A SIMPLIFIED DISPOSABLE BUBBLE OXYGENATOR REQUIRING NO BLOOD FOR PRIMING

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Recent developments in cardiac surgery have been followed by increases in the number of open-heart operations which require an artificial heart-lung machine. As a result, diluted blood in the extracorporeal circulation has been utilized because of the increasing requirements for fresh blood and in order to reduce side-effects.

Since 1960, Neptune, Cooley, De Wall, Zuhdi, etc. reported the complete replacement of blood with blood substitutes, such as 5% glucose in distilled water, physiological saline solution or low-molecular weight dextran, to prime the circuit of the artificial heart-lung machine. Then improvements in and simplification of the oxygenator have been made.

With this thought in mind, the authors have developed a simplified disposable oxygenator and have obtained good results in its clinical use. The details and indications for the utilization of this machine follow.

1. A small-sized disposable oxygenator

The oxygenator is a bubble-type made of vinyl chloride. As shown in Figure 1, the reservoir can be internally cooled or warmed. The debubbling and control of perfusion volume can be performed easily. The venous blood from the vena cava is collected at the bottom of oxygenator by gravity drainage and then is introduced into the debubbling chamber at the top of oxygenator through an internally located oxygenating tube.

Thereafter, the blood accumulates in the reservoir at the bottom of oxygenator after complete removal of bubbles in the debubbling chamber and then is pumped to the femoral artery. A part of the venous blood is shunted from oxygenating tube to reservoir. By this mechanism, the adjustment and maintenance of the fluid level in the reservoir can be carried out accurately and easily.

The oxygenator was maintained with a fluid volume of 400 to 800 cc, a perfusion flow rate of 1000 cc/min, and an oxygen flow rate of 1 to 2 L/min, with an arterial oxygen saturation of 90 to 100%. Usually, the extracorporeal circulation was kept at a low flow rate, for example 30-40 cc/kg/min, for 45-60 minutes with a plasma-Hb value of 60-80 mg%.
Fig. 1  Simplified disposable oxygenator
1) from vena cava 2) oxygenating tube 3) debubbling chamber with Saran-mesh 4) reservoir
5) rotary pump 6) air trap with filter 7) to femoral artery 8) suction 9) heat exchanger

The heat exchanger was a stainless steel U-shaped tube. The insertion of this exchanger into the blood reservoir was effective in reducing the fluid volume necessary to prime the oxygenator. The rate of heat exchange was one minute and forty-two seconds to reduce 1°C and one minute and forty-six seconds to increase 1°C. This was available for cooling till about 30°C. One rotary pump was used as the artificial heart. At the end of the extracorporeal circulation, the diluted blood in the circuit was totally supplied to the patients.

The artificial lung described here is inexpensive and disposable i.e. it can be discarded.

2. Discussion on blood substitute

The oxygenator was first investigated in experiments on dogs before its clinical use was attempted. The use of 5% glucose, 10% low molecular weight dextran, amino acids, PVP, or alginic acid as a blood substitute was compared to the utilization of blood as the priming fluid for the oxygenator. Because the hemoilution rate was supposed to be adequate at 20 to 30 cc/kg body weight, the experiments were performed with the priming at 30 cc/kg body weight. The mean arterial pressure,
total peripheral vascular resistance, various properties of the blood (hematocrit, number of erythrocytes, plasma hemoglobin and viscosity), acid-base balance, and renal blood flow were measured during perfusion (Table I). These results indicated

### TABLE I
The data during perfusion

<table>
<thead>
<tr>
<th></th>
<th>Homologous Blood</th>
<th>5% Glucose</th>
<th>LMWD</th>
<th>Alginic Acid</th>
<th>Amino Acids</th>
<th>PVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Peripheral Vascular Resistance</td>
<td>0.180</td>
<td>0.112</td>
<td>0.160</td>
<td>0.144</td>
<td>0.091</td>
<td>0.053</td>
</tr>
<tr>
<td>Ht (Reducing Rate) %</td>
<td>112.3</td>
<td>86.0</td>
<td>62.5</td>
<td>94.8</td>
<td>80.2</td>
<td>83.9</td>
</tr>
<tr>
<td>Blood Viscosity</td>
<td>3.78</td>
<td>3.01</td>
<td>3.60</td>
<td>3.03</td>
<td>2.99</td>
<td>2.93</td>
</tr>
<tr>
<td>Plasma Hb (mg%)</td>
<td>108</td>
<td>73</td>
<td>56</td>
<td>56</td>
<td>93</td>
<td>63</td>
</tr>
<tr>
<td>PH</td>
<td>7.32</td>
<td>7.26</td>
<td>7.30</td>
<td>7.22</td>
<td>7.23</td>
<td>7.15</td>
</tr>
<tr>
<td>Renal Blood Flow (cc/kg/min)</td>
<td>4.2</td>
<td>3.7</td>
<td>9.3</td>
<td>5.7</td>
<td>5.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>

*Fig. 2 The patient's course during extracorporeal circulation (Age: 5, Sex: female, Weight: 15.5 kg, Diagnosis: ASD)*
that each blood substitute had its own specificity; but all were available. In the present clinical use, only 5% glucose solution was utilized because a crystalloid solution, especially a 5% glucose solution, produced the least effect from hemodilution.

3. Clinical use

In clinical use, the priming solution was a 5% glucose solution and the dilution rate was 20-30 cc/kg. When the body weight of the patient was light fresh blood was added.

Up to the present time, this procedure has been applied to four cases of an ostium secundum type of atrial septal defect. The patient’s body weights ranged from 15 to 20 kg.

An example of the course of a cardiopulmonary bypass using this oxygenator is shown in Figure 2. In most cases, the total duration of perfusion was for 30-40 minutes. Heparin was usually added in ratio of 3-4 mg/kg, and protamine (4-6 mg/kg) was used as its neutralizer.

All cases had smooth postoperative courses without complications.

4. Comment

The present study utilizing a simplified oxygenator primed without heparinized fresh blood has demonstrated its usefulness.

A disposable bubble oxygenator has been devised by the authors, referring to the report by Cooley. This contains an internal heat exchanger for hypothermic perfusion in order to increase its safety. This disposable oxygenator is inexpensive and safe to use.

It has been demonstrated that the major advantages of this artificial lung are high oxygenation and decreased hemolysis. Its major disadvantages, especially during extracorporeal circulation for long periods of time, are its low flow rate and alterations in acid-base balance.

At the present time, the authors are using this apparatus for the surgical correction of congenital heart diseases which usually require less than one hour perfusion time.

The oxygenator needs only one fourth to one third of the volume of fresh blood currently required in available oxygenators for open heart surgery.

It is recommended that a rotating disc oxygenator (Kay-Cross) be used in complicated cases; an artificial heart-lung machine should be selected according to the indication. As a blood substitute, 5% glucose solution which produced less effects from hemodilution has been used.

5. Summary

A simplified, inexpensive disposable bubble oxygenator capable of performing hypothermic perfusion has been described. Due to its small internal volume, the oxygenator can be primed safely with a blood substitute. A five per cent glucose solution resulted in the least disturbance from hemodilution and gave good results in its clinical application.
REFERENCES


