Original Article

An In Vitro Comparison of Gas Transfer and Pressure Drop of the Bentley Duraflo Coated Spiral Gold and the Medtronic Carmeda Coated Maxima Hollow Fiber Membrane Oxygenators

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ABSTRACT

Two models of heparin coated, hollow fiber membrane oxygenators were tested in vitro to compare gas transfer and transoxygenator pressure drop using an established protocol. Oxygen and carbon dioxide transfer rates were measured at blood flows of 2.5 and 5.0 liters per minute with gas flow : blood flow ratios of 1:1 and 2:1 at both blood flows. All testing was performed under normothermic conditions. The data shows that oxygen transfer increases as blood flow is increased in both oxygenators. Similarly, carbon dioxide transfer is increased by both increased blood and gas flows. Finally, the pressure drop was dependent on blood flow rate alone. This study demonstrated these two oxygenators to be comparable in both oxygen and carbon dioxide transfer and also in transoxygenator pressure drop.

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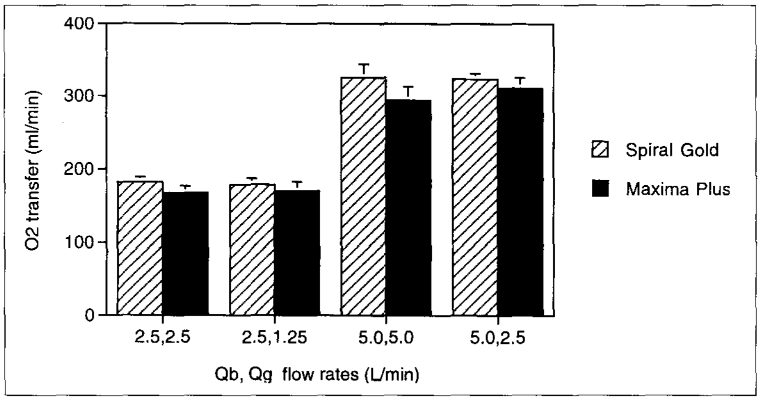
INTRODUCTION

The introduction of heparin coated oxygenators has been hailed as a significant advance in cardiopulmonary bypass (CPB). Consistent with the results achieved with heparin coated circuits, the manufacturers of the new generation of oxygenators advertise decreased bleeding after CPB and less complement activation (1-4). However, as a counter to these advantages, perfusionists have observed what appears to be a decrease in gas transfer in the heparin coated units that may vary with manufacturer. Manufacturers do report performance parameters including gas transfer and pressure drop, yet data is not comparable between brands due to widely differing testing conditions and methods. In order evaluate products from different manufacturers, we devised an in vitro testing protocol to evaluate membrane oxygenators while simulating the actual oxygenator conditions observed during CPB (5). The purpose of this study was to evaluate gas transfer and pressure drop of currently available heparin coated hollow fiber membrane oxygenators (HFMOs), the Bentley Spiral Gold[a] and the Medtronic Carmeda Maxima[b].

Figure 1: Oxygen transfer rates for the Bentley vs. Medtronic heparin coated oxygenators at varying blood flow (Qb) to gas flow (Qg) ratios.



MATERIALS AND METHODS

Oxygenators were obtained directly from the manufacturers. The test circuit consisted of a single-pass system, with the blood path of the circuit being continuous from a reservoir through a roller to a heat exchanger to the deoxygenator and a second reservoir. From this reservoir, the blood is pumped through the test HFMO with a centrifugal pump back to the first reservoir. A detailed description of all components of the circuit has been previously described (5). The circuit utilized fresh heparinized bovine blood with a hematocrit of 37 ± 2%. The protocol was approved by the Institutional Animal Care and Use Committee, and studies were performed in accordance with the "Guide for the Care and Use of Laboratory Animals," published by the National Institutes of Health (NIH Publication No. 85-23, revised 1985).

