THE INFLUENCE OF ANESTHETIC TECHNIQUE ON OXYGEN CONSUMPTION DURING TOTAL CARDIOPULMONARY BYPASS

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MAINTENANCE of anesthesia during total cardiopulmonary bypass for open heart surgery has been accomplished by two main techniques: (1) adding gases to the oxygenator during bypass [1, 2] or (2) administration of intravenous anesthetic agents and/or relaxants just before bypass.[3, 4] The purpose of this study is to compare the effects of the two methods on the physiologic status of the patient during perfusion, particularly the rate of oxygen consumption.

METHODS

The first 20 patients having open heart surgery at the University of Oregon Medical School Teaching Hospital were anesthetized with cyclopropane-ether-oxygen and maintained during bypass by introducing cyclopropane into the oxygenator at a flow rate of 1–2 liters/minute together with a mixture of 97.5 per cent oxygen and 2.5 per cent carbon dioxide at a flow rate of 12–14 liters/minute. This mixture of cyclopropane usually sufficed to keep the patient quiet, although mild to moderate diaphragmatic activity was present in most cases. If cyclopropane was discontinued during bypass, the patient would begin vigorous muscle activity within 3 to 5 minutes. Further administration of cyclopropane would result in cessation of movement in 1 to 2 minutes.

The remainder of the patients, undergoing open heart surgery at this institution, of which 23 are included in this report, have been anesthetized with thiopental-nitrous oxide-oxygen and maintained during bypass by giving an intravenous relaxant before the pump is started. The reason for the change in technique was the surgeon's desire to use cautery and because of the explosion hazard in adding large volumes of cyclopropane-oxygen-mixtures to the oxygenator. Eight of the patients were given *d*-tubocurarine in a dosage of 0.3 mg./kg. and 15 of the patients were given decamethonium in a dosage of 0.25 mg./kg. body weight. The relaxants were given about 3 minutes before the pump was started and with the dosage mentioned, most of the patients were completely quiet during bypass. If movement was noted or if vigorous diaphragmatic activity began, one-half the initial dose of relaxant together with a small amount of thiopental was given.

Perfusion rates approximating basal cardiac output were utilized in all patients. A rotating disk-type oxygenator was used. Arterial and venous blood samples were drawn from the patient approximately 5 minutes before starting bypass. Samples were drawn from the arterial and venous sides of the oxygenator 5, 25, and 45 minutes after starting bypass. Blood gas analyses were done by the Van Slyke manometric technique and *p*H was measured with a Cambridge research model *p*H meter. The arterial buffer base was calculated from the Singer-Hastings nomogram. Body temperatures were monitored with an esophageal probe. Further details of perfusion technique and laboratory determination are given in a previous publication.[5]

Flow rates were measured following perfusion by using the same pump settings and arterial catheter employed during perfusion and allowing the pump to discharge into a calibrated container. Oxygen consumptions were calculated from the flow rates and the arteriovenous oxygen differences. Predicted basal oxygen consumptions based on body weight were calculated from the tables of Clark.[6]

RESULTS

The data on flow rates, oxygen consumptions and venous saturations are given in tables 1 and 2. The mean flow rates and predicted oxygen consumption were the same in patients receiving cyclopropane during bypass (group

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TABLE 1

FLOW RATES, PREDICTED BASAL OXYGEN CONSUMPTIONS, ACTUAL OXYGEN CONSUMPTIONS AND VENOUS OXYGEN SATURATIONS DURING TOTAL CARDIOPULMONARY BYPASS IN PATIENTS RECEIVING CYCLOPROPANE DURING BYPASS

