorded during ether-air anesthesia. Desaturations of this magnitude occurred transiently during the present study as a result of inadequate ventilation arising from a variety of circumstances. However, we have demonstrated that desaturation could be easily corrected by effective manual control or assistance to respiration.

The advantage of a mechanical nonrebreathing system is further emphasized by the data

TABLE 4

THE OXYGEN TENSION IN INSPIRED AIR DURING SEMI-OPEN AND NONREBREATHING ETHER-AIR ANESTHESIA

Technique	Oxygen Tension			Ether Tension (mm. Hg)
	Samples Taken	Before Ether (mm. Hg)	After Ether (mm. Hg)	
Nonrebreathing, 760 mm. Hg	Between NRV and bellows	159	140–145	50–114
*Semi-open (corrected to 760 mm. Hg from 730 mm. Hg)	Under mask	128	104–124	26–78

* Data—Faulconer and Latrell.

relating to the available oxygen tensions. Comparing the oxygen tension under the mask reported by Faulconer and Lattrell[4] and that between the nonrebreathing valve and the bellows, the latter are consistently higher despite a higher tension of ether.

While control of respiration can apparently result in consistent oxygen saturation levels above 95 per cent, assistance to respiration does not offer such a guarantee. As seen in table 3, when assistance to respiration resulted in minute volume below 10 l./minute, saturations in the range of 91 to 93 per cent occurred. This emphasizes the need for adequate assistance.

The data in patients who breathed spontaneously contains some puzzling features; there does not appear to be a good correlation between ventilation and oxygen saturation in this group. The sample however is small and unusual circumstances can make the difference more apparent than real. For example, the respiratory data in patient 20, who had a diagnosis of pulmonary emphysema, distorts the whole group. What is of more import is that there is an apparent difference between patients who breathe spontaneously and those in whom respiration is assisted or controlled. What this difference is cannot be stated at this time. However, it is clear that mechanical assistance or control of respiration can provide adequate oxygen saturation.

SUMMARY

In 29 of 31 patients given ether-air anesthesia with the E.M.O. ether inhaler and the Oxford inflating bellows, blood oxygen saturation was maintained at 90 per cent or more during anesthesia. Voluntary respiration maintains oxygen saturation at 90 per cent, if ventilation is normal or above normal. It would appear from our data, when air is the diluent, that control of respiration is desirable if oxygen saturations of 95 per cent are to be achieved consistently. Transient falls in oxygen saturation related to inadequate ventilation may be rapidly corrected by manual ventilation with air alone using the bellows.

If ether-air anesthesia unsupplemented by oxygen is to be used, some method of manual ventilation should be available to maintain normal oxygen saturation.

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REFERENCES

1. Neff, W.: Ether anesthesia with improvised apparatus for intrathoracic operations under emergency circumstances, ANESTHESIOLOGY **6**: 337, 1945.
2. Mayer, E. C., and Neff, W.: Further experiences with endotracheal ether air anesthesia for intrathoracic surgery, ANESTHESIOLOGY **7**: 32, 1946.
3. Beecher, H. K.: Easy transportable apparatus for anesthesia with or without compressed oxygen, War Medicine **2**: 602, 1942.
4. Faulconer, A., Jr., and Lattrell, K. E.: Tension of oxygen and ether vapor during use of semi-open air-ether method of anesthesia, ANESTHESIOLOGY **10**: 247, (May) 1949.
5. Epstein, H. G., and Macintosh, R. R.: Anesthetic inhaler with automatic thermo-compensation, Anesthesia **11**: 83, 1956.
6. Macintosh, R. R.: Oxford inflating bellows, Brit. M. J. **2**: 202, 1953.
7. Deibler, G. E., Holmer, M. S., Campbell, P. L., and Gans, J.: Use of Tritox X-100 as hemolytic agent in spectro-photometric measurement of blood oxygen saturation, J. Appl. Physiol. **14**: 133, 1959.
8. Weitzner, S. W., Ikezono, E., and King, B. D.: Rate of arterial oxygen desaturation during apnea in humans, ANESTHESIOLOGY **20**: 624, 1959.