EVALUATION OF A VENTILATOR WITH FIXED VOLUME CONTROL AND VARIABLE REGULATED PRESSURE ^{1, 2}

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THE MANY METABOLIC ALTERATIONS which accompany wound trauma and anaesthesia have been studied by Bourne, Waters, Beecher, Moore, Holaday and others (1-10). These are the vital concern of the anaesthetist because the changes due to the stress reaction are aggravated by hypoxia and acidosis, which are usually the direct result of inadequate pulmonary ventilation.

The efficacy of automatic control of pulmonary ventilation during anaesthesia in preventing hypoxia and acidosis has been the subject of wide discussion recently. Many believe that automatic ventilators provide the anaesthetist and the surgeon with ideal conditions, and prevent hypoxia and acidosis. However, manual control of ventilation provides more satisfactory conditions because it is accompanied by closer attention to the patient. The latter method of controlled ventilation should be continued until the automatic ventilators presently available can be adjusted quickly, so that inattention to the operative field is only required momentarily. Then changes in the lung or changes in the blood chemistry can be corrected as soon as detected (11-17).

The disadvantages of available automatic ventilators have encouraged renewed interest in those which are manually operated, which inform the anaesthetist continuously of the volume and pressure amplitude of pulmonary ventilation, and allow him to maintain some "feeling" of the airway. When better ventilators are developed, the function of the hand may be gradually relieved by a motor.

In 1899 Rudolph Matas employed a modified hand respirator, to produce artificial respiration through a laryngeal tube during anaesthesia for thoracotomy (18). Since then many such devices have been employed for artificial respiration or resuscitation, but their application to clinical anaesthesia has been ignored. It is surprising that, even in recent years, no simple hand bellows with volume calibration and a suitable pressure gauge has been employed by anaesthetists.

Two hand ventilators have been reported during the last few years. One was described recently by Poppelbaum in Germany (Fig. 1). Adequate controlled respiration is provided with this ventilator if the carbon dioxide content of the expired air is kept below 3 per cent. This limitation requires regulation of several parameters of pulmonary ventilation as follows: minute volume, 6.0-9.0 litres, respiratory rate 12 to 20 per minute; the expiratory phase, at least two-thirds of the cycle; airway pressures, between + 9 and - 5 mm Hg when the chest is open, or + 11 and - 5 mm Hg in non-thoracic operations. *These patients must be fully relaxed with ether anaesthesia and intermittent doses of a muscle*

¹Preliminary report was presented at the Canadian Anaesthetists' Society Annual Meeting in Saskatoon, Saskatchewan, June 26, 1957.

²This investigation was assisted by equipment and a grant-in-aid from the Ohio Chemical and Surgical Company, Madison, Wisconsin.

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FIGURE 1 Poppelbaum Hand Ventilator 1, volume calibrated hand bellows, 2, carbon dioxide absorber, 3, water pressure manometer; 4, relay switch, 5, tap (opens during expiration), 6, carbon dioxide indicator, 7, endotracheal tube

FIGURE 2 Etsten Hand Ventilator 1, zero volume stop, 2, calibrated tidal volume scale, 3, rubber accordion bellows, 4, volume set screw stop, 5, exhalation valve, 6, gas delivery tube, 7, rebreathing bag attached to overflow vent on compensating valve, PNP, Marshalltown positive-negative pressure gauge, NP, negative pressure bias screw adjustment, FR, forearm rest, MCV, manual control lever.

relaxant. During light anaesthesia, a greater volume and pressure were required to ventilate the lungs adequately (19).

MacKay uses a standard Coxeter-Mushin bellows hinged to the operating table to provide manual positive-negative pressure ventilation. Pressures of $+15$ to -7 mm. Hg were used during intrathoracic and upper abdominal operations. The volume delivered was not measured, but occasional arterial blood pH determinations were made and found to exceed 7.5 (20).

Both authors were satisfied with their clinical results when these hand ventilators were used.

MATERIALS AND METHODS

The following report deals with the clinical and laboratory evaluation of a more elegant hand-operated ventilator developed by Etsten.⁴ The outlet of this

⁴Available commercially, from the Ohio Chemical and Surgical Equipment Company.

ventilator can be connected to a gas machine or directly to the patient's airway (see Fig. 2). The mechanical arrangements for use of this ventilator depended on the three anaesthetic systems which were studied.

Non-Rebreathing System

The manner in which the ventilator is modified when a non-rebreathing technique is used is shown in Figure 3. The rebreathing bag is removed from its

FIGURE 3 Anaesthetic systems

nipple, which is then left open to atmosphere and serves as an overflow vent. A non-return valve labelled (°) is slipped over the outlet to which the delivery tubing is usually attached. The collector bag is attached to the vertical nipple of the non-return valve. The delivery tubing, which is equipped with a non-rebreathing valve of the Fink type at its free end, is attached to the horizontal nipple of the non-return valve. The fresh gas is delivered through the supply tubing to the collector bag, where the slight resistance of a check valve in the non-return assembly will cause it to be stored until the bellows is expanded to the point where it provides sufficient negative pressure to pull the contents of the collector bag through the check valve. When the bellows is compressed, the gas cannot return to the collector bag and is forced through rigid tubing to the Fink valve, which is set so that the volumetric displacement of the bellows is added to the patient's lungs. At the end of the inspiratory stroke, the bellows rises, the expiratory diaphragm in the Fink valve opens, and the patient exhales to the atmosphere. At the same time the bellows draws a fresh charge of gas from the collector bag. The negative pressure (shown on the gauge) during expiration is transmitted only as far as the inhalation diaphragm of the Fink valve. When the supply of gas from the source is in excess of that required to ventilate the patient, the collector bag fills slowly until gas is driven through the check valve of the non-return assembly and inflates the bellows sufficiently to open the compensating valve of the ventilator. Thereafter, the excess gas is vented to the atmosphere. Venting the excess gas in this way acts as an automatic safety device. Similarly, should the supply of fresh gas be insufficient for the patient's needs to the point where the collector bag is emptied, the negative pressure in the system rises sufficiently to open the compensating valve and draws air through the overflow vent to make up what would otherwise be a ventilatory deficiency. This safety feature is likewise automatic.

Semi-closed System

The ventilator is attached directly to the rebreathing bag nipple of the gas machine. The rebreathing bag is connected to the bellows of the ventilator through a compensating valve, in order to reduce the need for frequent adjustment of the gas inflow. This valve is open normally only when the bellows is at its maximum expansion. It opens also when excessive negative pressure is generated within the bellows, as, for example, when the handle is forcibly raised or when there is a leak on the patient's side of the circuit. In this way the rebreathing bag serves as a reservoir which communicates with the breathing circuit at the end of each cycle, and at all times when the bellows is at the top of its stroke. The rebreathing bag fills when the rate of gas flow exceeds the rate of utilization, and deflates if utilization exceeds inflow. In either case, the anaesthetist becomes aware of the need for adjusting the delivery rate. At the usual flow rates employed with this system (8-14 L.), 175-200 ml. of gas are contributed to the set tidal volume by fresh gas when the duration of the inhalation phase of the breathing cycle is one-third of the respiration cycle. *This volume is ignored when estimating the tidal volume setting in the Magill system (Mapleson A), because the corrugated tube from the gas machine to the patient expands during the inflation phase with a volume of gas similar in amount. This "excess"*

volume begins to escape through the exhalation valve when inspiratory pressure is approaching its peak, and is completely lost during the exhalation phase. It was hoped also that this "excess" flow would reduce the amount of rebreathing that occurs in such a system when non-distensible tubes were used.

Closed Circle System

The ventilator is attached in the same way as for the semi-closed system. If distensible corrugated tubing is used in this system, the volume of its expansion must be measured and added to the tidal volume setting.

If the occasion requires a "third hand," the manual lever may be driven automatically by a motor (double action pneumatic piston). The tidal volume and the duration of inspiration, expiration and rest phase can be adjusted within certain limits, each by a knurled nut on the face of the motor. When the maximum tidal volume adjustment of one litre is set, the expiration phase at atmospheric pressure is limited to one-third of the total cycle. As the tidal volume is reduced to the usual clinical range (400-650 ml) a much longer expiration phase may be provided (greater than two-thirds). When manual control is once again feasible or desirable, the motor may be swung aside on the supporting stand.

The clinical efficacy of the Etsten Ventilator has been studied in 332 patients during general anaesthesia for major operations. These patients fall into four main groups as shown in Table I. In the first group, there were 25 patients who were placed in the lateral flexed position for intrathoracic operations. For most the non-rebreathing technique was employed. In the second group, there were 60 patients who were placed in the prone-jackknife position with the shoulder girdle and the iliac crest supported on a mattress as described by Bardeen (21) to allow free mobility of the chest and abdomen during operations on the spinal column (spinal cord tumor, spinal fusion and discectomy). In the third group, there were 132 patients who were placed in the supine horizontal position for upper abdominal and major superficial operations. The fourth group contained 115 patients who were placed supine and in varying degrees of head low, or Trendelenburg position ($5-15^\circ$), on a Hewer mattress.

For each patient the following were noted: body surface area in square metres, derived from the measured height and weight, body build, coded as medium when the height, weight and age of the patient were within the normal weight limits as listed by the Life Extension Institute (New York City); the underweight patient was coded as lean, and the overweight patient as obese, respectively; and the physical state was coded as 1 to 7, according to the method recommended by the American Society of Anesthesiology. The majority of patients were premedicated with meperidine and either scopolamine or atropine. Others received ataractic drugs (Phenergan®, Sparine®, Stemetil®, or Trilafon®). All premedicant drugs were administered intramuscularly, approximately one hour before induction of anaesthesia.