Patient	Age	Flow L./M.²/min.	Pred. O_2 Cons. cc./M.²/min.	5 Minutes		25 Minutes		45 Minutes	
				O_2 Cons. cc./M.²/min.	Venous O_2 Sat. %	O_2 Cons. cc./M.²/min.	Venous O_2 Sat. %	O_2 Cons. cc./M.²/min.	Venous O_2 Sat. %
1	9	2.74	160	108	71	132	59	170	51
2	7	2.86	147	127	69	181	67	190	53
3	7	2.73	184	142	76	150	71	210	58
4	7	2.54	166	112	74	124	70		
5	8	3.05	144	121	68	154	66	177	61
6	10	3.52	162	90	75	153	69	184	74
7	2½	2.78	184	128	77	122	79		
8	7	3.00	173	171	68				
9	3	2.58	163	129	72				
10	2	2.35	169	141	67	136	68	119	74
11	12	1.74	133	83	75	79	81	90	72
12	4½	2.64	177	106	79	126	75	130	79
13	11	2.68	149	113	82	121	74		
14	3½	2.47	174	96	72	156	63		
15	6	3.30	170	184	70	264	63		
16	7	2.18	167	85	79	127	72		
17	4	2.61	186	141	68	120	70	130	68
18	5	2.42	179	167	70	152	58		
19	4	2.24	173	170	57				
20	3½	2.86	173	112	73	105	73	220	59
Mean	6	2.66	167	126	72	141	69	162	65
*95% C.L.		±0.02	±4	±12	±9	±16	±4	±34	±6

* 95 per cent confidence limits.

1) as in the patients receiving relaxants before bypass (group 2). In the cyclopropane group the actual oxygen consumption showed a distinct tendency to increase as bypass time increased, but in the relaxant group, the actual oxygen consumption remained the same throughout bypass. A comparison of the two groups showed that after 5 minutes of bypass, the mean actual oxygen consumptions were not significantly different but that at the 25 and 45 minute bypass time intervals the mean actual oxygen consumptions of the cyclopropane group were 29 and 50 per cent greater respectively than the consumptions of the relaxant group. These differences are significant at the 0.01 level. The difference in actual oxygen consumptions is demonstrated in figure 1. The actual oxygen consumptions in both groups were significantly lower than the mean predicted basal value except at the 45-minute time interval in the cyclopropane group where the mean actual consumption was the same as the mean predicted basal value.

Venous saturations were lower in the cyclopropane group than in the relaxant group as would be expected from the oxygen consumption values. At the 5, 25 and 45 minute time intervals after beginning bypass in the cyclopropane group, the mean venous saturations were 72, 69, and 65 per cent respectively, while the mean venous saturations in the relaxant group at the same time intervals were 80, 78 and 79 percent. The difference in venous saturations between the two groups are significant at the 0.01 level at the 25 and 45 minute intervals.

Mean buffer base, *p*H and P_{CO_2} values for both groups before and during bypass are shown in table 3. Samples were drawn for the pre-bypass determinations approximately 5 minutes before the perfusion started. Mean buffer base, P_{CO_2} and *p*H values before bypass

TABLE 2

FLOW RATES, PREDICTED BASAL OXYGEN CONSUMPTIONS, ACTUAL OXYGEN CONSUMPTIONS AND VENOUS OXYGEN SATURATIONS DURING TOTAL CARDIOPULMONARY BYPASS IN PATIENTS RECEIVING RELAXANTS BEFORE BYPASS

Patient	Age (years)	Flow L./M.²/min.	Pred. O_2 Cons. cc./M.²/min.	5 Minutes		25 Minutes		45 Minutes	
				O_2 Cons. cc /M.²/min.	Venous O_2 Sat. %	O_2 Cons. cc./M.²/min.	Venous O_2 Sat. %	O_2 Cons. cc./M.²/min.	Venous O_2 Sat. %
21	6	2.07	164	104	80	104	79		
22	5	2.54	201	91	76				
23	12	2.52	159	68	88	87	82		
24	10	2.46	156	90	77				
25	5	2.24	182	82	80	69	75	108	75
26	4½	2.32	187	86	79	108	74		
27	16	2.78	137	66	84	96	79		
28	9	2.70	172	137	81	104	85		
29	5	2.56	187	87	79	80	82		
30	8	2.64	153	109	81	97	82		
31	7	2.74	172	79	89	96	83	130	81
32	11	2.57	143	90	85	92	83	110	79
33	5	2.90	185	173	78	133	76	90	86
34	2	2.70	215	130	75				
35	10	2.50	167	88	82	118	69		
36	16	1.88	91	87	77	187	77	94	75
37	16	2.74	164	78	88	116	64		
38	4½	2.52	169	108	82	123	76		
39	10	2.68	170	96	87	112	81	108	82
40	7	3.46	182	108	82				
41	7½	3.26	182	108	65	117	80		
42	7	2.95	188	232	63	142	73	123	76
43	6	3.25	183	126	80				
Mean	8	2.65	170	105	80	110	78	109	79
*95% C.L.		±0.02	±4	±20	±12	±11	±2	±12	±7

