Artificial Maintenance of the Systemic Circulation without Participation of the Right Ventricle

By William L. Jamison, M.D., William Gemeinhardt, Jahangir Alai, M.D., and Charles P. Bailey, M.D.

A pump of 50 cc. reservoir capacity, only 10 cm. in diameter, was placed in the systemic circuit between the left auricular appendage and the left common carotid artery in each of 10 clogs so that the systemic circulation was maintained by the pump during complete cardiac arrest resulting from experimentally produced ventricular fibrillation. All dogs recovered completely.

Resuscitation of the heart in patients with cardiac arrest or ventricular fibrillation is usually accomplished with cardiac massage. This restores circulation in both the pulmonary and the systemic circuits, but at times it seems to be inadequate because the blood pressure and the pulse cannot be adequately maintained. A further disadvantage is that a surgical procedure cannot be performed on the heart while manual massage is being carried out. In seeking to overcome these disadvantages, we turned our attention to mechanical methods of restoring circulation. The device to pump blood will be described later.

The pumping circuit and the method of cannulation posed a great problem. Cannulation of both the systemic and pulmonary circuits in order to connect a pump to each circuit and thus use two separate pumps was thought to be too traumatic and time-consuming a procedure to be carried out successfully. Therefore, it was decided to cannulate the left auricle and the left common carotid artery and to use one pump. If blood was drawn from the left auricle and reintroduced, in retrograde fashion, into the common carotid artery, the pump would be in the position of a left heart (fig. 1). Pumping action of the heart could then be stopped by causing ventricular fibrillation. Thus it would be possible to see whether the pump, acting as a left ventricle, would have sufficient force to send blood through the arterial circulation, venous circulation, right auricle, right ventricle, and lungs, and back into the left auricle. If this were possible, a new technic of cardiac resuscitation could be developed.

Previous work by other investigators indicated that this would be possible. Rodhard and Wagner by-passed the right ventricle by anastomosing the right auricular appendage to the pulmonary artery. The pulmonary artery was then tied off on the cardiac side proximally to the anastomosis. Starr, Jeffers, and Mead charred the right ventricle, using electrocautery, without getting a rise in venous pressure. Bakos repeated the work of Starr and his associates and arrived at similar conclusions. Kagan destroyed 75 to 85 per cent of the outer wall of the right ventricle by cauterization and concluded that a normal contractile right ventricular wall was not necessary for the maintenance of a normal circulation. Donald and Essex found that ligation of the right coronary artery in dogs, which deprives the right ventricle 50 to 73 per cent of its blood supply does not result in extensive change in the systemic circulation.

Materials and Methods

The artificial perfusion system and its connections are shown in figures 1 and 2. The pump was compact, measuring 10 cm. in diameter and having a reservoir capacity of 50 cc. It was possible to vary the stroke volume between 5 and 15 cc., and the
rate between 80 and 200 strokes per minute. A filter with 56 wires to 2.5 cm. was used on the arterial side of the pump.

Tygon tubing having inside and outside diameters of 9.525 mm. and 11.12 mm., respectively, was used to connect the pump to the animal. The auricular cannula was 2 cm. long, had outside and inside diameters of 1.0 and 0.8 cm. respectively, and had 10 holes, each 0.25 cm. in diameter, in the barrel. The outside of the cannula contained multiple ridges to prevent slipping. The arterial cannula was 3.5 cm. long and had inside and outside diameters of 0.31 and 0.35 cm. respectively.

Arterial mean pressures were taken with a mer-
TABLE 1.—Maintenance of Circulation during Experimentally Produced Ventricular Fibrillation.  