Anaesthesia was induced with a muscle relaxant, and a sleep dose of thiopental, followed by intubation with the largest cuffed endotracheal tube which would pass with ease. It was maintained at the lightest level consistent with the

TABLE I
SUMMARY OF CASE STUDIES

Groups	Operative site	Posture	Mean age	Mean anaesth time (min)	Blood analyses	Anaesthetic systems			Etsten ventilator control	
						NR	SC (Number of patients)	CC	Manual	Motor
I	Intrathoracic (25 patients)	Lateral flexed	39	190	13 (72)*	20	3	2	20	5
II	Spine (60 patients)	Prone jack-knife	41	225	18 (81)	29	29	2	41	19
III	Gallbladder (60 patients)	Supine horizontal	52	130	18	24	12	24	39	21
	Stomach (40 patients)	Supine horizontal	56	165	10 (155)	15	5	20	24	16
IV	Ventral hernia (11 patients)	Supine horizontal	59	105	2	7	2	2	7	4
	Miscellaneous (21 patients)	Supine horizontal	48	145	0	12	7	2	9	12
	Pelvic gynaec (60 patients)	Trendelenburg	42	115	13	26	8	26	46	14
	Bowel (43 patients)	Head low	59	130	10 (143)	18	5	20	27	16
	Abd-perineal (12 patients)	Head low-lithotomy	58	195	6	7	1	4	7	5
Totals	332 patients*				90 (451)	158	72	102	220	112
Patient controls	Various (12 patients)	Various	44	170	12 (58)	5	3	4	Manual compression of the respiration of the breathing bag	
Normal controls	No operation (8 subjects)	Supine horizontal	32		8 (16)	No anaesthesia				

*Number of blood samples

operative procedure, employing a balanced technique. When cautery was used, the primary agent was nitrous oxide-oxygen (2:1) with total flows set usually at 12 litres, supplemented by meperidine intravenously and trichlorethylene in a semi-closed system of the Magill type (Mapleson A) or in a non-rebreathing system. Otherwise cyclopropane was used with a trace of ether in a circle closed system or nitrous oxide was used with a trace of ether in a semi-closed system.

The main object of this study was to test the prediction of a respiratory rate, volume and pressure amplitude which would maintain the arterial blood at a $p\text{CO}_2$ near 40 mm. Hg and a pH near 7.35.⁵ Arterial blood samples were therefore obtained for analysis from the brachial artery in 90 patients immediately before induction of anaesthesia, at approximately half-hour intervals during anaesthesia (when possible), just prior to its termination, and within 30 minutes of discontinuing the anaesthetic.

During the period of anaesthesia 5 per cent dextrose in water and whole blood transfusions were administered as was found necessary, according to weighed or estimated losses. No base was administered to any of these patients during the anaesthetic period or until the last blood sample was drawn so that the blood data observed represented the patients' unmodified respiratory and metabolic responses to ventilation and the anaesthetics. The patients' body temperatures were not altered intentionally from normal levels in any of these operations in order to avoid gross errors in the constants for determining changes in the blood chemistry.

Each arterial blood sample was drawn anaerobically into specially prepared 10 ml. heparinized syringes. After gentle mixing, aliquots of the samples were analysed in duplicate as follows. The pH was measured immediately (or within two hours if the blood was iced) at room temperature, in a Cambridge glass electrode pH meter and corrected to body temperature (37°C) (23, 24). The haematocrit was determined by centrifuging the blood in a Wintrobe tube at 2,000 r.p.m. for 30 minutes. The oxygen capacity of the blood was determined directly by equilibration in room air for 15 minutes, according to Roughton *et al.* (25). The oxygen capacity was corrected for the effect of temperature of the Van Slyke apparatus on the dissolved oxygen. The haemoglobin content was calculated from: corrected oxygen capacity / 1.34. The oxygen and carbon dioxide content of the whole blood were determined by vacuum extraction and manometric measurement (26, 27, 28). The total carbon dioxide content of the plasma was calculated from the total CO_2 , haematocrit and pH, according to Van Slyke and Sendroy (29). The oxygen tension was derived from Dill's nomogram (30). The percentage of oxygen saturation was calculated from content/capacity and was also determined on whole haemolyzed blood, using a lucite cuvette adapted to the Beckman model DU Spectrophotometer, according to the Hickman and Frayser modification of the Nahas technique (31, 32). These two methods for determining oxygen saturation were comparable ($\text{SD} = \pm 1$ per cent). (33). The carbon dioxide tension in arterial blood and the bicarbonate concentration in the plasma were calculated from the formula derived from the Henderson-Hasselbalch equation (34, 35, 36). From each analysis of blood gas which was

⁵These are the approximate "normal" values found in normal subjects by our laboratory.

carried out, the pH (the abscissa) and the bicarbonate concentration (the ordinate) were graphed, according to the method of Davenport (35)

Controlled respiration with the Etsten ventilator was manual in 220 cases and automatic in 112. The characteristics of the ventilation cycle (volume and pressure), were determined according to the normal weight applied to Radford's nomogram and with further allowance for abnormal postures and pulmonary emphysema (37, 38). The volume setting was checked on occasion during anaesthesia by incorporating the Bennett respiratory ventilation meter with rezero and anaesthesia bypass system (Model 104B) just proximal to the endotracheal tube (see Fig 4). The rate of respiration was adjusted to 18 per minute in all but a few cases, with the inspiratory phase approximately 1 second in duration and an inspiratory peak pressure of 15 mm of Hg. The expiratory phase lasted approximately 2 seconds with the initial fraction (0.4 to 1 sec) of this phase adjusted to 2 mm below atmospheric pressure and the remainder of the cycle at atmospheric pressure. These characteristics of the ventilation cycle assumed that the inspiratory flow rate (30 to 55 litres per minute) was sufficient to provide the range of inspiratory volume desired (350 to 750 ml), and could

FIGURE 4 Clinical arrangement of apparatus: F, Fink-type non-rebreathing valve, VM, Bennett ventilation meter (Model 104B), M, motor-driven by compressed air or oxygen (non-explosive), EV, Etsten ventilator, GS, gas supply (Nitrous oxide-oxygen) directed through trichlorethylene in the non-rebreathing circuit of a Heidbrink anaesthetic machine.

be delivered in one second and removed in two seconds through the endotracheal tube by the ventilator. In order to prevent any loss of the volume in the external anaesthetic circuit, the gases were cycled through non-distensible tubing in every case.

RESULTS

A condensed summary of the results of the blood analyses appears in Table II. Protocol data not essential to the discussion were deleted from this table to conserve space. The variation (standard deviation of the mean) observed in the blood data was analysed. This variation was compared with that of eight normal, healthy, unpremedicated subjects from whom two separate arterial blood samples were each analysed in duplicate to determine "normal values" observed in our laboratory (Table III), and with arterial blood studies on twelve patients whose respiration was controlled by manual compression of the rebreathing bag. The Fisher-t test was applied to the blood data from each patient to determine whether the probability "p" of the differences observed under the conditions of the study could be due to chance alone (Table IV)

Blood Data

Intrathoracic operations. During the course of 13 of the 20 operations in the lateral flexed position employing the non-rebreathing system, 72 arterial blood samples were analysed. Regardless of the patient's age, general condition, or disease process in the lungs, there was full oxygen saturation of the blood, adequate removal of carbon dioxide and no significant rise in the fixed acids (see Figs. 5, 6 and 7). In no patient was there gross alteration in the blood pressure or pulse rate due to the anaesthetic method or agents. In some there was a slight elevation of the blood pressure until the pleura was opened and then it returned to the preoperative level. This is the reverse of what is usually seen with manual compression of the rebreathing bag. When the patient was allowed to breath spontaneously after the pleura was closed, the slight alkalosis, which had developed during controlled respiration, disappeared promptly. There was no marked tendency toward a respiratory acidosis *but hypoxia could only be avoided by continuing the administration of 100 per cent oxygen by mask or nasal catheter during the early postanesthetic period.* Recovery from anaesthetic was prompt and in none of these patients was there an alarming depression of the vital signs. The other five thoracotomy patients were managed by the semi-closed system (3 cases) and the closed circle system (2 cases) without clinical difficulty. No blood data were obtained from these. In long intrathoracic operations, manual compression of the rebreathing bag was not as efficient as controlled respiration with the ventilator (see Fig. 8).

Spinal operations. During 18 of the 60 operations in the prone jackknife position, 81 arterial blood samples were analysed. The non-rebreathing system was employed in 29 patients. Blood data obtained from 9 of these revealed that there was no significant alteration in the pH or carbon dioxide tension (see Figs. 9 and 10), except in one patient (S-22). In the latter case, the change was due to a technical defect (see Discussion). The semi-closed system of the Magill type

