Haemodynamics during Partial Extracorporeal Circulation in the Dog

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Summary. Circulatory changes were studied in 9 mongrel dogs during partial extracorporeal circulation from the right atrium to the carotid and/or femoral artery. The bypass circuit consisted of a membrane oxygenator and a roller pump. Cardiac output and arterial pressure decreased during bypass, but changed little when extracorporeal flow (EF) was increased from 1/10 to 3/4 of control cardiac output. Right atrial and pulmonary wedge pressures were lower than control. Total blood flow was equal to control when EF was 1/2 of the control cardiac output, and exceeded control flow at 3/4. Such enhanced venous return presumably resulted from sympathetic stimulation via atrial mechanoreceptors.

Key words: Haemodynamics – Extracorporeal circulation – Membrane lung.

INTRODUCTION

In acute respiratory failure, respiratory assistance can be provided by extracorporeal oxygenation [9] through partial circulatory bypass. This procedure is well tolerated for as long as deemed necessary by the acute episode but the haemodynamics of circulatory bypass have received limited attention especially at low blood flow rates. This study was undertaken in order to determine the circulatory response to partial bypass, by measuring the cardiac output and the inflow and outflow pressures on both sides of the heart in anaesthetized dogs breathing spontaneously.

MATERIALS AND METHODS

Ten mongrel dogs, weighing from 19–33 kg (average 26 kg), were anaesthetized with thiopental sodium and chloralose; anaesthesia was subsequently maintained with chloralose as required. Cannulae were inserted into the right carotid artery, jugular vein, and femoral artery and vein. The venous cannulae (type Malecot R.P.) were advanced up to or near the right atrium, as could be roughly judged by inspection. A triple-lumen, balloon-tipped catheter was inserted into the left jugular vein and advanced until the tip was in a pulmonary artery, and good wedge pressure could be recorded when the balloon was inflated. The proximal lumen was then in or near the right atrium. A thermodilution catheter was advanced into the left carotid artery, about 30 cm inside the artery, so that the tip of the catheter was near the aortic arch. In some dogs a small catheter was also placed in the left femoral artery for dye dilution curves.

Arterial blood was sampled in the aorta via the carotid artery catheter, and mixed venous blood from the pulmonary artery via the venous catheter. Oxygen saturation in blood samples was measured in a Haemoreflector (Kipp). Cardiac output was measured by thermodilution, with injection into the pulmonary artery and measurement in the aorta. The right heart output could not be measured during bypass, since part of the injectate was diverted into the extracorporeal circuit. Carotid, pulmonary artery, wedge and right atrial pressures were monitored and recorded on photographic paper (TELCO). Static calibration was checked before each experiment.

Dye dilution curves were obtained after injection of cardio-green into the outflow branch of the extracorporeal circuit, and sampling from the thoracic aorta through a Gilford densitometer. Different lengths of catheter were used in order to determine at which level in the aorta mixing of circuit and animal blood was taking place. This was done for one value of bypass flow only (1/10 or 1/2 control cardiac output).

The bypass circuit consisted of a membrane oxygenator (Rhone-Poulenc) with a gas exchange area of 1 m², through which blood was pumped by a roller pump (Sarns 3501). Inflow and outflow pressures were measured as well as the flow (electromagnetic flowprobe). Blood could be sampled from both inflow and outflow lines. The circuit was primed with 500 ml of saline or bicarbonate solution.

After administering heparine (2 mg/kg i.v.) cannulae and catheters were inserted, and control measurements of blood gases, cardiac output, systemic and pulmonary artery, right atrial and pulmonary wedge pressures were made. The veno-arterial bypass was then put into operation. The flow in the extracorporeal circuit was chosen in relation to the control cardiac output: 1/10, 1/4, 1/2, 3/4 in random order. In the first experiment, the first bypass flow was 3/4th of the control cardiac output, by random choice. However this gave rise to severe cardiac arrhythmia, bradycardia and finally death. In the subsequent experiments (9 dogs) only the
Table 1
Control values of haemodynamic data

<table>
<thead>
<tr>
<th></th>
<th>( \dot{Q} ) (l/min)</th>
<th>HR (beat/min)</th>
<th>( P_a ) (mm Hg)</th>
<th>( P_{pw} - P_w ) (mm Hg)</th>
<th>( P_{ra} ) (mm Hg)</th>
<th>( P_w ) (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x )</td>
<td>2.9</td>
<td>148</td>
<td>146</td>
<td>11.5</td>
<td>0.7</td>
<td>2.9</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.7</td>
<td>40</td>
<td>43</td>
<td>4.0</td>
<td>0.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

three lowest bypass flows were studied in random order. The highest flow could be achieved in 6 dogs only, and in 4 of them it required rapid infusion to expand blood volume in order to prevent venous collapse. It was difficult to maintain a steady state under these conditions, and for this reason, the results for that flow concern 3 dogs only: 2 without infusion and 1 for whom control data could be obtained immediately after the bypass period. Otherwise, no infusion was given during bypass.

Measurements were done after at least 10 min at equilibrium. Cardiac output and pressures were measured twice for each extracorporeal flow (EF) with reinfusion in the femoral artery alone, and with reinfusion both in femoral and carotid artery. Blood samples were taken once per EF period.

As the control values varied widely from dog to dog, the flow results during partial bypass were expressed, for each measurement, as a percentage of the corresponding control value; right atrial and wedge pressures were expressed as difference from control, since their changes were large in respect to the absolute values. Systemic and pulmonary arterial pressures were calculated as percentage of control values, then expressed as absolute changes from control data. Mean values were compared using Student's t-test for paired data.

RESULTS

Control data are shown in Table 1. Figure 1 shows the percentage of control values for total flow (\( \dot{Q}_T \)), cardiac output (\( \dot{Q}_{LV} \)) and extracorporeal flow (EF) during the bypass periods. These are not related to time, since the bypass periods were realised in random order, except for \( \dot{Q}_0 \) 3/4 (see "Methods"). Each period is represented by two points, the first corresponds to femoral artery re-entry, the second to femoral + carotid re-entry. No significant difference could be found between these two sets of points.

Extracorporeal flow was equal to what was intended, except for \( \dot{Q}_0 \) 3/4 where only 70% of \( \dot{Q}_0 \) could be obtained. Due to the marked depression of cardiac output, which was almost constant during the entire experiment, total flow was below \( \dot{Q}_0 \) when EF was 1/10th and 1/4th of \( \dot{Q}_0 \).

Absolute changes in right atrial (\( \Delta P_{ra} \)) pulmonary wedge pressures, arterial pressure (\( P_a \)) and pressure drop in the pulmonary circulation (\( P_{pw} - P_w \)) are shown in Figure 2. These pressures were all below their control value, without significant change between periods. Right atrial pressure was about 1.5 mm Hg lower than during the control period, wedge pressure was about 3 mm Hg lower, arterial pressure averaged 75% of control and pulmonary pressure drop ranged from 52–80% of the control value. As blood from the extracorporeal circuit was reinjected into the right carotid and/or femoral artery, and arterial pressure was measured by a catheter placed in the aorta via the left carotid artery, arterial pressure measurements were not influenced by extracorporeal flow, and were not different with or without carotid re-injection.

Heart rate was very high during the control period (Table 1), and average values were still higher during bypass, but these values varied widely from dog to dog and from period to period, and the differences were not significant.

Blood gases did not vary significantly. However, as can be seen in Figure 3, mixed venous oxygen