A Comparison of Two Bentley Oxygenators

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Introduction

Few studies have been published reporting the use of one of the oldest hard-shell bubble oxygenators on the market.[1] The Bentley Q-100* oxygenator was first released for clinical use in 1964. It was ten years later, in January of 1974, that Bentley introduced their Q-200 oxygenator, while still marketing the original Q-100 model. The Q-200A was released by Bentley in July, 1975. Then, in October, 1977, Bentley released a new oxygenator. Pre-clinical research had begun about two years prior to this date. There have been several studies undertaken to evaluate the Bentley Spiraflo BOS-10* oxygenator.[2,3,4] The purpose of this study is to report the gas to blood flow ratios of Bentley's oldest and newest hard-shell bubble oxygenators—the Q-100 and the BOS-10.

A total of forty patients underwent cardiopulmonary bypass for cardiac surgery. The Bentley Q-100 was used in the bypass circuit for twenty of the forty patients, and the Bentley BOS-10 oxygenator was used on the other twenty (TABLE I). The average age of the Q-100 group was 57 years, and their mean body weight was 76 kg. Those patients who were perfused using the BOS-10 oxygenator had an average age of 56 years, and a mean body weight of 78 kg (TABLE II).

Materials and Methods

For the purpose of this study our cardiopulmonary bypass circuit was kept identical while evaluating the BOS-10 oxygenator against the Q-100. This circuit included a Bentley Q-120* cardiotomy reservoir and a Swank CA-100** cardiotomy filter. A left vent was placed into the left atrium near the junction of the pulmonary vein and left atrium, through the mitral valve, and into the left ventricle. Gravity drainage was utilized to vent the heart leading to the venous lines via a "Y" connection and to the oxygenator. The gas source used was a single tank of 97/2%, O_2/CO_2.

Our priming volumes consisted of 1700 ml of lactated Ringer's plus two units of CPD packed cells, approximately 250 ml each. To the lactated Ringer's is added 10 mEq of sodium bicarbonate per 500 ml to buffer the prime. Our present protocol calls for 2000 units of beef lung heparin per unit of packed cells or blood, and 5 ml of 10% calcium chloride. This gives us the anticoagulation desired to avoid clot formation within the extra-corporeal circuit while reconstituting the CPD blood.

A patient dose of 20% Mannitol was given at the beginning of each bypass procedure according to the patient's weight. Phenylephrine hydrochloride was used, if necessary, to maintain a mean arterial blood pressure of 70–90 mmHg. Additional sodium bicarbonate was administered to adjust the pH when necessary. If additional volume was required, whole blood or packed cells were used in the place of 5% Dextrose in 1/4 saline to maintain a hematocrit above 29%. The patient was systematically heparinized with 300 units per kg body weight of beef lung heparin prior to cannulation, and re-heparinization was administered per ACT testing.

All patients were cooled to 30–32°C as measured by

* Bentley Laboratories, Inc., Irvine, CA. 92714

** Pioneer Viggo, Inc., Beaverton, OR 97005

TABLE I
Procedures

	Q-100	BOS-10
ACB × 1	0	4
ACB × 2	3	7
ACB × 3	9	7
ACB × 4	3	0
AVR	1	0
MVR	2	0
AVR + MVR	0	1
AVR + ACB × 1	1	1
ASD	1	0
Totals	20	20

Key: ACB = Aorta-coronary bypass; AVR = Aortic valve replacement; MVR = Mitral valve replacement; ASD = Atrial septal defect

an esophageal temperature probe. At this cool temperature, the blood flows were maintained at 2.0 LPM-M^2. As the patient's temperature began to increase to 37°C during the warming process, the blood flows were increased up to 2.4 LPM-M^2. The water temperature during the warming process never exceeded 42°C.

Ten minutes after the initiation of cardiopulmonary bypass, the first arterial/venous blood sample was drawn. The second sample was drawn twenty minutes after the initiation of bypass, and a blood gas sample was taken every twenty minutes thereafter.