Data of Experiments

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Wt. lb</th>
<th>Heparin Na, cc</th>
<th>Prostamine, SO, cc</th>
<th>Vasoxyl mg</th>
<th>Arterial Press. mm. Hg</th>
<th>Min. Fibr.</th>
<th>Na Pentothal mg</th>
<th>Reservoir</th>
<th>Pump</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>813</td>
<td>27</td>
<td>3</td>
<td>3</td>
<td>80-160</td>
<td>10</td>
<td>150</td>
<td>50 cc.</td>
<td>Died 2 days postop. from pneumonia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1022</td>
<td>24</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>60-140</td>
<td>10</td>
<td>600 cc.</td>
<td>Alive 77 days postop.*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1035</td>
<td>40</td>
<td>3.5</td>
<td>1.5</td>
<td>3</td>
<td>80</td>
<td>10</td>
<td>600 cc.</td>
<td>120 cc.</td>
<td>Died 70 days postop.*</td>
<td></td>
</tr>
<tr>
<td>1049</td>
<td>25</td>
<td>2</td>
<td>1</td>
<td>0-90</td>
<td>10</td>
<td>350</td>
<td>120 cc.</td>
<td>Rec. Died 3 wks. postop. from pneumonia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1070</td>
<td>41</td>
<td>3.5</td>
<td>1.5</td>
<td>4</td>
<td>20-130</td>
<td>11</td>
<td>300 cc.</td>
<td>Alive 54 days postop.*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1210</td>
<td>31</td>
<td>2.5</td>
<td>1.5</td>
<td>4</td>
<td>0-110</td>
<td>25</td>
<td>300 cc.</td>
<td>Alive 42 days postop.*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1096</td>
<td>21</td>
<td>1.5</td>
<td>1</td>
<td>4</td>
<td>60-120</td>
<td>15</td>
<td>300 cc.</td>
<td>Rec. but had empyema. Died 1 wk. later of pneumonia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1263</td>
<td>20.5</td>
<td>1.5</td>
<td>5</td>
<td>40-140</td>
<td>10</td>
<td>600</td>
<td>50 cc.</td>
<td>Rec. Died 5 days postop. from pneumonia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1206</td>
<td>37</td>
<td>3.0</td>
<td>1</td>
<td>6</td>
<td>130-70</td>
<td>45</td>
<td>400 cc.</td>
<td>Alive 21 days postop.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1281</td>
<td>34</td>
<td>3.0</td>
<td>1</td>
<td>4</td>
<td>110-0</td>
<td>20</td>
<td>350 cc.</td>
<td>Alive 21 days postop.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Still living at time of writing.
† The first figure is the highest and the second figure is the lowest mean pressure occurring during the experiment.

Each dog received 600,000 units of penicillin procaine intramuscularly before regaining consciousness.

curly manometer connected to the cephalic end of the left common carotid artery.

Venous pressures were determined by inserting the free end of a length of Polyethylene medical tubing (7.5 mm. and 2.75 mm. inside and outside diameters, respectively) into the superior portion of the left femoral vein. Readings were taken by holding the tubing against and parallel to a vertical sterile steel rule graduate in centimeters.

Since the pump was very small, it could be brought close to the incision, thus making it possible to use a minimal amount of tubing and a pump with a reservoir of low capacity (fig. 2). Suction was produced by this pump, as shown by the fact that when the stroke volume is increased too much, the Tygon tubing tends to collapse. When this occurred, the stroke volume was reduced immediately and kept at less than the amount necessary to produce collapse. Flow appeared to be best when the rate was kept at approximately 100 beats per minute and the stroke volume was varied.

Blood was returned to the animal by pumping it retrograde through the central end of the isolated left common carotid artery (fig. 2).

The defibrillator*, consisted of copper plates measuring 5 X 5 cm. They were connected to a drop cord with plastic or wooden handles. Our laboratory nurse was taught to hold the plug near the receptacle, and when the command, "Hit," was given, to insert the plug into the receptacle and quickly withdraw it. Thus 110 volt 60 cycle alternating current is used. This method proved safe in our hands, with no untoward results. The heart was fibrillated by holding the plates parallel, and at right angles, to the heart; defibrillation was accomplished by holding the plates so that the heart was between them.

Essential data are recorded in table 1. Mongrel dogs varying in weight from 8.4 Kg. to 16.4 Kg. were used. Sodium pentothal in a 5 per cent solution was given in the minimal doses (300 to 600 mg.) necessary for anesthesia. Heparin sodium* (10 mg. per cubic centimeter) was given at the time of cannulation in doses of 2 to 2.5 mg. per Kg. The adequacy of this dosage was indicated by absence of fibrin on the filter of the pump after the experiment had ended. If careful hemostasis was maintained during the process of opening the chest and before the heparin was given, untoward hemorrhage did not result from the use of heparin. It is our opinion, based on observation, that heparin will not dissolve clots already formed, though it may increase capillary bleeding.