All testing was performed under normothermic conditions. Two blood flows were tested: 2.5 L/min and 5 L/min, with blood (Qb) to gas (Qg) flow ratios of 1:1 and 2:1 sequentially at each blood flow. Venous inlet conditions were:

Oxyhemoglobin Saturation	65 ± 1%
Hematocrit	37 ± 2%
Base Excess	0 ± 5mmol/L
pCO_2	45 ± 2mmHg
Temperature	37 ± 1°C

Each unit was run for a minimum for 20 minutes to allow for stabilization before blood samples were drawn for blood gas analysis. Arterial and venous samples were drawn simultaneously for blood gas analysis and O_2 hemoglobin saturation measurement. Oxygen transfer was calculated using the Fick principle:

$$O_2 \text{ transfer rate} = [(\text{Art Sat} - \text{Ven Sat}) \times 1.39 \times \text{Hgb}] + \text{Sol}(pO_2)\ (\text{ml/min})$$

Carbon dioxide transfer was calculated using the Fick principle:

$$CO_2 \text{ transfer rate} = \frac{[\text{ Exhaust } CO_2\ (\%)\ (Qg)\ ]}{100\ Qb}$$

where: Exhaust CO_2 = % of Exhaust CO_2 gas
Qg = oxygenator exhaust gas flow rate
Qb = oxygenator blood flow rate

Pressure drop was calculated as the difference between inlet blood pressure and outlet blood pressure, as measured directly with fluid filled pressure transducers[c] connected via luer lock connectors on either side of the oxygenator and recorded on a Physio-Control VSM-1 physiological monitor[d]. All measurements were repeated twice at each of the four blood flow/gas flow conditions, for each oxygenator.

RESULTS

As would be expected, oxygen transfer was increased primarily by increasing blood flow rates (Figure 1). There was no statistical difference between the Bentley and Medtronic models at any of the four blood flow/gas flow conditions (Table 1). Carbon dioxide transfer was increased both by increased blood and gas flows (Figure 2). Again, there was no statistical difference between the two models of oxygenators (Table 2). Finally, pressure drop was increased with higher blood flow rates, consistent with expectations (Figure 3). No difference was seen between the two models in terms of pressure drop (Table 3).

DISCUSSION

This study showed no difference in gas transfer or pressure drop of either of the two currently available HFMOs, the Bentley Spiral Gold model or the Medtronic Max-ima Plus. However, we acknowledge that this was a limited study, utilizing a small number of oxygenators for testing. The use of the test circuit allows for the evaluation and comparison of these HFMOs in a controlled clinical simulation. We have previously found that clinical results follow the trend observed in these in vitro simulation studies, and thus would expect no difference in the clinical arena.

REFERENCES

1. Videm V, Mollnes TE, Garred P, Svennevig JL. Biocompatibility of extracorporeal circulation: In vitro comparison of heparin-coated and uncoated oxygenator circuits. J Thorac Cardiovasc Surg. 1991; 101: 654-60.
2. Videm V. Svennevig JL, Fosse E, Semb G, Osterud A, Mollnes TE. Reduced complement activation with heparin-coated oxygenator and tubings in coronary bypass operations. J Thorac Cardiovasc Surg. 1992; 103: 806-13.
3. Kirschfink M, Kovacs G, Mottaghy K. Extracorporeal circulation: In vivo and in vitro analysis of complement activation by heparin-bonded surfaces. Circ Shock. 1993; 40: 221-6.
4. Nilsson L, Storm KE, Thelin S, Bagge L, Hultman J, Thorelius J, Nilsson U. Heparin-coated equipment reduces complement activation during cardiopulmonary bypass in the pig. Artif Organs. 1990; 14: 46-8.