The induction of anesthesia was with Sodium Pentathol and Anectine. The level of anesthesia desired was maintained with Nitrous Oxide, Halothane or Enflurane, and muscle relaxants.

Description of Q-100

When the Q-100 oxygenator is mounted so that the minimum blood level arrow is parallel to the blood level in the oxygenator, the oxygenator itself will hang at an angle to the floor. The venous side of the oxygenator consists of the venous inlet, cardiotomy inlet, and venous sampling port. Oxygenation takes place in the oxygen diffuser assembly by means of an oxygen plate with holes of a uniform size. The oxygen column turns back upon itself, thus extending the time the blood is in the column and exposed to the bubbling oxygen.

The blood passes from the column through the defoaming system, and spills into the arterial reservoir. The defoaming system is made-up of a silicon treated polyurethane mesh surrounded by a nylon tricot sock. The arterial reservoir will hold up to three liters of volume. Incorporated with the arterial reservoir is the integral heat exchanger. This heat exchanger is coated with polyurethane, and has a recommended maximum operating pressure of 10 psi. A water pressure limiting device was used to maintain a 10 psi water pressure while using the Q-100. The water flows in at the arterial end of the oxygenator/heat exchanger and out at the opposite end (TABLE III).

TABLE II
Patient data

		Q-100	BOS-10
Body weight (Kg)	range	48–99	64–114
	mean	76.6	78.4
Age (years)	range	39–78	39–77
	mean	57.0	56.1

Description of BOS-10

The BOS-10 oxygenator has been described in detail previous to this report.[2] Since the completion of this study, Bentley Laboratories has made some modifications in the Spiraflo BOS-10 oxygenator. These include an expanded oxygen transfer rate, the addition of a microgaseous emboli inhibitor, an all aluminum heat exchanger, and other modifications that improve

TABLE III
Two Oxygenators at a Glance

	Q-100	BOS-10
1. Oxygen dispersion plate	produces bubbles of a uniform size	produces both small and large bubbles
2. Defoamer	silicon treated polyurethane mesh surrounded by a nylon tricot sock	two stages: a. polypropylene b. polyurethane surrounded by a nylon tricot sock
3. Arterial reservoir	made of two sheets of polycarbonate with a maximum holding capacity of 3 L	single, injected mold of polycarbonate with a maximum holding capacity of 3 L
4. Heat exchanger	arterial side, polyurethane coated with a maximum operating pressure of 10 psi	venous side, helically twisted brass tube coated with bioCote® with a maximum operating pressure of 75 psi
5. Minimum priming volume	1350 ml (500 ml reservoir level)	750 ml (500 ml reservoir level)

the convenience and safety of the unit. The BOS-10 oxygenators used for this study were of the old design before these modifications. The following is a short description of the BOS-10 oxygenator used for this study.

Located at the top of the BOS-10 oxygenator is the venous inlet, cardiotomy inlet, quick prime connection, fluid administration port, venous sampling port, and oxygen inlet. Oxygenation takes place at the top of the oxygenator in the mixing chamber. The oxygen dispersion plate produces both small and large bubbles for oxygen transfer and carbon dioxide removal. The blood exits the mixing chamber, falls across the mixing cone, and then downward over the helically twisted heating coil. The heating coil is made of a seamless brass tube coated with bioCote.® The bioCote® is used by Bentley to insure the smooth flow of blood over the heating coil and discourage any clot formation on the coil. The manufacturer has tested the heat exchanger to 115 psi, but recommends an operating pressure of 75 psi at a water flow of 10 LPM. The surface area exposed to the blood is 400 square inches.

