

## HYPOTHERMIA AND CORONARY PERFUSION FOR SURGERY OF ATRIAL AND VALVULAR DEFECTS

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THE USE of pump oxygenators to facilitate repair of cardiac defects has become widespread throughout the major teaching centers. The ultimate realization of a smoothly coordinated team performing open heart surgery with low operative risk is not achieved easily. Elimination of the metabolic, surgical and anesthetic problems which occur with cardiopulmonary bypass must be carefully worked out in the laboratory. In spite of seemingly adequate preparation in the laboratory, most centers have had to endure a disproportionately high mortality rate in the early experiences with cardiopulmonary bypass. The large amount of blood required to prime and operate most of the present-day oxygenators has often placed a burden on blood bank facilities. The problems of collection and crossmatching up to 15 units of blood for one operation have led some groups to utilize the blood for two patients of similar blood grouping.<sup>1</sup>

Because of the above problems incumbent on the use of pump oxygenators, it appears unlikely that their use outside of major medical centers will be feasible, at least in the immediate future. In the meantime, it is evident that an ever increasing number of patients with correctable defects are available for surgery in areas outside the scope of the larger medical centers,<sup>2</sup> who may be denied surgery because of lack of a simple, safe method for performing open heart surgery.

This paper explains the management of 30 patients undergoing open heart surgery for the repair of auricular septal defects and/or pulmonary valvular stenosis, by employing hypothermia and coronary perfusion. The operative technique and detailed cardiac follow-up have been described elsewhere.<sup>3</sup>

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### CLINICAL MATERIAL

Patients selected for correction under this technique have had either a simple valvular pulmonary stenosis, an ostium secundum auricular septal defect or one of the less complicated varieties of anomalous pulmonary venous drainage associated with a high auricular septal defect. Clinical evaluation in the pulmonic stenoses group has been aimed at excluding patients who have infundibular pulmonary stenosis and associated abnormalities of the ventricular septum. In the auricular septal group we have eliminated patients having defects of the ostium primum variety and anomalies of the pulmonary venous return not readily amenable to redirection into the left atrium. All patients in this group have been subjected to cardiac catheterization before operation, and the clinical and catheterization data were carefully analyzed to exclude the possibilities mentioned, all of which in our opinion are not properly handled with this technique.

In the pulmonic stenosis group, our operative indications have included definite symptomatology, significant and progressive right ventricular hypertrophy by electrocardiogram, progressive cardiomegaly and, by cardiac catheterization, a right ventricular pressure of 100 mm. of mercury or over. Operative indications in the auricular level shunting anomalies have been significant symptomatology and/or growth retardation, definite cardiomegaly and, by catheterization, a left to right shunt exceeding 1 1/2 liters/minute/meter.<sup>2</sup>

### METHOD

With a few exceptions, all patients were premedicated with from 4 to 5 mg./kg. of sodium pentobarbital and 0.01 mg./kg. of scopolamine intramuscularly, one and a half hours prior to operation. Patients arrived at the operating room sleeping lightly.

Many methods of inducing anesthesia have been used, although cyclopropane was used

most frequently in children and thiopental most commonly in adults. Shortly after induction, electrocardiographic and electroencephalographic leads were attached to the patient. Both an esophageal and a rectal thermister were inserted. During cooling, the electrocardiogram has been useful not only for its monitoring of heart action but also for the detection of occult shivering which retards cooling and augments acidosis. Tracheal intubation was accomplished in a light plane of anesthesia with the use of succinylcholine. Gas oxygen and ether were then utilized to maintain anesthesia during the cooling process. From this point, steadfast hyperventilation was maintained until the completion of surgery, with the exception of the short period of circulatory occlusion for cardiotomy.

At this point, the patient was lifted from the operating table and placed in a tub half filled with cold water. The patient was suspended in the water on a canvas hammock. Cooling was accomplished by adding about 100 pounds of ice cubes. Shivering, when it occurred was most effectively treated by adding a little more ether to the system, although relaxants were of temporary value. As cooling progressed, the ether was washed out via the semiclosed circle system. When the desired temperature was reached, usually oxygen alone was used in the system or with 50 per cent nitrous oxide. Hyperventilation plays an important ancillary role in keeping the patient quiet during surgery.<sup>4, 5</sup>

When the desired esophageal temperature was reached, the patient was removed from the tub and placed on the operating table. The table had been previously covered with a rubber mattress containing coils through which a liquid could be circulated.<sup>6</sup> This was covered with a bed sheet and a blanket of cotton, on which the patient was placed. The blanket was used to dry the patient thoroughly and was then removed. Small pieces of foam rubber were placed under both heels and beneath the sacrum, since it was believed that these areas were most subject to bruising from pressure and hypothermia.