* 95 per cent confidence limits.

in both groups were consistent with a mild respiratory alkalosis due to hyperventilation. The mean buffer base in the cyclopropane group before bypass was 44.0 mEq./l. and in the relaxant group, the mean buffer base before bypass was 48.7 mEq./l. The lower mean buffer base in the cyclopropane group is significant at the 0.01 level. Mean *p*H and

TABLE 3

MEAN ARTERIAL BUFFER BASE, *p*H AND P_{CO_2} VALUES ±95 PER CENT CONFIDENCE LIMITS BEFORE AND DURING BYPASS IN PATIENTS GIVEN CYCLOPROPANE (GROUP 1) OR RELAXANTS (GROUP 2)

		Before Bypass	5 Minutes	25 Minutes	45 Minutes
BB mEq./l.	Group 1	44.0 ± 1.0	41.6 ± 1.0	41.4 ± 2.6	40.9 ± 1.7
	Group 2	48.7 ± 0.7	44.2 ± 0.7	43.9 ± 2.5	43.2 ± 1.6
*p*H	Group 1	7.42 ± 0.01	7.36 ± 0.02	7.37 ± 0.02	7.35 ± 0.02
	Group 2	7.45 ± 0.01	7.39 ± 0.01	7.40 ± 0.01	7.39 ± 0.02
P_{CO_2} mm. Hg	Group 1	34.4 ± 2.2	35.1 ± 2.7	34.1 ± 3.8	35.7 ± 2.9
	Group 2	37.1 ± 2.7	35.4 ± 2.5	34.8 ± 2.3	33.7 ± 2.4

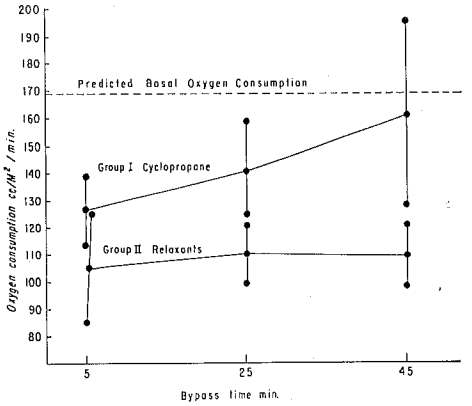

FIG. 1. Mean oxygen consumptions at three time intervals during cardiopulmonary bypass in patients given cyclopropane (group 1) or relaxants (group 2). Length of vertical lines through each point indicates 95 per cent confidence limits. Dotted line indicates predicted basal oxygen consumption for both groups. Differences between group 1 and group 2 are significant at 25 and 45 minute intervals. All values are significantly lower than predicted basal value except at 45 minute interval in group 1.