TABLE II
SUMMARY OF ARTERIAL BLOOD ANALYSES

Operation site	Anaesthetic system	Preoperative			Steady Anesthesia			During and end of anaesthesia			Pleura closed spontaneous breathing			Postoperative		
		pH	O ₂ Sat (%)	pCO ₂ (mm Hg)	HCO ₃ /L)	pH	O ₂ Sat (%)	pCO ₂ (mm Hg)	HCO ₃ /L)	pH	O ₂ Sat (%)	pCO ₂ (mm Hg)	HCO ₃ /L)	pH	O ₂ Sat (%)	pCO ₂ (mm Hg)
Intra-thoracic	NR Mean (13)	7.37	94	39	21.8	7.48	100	26	18.9	7.49	100	27	18.8	7.39	100	34
	SD ±	0.04		5.5	1.5	0.05		4	1.7	0.05		5	2.0	0.08		7
Spinal	NR Mean (9)	7.32	97	42	21.2	7.38	100	33	19.2	7.40	100	31	18.3	7.32	98	40
	SD ±	0.04		6	2.1	0.04		4	1.2	0.04		6	1.4	0.06		7
Upper abdominal	SC Mean (9)	7.35	97	42	22.0	7.29	100	48	22.0	7.28	100	48	21.7	7.24	98	54
	SD ±	0.04		4	1.6	0.04		7	1.8	0.06		8	1.6	0.04		7
	NR Mean (16)	7.35	93	41	22.	7.46	100	28	19.2	7.45	100	29	19.5	7.34	99	38
	SD ±	0.02		2	1.4	0.06		4	1.1	0.08		5	1.4	0.05		3
	SC Mean (7)	7.37	95	40	23.8	7.37	100	42	24.0	7.36	100	41	23.4	7.35	98	44
	SD ±	0.05		5	2.0	0.06		3	4.3	0.06		4	3.9	0.03		8
Lower abdominal	CC Mean (7)	7.34	94	43	22.4	7.40	100	35	20.6	7.42	100	33	20.5	7.37	97	38
	SD ±	0.03		3	1.3	0.05		4	1.3	0.06		4	1.5	0.05		6
	NR Mean (21)	7.34	96	39	21.4	7.46	100	26	18.3	7.46	100	26	18.2	7.32	98	40
	SD ±	0.03		4	1.7	0.05		4	1.6	0.05		5	2.0	0.05		7
	SC Mean (3)	7.35	99	40	21.6	7.31	100-44	44	21.6	7.29	100	47	21.7	7.25	97	52
	SD ±	0.03		5	1.6	0.03		5	0.9	0.04		6	1.3	0.06		6
	CC Mean (5)	7.34	97	37	19.7	7.37	100	35	19.9	7.38	100	36	19.3	7.29	90	42
	SD ±	0.04		2	1.2	0.06		7	2.3	0.06		8	2.7	0.05		4

*Number of patients

TABLE III
ARTERIAL BLOOD ANALYSIS ON NORMAL UNMEDICATED SUBJECTS

	pH	Total CO ₂ content (mM /L)	Plasma CO ₂ content (mM /L)	Haematocrit (%)	Oxygen saturation (%)	Plasma HCO ₃ content (mM /L)	pCO ₂ (mm Hg)
WS	7 35	20 9	25 2	43	99	23 9	45
	7 34	21 1	25 3	43	97	23 9	46
DE	7 31	18 6	22 2	43	95	20 9	43
	7 32	17 7	21 1	41		19 9	40
KV	7 34	18 2	22 2	43	93	21 0	42
	7 36	19 8	23 8	43	92	22 6	41
GM	7 32	18 5	22 2	47	96	20 9	42
	7 32	19 2	23 1	49	97	21 8	44
KYL	7 30	18 1	21 9	46	100	20 6	43
	7 32	17 7	21 3	45	98	20 1	40
JK	7 33	17 1	19 9	38	97	18 8	37
	7 33	17 7	20 8	40	92	19 7	38
VE	7 30	18 3	21 3	37	100	20 1	42
	7 32	17 9	20 9	37	100	19 9	39
PR	7 34	15 8	18 4	36	98	17 4	33
	7 33	15 8	18 3	36	98	17 3	34
Mean	7 33	18 3	21 7	42	97	20 6	40 6
SD	± 015	1 5	2 0	4	2 5	1 9	3 6
SE	± 005	0 5	0 7	1 5	0 9	0 7	1 3

FIGURE 5 Graph of arterial blood pH and plasma bicarbonate content

(Mapleson A system) was employed in 29 patients and blood data obtained from 9 of these revealed that there was a slight but progressive development of respiratory acidosis which persisted after the patient was turned to the supine position (see Figs. 10 and 11). This is the same effect as seen with hand-squeeze (see Fig. 12). The closed circle system was employed in only two cases and no blood data were obtained.

The blood pressure of patients in the prone jackknife position was steady during the anaesthesia, but the pulse pressure was reduced. Most of these patients became moderately hypotensive in the postoperative period, in spite of

TABLE IV
SUMMARY OF STATISTICAL ANALYSIS OF BLOOD DATA
(Significant *p* values)

Operation site	Anaesthetic system	pH				pCO ₂				HCO ₃			
		1 vs 2*	2 vs 3†	3 vs 4‡	1 vs 2	2 vs 3	3 vs 4	1 vs 2	2 vs 3	3 vs 4	1 vs 2	2 vs 3	3 vs 4
Intrathoracic	NR (13)§	001	01	ns	001	01	01	05	ns	02			
Spinal	NR (9)	05	ns	02	02	ns	01	ns	ns	01	(There is no statistical difference between steady anaesthesia and after pleura was opened)		
	SC (9)	05	ns	ns	05	ns	ns	ns	ns	ns	ns	ns	ns
	NR (16)	001	ns	001	001	ns	01	01	ns	ns	ns	ns	ns
	SC (7)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Lower abdominal	CC (7)	05	ns	ns	01	ns	ns	05	ns	ns	ns	ns	ns
	NR (21)	001	ns	001	001	ns	001	001	ns	001	ns	ns	001
	SC (3)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	CC (5)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*1 vs 2 is the difference observed between the preanaesthetic and steady anaesthesia blood samples
†2 vs 3 is the difference observed between the steady anaesthesia and samples drawn to the end of anaesthesia
‡3 vs 4 is the difference observed between the end anaesthetic and postoperative samples
§Number of patients

CONTROLLED RESPIRATION STUDY

Patient T 9 Hosp 25079 Age 27 Sex M Ht. 66" Wt. 126# B S A 1.65 Physical State Anaesth 2487 Premed. D 75mg + Scop. .4mg. Anaesthetics Thiop. 425 + M 10 + NT Build Medium Pulm. Vent Method Etsten - NR Amplitude 15,-2,0 Phases 1:1:1 Blood Pressure Preop. 140/80 During Anaesth Steady (280 minutes) Postop - Steady.							
Ventilation Data		Control /-----General Anaesthesia-----/Postop					
Time		8.45	10.15	10.45	11.15	12.30	1.30
Tidal Volume		550-----550					
Rate		16	18	-----18			24
Min. Vol.		S R	11 L	-----11 L			S R
Arterial Blood Data		Room air		Pleura open-----		Pleura closed Room air	
Hbg.		15.0	14.3	15.0	14.7	14.7	14.3
Hct.		45	43	45	44	44	43
pH		7.33	7.42	7.44	7.48	7.44	7.39
Total CO ₂ content mM/L		19.5	16.7	15.2	14.3	14.7	17.2
Plasma CO ₂ content mM/L		23.5	20.3	18.5	17.7	18.0	20.9
Plasma HCO ₃ ⁻ mM/L		22.5	19.4	17.7	16.9	17.2	19.9
pCO ₂ mm.Hg.		43	31	27	24	26	34
O ₂ content Vol. %		19.4	23.2	25.2	24.3	21.5	21.2
O ₂ capacity Vol. %		20.1	19.2	20.1	19.7	19.7	19.7
pO ₂ mm.Hg.		86	100	-----100			
% O ₂ saturation		95	100	-----100			

Summary & Remarks Segmental resections and right upper lobectomy. Lateral flexed position. Anaesthesia was maintained with Nitrous oxide, Oxygen (8:4), and a trace of Trichlorethylene in a Non-rebreathing system. Ventilation was satisfactory throughout. Uneventful course.

FIGURE 6. Protocol chart of arterial blood data

CONTROLLED RESPIRATION STUDY

Patient T 25		Hosp. 23935	Age 66 Sex M	Ht. 65"	Wt. 120	B.S.A 1.58	Physical State 3
Anaesth. 2117		Premed.: D 25 + Atrop. .6mg.		Anaesthetics.Thiop. 400 + M 16 + D 30 + NO Build Lean			
Pulm. Vent Method Etsten - NR		Amplitude 15,-2,0		Phases 1:1:1			
Blood Pressure. Preop, 110/60		During Anaesth., 110-140/60-90 (180 minutes) Postop.: Uneventful					
Ventilation Data		Control /----- General Anaesthesia -----/ Postop					
Time		7.40	8.45	9.25	10.25	11.00	
Tidal Volume		500					
Rate		18					
Min. Vol.		9.9 L					
Arterial Blood Data		Room air		Pleura open	Pleura closed	Room air	
Hbg.		11.5	11.5	11.5	12.0	12.0	
Hct.		37	37	37.5	38.5	37.5	
pH		7.38	7.40	7.50	7.54	7.35	
Total CO ₂ content mM/L		21.9	18.9	18.3	17.8	18.3	
Plasma CO ₂ content mM/L		25.4	22.1	21.8	21.3	21.3	
Plasma HCO ₃ ⁻ mM/L		24.1	21.1	21.0	20.6	20.2	
pCO ₂ mm.Hg.		42	35	28	24	38	
O ₂ content Vol. %		14.0	16.9	18.1	18.6	16.0	
O ₂ capacity Vol. %		15.4	15.4	15.4	16.0	15.4	
pO ₂ mm.Hg.		64	100	100			
% O ₂ saturation		90	100	100			

Summary & Remarks Right Pneumonectomy and tracheotomy (Bronchogenic carcinoma) Lateral flexed position. Anaesthesia was maintained with Nitrous oxide, Oxygen (5:5), and intermittent small amounts of meperidine and dimethyl tubocurarine intravenously. Note respiratory alkalosis when pleura was opened. Vital signs were quite steady throughout. Uneventful course postoperatively.

FIGURE 7 Protocol chart of arterial blood data.

