The Effect of Gas Scavenging on Hollow Fiber Membrane Oxygenator Performance

Charles F. Jerabek, BS, CCP, Howard G. Walton, BA, CCP, Sally Doerfler, BA

Providence Medical Center
Portland, OR

Key words: Oxygenator, membrane, gas scavenging, oxygenator peformance, FiO_2

ABSTRACT

During a routine cardiopulmonary bypass a patient's blood gases did not respond in the expected manner. After detailed review it was determined that the gas scavenging system was affecting the hollow fiber membrane oxygenator's performance, even though it was set up according to manufacturer's recommendations. Using a closed oxygenator-deoxygenator system primed with recently outdated human blood,the hypothesis that changing gas scavenging suction levels affected oxygenator performance was tested. Pump speed, venous blood gas levels, temperature, hemoglobin, FIO_2 and sweep gas rate were all kept constant. The results showed that as suction levels increased, oxygenation capacity decreased according to the formula:

$$\text{Suction(mm.Hg)}=5130 * .98\text{\^{}}(\text{Art. } PO_2 - \text{Venous } PO_2)\ [R=-1].$$

However, ventilation capacity increased following the equation:

$$\text{Suction(mm.Hg)}=-945.26 + 65.67*(\text{Venous } PCO_2-\text{Art. } PCO_2)\ [R=.78].$$

Sweep gas flow rate was 2.5 liters/minute and FIO_2 was 50%. Results were comparable when a different FIO_2 was used as a baseline. The conclusion was that gas scavenging suction predictably affects hollow fiber membrane oxygenator performance and can be used as an adjunct in blood gas management. However, if a perfusionist wishes to minimize the effects of gas scavenging, then a regulated low pressure vacuum source must be used.

INTRODUCTION

The scavenging of waste gas in the operating room is a method used by anesthesiologists to minimize staff exposure to inhalation anesthetics as required by OSHA standards.[1] In cases requiring cardiopulmonary support at Providence Medical Center, this practice is also used on gases recovered from the membrane oxygenator. Manufacturers recommend that the gas scavenging system used on hollow fiber oxygenators be vented to atmosphere[2,6] to avoid accidental pressurization of the gas phase of the oxygenator and subsequent introduction of gas emboli into the blood stream should the scavenging line become occluded and to prevent negative pressure on the gas side of the oxygenator.

This relationship is illustrated by the equation:

TRANSMEMBRANE PRESSURE = (INLET PRESSURE + OUTLET PRESSURE) / 2 + SUCTION

While performing a routine cardiopulmonary bypass using an external flow hollow fiber membrane oxygenator (Sarns SMO)[a] the blood gas results deviated from the expected and published[4] values (**Table 1**). The hypothesis emerged that our gas scavenging system was adversely affecting oxygenator performance.

MATERIALS AND METHODS

To test this hypothesis a circuit was set up using an oxygenator/deoxygenator system (**Figure 1**). This circuit consisted of two Sarns SMO hollow fiber membrane oxygenators and was primed with blood and Plasmalyte-A to a hemoglobin level of 10.5 g/100ml. The oxygenator sweep gas was set at a flow rate of 2.5 liters/min among with a FIO_2 of 50 percent using a Sechrist[b] blender and flowmeter. Blood temperature was maintained at 36°C using the oxygenator's heat exchanger and monitored with a Yellow Springs[c] Series 400 thermistor probe at the oxygenator's arterial temperature probe site. Cardiac output was maintained at three liters per minute using a calibrated Shiley[d] Stockert heart lung machine and Tygon[e] S50HL Class VI tubing. Blood anticoagulation was assured by the addition of 10,000 units of bovine heparin to the priming solution. pH was adjusted using sodium bicarbonate. The deoxygenator was set to return a venous saturation value in the range of eighty to ninety percent and a PCO_2 level of 50. These values were obtained by regulating the flow of the nitrogen sweep gas in the deoxygenator, along with changing the flow of CO_2 mixed in

---

Address correspondence to: *Charles F. Jerabek, Department of Surgery, Providence Medical Center, 4805 N. E. Glisan, Portland, OR 97213*

[a] Sarns, Ann Arbor, MI
[b] Sechrist, Anaheim, CA
[c] Yellow Springs
[d] Shiley, Irvine, CA
[e] Tygon