The blood passes through a 2-stage defoamer before entering the arterial reservoir. This defoamer consists of polypropylene (stage 1), and polyurethane (stage 2). There is a grid support on the inside of the defoamer sponges, and a nylon tricot sock surrounding the outside of the defoamer. The arterial reservoir is a single, injected molded shell of polycarbonate with an arterial sampling port provided with an integral stopcock. The reservoir will hold up to three liters of fluid without compromising performance (TABLE III).

Results

The Student's two-tailed t-test was used to analyze the variance in the gas to blood flow ratios. While using the Q-100 oxygenator, our average gas to blood flow ratio was 1.43:1 with a mean arterial pO_2 of 157 mmHg. The BOS-10 oxygenator had a lower ratio of 0.64:1 with a mean arterial pO_2 of 174 mmHg (TABLES IV and V). These gas to blood flow ratios were compared (Q-100 1.43 ± 0.05 vs. BOS-10 0.64 ± 0.07) and found to be significantly lower ($p < 0.001$) in the BOS-10 group.

Conclusion

The BOS-10 oxygenator is much more efficient in oxygenating the blood than the Q-100. But we did experience some difficulty in adequately "blowing off" the CO_2 as a result of our low gas to blood flow ratios while using the BOS-10. This was also demonstrated in the paper written by G. D. Kemna and J. P. Dochery.[4] Our protocol calls for an arterial pO_2 between 100 and 200 mmHg. To keep within this range it was necessary to lower our gas flows. We are now using a dual gas source of 100%, O_2 and 98/2%, O_2/CO_2 with better results and more ability to control our blood gases. We hope to present these results in the future. We are also trying to adjust our blood flows considerably, but have met with minimal success.

A total of 2200 ml of priming volume was used for both oxygenators during this study. Since there is a minimal amount of volume hold-up within the oxygenating assembly of the BOS-10[2,3], one could operate this oxygenator at a safe level with less priming volume than with the Q-100 model. Bentley Laboratories has stated that the Q-100 requires 1350 ml of prime to give the perfusionist 500 ml in the arterial reservoir. Only 750 ml of prime is needed to acquire the same 500 ml level in the BOS-10 oxygenator.

We believe that the BOS-10 oxygenator is an improvement over the "Q" series, especially the Q-100

TABLE IV
Perfusion Data and Gas to Blood Flow Ratios

		Q-100	BOS-10
Bypass time (minutes)	range	54–173	32–202
	mean	115.1	89.4
Blood flow rate (LPM)	range	3.53–4.55	3.43–4.69
	mean	4.09	4.29
Gas flow rate (LPM)	range	4–8	1–6
	mean	5.8	2.7
Gas to blood flow ratio	range	1.03–1.98:1	0.26—1.25:1
	mean	1.43:1	0.64:1

TABLE V
Blood Gas and Related Data

	Q-100	BOS-10
Arterial pH (pH units)		
range	7.35–7.48	7.26–7.43
mean	7.41	7.34
Arterial CO_2 (mmHg)		
range	32–40	35–58
mean	36	44
Arterial pO_2 (mmHg)		
range	113–228	80–236
mean	157	174
Hematocrit (%)		
range	25–36	28–38
mean	31	33

model. The oxygenator is simple and easy to set-up. The gas to blood flow ratios are much lower with the BOS-10 unit thus causing less trauma to the bubbled blood. The heat exchanger is also more efficient than the one in the Q-100. Although the warming results were not included in this study, our warming times were less while using the BOS-10.

Summary

1. The Bentley BOS-10 Spiraflo bubble oxygenator was used with twenty adult patients undergoing aorta-coronary bypass surgery, valve replacements, or a combination of each. The performance of this oxygenator was compared with the older Bentley Q-100 model on a comparable patient population.

2. Our perfusion protocol remained essentially the same while using both oxygenators. The BOS-10 was found to be more efficient than the Q-100 oxygenator in the area of oxygen transfer. While using the BOS-10 oxygenator it was found to be more difficult to control the pCO_2 because of the low gas to blood flow ratios required to keep the arterial pO_2 within acceptable norms.

References

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