CONTROLLED RESPIRATION STUDY

Patient HM Hosp. # 25539 Age 43 Sex-M Ht. 69" Wt. 161# B.S.A. 1.89 Physical State 2
 Anaesth. # 2997 Premed.: AA + Scop. .4mg. Anaesthetics: Thiop. 500 + M 16 + D60 + NT Build Medium
 Pulm. Vent - Method Hand Squeeze SC Amplitude 15,0 Phases 1:2
 Blood Pressure Preop. 110/70 During Anaesth.: 110-160/70-110 (160 minutes) Postop.: Steady

Ventilation Data	Control	General Anaesthesia					Postop
	7.45	8.45	9.30	10.00	10.48	10.50	11.40
Time							
Tidal Volume	approx. 600						/
Rate	20	18			18	28	24
Min. Vol.	S.R.					S.R.	
Arterial Blood Data	Room air	Pleura open			Pleura closed		O ₂ tent
	15.7						14.6
Hbg.	46						43
Hct.	7.33	7.38	7.35	7.35	7.24	7.22	7.30
pH	20.7	18.1	18.9	17.7	20.7	21.1	20.4
Total CO ₂ content mM/L	24.8	21.6	22.6	21.2	24.9	25.2	24.2
Plasma CO ₂ content mM/L	23.4	20.6	21.4	20.1	23.3	23.5	22.8
Plasma HCO ₃ mM/L	45	35	40	38	54	58	48
pCO ₂ mm.Hg.							
O ₂ content Vol. %							
O ₂ capacity Vol. %							
pO ₂ mm.Hg.							
% O ₂ saturation	100						100

Summary & Remarks Segmental resection of left upper lobe (Tuberculoma). Lateral flexed position. Anaesthesia was maintained for 160 minutes with Nitrous oxide, Oxygen (83), and Trichlorethylene in a Semiclosed system (Mapleson A). Blood pressure was elevated until the pleura was opened, then fell to the preoperative level and remained steady into the postoperative period. Except for low grade fever and slight patchy atelectasis in the right lung field (PO 7-9) postoperative course was uneventful.

FIGURE 8 Protocol chart of arterial blood data

CONTROLLED RESPIRATION STUDY

Patient S 17 Hosp. # 25349 Age 35 Sex M Ht. 70" Wt. 177# B.S.A. 1.99 Physical State 1
 Anaesth. # 53 Premed.: EE + Scop. .4mg. Anaesthetics: Thiop. 800 + M14 + D 90 + NT Build Medium
 Pulm. Vent : Method Elsten - NR Mechanical Amplitude 15,-2,0 Phases 111
 Blood Pressure. Preop. 100/60 During Anaesth. Steady (320 minutes) Postop.: Uneventful

Ventilation Data	Control					Postop
	10.20	11.45	12.30	1.30	2.30	4.30
Time						
Tidal Volume	S R			650		S R
Rate	15			18		22
Min. Vol.				11.7 L		
Arterial Blood Data	Room air	General Anaesthesia				Room air
	16.2					15.7
Hbg.	47	47	48	49	49	49
Hct.	7.30	7.44	7.45	7.40	7.38	7.30
pH	18.4	14.8	14.8	15.2	14.9	17.4
Total CO ₂ content mM/L	23.5	18.6	18.5	19.1	18.3	21.8
Plasma CO ₂ content mM/L	22.2	17.8	17.7	18.2	17.4	20.5
Plasma HCO ₃ mM/L	45	27	26	30	31	43
pCO ₂ mm.Hg.						
O ₂ content Vol. %						
O ₂ capacity Vol. %						
pO ₂ mm.Hg.						
% O ₂ saturation	100					100

Summary & Remarks Discectomy L4-5. Prone jackknife position. Anaesthesia was maintained for 320 minutes with Nitrous oxide, Oxygen (84), and Trichlorethylene in a Non-rebreathing system. Uneventful course.

FIGURE 9 Protocol chart of arterial blood data

FIGURE 10 Graph of arterial blood pH and plasma bicarbonate content

CONTROLLED RESPIRATION STUDY

Patient S 36 Hosp. # 2833 Age 46 Sex M } Ht. 74" Wt 235# B.S.A 2 34 Physical State 2
 Anaesth. # 1356 Premed.: D 100 + Scop 6mg Anaesthetics Thiop 500 + M40 + D50 + NT Build Obese
 Pulm. Vent Method Etsten - SC Amplitude 15,-2,0 Phases I L I
 Blood Pressure. Preop 124/84 During Anaesth. Steady (270 minutes) Postop. Uneventful

Ventilation Data	Control	General Anaesthesia	Postop
Time	7 45	9.00	11 10
Tidal Volume	S R	750	750
Rate		18	18
Min Vol		13 5 L	13 5 L
Arterial Blood Data	Room air		Room air
Hbg.	14 6	15 6	15 6
Hct.	46	48 5	48
pH	7 35	7 23	7 19
Total CO ₂ content mM/L	17 6	18 6	19 9
Plasma CO ₂ content mM/L	21.2	22 4	23 8
Plasma HCO ₃ ⁻ mM/L	20 0	20.9	22.0
pCO ₂ mm.Hg.	39	51	60
O ₂ content Vol. %	18 5	24.8	24 5
O ₂ capacity Vol. %	19.0	20 2	20.2
pO ₂ mm.Hg	92	100	100
% O ₂ saturation	96	100	100

Summary & Remarks Discectomy L5 - S1, & Spinal fusion. Prone jackknife position Anaesthesia was maintained for 270 minutes with Nitrous oxide, Oxygen (7 3), and Trichlorethylene. Vital signs were steady throughout in spite of progressive respiratory acidosis. This acidosis is a characteristic occurrence when the semiclosed system of the Magill type (Mapleson A) is employed for patients in the prone position even when pulmonary ventilation appears to be adequate.

FIGURE 11 Protocol chart of arterial blood data

CONTROLLED RESPIRATION STUDY

Patient	L W	Hosp.	21313	Age	42	Sex	F	Ht.	65"	Wt.	136#	B.S.A.	1.67	Physical State	11	
Anaesth.	1523	Premed.:	D 50mg. + Atrop. .6mg										Anaesthetics:	Thiop. 400 + M 14 + D 20 + NT	Build	Medium
Pulm. Vent.	Method	Hand Squeeze	Amplitude	15, 0		Phases	1 2									
Blood Pressure:	Preop. 104/80		During Anaesth. - Steady (145 minutes)										Postop. : Uneventful			
Ventilation Data			Control										Postop.			
Time			7 40		8.50		9 25		10.10		10.30					
Tidal Volume			~ 650													
Rate			18 - 20													
Min. Vol.			10 5 +													
Arterial Blood Data			Room air		General Anaesthesia						Room air					
Hbg.			12.1								12.5					
Hct.			39		38		38		37		37					
pH			7.30		7.26		7.19		7.19		7.24					
Total CO ₂ content mM/L			19.7		19.6		19.9		18.7		17.9					
Plasma CO ₂ content mM/L			22.9		22.6		22.8		21.5		20.6					
Plasma HCO ₃ ⁻ mM/L			21.5		21.1		21.2		19.9		19.2					
pCO ₂ mm.Hg.			45		49		55		53		46					
O ₂ content Vol. %			15.2		19.6		21.1		22.3		19.3					
O ₂ capacity Vol. %			16.3													
pO ₂ mm.Hg.			96													
% O ₂ saturation			96		100								100			

Summary & Remarks Discoideotomy. Prone jackknife position. Anaesthesia was maintained for 145 minutes with Nitrous oxide, Oxygen (63), and Trichlorethylene in a Semiclosed system without CO₂ absorption (Mapleson A). Note progressive respiratory acidosis. Vital signs remained stable.

FIGURE 12 Protocol chart of arterial blood data

bandaging the legs. This was most evident when the semi-closed system was employed. However, the blood was fully saturated with oxygen and there was no significant accumulation of fixed acids. The latter indicates that there is no metabolic disturbance due to trichlorethylene, even when a slight respiratory acidosis develops.

Upper abdominal operations. During the course of 30 of the 132 operations in the supine horizontal position, 155 arterial blood samples were analysed. The non-rebreathing system was employed in 58 patients. Blood data obtained from 16 of these revealed that pulmonary ventilation was always adequate (see Figs. 13, 14, and 15). Moderate respiratory acidosis was observed postoperatively in one patient—an obese man who had a tight abdominal binder applied following repair of a large ventral hernia. This evidently splinted the diaphragm sufficiently to impede ventilation. The semi-closed system was employed in 26 patients. Blood data obtained from 7 of these revealed that pulmonary ventilation was adequate in each case (see Figs. 16 and 17). The closed circle system was employed in 48 patients and blood data obtained from 7 of these also revealed that pulmonary ventilation was adequate in every case (see Figs. 17 and 18).

CONTROLLED RESPIRATION STUDY

Patient C 33 Hosp # 25862 Age 56 Sex F Ht. 64" Wt. 140# B S.A. 1.69 Physical State 1
Anaesth. # 2703 Premed : AA * Scop. 4mg. Anaesthetics. Thiop. 450 + M 9 + NT Build Medium
Pulm. Vent : Method Etsten - NR Amplitude 15,-2,0 Phases 1:1:1
Blood Pressure: Preop. 136/80 During Anaesth. Steady (90 minutes) Postop. - Uneventful

Ventilation Data		Control				Postop
Time		7 30	8.15	8.45	9.15	9.45
Tidal Volume			550	550		
Rate		15	18	18	22	24
Min. Vol.		S R	9 9 L	9.9 L	S.R	S R
Arterial Blood Data		Room air / ----- General Anaesthesia ----- / Room air				
Hbg.		12.8	12.1	12.1	12.8	12.8
Hct		38	36.5	36.5	38	38
pH		7.36	7.53	7.55	7.36	7.37
Total CO ₂ content mM/L		21.1	16.8	16.7	20.7	20.2
Plasma CO ₂ content mM/L		24.7	20.1	19.9	24.3	23.8
Plasma HCO ₃ ⁻ mM/L		23.4	19.4	19.1	23.0	22.6
pCO ₂ mm.Hg		43	24	23	42	40
O ₂ content Vol. %		16.4	18.1	19.1	18.1	16.7
O ₂ capacity Vol. %		17.1	16.2	16.2	17.1	17.1
pO ₂ mm.Hg		79	100		100	90
% O ₂ saturation		94	100		100	96

Summary & Remarks Cholecystectomy and appendectomy. Supine horizontal position. Anaesthesia was maintained with Nitrous oxide, Oxygen (7.3), and a trace of Trichlorethylene, in a Non - rebreathing system. Mild respiratory alkalosis during anaesthesia. Uneventful course.