TABLE 1(PART A): CASE STUDY ARTERIAL BLOOD GAS RESULTS

TIME	VENOUS TEMP	PUMP SPEED	FIO2	SWEEP GAS FLOW	HGB	ART pH	ART pCO2	ART pO2	O2 SAT	BASE EXCESS	O2 CONTENT
10:16	31	4.3	70	3.5	5.7	7.38	29	128	99	-7.3	7.9
10:31	27	3.7	75	2.5	5.9	7.42	28	96	98	-5.1	8
10:40	26	3.8	80	2	6.3	7.45	27	114	99	-4.4	8.7
10:51	27	4.2	90	1.5	6.2	7.44	27	308	100	-5	9.2
11:01	27	4.3	70	1	6.3	7.43	28	178	99	-4.9	8.9
11:17	27	4.3	77	0.8	6	7.44	26	142	99	-5.1	8.4
11:30	27	4.4	77	0.8	6	7.44	26	121	99	-5.6	8.3
11:41	27	4.7	85	0.8	6.1	7.43	27	142	99	-5.4	8.5
11:52	27	4.6	90	0.8	6.3	7.42	27	159	99	-5.9	8.9
12:01	29	4.6	100	1.7	6.4	7.36	32	337	100	-6.3	9.6
12:11	32	2.5	100	2	6.2	7.45	30	260	100	-2.2	9.1
12:24	36	4.8	100	2.4	6.3	7.44	30	147	99	-3	8.8
12:37	37	5	100	3.9	6.9	7.28	45	342	100	-4.8	10.3
12:48	37	4.5	100	3.5	7.4	7.39	33	341	100	-4	11
12:51	37	4.4	90	3.5	7.8	7.38	34	186	99	-4.6	11.4

BSA = 1.73 HT = 155 CM WT = 74 KG

TABLE 1(PART B): VENOUS BLOOD GAS RESULTS AND CALCULATED PARAMETERS

TIME	VENOUS pO2	VENOUS SAT	VENOUS OXYGEN CONTENT	AVDO2	OXYGEN CONSUMP	OXYGEN AVAIL	OXYGEN EXTRACT	S.V.R.
10:16	43	73.5	5.7	2.2	94.4	342.9	0.275	1150
10:31	42	76	6.1	1.9	70.3	302.2	0.233	1499
10:40	41	77	6.6	2	79.3	336.6	0.236	1549
10:51	50	85.1	7.2	2	85.9	393.9	0.218	1542
11:01	45	81	7	2	84.2	384.4	0.219	1368
11:17	43	79.5	6.5	1.9	82.9	369.9	0.224	1209
11:30	40	76.3	6.3	2	90.7	368.2	0.246	1100
11:41	43	79.9	6.7	1.9	89.2	407.1	0.219	986
11:52	46	82	7.1	1.8	83.3	409.6	0.203	1313
12:01	55	87	7.6	2	92.3	449.7	0.205	1228
12:11	41	77.5	6.6	2.5	64.6	233.5	0.277	1655
12:24	32	63.2	5.4	3.4	164	428.3	0.383	1032
12:37	43	73.4	6.9	3.4	171.2	523.8	0.327	879
12:48	44	77	7.8	3.2	144.2	496.4	0.291	819
12:51	41	70.9	7.5	3.9	172.3	508.4	0.339	1112

TABLE 2: THE EFFECTS OF SUCTION ON OXYGENATOR EFFICIENCY

FIO2	GAS FLOW L/M	NEG SUCTION IN TORR	ART pO2	ART pCO2	HGB	ART SAT	VENOUS pO2	VENOUS pCO2	VENOUS SAT	A - V pO2 DIFFER	A - V pCO2 DIFFER	% pO2	% pCO2
50	2.5	0	300	35	10.5	99.8	61.4	49.1	89.5	239	14.3		
50	2.5	80	300	38	10.6	99.8	61.6	55.3	88.1	238.7	17.7	99.87	123.78
50	2.5	120	269	33	10.5	99.7	58.4	48.8	87.9	211.4	16.1	88.45	112.59
50	2.5	180	251	33	10.6	99.7	57.9	50.4	87.1	193.5	17.9	80.96	125.17
50	2.5	220	239	32	10.6	99.7	60.4	48.4	88.4	178.2	16.6	74.56	116.08
50	2.5	400	207	31	10.5	99.6	60.5	50.1	88.4	146.2	19	61.17	132.86
50	2.5	0	266	36	10.6	99.8	57.1	45.8	92.1	209.1	9.8		
100	2.5	0	536	44	10.5	99.9	94.9	67.2	95.4	440.7	12.9		
100	2.5	400	360	43	10.6	99.8	93	61.8	94.8	266.6	18.5		

