TECHNIQUE

A Reliable Method for Determination of Initial Sweep Gas Flow Rates Using the CML Oxygenator

Gerard J. Myers
Izaak Walton Killam and Victoria General Hospitals
Halifax, Nova Scotia, Canada

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Abstract

(*J. Extra-Corpor. Technol.* 18(4) p.221-224 Winter 1986) The Cobe Membrane Lung Oxygenator is a Z folded flat plate membrane made of polypropylene material, with an effective surface area of $2.5m^2$. Since its introduction to the market in 1982, it has provided perfusionists with all the benefits of the membrane technology, while utilizing an ease of operation that is equal to the bubble oxygenator. Cobe's initial recommendation for use was to maintain a constant sweep gas flow rate of 10 liters/minute and control the pCO_2 by adding extraneous carbon dioxide to this ventilating gas. However, the use of Alpha Stat Control (non-temperature correction) for acid base balance requires the elimination of all extraneous carbon dioxide during bypass, and thereby has required perfusionists to rely on their own experience with this membrane, or follow Cobe's second recommendation of establishing an initial sweep gas flow rate of 1:1 (gas:blood).

Presented here is a method of determining the initial sweep gas flow rate while using Alpha Stat Control. This method appears useful during the initiation of bypass and the use of moderate hypothermic temperature. A well-known parameter in respiratory medicine, the V/Q ratio, is used in the determination and must be established prior to bypass.

The results of this paper indicate that use of the V/Q ratio in establishing a desired $PaCO_2$ for the first 10 minutes of bypass is more reliable and consistent than the use of the 1:1 gas to blood flow ratio. However, the method has proved useful only for the initial blood gas sampling, after which sweep gas flows must be reduced to a V/Q of at least 1.0 for the remainder of the case. Use of the V/Q ratio appears to allow the perfusionist to predict the initial $PaCO_2$ within an accuracy of ± 4 mmHg.

Introduction

Since the Cobe Membrane Lung[a] (CML) entered the perfusion market, the majority of those perfusionists using this device have applied one of the previously mentioned guidelines for setting sweep gas flow rates (Cobe catalog # 50-100). As previously stated, one of these recommendations required the operator to maintain a constant sweep gas flow rate of 10 liters/minute (LPM), and control the $PaCO_2$ by adding carbon dioxide (CO_2) through a flowmeter provided on the Cobe blender. This is the most popular method of conducting bypass when pH Stat Control (temperature correction) is used. Recent information[1,2] has led many perfusionists to adopt the alpha stat method of controlling blood gases, thereby eliminating the addition of CO_2 to the bypass procedure. This alpha stat method required us to use the manufacturer's other recommendation of a 1:1 gas to blood flow ratio. As indicated in Table 1, this resulted in some very inconsistent blood gas results on the initial blood samples.

Direct communications to: Gerard Myers, 12 Londra Court, Dartmouth, Nova Scotia, Canada, B2W 5A5

[a] Cobe Laboratories, Inc., Lakewood, CO, 80215

Table 1
Use of 1:1 Gas to Blood Flow Ratio at the Initiation of Bypass

	pH	Venous Blood Temp.	pCO_2	Blood Flow lpm	Gas Flow lpm	Gas:Blood Ratio
pt A	7.36	27 °C	45 mmHg	4.7	5.0	1.1:1
pt B	7.27	27 °C	55 mmHg	3.8	4.0	1.1:1
pt C	7.32	27.7 °C	46 mmHg	4.0	4.0	1:1
pt D	7.32	28.5 °C	43 mmHg	5.5	5.0	0.9:1
pt E	7.29	25.5 °C	59 mmHg	4.9	7.0	1.4:1
pt F	7.38	27 °C	44 mmHg	5.0	5.0	1:1
pt G	7.29	25.6 °C	52 mmHg	5.9	4.0	0.7:1
pt H	7.31	29 °C	49 mmHg	5.0	5.0	1:1
pt I	7.37	28 °C	46 mmHg	5.0	5.0	1:1
pt J	7.44	25 °C	50 mmHg	4.6	4.5	1:1
Mean	7.34	27 °C	48.9 mmHg	4.84	4.85	0.96:1.1
S.D.	0.32	0.91	4.9	0.59	0.84	—

This prompted some hypothetical views based on the theoretical concepts of a membrane oxygenator. These membranes are more or less functioning as one large alveolar—capillary unit, with no direct blood to gas interface and diffusion acting as the method of gas transfer. In the oxygenator, minute ventilation ($\dot{V}$) is determined by the sweep gas flow rate coming from the blender. The cardiac output (CO) is determined by the arterial pump head revolutions and the tubing stroke volume, which subsequently determines the blood flow (Q). We use an optimum Q for hypothermic cardiopulmonary bypass (HCPB) of 2.5 liters/meter^2/min. in the adult patient.