P_{CO_2} values were not significantly different before bypass. In both groups there was a significant drop in buffer base and *p*H from the pre-bypass period to the 5 minute interval after starting bypass. After 5 minutes of bypass, the mean buffer base was 41.6 mEq./l. in the cyclopropane group and 44.2 mEq./l. in the relaxant group. Both the change from pre-bypass buffer base values and the difference between the two groups is significant at the 0.01 level. The mean *p*H fell from 7.42 to 7.36 in the cyclopropane group in the first 5 minutes of bypass, and from 7.45 to 7.39 in the relaxant group in the same time interval. The change from pre-bypass *p*H values is significant at the 0.01 level in both groups, but the difference between the groups is not significant. There were no further significant changes in the *p*H or buffer base values in either group at the 25 or 45 minute time interval, and there was no significant difference between the two groups at either time interval. Mean P_{CO_2} values were unchanged during bypass, and there was no significant difference in the mean P_{CO_2} between the two groups at any time interval. Two patients (nos. 1 and 2) in the cyclopropane group showed a mild metabolic acidosis after 45 minutes of bypass with a *p*H fall to 7.26 in both instances. One of these patients (no. 2) was extremely light and exhibited more muscle activity than usual throughout bypass. The other patient (no. 1) was subjected to arterial unsaturation (81–86 per cent) because of a faulty cuvette oximeter. All other patients in both groups had arterial saturations above 98 per cent throughout bypass.

Arterial pressures measured at the beginning of bypass averaged 65 mm. of mercury in the cyclopropane group and 69 mm. in the relaxant group. Pressures measured after the intracardiac procedure was completed and immediately before the removal of the caval tapes averaged 72 mm. of mercury in the cyclopropane group and 74 mm. of mercury in the relaxant group. Neither of these differences are significant.

Body temperature at the end of bypass averaged 98.0 F. in both groups.

DISCUSSION

Anesthesia and premedication usually depress oxygen consumption below basal values.[7] In our series, the group of patients maintained on cyclopropane had oxygen consumptions significantly lower than basal values during the early stages of bypass, but as bypass time increased, the oxygen consumption increased to basal values. The reason for this increase is not clear, but may have been due to the tendency of the anesthesiologist to lighten the anesthesia as the bypass became more prolonged. Patients in the relaxant group had oxygen consumptions even lower than the cyclopropane group, with no tendency to increase with bypass time.

The rate of oxygen consumption assumes particular importance during cardiopulmonary bypass since the pump flow rate simulates a fixed cardiac output. Oxygen consumptions which are too large to be compatible with this fixed output may lead to an inadequate perfusion with consequent metabolic acidosis and other grave sequelae. Flow rates used during perfusion for cardiopulmonary bypass under normothermic conditions may be the same as, or significantly less than, basal cardiac output. If a flow rate is selected which is approximately equal to basal cardiac output, and the metabolic oxygen demand of the patient is greater

than basal, the perfusion may not be adequate to maintain normal tissue metabolism. Flow rates less than basal cardiac output in a normothermic patient impose even more limitation on the maximum rate of oxygen consumption consistent with an adequate perfusion. Some authorities feel that to insure adequate perfusion, the flow rate and oxygen consumption should be such as to maintain the venous saturation at 70 per cent or above.[8] In our series, 9 of the patients given cyclopropane had venous saturations which at some time during bypass were less than 65 per cent, and the lowest saturation recorded in this group was 51 per cent. The lowest venous saturation recorded in the relaxant group was 64 per cent and the remainder of the patients in the group had venous saturations above 65 per cent, with most falling in the range of 70 per cent and above.

Mean arterial buffer base and *p*H values did not indicate any trend toward metabolic acidosis in either group during bypass. The only noteworthy change in mean buffer base and *p*H values was the drop in buffer base and *p*H from the preperfusion period to the 5 minutes bypass time interval. This change is most probably due to the metabolic acidosis which develops in blood used to prime the oxygenator. The lower preperfusion buffer base in the first group of patients to whom cyclopropane-ether-oxygen anesthesia was given is probably due in part to the accumulation of fixed acids which occurs with ether administration.[9]

Our observations supplement those of Mendelsohn and associates [1] who used cyclopropane during bypass and noted that there was a strong correlation between the amount of diaphragmatic activity and the degree of metabolic acidosis. Although only one of our patients given cyclopropane developed a mild metabolic acidosis because of excessive oxygen consumption during bypass, we felt that the patients given cyclopropane showed more muscle activity in the extremities and diaphragm than those patients given relaxants during bypass.