TABLE 3: INITIAL SUCTION LEVEL VERSUS NEGATIVE LINE PRESSURE QUANTIFICATION

SUCTION LEVEL IN TORR	LINE GAUGE DISPLACEMENT IN CM
0	0
80	1
120	2.5
180	4.5
220	6
400	OFF SCALE

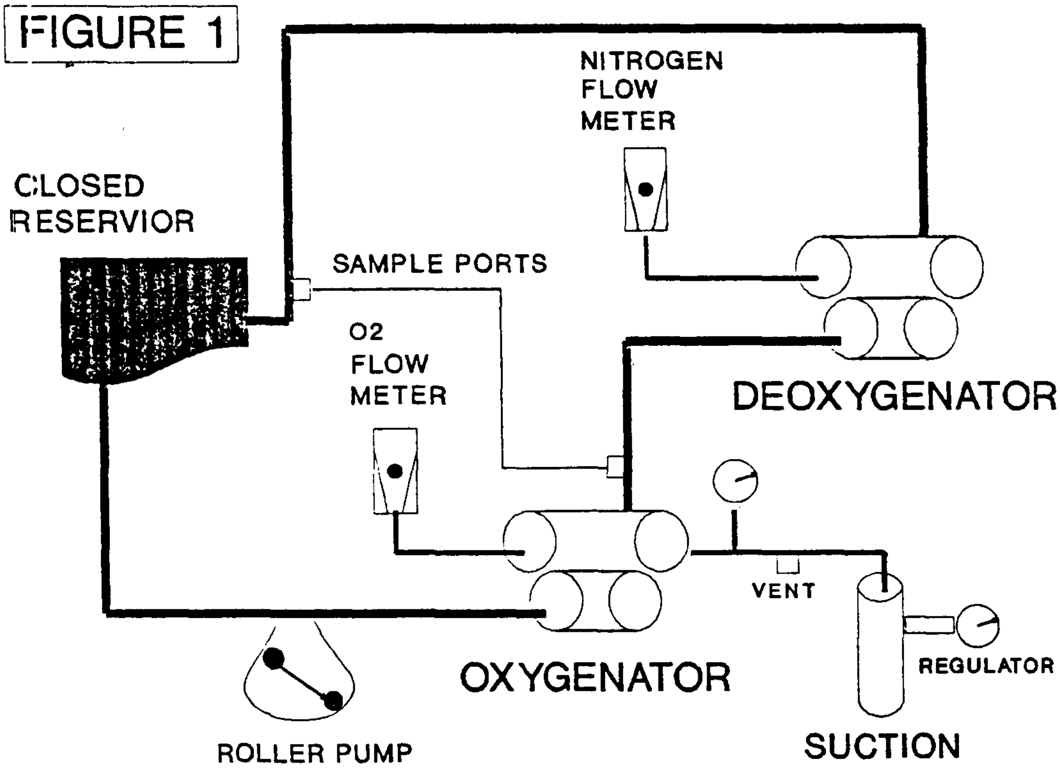
TABLE 4: NEGATIVE PRESSURES EXERTED AT VARIOUS SUCTION LEVELS

GAS FLOW L/M	VACUUM PRESSURE IN NEG TORR	OPEN LINE NEG PRESSURE IN TORR	CLOSED SYSTEM NEG PRESSURE
2.5	0	0	0
2.5	50	0	0
2.5	100	1	3
2.5	150	2	5
2.5	200	4	6
2.5	250	6	8
2.5	300	8	11
2.5	350	11	17
2.5	MAX	14	25

TABLE 5: VACUUM LEVELS REQUIRED TO MANAGE SWEEP GAS FLOWS

GAS FLOW L/M	MIN VACUUM REQ FOR NEG PRESS
0.5	10
1	15
1.5	20
2	30
2.5	35
3	35
3.5	35
4	35
4.5	35
5	35
5.5	35
6	40
8	50
12	80