In an anesthetized, intubated patient prior to bypass, $\dot{V}$ is controlled by the anesthetist with mechanical ventilation. V is determined by both the respiratory rate (RR) and the tidal volume (TV) in the formula RR x TV = $\dot{V}$. On the other hand, $\dot{Q}$ is determined by the patient's heart rate times his or her stroke volume, or the CO. A $\dot{V}/\dot{Q}$ ratio can then be easily determined prior to bypass, the efficiency of which is confirmed by a pre-bypass blood gas sample. Hence, one should now be able to establish a similar $\dot{V}/\dot{Q}$ ratio for bypass by using the sweep gas flow and the pump flow rate (2.5 liters/meter^2/min). This should theoretically allow the perfusionist to maintain the $PaCO_2$ very close to pre-bypass values.

Methods

Blood gas results on 10 consecutive patients were reviewed using the $\dot{V}/\dot{Q}$ determinations. Before the start of bypass, the patients' RR and TV were obtained from the Ohio 7000 ventilator[b] with bellows. The CO was recorded on the Seimens Sirecust 404 cardiac output module[c] through a Swan Ganz catheter[d]. A simultaneous blood sample was drawn for gas analysis on the Corning 175 blood gas analyzer[e]. Recording of nasopharyngeal temperature, pH and $PaCO_2$ were made at this time.

Prior to the start of bypass, the $\dot{V}/\dot{Q}$ was established, and the optimum top flow (Q) for bypass was calculated in the usual manner (2.5 liters/meter^2/min). To obtain the required sweep gas flow rate for the initiation of bypass, the calculated $\dot{Q}$ was simply multiplied by the pre-bypass $\dot{V}/\dot{Q}$ ratio.

$$(\dot{V}/\dot{Q}\text{ ratio})\ \dot{Q} = \text{Sweep Gas Flow}$$

Blood samples for gas analysis were drawn 10 minutes after the start of bypass and cooling. The mean temperature of the venous blood at the time of sampling was 26.6 °C (Table 2). Arterial blood samples were drawn again prior to the termination of bypass, at a mean venous blood temperature of 35.9 °C (Table 3).

After the initial blood samples were taken, patients 5 through 10 were returned to $\dot{V}/\dot{Q}$ ratios of 1.1 (mean). Patients 1 through 4 were maintained on their initial

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[b] Ohio Medical, Rexdale, Ontario, Canada
[c] Seimens, Mississauga, Ontario, Canada
[d] Edwards Laboratories, Inc., Santa Ana, CA, 92711
[e] Corning Medical and Glass Works, Medfield, MA 02052

Table 2
Use of $\dot{V}/\dot{Q}$ Ratio to Establish Gas to Blood Flow Ratio at the Initiation of Bypass

	Pre-Bypass						On Bypass (10 minutes)					
	pH	pCO_2	Naso. Temp.	$\dot{Q}$	$\dot{V}$	$\dot{V}/\dot{Q}$	pH	pCO_2	Blood Temp.	$\dot{Q}$	$\dot{V}$	$\dot{V}/\dot{Q}$
pt 1	7.46	34	36.1	4.9	9.0	1.8	7.41	39	25	4.0	7.3	1.8
pt 2	7.49	39	35	5.1	8.5	1.6	7.39	42	27	5.2	8.5	1.6
pt 3	7.52	36	35.8	3.9	9.0	2.3	7.50	35	23.4	4.3	10	2.3
pt 4	7.49	34	36	4.9	5.9	1.2	7.36	41	26	4.6	5.6	1.2
pt 5	7.47	34	34.8	4.2	7.5	1.8	7.46	36	26	4.7	8.5	1.8
pt 6	7.49	33	34.1	3.1	7.2	2.3	7.45	36	25	4.9	11	2.3
pt 7	7.52	32	34	2.7	6.3	2.3	7.50	28	30	4.5	10	2.2
pt 8	7.45	38	34.9	4.3	7.0	1.6	7.44	35	25.9	4.5	8.0	1.7
pt 9	7.43	38	35.6	3.5	7.0	2.0	7.50	32	30	3.1	6.3	2.0
pt 10	7.50	37	35.1	2.6	8.5	3.3	7.51	32	28	4.8	16.5	3.5
Mean	7.48	35.5	35.1	3.9	7.6	2.0	7.45	35.6	26.6	4.5	9.2	2.0
S.D.	0.03	2.29	0.67	0.86	1.03	0.65	0.05	4.08	1.26	0.55	2.90	0.59