FIGURE 13 Protocol chart of arterial blood data

CONTROLLED RESPIRATION STUDY

Patient G 24 Hosp # 23672 Age 65 Sex M Ht 61" Wt 107# B S A 1.45 Physical State 2
Anaesth. # 2512 Premed : D 50mg + Atrop .6mg Anaesthetics Thiop. 450 + M13 + NT Build Lean
Pulm. Vent Method Etsten - NR Mechanical Amplitude 13,-2,0 Phases 1:1:1
Blood Pressure. Preop 135/80 During Anaesth. 150 - 80/80 - 60 (185 min) Postop Chest @ PO2 2days

Ventilation Data		Control				Postop
Time		9 38	10 30	11.15	12 15	1 00
Tidal Volume		S R	600			600
Rate		16	18			18
Min. Vol.			10 8 L			10 8 L
Arterial Blood Data		Room air / ----- General Anaesthesia ----- / Room air				
Hbg.		11.6				12.3
Hct		35	34	36	36	36
pH		7.36	7.51	7.54	7.45	7.45
Total CO ₂ content mM/L		20.7	17.3	16.1	17.0	17.3
Plasma CO ₂ content mM/L		23.9	20.4	19.2	20.4	21.7
Plasma HCO ₃ ⁻ mM/L		22.7	19.6	18.6	19.6	20.8
pCO ₂ mm.Hg		41	25	22	28	29
O ₂ content Vol. %		14.6	19.4	20.6	19.8	19.1
O ₂ capacity Vol. %		15.6				16.7
pO ₂ mm.Hg						
% O ₂ saturation		92	100			100

Summary & Remarks Subtotal Gastrectomy. Supine horizontal position. Anaesthesia was maintained for 185 minutes with Nitrous oxide, Oxygen (8.3), and a trace of Trichlorethylene in a Non - rebreathing system. Vital signs remained steady following moderate decrease of blood pressure during induction. Note that moderate respiratory alkalosis developed while the patient was ventilated mechanically. Anaesthetic course was uneventful otherwise. Fever and chest rales occurred on PO2, and lasted 2 days.

FIGURE 14. Protocol chart of arterial blood data.

FIGURE 15 Graph of arterial blood pH and plasma bicarbonate content

CONTROLLED RESPIRATION STUDY

Patient C 26 Hosp.# 21481 Age 51 Sex F Ht 60" Wt 168# B S.A. 1.72 Physical State 2
 Anaesth.# 1267 Premed D 50mg. + Scop. .4mg Anaesthetics Thiop. 400 + dT 36 + NT Build Obese
 Pulm Vent Method Etsten - SC Amplitude 15,-2,0 Phases 111
 Blood Pressure* Preop. 120/78 During Anaesth Steady (210 minutes) Postop.: Uneventful

Ventilation Data	Control				Postop
Time	8 30	9.15	10 30	11 15	
Tidal Volume		500	500		
Pate	30	18	18	32	
Min Vol		9.0 L	9.0 L		
Arterial Blood Data	Room air /-----General Anaesthesia-----/ Room air				
Hbg	14.5	14.5	14.5	14.5	
Hct.	42	42	42	42	
pH	7.36	7.33	7.33	7.35	
Total CO ₂ content mM/L	20.5	19.0	19.0	19.2	
Plasma CO ₂ content mM/L	24.6	22.7	22.7	22.9	
Plasma HCO ₃ ⁻ mM/L	23.3	21.4	21.4	21.8	
pCO ₂ mm.Hg	43	42	42	41	
O ₂ content Vol. %	20.2	20.1	20.6	20.6	
O ₂ capacity Vol %	19.4	19.4	19.4	19.4	
pO ₂ mm.Hg.	100-----	100-----	100-----	100-----	
% O ₂ saturation	100-----	100-----	100-----	100-----	

Summary & Remarks Cholecystectomy, vagotomy, pyloroplasty and appendectomy Anaesthesia was maintained with Nitrous oxide, Oxygen (7.3), and a trace of Trichlorethylene, in a Semiclosed system (Mapleson A). No alteration in pCO₂ - Uneventful course

FIGURE 16 Protocol chart of arterial blood data

FIGURE 17 Graph of arterial blood pH and plasma bicarbonate content

CONTROLLED RESPIRATION STUDY

Patient C 32 Hosp # 25552 Age 56 Sex F ht 62" wt 159# B S.A 1 72 Physical State 2
 Anaesth # 2635 Premed EE + Scp 4mg Anaesthesia Thiop 500 + M II + CE Build Obese
 Pulm. Vent Method Etsten - CC Amplitude 15,-2,0 Phases I I I
 Blood Pressure Freq 120/80 During Anaesth Steady (115 minutes) Postop Uneventful

Ventilation Data	Control				Postop	
Time	9 00	10 15	10 45	11 15	11 45	12 15
Tidal Volume	S R	600	-----	600	S R	-----
Rate	14	18	-----	18	24	20
Min Vol.		10.8 L	-----	10.8 L		
Arterial Blood Data	Room air	General Anaesthesia				Room air
Hgb.	14.9	14.4	14.9	14.4	14.9	14.9
Hct.	45	44	45	43.5	45	45
pH	7.34	7.44	7.44	7.46	7.38	7.38
Total CO ₂ content mM/L	21.1	18.6	18.4	17.9	20.2	19.5
Plasma CO ₂ content mM/L	25.4	22.7	22.5	21.9	24.5	23.7
Plasma HCO ₃ ⁻ mM/L	24.0	21.7	21.5	21.0	23.3	22.6
pCO ₂ mm.Hg.	46	33	33	30	40	39
O ₂ content Vol. %	18.6	20.3	20.0	19.7	20.7	18.9
O ₂ capacity Vol %	20.0	19.3	20.0	19.3	20.0	20.0
pO ₂ mm.Hg	72	100	-----	-----	100	83
% O ₂ saturation	92	100	99	100	100	95

Summary & Remarks Cholecystectomy. Supine horizontal position Anaesthesia was maintained for 115 minutes with Cyclopropane and a trace of Ether in a Closed Circle system with CO₂ absorption. Ventilation was satisfactory. Uneventful course.

FIGURE 18 Protocol chart of arterial blood data.

Lower abdominal operations. During 29 of the 115 operations in the head low or Trendelenburg position, 143 arterial blood samples were analysed. The non-rebreathing system was employed in 51 patients. Blood data obtained in 21 of these revealed that pulmonary ventilation was adequate in every patient (see Figs 19, 20, and 21). The semi-closed system was employed in 14 patients. Blood data obtained from 3 of these revealed that there was no statistically significant change, but a slight progressive trend toward respiratory acidosis was evident (see Fig 22). The closed circle system was employed in 50 patients. Blood data obtained from 5 of these revealed that pulmonary ventilation was adequate in each case (see Figs 22, 23, and 24).

The 112 patients on whom automatic control of pulmonary ventilation was used were selected among the four groups described above. Its use was limited mainly to those patients who were poor risks from an anaesthetic and surgical point of view and/or who were extremely obese or emphysematous, and when a "third hand" would be a considerable advantage in the management of the anaesthetic. In no procedure was it found necessary to discontinue the use of the motor owing to mechanical difficulty or to difficulty in providing the desirable pressure amplitude. In a few patients it was thought desirable to have a longer expiration phase at atmospheric pressure, but this could not be adjusted. However, no apparent difficulty developed when a compromise adjustment was

CONTROLLED RESPIRATION STUDY

Patient	P 45	Hosp. #	8998	Age	49	Sex	F	Ht.	67"	Wt.	138#	B. S. A.	1.72	Physical State	3
Anaesth. #	2235	Premed :	D 50mg	+ Atrop	4mg	Anaesthetics:	Thiop. 425 + M 12 + NT	Build Medium							
Pulm. Vent. Method	Etsten - NR	Amplitude	15,-2,0		Phases		1 1 1								
Blood Pressure- Preop	110/60		During Anaesth.. Steady (160 minutes)				Postop.: Uneventful								
Ventilation Data			Control										Postop		
Time			7.45	8.55	9.25	9.55	10.35	11.25							
Tidal Volume			S R	550				550	S R						
Rate			20	18				18	24						
Min. Vol.			9.9 L				9.9 L								
Arterial Blood Data			Room air	General Anaesthesia						Room air					
Hbg.			9.9	9.9	10.5	10.8	10.8	10.8		10.8					
Hct			31	31	33	34	34	34		34					
pH			7.36	7.46	7.46	7.52	7.52	7.34		7.34					
Total CO ₂ content mM/L			19.3	17.1	17.3	16.2	16.6	18.8		18.8					
Plasma CO ₂ content mM/L			22.0	19.5	20.0	18.9	19.4	21.5		21.5					
Plasma HCO ₃ mM/L			20.9	18.7	19.2	18.2	18.7	20.3		20.3					
pCO ₂ mm.Hg.			38	27	28	23	24	39		39					
O ₂ content Vol. %			13.4	16.7	16.9	19.2	16.7	16.5		16.5					
O ₂ capacity Vol. %			13.2	13.2	14.1	14.5	14.5	14.5		14.5					
pO ₂ mm.Hg.															
% O ₂ saturation			99	100	100										

Summary & Remarks Total hysterectomy. Head low 15° position. Anaesthesia was maintained for 155 minutes with Nitrous oxide, Oxygen (8:3), and a trace of Trichlorethylene in a Non-rebreathing system. Vital signs stable throughout.