Table 1: Oxygen Transfer (ml/min)

Qb (L/min)	Qg (L/min)	Spiral Gold	Maxima Plus
2.5	2.5	182.1 ± 7.3	167.6 ± 9.8
2.5	1.25	178.8 ± 8.2	170.1 ± 12.9
5.0	5.0	325.2 ± 19.0	294.1 ± 18.8
5.0	2.5	322.9 ± 8.2	310.9 ± 14.2

Figure 2: Carbon dioxide transfer rates for the Bentley vs. Medtronic heparin coated oxygenators at varying blood flow (Qb) to gas flow (Qg) ratios

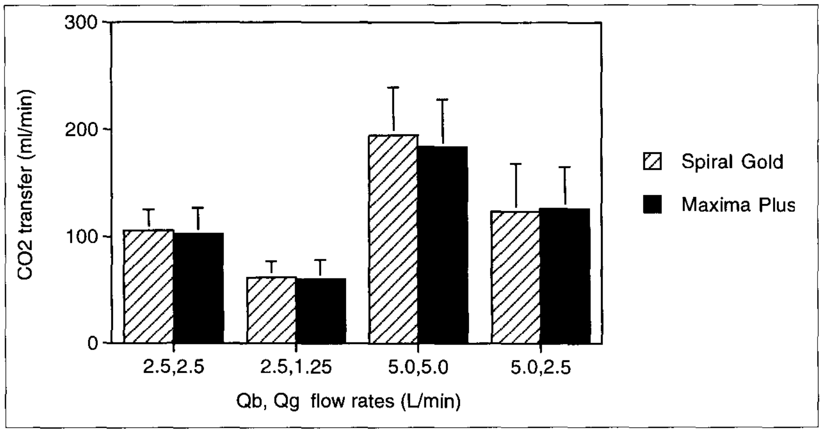


Figure 3: Pressure drop for the Bentley vs. Medtronic heparin coated oxygenators at varying blood flow (Qb) to gas flow (Qg) ratios

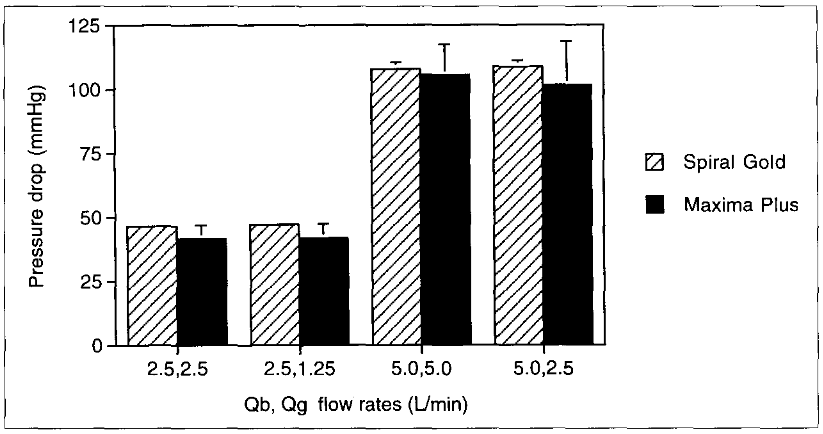


Table 2: Carbon Dioxide Transfer (ml/min)

Qb (L/min)	Qg (L/min)	Spiral Gold	Maxima Plus
2.5	2.5	105.4 ± 19.9	102.5 ± 24.6
2.5	1.25	61.7 ± 15.1	60.0 ± 18.1
5.0	5.0	195.0 ± 44.6	183.8 ± 44.8
5.0	2.5	123.8 ± 44.8	136.3 ± 39.0

Table 3: Pressure Drop (ml/min)

Qb (L/min)	Qg (L/min)	Spiral Gold	Maxima Plus
2.5	2.5	46.5 ± 0.8	41.5 ± 5.2
2.5	1.25	47.0 ± 1.0	41.8 ± 5.5
5.0	5.0	107.9 ± 2.6	105.5 ± 12.0
5.0	2.5	108.7 ± 2.5	101.5 ± 17.2

5. Vocelka CR, Burdge EC, Kunzelman KS, Thomas R, Verrier ED. An in vitro protocol for evaluation and comparison of membrane oxygenators. J Extra-Corpor Technol. 1993; 25(2): 161-66.