Original Article

Comparison of Gaseous Microemboli Counts in Arterial, Simultaneous and Venous Heat Exchange with a Hollow Fiber Membrane Oxygenator

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ABSTRACT

Potential sources of gaseous microemboli during cardiopulmonary bypass are varied. However, it is known that membrane oxygenators generate fewer gaseous microemboli than bubble oxygenators and that bubblers cannot utilize arterial heat exchange without generating significant gaseous microemboli during rewarming. A membrane oxygenator utilizing simultaneous gas and heat exchange raises the concern that concurrent gas and heat exchange would result in a higher production of gaseous microemboli compared to conventional venous heat exchange devices. This in vitro study compared venous, simultaneous, arterial and control (venous) heat exchanger gaseous microemboli counts during rewarming. No significant difference was found between the four heat exchangers when comparing inlet and outlet gaseous microemboli counts. This in vitro study suggests that there is no difference in gaseous microemboli generation when varying the position of the heat exchanger in the extracorporeal circuit incorporating a microporous membrane oxygenator.

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INTRODUCTION

Gaseous microemboli (GME) may be a major cause of cerebral dysfunction following cardiopulmonary bypass (1,2). The primary sources of GME are failure to properly de-air the heart, cannulation for cardiopulmonary bypass and the cardiopulmonary bypass circuit. (3,4) Of those that originate from the bypass circuit bubbler oxygenators appear to be the most significant producers of GME relative to low reservoir level, gas to blood flow ratio, blood flow, PaO₂, injection of cold solutions, extreme pressure drops and temperature changes (2,5). Membrane oxygenators appear to have significantly less GME generation than bubbler oxygenators but may also be affected by the same factors that affect bubbler oxygenator GME generation. (3,6,7,8) Even closed membrane oxygenator extracorporeal circuits are not completely without arterial GME transfer from venous line air embolism or the injection of room temperature solutions (3,8).

Due to the possible generation of GME during rapid warming of blood, authors have stated that heat exchangers in the cardiopulmonary bypass circuit should be placed on the proximal or venous side, rather than distal to the oxygenating device. (9) These statements are basically theoretical speculation and for the most part refer to bubbler oxygenators. (2,10) The Univox (Figure 1) exhibits a unique design whereby gas exchange and heat transfer occur simultaneously. To our knowledge and search of the literature the issue of simultaneous heat exchange and oxygenation in a membrane oxygenator has not been addressed. A theoretical concern with a simultaneous gas and heat transfer design is the possibility of driving dissolved gas out of solution during rewarming. (9) This would occur as a result of reduced solubility of gas in blood as the blood-gas mixture is being warmed. High arterial pO₂ presents the greatest threat of this occurring in membrane oxygenators. (11)

The purpose of this study is to test the simultaneous gas and heat transfer design of the Bentley Univox for changes in outlet GME levels during rewarming. The Univox will be compared to pure arterial and venous heat exchange systems as well as a control, the Sarns' membrane oxygenator.

MATERIALS AND METHODS

A circuit was set up (Figure 2) on three separate days

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utilizing a different Univox oxygenator, Sarns membrane oxygenator (control) and two A Vecor adult heat exchangers for each test circuit. The circuit arrangement tested four heat exchanger designs: 1) Univox simultaneous gas transfer and heat exchange, 2) post Univox heat exchange (arterial), 3) pre-Univox heat exchange (venous), 4) control (venous heat exchange with Sarns membrane oxygenator). A Shiley bubbler oxygenator was incorporated in parallel to produce gaseous microemboli for calibration of the Hatteland BD-100 microbubble counter. A dual channel strip chart recorded the peak voltages and the histogram of the BD-100 output. Two of the circuits utilized bovine blood. The third utilized out-dated human blood. Hematocrits were 25% with the bovine blood and 19% in the human blood circuit. The batch was deoxygenated by using a 5% oxygen, 5% carbon dioxide, balance nitrogen gas mixture. Three trials were performed with each circuit on each type of heat exchange device. The output of the BD-100 was recorded on a dual channel strip chart recorder. The system was initially primed with crystalloid, then with blood. The BD-100 probes were balanced so that the probes responded equally to a given signal. The output of the BD-100 was calibrated by attaching the probes sequentially in the circuit then generating GME less than or equal to 180 microns from the screen filter of the bubbler oxygenator and then generating GME less than or equal to 40 microns from an arterial filter.

The probes were attached to the inlet and outlet of the experimental unit and before each trial 40 micron bubbles challenged the system to insure probe consistency. After each challenge with bubbles, the system was debubbled before the next trial. The circuit blood was deoxygenated and cooled to approximately 25°C and the water in the Sarns Cooler Heater was prewarmed to 42°C. The circuit was recirculated at 4.5 L/minute. Simultaneously the blood path was diverted to a separate container, the blood was oxygenated with 100% oxygen and the prewarmed water was diverted through the test device for two minutes. GME counts were recorded by continuous strip chart and histograms before, during and after the test period. Arterial pO2 levels were maximized at approximately 550 mmHg and pressures distal to the test devices were held constant at 100 mmHg.

A 3-way analysis of variance using device, circuit and trial number was utilized to analyze the data.
RESULTS

The Univox simultaneous gas transfer and heat exchange design was evaluated relative to GME production and compared with an arterial, venous and Sarns venous heat exchange design. Inlet GME counts challenging each test circuit are depicted in Figure 3 and show no difference between the four devices (p<0.05). Outlet GME counts are represented by Figure 4. Results demonstrate lower outlet GME counts compared to inlet counts between the four devices. Inlet minus outlet GME counts were calculated and analysis revealed no difference between the means of the four devices (Figure 5).

DISCUSSION

This study has shown that the position of the heat exchanger in the membrane oxygenator system does not affect the production of microemboli during rewarming. A single oxygenating device (hollow fiber, blood outside the fibers) was utilized for simultaneous, arterial and venous heat exchange with these being compared to a similar hollow fiber membrane oxygenator with an integral venous heat exchanger.

All heat exchangers were challenged with similar bubble counts with the output exhibiting no difference in bubble counts. In addition, it was shown that in all the membrane systems tested the bubble count in the output was significantly less than the input counts. These results demonstrate the ability of hollow fiber membrane oxygenators to remove GME.

A clinically relevant hematocrit limit (19 to 25%) was tested. As the hematocrit (and the viscosity) decreases the gas solubility will decrease. It would seem that as hematocrit decreased the GME would potentially increase, this was not observed.

A high \( pO_2 \) was produced in the output of this study. It was assumed that the blood rewarmed at high \( pO_2 \) would generate more GME than blood rewarmed at low \( pO_2 \). This is one theory supporting venous rewarming that was not substantiated in these trials.

The maximum water to blood temperature gradient obtain-
able with the heater/cooler was 17°C but stabilized between 10°C and 15°C. Lower test blood flows would have increased this gradient. Heat exchanger performance factors were about 0.4 to 0.55 during these observations.

This in vitro experiment demonstrated no significant difference in production of GME when varying the position of the heat exchanger in the extracorporeal membrane oxygenator system during rewarming.

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REFERENCES