FIGURE 19 Protocol chart of arterial blood data

made. During many of the anaesthetics, the employment of this device greatly facilitated the management of the patient, and in a few cases it obviously avoided the development of a harassing situation

CONTROLLED RESPIRATION STUDY

Patient	AP 10	Hosp.-	25453	Age	64	Sex	F	Ht.	67"	Wt.	113#	B	S.A.	1	57	Physical State	2	
Anaesth.#	2670	Premed.:	D 25mg + Atrop	4mg	Anaesthetics	Thiop	375 + MIO + NT										Build	Lean
Pulm. Vent	Method	Etsten - NR	Amplitude	15,-2,0	Phases	1 1 1												
Blood Pressure:	Preop.	110/60	During Anaesth. Steady (190 minutes)				Postop. Uneventful											
Ventilation Data			Control										Postop					
Time			7 40	8 30	9 00	9 30	10 00	10 30	11 15									
Tidal Volume			S R	500	-----				500	S R								
Rate			16	18	-----				18	22								
Min. Vol.			9 0 L				-----				9 0 L							
Arterial Blood Data			Room air / ----- General Anaesthesia ----- /										Room air					
Hbg.			12 8	12 8	13.4	14 4	13 4	13 4	14 4									
Hct.			40	39 5	42	44	42	43	45									
pH			7 28	7 45	7 46	7 39	7 40	7 41	7 28									
Total CO ₂ content mM/L			20 3	17 2	16 0	16 1	16 3	16 3	19 2									
Plasma CO ₂ content mM/L			23 5	19 8	19 3	18 8	19 5	19 5	22 8									
Plasma HCO ₃ ⁻ mM/L			22 1	19 0	18 5	17 9	18 6	18 6	21 4									
pCO ₂ mm.Hg			48	28	27	30	31	30	47									
O ₂ content Vol. %			19 9	20 4	21 1	21 9	21 0	22 6	20 9									
O ₂ capacity Vol.%			17 1	17 1	18 0	19 3	18 0	18 0	19 2									
pO ₂ mm.Hg			100	-----						100								
% O ₂ saturation			100	-----						100								

Summary & Remarks Abdominal perineal resection Lithotomy position with 10° head low Anaesthesia was maintained with Nitrous oxide (9L), Oxygen (3L), and a trace of Trichlorethylene, in a non-rebreathing system Ventilation was satisfactory throughout There was a mild respiratory acidosis preoperatively, which returned after artificial respiration was discontinued

FIGURE 20 Protocol chart of arterial blood data

FIGURE 21. Graph of arterial blood pH and plasma bicarbonate content

FIGURE 22 Graph of arterial blood pH and plasma bicarbonate content

CONTROLLED RESPIRATION STUDY

Patient P 34 Hosp 24225 Age 45 Sex F Ht. 64" Wt. 148# B.S.A. 1.72 Physical State
 Anaesth 2159 Premed Phenergan 25mg. + Atropine 4 Anaesthetics Thiop. 450 + M 12 + CE Build Medium
 Pulm. Vent Method Etsten - CC Amplitude 15, -2, 0 Phases 1:1 L
 Blood Pressure Preop. 100/50 During Anaesth. Steady (120 minutes) Postop. Uneventful

Ventilation Data		Control				Postop
Time		7.30	8.30	9.00	9.30	10.00
Tidal Volume		550				550
Rate		20	18	18	18	24
Min. Vol.		S R	9.9 L	9.9 L		S R
Arterial Blood Data		Room air / General Anaesthesia / Room air				
Hbg		11.7				11.7
Hct.		39	40	39		40
pH		7.32	7.44	7.39	7.42	7.29
Total CO ₂ content mM/L		16.6	16.3	15.5	14.9	17.7
Plasma CO ₂ content mM/L		19.4	19.3	18.2	17.5	20.5
Plasma HCO ₃ ⁻ mM/L		18.3	18.4	17.3	16.7	19.3
pCO ₂ mm.Hg		37	28	29	27	41
O ₂ content Vol. %		15.5	16.5	17.3	18.3	15.1
O ₂ capacity Vol. %		15.6	15.6			
pO ₂ mm.Hg		100			100	90
% O ₂ saturation		98	100		100	95

Summary & Remarks Total Hysterectomy Head low 15° (Trendelenburg) position Anaesthesia was maintained for 115 minutes with Cyclopropane and a trace of Ether in a closed circle system with CO₂ absorption. Uneventful postoperative course.

FIGURE 23 Protocol chart of arterial blood data

CONTROLLED RESPIRATION STUDY

Patient AP 7 Hosp. 25422 Age 62 Sex M Ht. 66" Wt. 130# B.S.A. 1.66 Physical State 3
 Anaesth. 2602 Premed.: AA + Scop 4mg Anaesthetics Thiop 450 + M 8 + CE Build Medium
 Pulm. Vent Method Etsten-CC Amplitude 15, -2, 0 Phases 1:1
 Blood Pressure Preop 110/70 During Anaesth. Elevated while legs raised Postop. Steady

Ventilation Data		Control										Postop
Time		7.40	8.35	9.05	9.35	10.05	10.35	11.05	11.35	12.05	12.40	
Tidal Volume		S R	600							600	S R	
Rate		14	18							20		
Min. Vol		10.8 L								10.8		
Arterial Blood Data		Room air / General Anaesthesia / Room air										
Hbg.		13.0	13.5	13.5	14.5	14.1	14.1	13.5	11.5	12.0	11.5	
Hct		40	41	41.5	45	43.5	44	41	35.5	37	35.5	
pH		7.34	7.43	7.44	7.45	7.45	7.44	7.44	7.44	7.26	7.28	
Total CO ₂ content mM/L		17.5	14.9	15.4	14.4	14.4	15.0	15.4	14.3	17.4	16.4	
Plasma CO ₂ content mM/L		20.6	17.9	18.5	17.7	17.5	18.1	18.5	16.8	20.0	18.8	
Plasma HCO ₃ ⁻ mM/L		19.5	17.1	17.7	17.0	16.8	17.3	17.7	16.1	18.7	17.6	
pCO ₂ mm.Hg.		37	27	26	25	25	26	27	24	43	39	
O ₂ content Vol.%		17.3	20.9	19.9	20.1	20.8	22.2	19.6	18.1	18.0	14.1	
O ₂ capacity Vol.%		17.4	18.1	18.1	19.6	18.9	18.9	18.1	15.4	16.1	15.4	
pO ₂ mm.Hg		100									90	
% O ₂ saturation		98	100							70		

Summary & Remarks Abdominal perineal resection Lithotomy position with 10° head low. Anaesthesia was maintained with 10 to 15% Cyclopropane, and a trace of Ether in a closed circle CO₂ absorption system. Severe bleeding and pelvic traction during the late part of the operation caused a marked fall in blood pressure, which stabilized after atropine, rapid blood transfusion and a vasopressor. Postanaesthetic course was uneventful. There was a mild metabolic acidosis in the immediate postoperative period.

FIGURE 24 Protocol chart of arterial blood data

FIGURE 25 Anaesthetic chart

FIGURE 26. Anaesthetic chart.

DISCUSSION

Effect of Anaesthetic System

Non-rebreathing system The small resistance, the negligible dead space and the elimination of rebreathing have the same advantages as have been described for children (39). The Fmk type of non-rebreathing valve, in which the exhalation valve is occluded automatically during inhalation, makes the use of controlled respiration in the adult a much easier task (40). The operation of this valve is even more efficient when it is used with a positive and negative pressure ventilator. Although the subatmospheric pressure is not transmitted to the patient's airway, it serves to assure airtight closure of the inhalation valve diaphragm during expiration and prevents sticking of the inspiratory and expiratory valve diaphragms. One important point to remember about this valve, when used in conjunction with a fixed volume and pressure variable ventilator, is that the safety outlet must be closed tight to prevent escape of gas during inflation. This outlet was left partially open inadvertently in a patient undergoing an extensive exploratory operation of the thoracic spine. This leak in the system was sufficient to prevent adequate pulmonary ventilation. Otherwise, pulmonary ventilation with this system was sufficient to maintain normal acid-base balance in every case.

The semi-closed system designed by Ivan Magill permits most of the gas expired by the patient to escape into the atmosphere through a pressure relief valve set close to the lips. The remaining portion returns to mix with the oncoming flow of fresh gases. The original purpose of this system was to conserve gas and to utilize the patient's exhaled carbon dioxide as a respiratory stimulant (i.e., increase the depth of breathing).

Several studies of this system during spontaneous respiration under anaesthesia have established that unless fresh gas in excess of the minute volume of respiration is delivered, progressive respiratory acidosis will develop (41-47). The average adult requires a flow of at least 8 litres. When mechanical impedance affects the movement of the diaphragm or the intercostal muscles, even higher flows are insufficient.

When controlled respiration is employed with this system to overcome the mechanical impedance, it is difficult to know how much of the increased flow escapes through the pressure relief valve during inspiration. The raised resistance to breathing would also tend to cause more gas to return to the rebreathing bag during expiration. This system is therefore not as suitable for major or long procedures, in which respiration is controlled for the patient in an abnormal position because two undesirable defects are present—a large external dead space in the circuit and excessive resistance in the patient (48). Both of these enhance the tendency to respiratory acidosis. This explains why a mild respiratory acidosis developed in those patients in the prone position, in spite of clinically satisfactory pulmonary ventilation.

If it is necessary to conserve gas, the circle semi-closed system with carbon dioxide absorption should be employed. This means that trichlorethylene cannot be used, but this is not a great drawback as balanced anaesthesia may be carried on with intravenous analgesics (meperidine) or with Fluothane (0.3-0.5 per cent) together with nitrous oxide-oxygen (2:1).

The closed circle system came into widespread use with the introduction of cyclopropane (49, 50). This system was highly satisfactory, because it absorbed the expired carbon dioxide, conserved heat and water vapour, and permitted economy of anaesthetic gases (51).