FIGURE 1



PRESSURE QUANTIFICATION SETUP

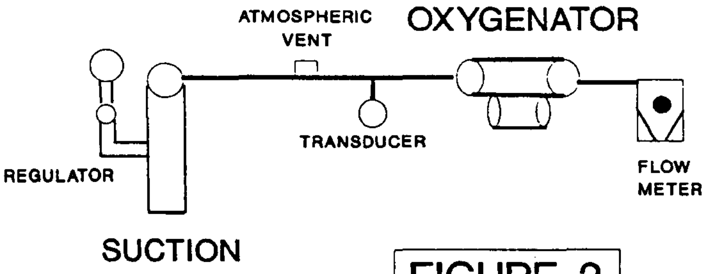
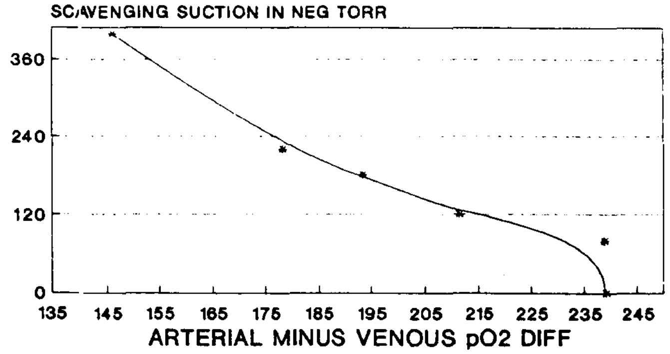


FIGURE 2

FIGURE 3

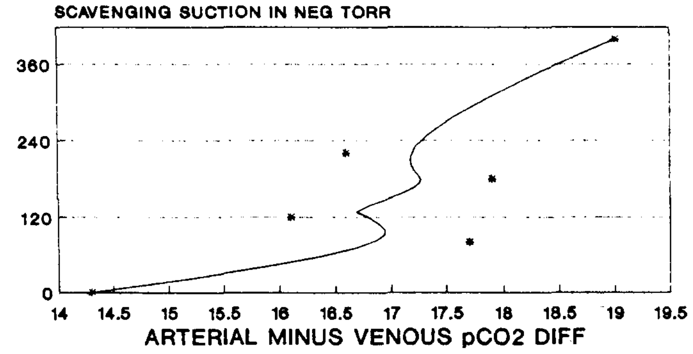
pO2 CHANGE OBSERVED AT VARIOUS GAS SCAVENGING LEVELS



R=-1
A-V pO2 = 901.99 * (SUCTION ^ -0.3)

FIGURE 4

pCO2 CHANGE OBSERVED AT VARIOUS GAS SCAVENGING LEVELS



R=.78
A-V pCO2 = (945.26 + SUCTION) / 65.67

VACUUM TEST CIRCUIT

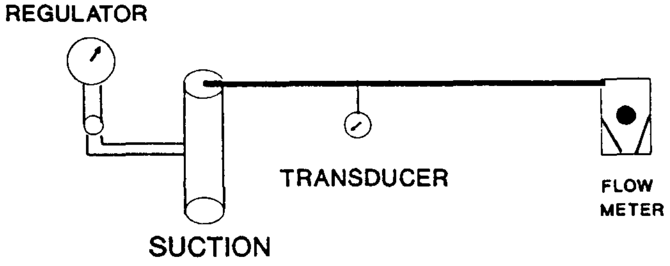


FIGURE 5

with the nitrogen. Arterial and venous blood gas samples were taken simultaneously when a steady venous saturation was recorded using venous blood gas samples individually. Gas scavenging was controlled with a Baxter pressure regulator. Blood samples were obtained at several suction levels. The scavenging line was also monitored for negative pressure at a site distal to the entrainment of atmospheric gases using a homemade manometer. Due to limitations in equipment capability, the AAMI conditions of 12 g/dl hemoglobin, 65% inlet oxygen saturation and47 mm Hg venous PCO_2 could not be met. A subsequent circuit was then designed (**Figure 2**) to quantify the negative line pressure generated versus vacuum rate. This circuit consisted of a Sarns SMO oxygenator, a controlled gas inlet flow of 2.5 liters per minute, the manufacturer's recommended gas scavenging system, a Baxter[f] suction regulator and a Sorenson[g] strain gauge pressure transducer between the oxygenator and atmospheric vent in the gas scavenging line.

RESULTS

Table 2 shows the blood gas results at different suction gauge settings. The negative value is assumed in all equations and a vacuum level of 400 mm Hg indicates that the vacuum gauge was reading negative 400 mm Hg which is greater than a level of 300 mm Hg. The PO_2 decreased significantly with increasing vacuum while the decrease in PCO_2 was less pronounced. The line pressure experiment results (**Table 3**) showed that the oxygenator was being subjected to increasingly negative gas pressures as the suction was increased in spite of the atmospheric venting. When the suction pressure used to regulate gas venting exceeded 180 mmHg and our in line measurement scale went out of range, no attempt was made to recalibrates it in order to quantify the effect of increased suction rates on post vent line pressure at the time of the experiment. Subsequently, a strain gauge transducer was hooked up to the scavenger line and the results are listed in table four.