Table 3
Prior to Termination of Bypass

	pH	pCO_2	Venous Blood Temp.	$\dot{Q}$	$\dot{V}$	$\dot{V}/\dot{Q}$	Pre-Bypass $\dot{V}/\dot{Q}$
pt 1	7.57	23 mmHg	37 °C	4.2	7.8	1.8	1.8
pt 2	7.46	33 mmHg	35 °C	4.9	8.0	1.6	1.6
pt 3	7.50	27 mmHg	35 °C	4.7	11.0	2.3	2.3
pt 4	7.42	38 mmHg	36 °C	4.6	5.8	1.2	1.2
pt 5	7.44	36 mmHg	36 °C	5.2	5.0	0.96	1.8
pt 6	7.38	37 mmHg	37 °C	5.2	5.0	0.96	2.3
pt 7	7.38	39 mmHg	35 °C	4.5	5.5	1.2	2.3
pt 8	7.45	29 mmHg	36 °C	4.6	4.5	0.97	1.6
pt 9	7.54	31 mmHg	36 °C	4.0	4.0	1.0	2.0
p 10	7.51	32 mmHg	36 °C	4.1	5.0	1.2	3.6
Mean	7.47	32.5	35.9	4.6	6.2	1.3	2.05
S.D.	0.51	2.02	0.81	0.48	1.24	0.54	0.62

$\dot{V}/\dot{Q}$ ratios for the remainder of bypass (Table 3). All patients had an uneventful termination of bypass.

Results

As indicated in Table 1, the use of a simple 1:1 gas to blood flow ratio at the initiation of bypass yields some very inconsistent blood gas results. Even a ratio of 1.4:1 proved inadequate in patient E, as indicated in the $PaCO_2$ of 59 mmHg. However, the results obtained from the use of the $\dot{V}/\dot{Q}$ ratio were more reliable and considerably more consistent (Table 2). According to the latter findings, the $PaCO_2$ may be predicted to a relative accuracy of ± 4 mmHg when using the $\dot{V}/\dot{Q}$ ratio for the initial blood gas sample. During bypass when the initial blood sample was taken, mean venous blood temperatures were around 26.6 °C for the $\dot{V}/\dot{Q}$ trials, and 27 °C for the 1:1 ratio trials.

During the $\dot{V}/\dot{Q}$ trials the mean pre-bypass $PaCO_2$

was: 35.5 mmHg, while the mean bypass $PaCO_2$ (initial) was 35.6 mmHg. In the 1:1 gas to blood ratio group, the mean $PaCO_2$ on the initial bypass blood samples was 48.9 mmHg. Prior to the termination of bypass, the mean $PaCO_2$ of patients 1 through 4 was 30.3 mmHg, and the mean $PaCO_2$ of patients 5 through was 34.0 mmHg. (Table 3).

Discussion

During the $\dot{V}/\dot{Q}$ trials, control over the $PaCO_2$ was achieved by using a wide variation in the initial sweep gas flow rates, which ranged from 5.6 lpm to 16.5 lpm. This finding may attest to the theory that each patient's $\dot{V}/\dot{Q}$ ratio will vary at the start of bypass, and therefore an initial 1:1 gas to blood ratio may not suffice with this oxygenator. It should be noted that those patients requiring the higher sweep gas flows had the greatest pre-bypass $\dot{V}/\dot{Q}$ mismatch, possibly due to a low output state or an increase in the amount of A-V shunting that was present.

It should also be noted that these variable sweep gas flow rates were effective up to 10 minutes after cooling was started, as shown by the mean blood temperature of 26.6 °C. Our basic understanding of hypothermia tells us that metabolism and CO_2 production decrease as the temperature drops. This appears to hold true for the remainder of HCPB, as evidenced by the necessity to reduce the $\dot{V}/\dot{Q}$ ratio to 1.0 for the remainder of bypass.

A possible explanation for this paradox must be explored, and perhaps may be found when we accept the fact that the start of any bypass procedure is described in the literature as an induced state of clinical shock.[3] At the start of this induced shock mean arterial pressures drop, catecholamine release increases, fluids shift and areas of the body become hypoperfused. This period of bypass is often referred to as Phenomenon A,[4] and may possibly result in an increase in the oxygen extraction and CO_2 production at the tissue level, in spite of the ongoing hypothermia.

This might explain the necessity to maintain a $\dot{V}/\dot{Q}$ ratio similar to the patient's own for the initial 10 minutes of bypass, even during moderate hypothermia. Maintaining the $\dot{V}/\dot{Q}$ would allow the effective removal of an increased CO_2 production until the body was able to adapt to its induced shock-like state and peripheral perfusion improved. Is it possible that this period of adjustment is 10 minutes, or sometimes more?

Regardless, when obtaining a CO is possible, the use of the $\dot{V}/\dot{Q}$ ratio in determining sweep gas flow rate with the CML oxygenator may be a definite advantage to the perfusionist. But we must consider that this method has only been applied to the CML oxygenator, and may not be effective with other membrane oxygenators.

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