Recent workers say that the canisters and the carbon dioxide absorbents generally used are inefficient (52-54). Several new styles of canisters and new brands of absorbents have been recommended. These are said to increase the efficiency of carbon dioxide absorbers in two ways: by presenting a larger volume of absorbent to the expired gas, in order to reduce the rate of exposure, and permit a continuous process of "regeneration", and by reducing channeling of the gases along the wall of the canister. The latter is accomplished by coning the lower part of the canister or by inserting baffle plates.

In this study, the older types of canister were used and were found to be efficient if fresh absorbent was properly packed in the canister, if the duration of use was limited (4 to 6 hours), and if rests ($\frac{1}{2}$ -1 hour) were allowed during long anaesthetics. A previous study of cyclopropane-oxygen in a closed circle system with controlled respiration showed also that the $p\text{CO}_2$ of patients in the supine position could usually be maintained at normal levels (55). There was no difficulty in maintaining normal acid-base homeostasis in the closed system, even with the abnormal postures reported here.

The conclusion to be drawn is: no matter how efficient the absorption system, the pH will fall and the $p\text{CO}_2$ will rise if ventilation is not adequate. With adequate pulmonary ventilation, only poor quality absorbent, inefficient valves (high resistance) or leaks in the system will cause respiratory acidosis to develop.

Effect of Posture

The effect on pulmonary ventilation of various postures employed for the convenience of the surgeon has been reviewed in previous publications (16, 56). The change from erect to the recumbent posture only slightly decreases total lung capacity, vital capacity and residual volume, but there is a large decrease in expiratory reserve volume with an inadequate compensatory increase in the inspiratory reserve volume. Pulmonary mixing is also less adequate in the supine position. In the lateral position, the lower lung has a decreased expiratory reserve volume. When cardiopulmonary disease is present, there is a marked decrease in pulmonary compliance and increased mechanical resistance of the lungs. The resistance to air flow is considerably higher during expiration than during inspiration in all subjects (57-60).

These physical changes in the lungs are aggravated by anaesthesia, as there is even less change in volume with change in airway pressure. This effect is exaggerated if the patient is obese, or in an abnormal posture. In the lateral flexed position for thoracotomy the main impedance is on the lower lung which must perform the greater part of the ventilation since the lung on the side of operation is partially, or in some cases, entirely collapsed. In the prone jackknife position, the difficulty is not only one of ventilation but also, unless the abdomen and chest are relatively free from pressure, there is marked increase in venous pressure which causes difficulty owing to persistent bleeding in the operative

field (61) The head low-lithotomy position, as is required for combined abdominal perineal resection, appeared to have little or no effect, even in the presence of emphysema if the patient was not obese. Expiration was not hindered by abnormal postures as compression of the chest or abdomen assists this phase

Effect of Airway Pressures

In this study it was found that an inspiratory peak pressure of 15 mm Hg was necessary in most of the patients to maintain adequate pulmonary ventilation with the rates and volumes selected This pressure had no deleterious effect on cardiovascular homeostasis, provided that the positive pressure phase (inspiration) did not last longer than one-third of the cycle, and the airway pressure during the expiratory phase remained at or below the ambient pressure in both the open chest and closed chest operations (15). The short period of subatmospheric pressure of low amplitude following inhalation appeared to support the blood pressure during the abdominal operations.

Automatic Cycling of the Mechanical Ventilator

When the anaesthetist is confronted by a patient who poses difficulties in ventilation owing to obesity, emphysema, or abnormal postures, an efficient automatic mechanical device removes a major bane In this situation the ventilator is as helpful to the patient and the anaesthetist as a self-retaining retractor is to the surgeon All other things being equal, any prolonged anaesthetic, particularly when the surgical requirements call for controlled respiration, is much better managed with an efficient automatic ventilator When applied to the non-rebreathing or closed circle system, after the volume and pressure in the anaesthetic circuit had been properly regulated, the Etsten ventilator provided adequate ventilation as efficiently when operated by the motor as by hand The only deficiency suspected, but not specifically observed with the pneumatic piston motor used in this study, was the need for a longer period for exhalation in the patients with severe emphysema.

Clinical Signs and Mechanical Indicators

Many warning signs precede the induction of anaesthesia, and place the anaesthetist duly on guard (62). It is unfortunate, however, that serious deficiencies in anaesthetic management produce few signals. The anaesthetist must therefore rely on prevention, rather than treatment. When signs (cold sweat, pallor, cyanosis, tachycardia, hypotension, tracheal tug, etc.) do appear, treatment is almost always instituted in the face of an impending catastrophe.

Adequate pulmonary ventilation is the most important requisite of a smooth anaesthetic for major operations. It is also the most difficult parameter to define in the operating room when the airway pressure and tidal volume are not monitored (63). Some physical methods for detecting acid base derangements due to inadequate pulmonary ventilation (respiratory acidosis) in its early stages have been described. There is a correlation between the level of the arterial blood $p\text{CO}_2$ and the presence or absence of spontaneous respiratory efforts during surgical pneumothorax When the tension of carbon dioxide is elevated,

spontaneous respiratory efforts are made whenever there is a pause in the controlled ventilation administered by the anaesthetist, whereas no spontaneous respiratory efforts are made when the $p\text{CO}_2$ is normal or low (64). This is a reliable sign, and is a guide to remember in all major operative procedures when controlled respiration is employed. The only time in the anaesthetic period when it cannot be relied upon is when anaesthesia is lightened as, for example, at the end of the operation. Then the patient must be allowed to "take over." The only course open to the anaesthetist at this time is to prevent hypoxia from occurring along with the tendency toward respiratory acidosis, as this combination is undoubtedly a primary cause of severe myocardial depression (65). In order to avoid this depression, it appears most efficacious to induce a mild respiratory alkalosis during anaesthesia, and during the concluding minutes of the operation to allow the patient to breathe spontaneously (even though inadequately at first) while oxygen only is administered. In this way, diffusion hypoxia is less likely to accompany the rise of $p\text{CO}_2$ to normal or slightly elevated levels.

The force of expiration is another important sign of pulmonary ventilation which has been mentioned. This phase of the respiratory cycle should be carefully observed, for the development of "expiratory dominance" may be an important sign of hypoxia and hypercarbia (66), and is therefore an indication of inadequate pulmonary ventilation in the patient who is breathing spontaneously. Morton studied the force of expiration as a sign of anaesthesia, and found that when expiratory force decreased there was primarily evidence of severe depression of pulmonary ventilation by deep anaesthesia (67). During intra-thoracic operations it was found also to be evidence of trapping of air in the lungs, even when automatic positive and negative pressure respiration is employed. Trapping leads rapidly to hypoxia, hypercarbia and impedes the work of the surgeon (16).

The resistance to air flow is an important consideration in setting the volume and pressure amplitude of a ventilator, especially in patients with emphysema, bronchitis and asthma. The resistance to air flow during quiet inspiration is normally less than 2 cm. $\text{H}_2\text{O/L./sec.}$ This resistance is increased four times in the emphysematous patient and almost ten times in the asthmatic patient (68-71). Since the resistance to air flow is greater during expiration, it is understandable why a forced expiratory effort, or the application of excessive subatmospheric pressure to the airway during anaesthesia, will produce, by the trapping phenomenon, a level of intrathoracic pressure which might plateau and even decrease the flow rate.

Light general anaesthesia with muscle relaxants for abdominal operations is sometimes inadequate, and is often accompanied by a variety of untoward effects, such as sudden hypotension, pallor and sweating, and postoperative mental exhaustion (72). With balanced light anaesthesia (hypnosis, analgesia and muscle relaxation) and concurrent replacement of fluid losses, judicious use of atropine and adequate pulmonary ventilation, these symptoms are not seen as commonly.

From this study it is evident that the best guide to prevention of hypoxia and

acidosis is to provide a known tidal volume, rate of respiration, and airway pressure determined according to the "normal" body weight and modified according to various impedances to ventilation (16, 73-77).

SUMMARY AND CONCLUSIONS

Pulmonary ventilation was controlled mechanically and automatically in over 300 selected major operative procedures in order to decide upon the efficacy of regulating such control by a predetermined volume and pressure amplitude. The volume selected was derived from Radford's nomogram, modified according to the "normal" weight for the patient as noted in a table of heights and weights related to the age group, and corrected for abnormal postures and the presence of pulmonary emphysema. The pressure amplitude was maintained as uniform as possible and was selected on the basis of previous experience with similar mechanical respirators. A three-phase cycle, lasting about three seconds, consisting of an initial accelerated rise to peak inspiratory pressure lasting approximately one-third of the cycle, followed by a short period of subatmospheric pressure and the remainder at atmospheric pressure was found to approach the ideal clinical condition most closely (15, 78, 79).

These characteristics of the ventilation cycle were applied mainly to the three commonly employed anaesthetic circuits: the non-rebreathing system employing a series of non-return valves, including the Fink-type valve, the Magill or Mapleson A type of semi-closed system, and the closed circle system. Nitrous oxide was the primary anaesthetic maintenance agent, with supplements of trichloroethylene, meperidine (intravenously) or occasionally a trace of ether, when the first two systems were used. Cyclopropane was the primary maintenance agent, usually with a trace of ether, when the closed circle system was employed. In every case, non-distensible tubing connected the anaesthetic machine to the patient and to the ventilator in order to ensure the delivery of the volume as set. This volume was checked with a ventilation meter, and was found to agree within the permissible volume error of the meter.

The first criterion for deciding whether such control of pulmonary ventilation was satisfactory depended upon data derived from arterial blood samples, drawn anaerobically from a representative number of patients after premedication, during the course of the anaesthetic and in the immediate postanaesthetic period. These were compared with data derived from several normal healthy adults, and from several patients whose respiration was controlled by manual compression of the rebreathing bag. The blood data measured directly included pH, haematocrit, total carbon dioxide content, oxygen capacity, oxygen content and oxygen saturation. From these were derived the haemoglobin content, plasma CO_2 content, plasma bicarbonate content, carbon dioxide tension and oxygen tension.