When the results were evaluated using regression analysis option of the Windows Graph program by Micrografx (**Figures 3 and 4**) the listed formulas and degree of correlation emerged.

DISCUSSION

The results of this simple experiment show that as the negative pressure on the gas phase of a hollow fiber membrane oxygenator increases, there is a logarithmic decrease in the oxygenator's ability to oxygenate blood (R = 1.0) down to an efficiency of 61% at 400 mm Hg following the equation:

ART. PO_2 - VENOUS PO_2 = 901.99 * (SUCTION IN mmHg ^ -0.3)

The effect of high gas scavenging suction on an oxygenator's ability to remove CO_2 is not quite as predictable (R = 0.78). The maximum percent increase occurred at a suction level of 400 mmHg with an increase in PCO_2 gas exchange efficiency of 123% with the curve following the linear equation:

VENOUS PCO_2 - ART. PCO_2 = (SUCTION IN mmHg + 945.26)/ 65.67

As is often the case, when a single entity is isolated, it becomes clear that there were other forces influencing the result. The abnormal blood gas values reported in the case listed in table one were only partially caused by the unregulated gas scavenging vacuum. The observed low PCO_2 values were lower than the in vivo study model would predict suggesting some metabolic abnormality with the patient or a lack of accuracy in the PCO_2 gradient prediction. However, the PO_2 values fit the range predicted with an unregulated maximum gas scavenging (greater than 400 mm Hg) of the experiment when using the data published by Dearing as a baseline.[4] Using blood sample twelve as an example, the PO_2 gradient was 104. When this value was corrected for gas scavenging suction impact (/.61), the final PO_2 gradient increased to 170. This value was comparable to Dearing's adjusted value of 187 (published average PO_2 gradient of 97 corrected for FIO_2 (100/52)). This calculation showed that there was no problem with the oxygenator in question. It should be noted at this point that the parameter used to measure an oxygenator's response to suction was just straight PO_2 levels and not oxygen availability or consumption.[5] The reason for this choice is that the authors believe that this value more truly indicates oxygenator performance since the factors of hemoglobin level, patient status, and position and shape of the hemoglobin dissociation curve are eliminated as variables.

This study was performed using Sarns SMO hollow fiber membrane oxygenator; however, we feel the results will apply to all membrane oxygenators which do not contain an atmospheric entrainment port built into their housing (one example of an oxygenator with an entrainment port is the Shiley M-2000 membrane oxygenator). The literature supplied with the oxygenators deals with the set up of the scavenging line but ignores the variation encountered with the scavenging source. If gas scavenges is to be effective yet have minimal influence on an oxygenator's performance, the suction source must be regulated. A vacuum pressure of 40 mm Hg will handle up to 6 l/m of gas flow without spilling any gas into the operating room's atmosphere using 10 feet of standard connecting tubing. **Figure 5** shows the circuit used to obtain these results while table five lists the range evaluated.

We have found it beneficial to use the increased suction pressure as an adjunct to our blood gas control. One example of this modification of blood gas control is that during valve replacement surgery, the surgeons flush the field with CO_2. At hypothermia we have been able to blow off the excess CO_2 while maintaining a reasonable PO_2 with the aid of suction variation.

Although we are not recommending that suction regulation of arterial blood gases in hollow fiber membrane oxygenators become common practice, we feel that by being aware of its effects patient safety will be enhanced and oxygenator replacement during cases due to a falsely perceived oxygenator failure might decrease if excessive gas scavenging suction was examined as a cause of decreased arterial PO_2 values.

---

f. Baxter, Irvine, CA

g. Sorensen

REFERENCES

1. OSHA.: Occupational exposure to waste anesthetic gases and vapors. # HE20.7110:AN3/985, 1985.
2. Sarns 3M Health Care Group: Form 16279001 Rev. C. 1987.
3. Minnitech Corporation: Hemocor Plus Hemoconcentrator Instructions for Use. Form 67099-001/C, 1987.
4. Dearing JP. et al.: Clinical trials of a new low prime hollow fiber membrane oxygenator. *JECT*. 18(2):49-54, 1986.
5. Higgins M et al.: Is your oxygenator failing? Diagnosis and suggested treatment. *JECT*. 19(3):330-337, 1987.
6. Lavanchy C.: Scavenging gas from membrane oxygenators. *Health Devices*. Sept.-Oct.:343-344, 1987.