From the technical standpoint, either anesthetic technique seemed to be satisfactory and no patient in our series suffered any serious complications as a result of the type of anesthetic management. None of the patients recalled any return of consciousness during surgery, and all patients resumed spontaneous respirations within 10 to 20 minutes after discontinuing bypass.

In a previous paper,[5] it was pointed out that oxygen consumption during perfusion may be quite variable and not necessarily the same as basal consumption predicted on the basis of body size. The data presented in the present paper show that the anesthetic technique is an important factor in producing this variation. The lower oxygen consumption in the relaxant group is most probably due to the smaller amount of muscle activity observed in these patients. It would, no doubt, be possible to achieve the same degree of inactivity by adding a sufficient amount of cyclopropane or other anesthetic agent to the oxygenator, but this method would present the hazard of loss of vasomotor tone or other complications from excessively deep anesthesia. The technique of giving a muscle relaxant prior to bypass seems to us to be the easiest and safest way to provide a quiet patient whose oxygen demand is less than basal requirements.

Summary

Anesthesia was maintained during total cardiopulmonary bypass in 20 patients by introducing cyclopropane into the oxygenator. An additional 23 patients were given muscle relaxants before starting bypass and no anesthetic gases were added to the oxygenator. Flow rates in both groups approximated basal cardiac output. The mean oxygen consumptions in the two groups of patients were not significantly different after 5 minutes of bypass; but after 25 and 45 minutes of bypass, the mean oxygen consumptions in the cyclopropane group were 29 and 50 per cent greater respectively than the consumptions of the relaxant group. The mean oxygen consumptions were significantly lower than the predicted basal value at all time intervals except in the cyclopropane group after 45 minutes of bypass, at which time the mean oxygen consumption was equal to basal. Mean venous saturations during bypass were significantly lower in the cyclopropane group after 25 and 45 minutes of bypass. At 25 minutes, mean venous saturation was 69 per cent in the cyclopropane

group and 78 per cent in the relaxant group; at 45 minutes mean venous saturation was 65 per cent in the cyclopropane group and 79 per cent in the relaxant group. Mean buffer base and *p*H values did not indicate a tendency toward metabolic acidosis during bypass in either group. Mean arterial pressures during bypass were the same in both groups. The lower oxygen consumptions in the relaxant group appear to be due to the minimal amount of skeletal muscle activity observed in these patients during bypass.

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TETANUS Nine cases of severe tetanus were treated with heavy sedation with hypnotics, narcotics, phenothiazine derivatives and nitrous oxide. Full curarization was employed in conjunction with positive pressure mechanical respiration thru a tracheotomy. Complications associated with these cases were pulmonary embolism attributed to prolonged relaxation, bone marrow depression attributed to the nitrous oxide, hyperglycemia and ketosis attributed to the tetanus and azotemia and pulmonary infections. (*Lawrence, J. R., and Sando, M. J. W.: Treatment of Severe Tetanus, Brit. Med. J. 2: 113 (Aug. 1) 1959.*)

TETANUS NEONATORUM Ten cases of tetanus neonatorum were treated with heavy sedation, large doses of intramuscular curare or mephenesin, tracheotomy following intubation and mechanical intermittent positive pressure respiration. Two infants survived the episode of tetanus but died for other reasons. Three infants survived. Exuberant granulation tissue imperiled the trachotomy airway in some cases. (*Smyth, P. M., and Bull, A.: Treatment of Tetanus Neonatorum with Intermittent Positive-Pressure Respiration, Brit. Med. J. 2: 108 (Aug. 1) 1959.*)

LOCAL FOR CHILDREN From his own large practical experience, the author expresses the opinion that any operative interference in children in the oro-facial region can be carried out under local anaesthesia (infiltrative conduction anaesthesia), and only in rare instances under a combination of one of these methods with light or full narcosis with nitrous oxide. The article gives the method of infiltration and conduction anaesthesia, and the special features of their application in children. (*Vaisblat, S. N.: Special Features of Local Anaesthesia in the Stomatological Treatment of Children, Vrach. Delo 8: 839 1957.*)