The second criterion depended upon the clinical observations during each individual anaesthetic as to the general condition of the patient during and after the operation, and the facility of maintaining cardiovascular homeostasis.

Whenever the non-rebreathing system was employed, anaesthesia was easy to maintain at levels of hypnosis, analgesia and muscle relaxation which were satisfactory to the surgeon and the anaesthetist. The general condition of the good risk patients was not affected adversely, when the patients were seriously ill on arrival for operation, their condition did not deteriorate and in most instances improved. Pulmonary ventilation, according to the blood data, was adequate in every case but one, in which an error in the mechanics of the non-rebreathing valve was overlooked. Although a slight respiratory alkalosis developed in the majority of the patients managed with this system, there was no evidence of a compensatory metabolic alteration in the fixed acids, the respiratory alkalosis disappeared promptly, immediately after anaesthesia, and the return of spontaneous respiration was never delayed because of the method of ventilation. These conditions prevailed in every type of operation that was studied with the non-rebreathing system.

When the semi-closed system was employed, with nitrous oxide, meperidine and trichlorethylene, pulmonary ventilation was adequate in those patients whose chest mobility was not impaired or hampered by abnormal postures. In the prone jackknife position and in the head low position, there was a slight but definite trend toward respiratory acidosis which continued into the postanesthetic period. This alteration was not accompanied by change in fixed acids. Moderate but persistent hypotension and a small pulse pressure were usually seen with the prone jackknife position. The hypotension extended to the postoperative period only when this system was used.

The closed circle system employed with cyclopropane and a trace of ether, provided satisfactory operating conditions, and pulmonary ventilation in each case maintained acid base homeostasis. Only with moderately deep ether anaesthesia could a mixed respiratory and metabolic acidosis be overlooked in this system (80).

It was evident from these data that respiratory disturbances of acid base balance and disturbances of cardiovascular homeostasis need not occur during clinical anaesthesia, if adequate pulmonary ventilation is provided. It appears evident also that metabolic acidosis does not always accompany respiratory acidosis, and does not appear when trace amounts of diethyl ether are used with nitrous oxide or cyclopropane. With a non-rebreathing system, all non-return valves and the expiratory valve must function perfectly; a semi-closed system is suitable only if high gas flows can be provided and abnormal postures are not required, and the closed circle system is highly efficient if the carbon dioxide absorbent is packed properly in the canister and the valves function with very low resistance. The dictum of Leigh that "Careful observation both of the respiration and of the signs of its inefficiency is the most important function of the anaesthetist" (81) bears re-emphasis, but to it one must now add the statement: in major operative procedures, pulmonary ventilation should be controlled according to a predetermined volume and pressure amplitude according to the individual patient, to the anaesthetic circuit employed, and to the posture adopted.

ACKNOWLEDGMENTS

I am indebted to Miss Bertha Cox, who carried out the analysis of the blood samples, to N. Shklov, Ph.D. for statistical analysis of the data; and to Dr. H. F. Poppelbaum of Stralsund, Germany, for permission to publish the diagram of his ventilator

RÉSUMÉ

Sur au-delà de 300 cas, nous avons contrôlé, mécaniquement et automatiquement, la ventilation pulmonaire au cours d'opérations majeures afin d'apprécier l'efficacité d'un tel contrôle dont le volume, la pression et l'amplitude étaient décidés au préalable. On a choisi le volume d'après le monogramme de Radford et calculé d'après le poids "normal" du malade tel que mentionné dans une table de tailles et poids selon l'âge, et corrigé selon les positions anormales et la présence d'emphysème pulmonaire. Nous avons conservé, autant que possible, un volume et une pression uniformes que nous avons déterminés d'après notre expérience acquise avec de semblables respirateurs mécanique. Un cycle à trois phases, d'une durée approximative de trois secondes, consistant en une élévation rapide initiale vers une pression inspiratoire maximale d'une durée égale environ à un tiers du cycle, suivi d'une courte période de pression inférieure à la pression atmosphérique, et le reste du cycle à une pression égale à la pression atmosphérique nous a paru réaliser à très peu près, la ventilation clinique idéale (15, 78, 79)

Nous avons étudié ces caractéristiques du cycle de ventilation en employant les trois différents circuits d'usage courant en anesthésie en évitant la réinspiration au moyen d'une série de valves, dont la valve du type de Fink, le système semi-fermé de Magill ou de Mapleson A et le système à circuit fermé. Nous avons employé comme agents avec les deux premiers systèmes de circuit le protoxyde d'azote comme agent principal, avec des traces de trichlorethylène, de la meperidine (1 v) et, à l'occasion, des traces d'éther. Lorsque nous avons employé le circuit fermé, nous avons utilisé le cyclopropane comme agent principal et, habituellement, un peu d'éther. Dans tous les cas, de façon à assurer que le volume déterminé était porté au malade, nous avons employé des tubes à parois non extensibles entre le malade, la machine et le ventilateur. On a vérifié ce volume par un ventilomètre et on n'a trouvé qu'une marge d'erreur admissible dans de pareilles circonstances.

Comme premier critère pour établir l'efficacité satisfaisante de la ventilation pulmonaire contrôlée, nous avons comparé les résultats obtenus des analyses du sang artériel prélevé à l'abri de l'air chez un bon nombre de malades, après la prémédication, au cours de l'anesthésie et immédiatement après l'anesthésie. Nous avons comparé ces résultats avec ceux obtenus chez des adultes en santé et chez plusieurs malades dont la respiration était contrôlée par compression manuelle sur le ballon. On a cherché dans le sang. le pH, l'hématocrite, le contenu total de gaz carbonique, la capacité en oxygène, le contenu en oxygène et la saturation en oxygène. De ces données, on a trouvé. l'hémoglobine, le gaz

carbonique plasmatique, le bicarbonate plasmatique, la tension de gaz carbonique et d'oxygène.

Comme deuxième critère, nous avons accepté les observations cliniques faites durant l'anesthésie de chacun des malades portant sur l'état général de chacun au cours de l'opération et après l'opération et sur la facilité de maintenir l'équilibre cardiovasculaire

A chaque fois que nous avons employé un système sans réinspiration, nous avons réussi à maintenir facilement les niveaux d'anesthésie désirés par le chirurgien et l'anesthésie, soit pour le sommeil, l'analgesie, ou le relâchement musculaire. L'état général des malades en bonne santé n'a pas été touché outre mesure, l'état des malades sérieusement touchés à l'arrivée à la salle d'opération ne s'est pas aggravé et, dans bien des cas, s'est amélioré. D'après les résultats des analyses de sang, la ventilation pulmonaire est demeurée satisfaisante à l'exception d'un cas où une erreur s'est glissée dans la mécanique des valves. En dépit du fait que nous ayons observé une légère alcalose respiratoire chez la plupart des malades traités de cette façon, nous n'avons pas noté de réactions métaboliques compensatrices dans les acides fixes, l'alcalose respiratoire est disparue rapidement, aussitôt après l'anesthésie, et le retour de la respiration spontanée n'a jamais été tardif à cause de ce système de ventilation. Cet état de chose a été observé au cours de toutes les opérations où le système de non-réinspiration a été étudié.

Quand nous avons employé un système semi-fermé, avec le protoxyde, la meperidine et le trichlorethylène, chez les malades où la ventilation pulmonaire n'était pas modifiée ou inhibée par les positions anormales qui agissent sur la mobilité thoracique, la ventilation pulmonaire est demeurée adéquate. En position ventrale avec flexion et en position de Trendelenbourg, il est apparu une légère mais constante tendance à l'acidose respiratoire qui a persisté au cours de la période post-anesthésique. Toutefois, cela n'a pas modifié les acides fixes. En position ventrale avec flexion, on a noté une hypotension légère mais persistante ainsi qu'une différentielle pincée. L'hypotension a persisté jusqu'à la période postopératoire seulement lorsque ce système a été employé.

Avec l'emploi du circuit fermé, du cyclopropane et d'un peu d'éther, dans tous les cas, nous avons obtenu une anesthésie satisfaisante au cours des opérations et le maintien de l'équilibre acide-base. C'est seulement avec une anesthésie à l'éther plutôt profonde que nous avons constaté une acidose respiratoire et métabolique avec ce système (80).

Il devient évident, d'après ces résultats, qu'on ne devrait pas observer, durant l'anesthésie clinique, de modifications de l'équilibre acide-base ni de modifications de l'équilibre cardio-vasculaire, si l'on maintient une ventilation pulmonaire adéquate. Il apparaît également que l'acidose métabolique n'accompagne pas toujours l'acidose respiratoire et qu'elle n'apparaît pas lorsqu'on emploie des traces d'éther diéthylique avec le protoxyde ou le cyclopropane. Quand on emploie un système de non-réinspiration, toutes les valves empêchant le retour et la valve d'expiration doivent fonctionner d'une façon parfaite. Il convient d'employer le système semi-fermé seulement si l'on peut donner un grand débit

de gaz et si la chirurgie n'exige pas de position anormale. Quant au circuit fermé, il est tout-à-fait efficace à condition que l'absorbant du gaz carbonique soit bien tassé dans le contenant et que les valves n'offrent qu'une résistance minime. Le dicton de Leigh. "une observation attentive de la respiration et des signes de son efficacité demeure la fonction la plus importante de l'anesthésiste" (81) mérite qu'on insiste, mais, maintenant, il faut lui ajouter "au cours des opérations majeures, la ventilation pulmonaire devrait être contrôlée à un volume, une pression et une amplitude déterminés d'avance pour chacun des malades, selon la variété de circuit anesthésique employé et la position exigée."

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