The dosage of protamine sulfate in one per cent solution (given after the chest was closed) varied from 1 to 1.5 cc. Vasoxyl (hydrochloride methoxamine hydrochloride) was injected intravenously in amounts ranging from 3 to 8 mg.

Hemolysis caused by the pump was minimal, no red tint being visible in the centrifuged blood. Penicillin procaine, 600,000 units, was given at the end of surgery.

* Manufactured by The Vitarine Company, Inc., New York, N. Y.
† Manufactured by Eli Lilly and Company, Indianapolis, Ind.
‡ Manufactured by Burroughs Wellcome & Co., Inc., Tuckahoe, N. Y.
RESULT

The reactions in dog 1210 during various steps of the procedure are typical. Before the chest was opened, the arterial blood pressure ranged from 90 to 100 mm. Hg. By the time the chest had been opened, it had become stabilized at 100 mm. Hg. After cannulation of the left auricle and the left common carotid artery, it remained at 100 mm. Hg. The pump was then started, and the pressure fell to 90. However, as the stroke volume of the pump increased, the pressure rose to 100 again. Ventricular fibrillation was then induced. Arterial pressure immediately fell to zero and remained at that level for four minutes. While the pressure was at zero, two doses of Vasoxyl of 2 mg. each were given intravenously. The pressure then rose to 80 mm. Hg.

During the period of low pressure, blood accumulated on the venous side, and it was necessary to use vasoconstrictors to compensate for the low arterial blood volume. The venous pressure for this experiment is not available, but in eight other similar experiments in which the arterial pressure varied between 120 and 205, the venous pressure in the left femoral vein varied between 125 and 200 mm. of water. The venous pressure in two normal mongrel dogs weighing 10 Kg. to 14 Kg. was between 25 and 50 mm. of water. In the next six minutes, the arterial pressure rose to 110 mm. Hg. and remained at that level until 20 minutes after ventricular fibrillation. When the heart was defibrillated with one electric shock.

The pump was stopped two minutes after defibrillation, and the arterial pressure at this time was 110 mm. Hg. The pressure usually rose to 140 or 150 mm. Hg, where it remained for a brief interval, and then dropped again to the previous level after blood from the right side of the heart had been shunted back into the arterial circulation.

Decannulation was then performed and the chest was closed. The arterial pressure at this time was 100 mm. Hg. Protamine sulfate, 1.5 cc., or just one-half the calculated dose necessary to neutralize the amount of heparin given, was then slowly introduced intravenously in 100 cc. of saline solution. The dog reacted completely in one hour without any gross evidence of cerebral injury. Before consciousness was regained, 600,000 units of penicillin procaine were injected intramuscularly. It will be noted from data in table 1 that the pump maintained the circulation in 10 dogs throughout the period of experimental fibrillation and defibrillation and that all dogs survived the operation, six of them being alive at the time of writing and for a period ranging from 42 to 77 days. The period of survival of the remaining four, all of which died of pneumonia, was 2, 5, 7, and 21 days respectively. The incidence of pneumonia with empyema in these animals was related to the airborne droplet infection which is inherent in the arrangement of the kennels in our laboratory, and did not seem to be associated with the experimental procedures.

SUMMARY

A pump, using a combination of pressure and suction, and an artificial circuit are described by which we were able, after purposeful ventricular fibrillation, not only to maintain arterial pressure, but also force blood through the right heart and pulmonary circuit in 10 dogs. This suggests that the left ventricle, given enough power, could take over the work of the right heart. Since blood pool on the venous side during ventricular fibrillation, a vasoconstrictor drug is required to restore the normal distribution.

The ventricular fibrillation induced could be abrogated in every instance without cardiac massage by use of a simple electric defibrillator, and after surgical repair of the thorax the animals survived for varying periods of time.

REFERENCES

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