Transfusion of citrated blood was begun soon after the operation began via one of two

large bore needles, keeping abreast of blood loss, in order to obviate rapid transfusion should unexpected blood loss occur later. Blood used for coronary perfusion was collected by the surgeon from the patient's aorta into a heparinized vacuum blood bottle. This was done a few minutes before occlusion and cardiotomy. If the patient had been receiving nitrous oxide, oxygen alone was used for 5 minutes prior to collection of the blood, to insure maximum oxygen saturation. Coincidental with the withdrawal of the patient's blood, warmed, heparinized, freshly collected donor blood was transfused into an arm vein. The exchange transfusion could be given rapidly under pressure if the blood had been adequately warmed, and without anticipation of alarming cardiac activity.

Before circulatory occlusion, a small dose of a relaxant was given and the patient ventilated with 100 per cent oxygen. Active ventilation was stopped during the occlusion period. The aorta and pulmonary arteries clamped and the coronary perfusion needle introduced into the base of the aorta. The cardiotomy was then performed and coronary perfusion begun. Perfusion was manually controlled by the anesthetist with commercially available blood administration set incorporating a pressure unit. Perfusion rate was usually from 2 to 3 cc./kg./min.<sup>7</sup> Pulmonary valvulotomies were performed by direct vision radical incisions along the commissures of fused valve leaflets to produce bicuspid or tricuspid valves. The atrial septal defects were closed with a continuous over and over stitch of fine silk between 2 stay sutures placed in the superior and inferior ends of the defect. Three patients have had both defects corrected at the same operation during separate occlusion periods.

Since a lag period of approximately  $\frac{1}{2}$  hour existed before a change in the esophageal temperature was observed, we began gradual warming of the patient about  $\frac{1}{2}$  to 1 hour prior to occlusion. We attempted to achieve an esophageal temperature of 30 C. with the temperature on the rise at the time of circulatory occlusion. Should ventricular fibrillation occur following occlusion, the salutary effect of warming<sup>8, 9</sup> can be accomplished more quickly. Warming was begun by perfusion of the blan-

\* Therm-o-rite Products Company.

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ket on which the patient lay at a temperature of 110–120 F. During this time, ventilation was actively controlled and nitrous oxide usually was necessary to quiet the patient.

Extubation of the trachea was feasible at the end of the operation. Some patients, free of the quiescence produced by hyperventilation, were intolerant of an endotracheal tube when the esophageal temperature was 31–32 C. Others required assistance of ventilation at 34 C. We have been unable to correlate the temperature with the optimal time for extubation. Instead, we relied principally upon spontaneous ventilatory ability. Employment of a ventilation meter to measure tidal and minute volumes has been of great aid in doubtful cases.

No further warming was done following extubation. A rubber mattress was placed on the patient's bed in anticipation of the rebound hyperpyrexia of 2–3 degrees C., which occasionally results.

#### OBSERVATIONS

Figure 1 illustrates that the relationship between the patient's weight and the time necessary in the tub to obtain an average temperature of 32.2 C. (31.5–33.0) approached a straight line. One adult required 85 minutes to cool, but postoperatively she developed signs and symptoms of hyperthyroidism.

Following removal from the tub, the temperature continued to fall over the next 30 minutes to 1 hour. The average drop in this series was 3.4 C. or, as Swan<sup>9</sup> has noticed, about two-thirds of that occurring during active cooling. There was no case of an unusual downward drift in temperature following removal from the ice bath. In no instance did a drop in temperature occur which equaled the drop occurring during active cooling. The esophageal temperature on removal from the ice bath varied from 31.5 to 33 C.; the low point range varied from 28.3 to 30.2 C. with an average of 28.8 C. It was not necessary to utilize the blanket beneath the patient either to lower the patient's temperature or to check a downward drop during surgery. The average esophageal temperature at the time of occlusion was 30.0 C.

Although rectal temperatures during the cooling phase have been shown to be unre-

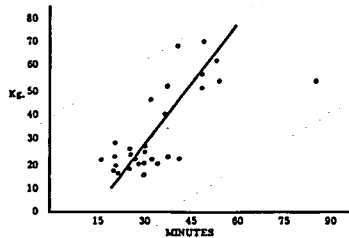


FIG. 1. Relationship of patient's weight and time in tub required to reach desired esophageal temperature. Average 32.2 C., range 31.5–33 C.

liable,<sup>10</sup> we continued to record rectal temperature as a check on esophageal temperature during surgery and for convenience in the recovery room. At the end of active cooling, rectal temperatures lagged behind the esophageal temperatures by as much as 1.7 C. Consequently, decision to remove the patient from the tub was based upon the esophageal temperature, regardless of the rectal temperature.

During cooling, the electrocardiogram was regularly evaluated by standard lead 2 showed progressive degrees of bradycardia, prolongation of the P-R interval, prolongation of the Q-T interval, occasionally the occurrence of auricular-ventricular dissociation and, on a number of occasions, auricular fibrillation. During the period of occlusion and coronary perfusion with warm, oxygenated, heparinized blood, we saw regularly a progressive improvement in the measured characteristics of the electrocardiogram. The rate increased, the P-R and Q-T intervals decreased; if block was present it has frequently disappeared and evidences of ectopic rhythmicity even during vigorous intracardiac manipulation was infrequent.

The electroencephalogram was an aid in maintaining a light plane of anesthesia during cooling and throughout the operation. Adequacy of cerebral perfusion was evident by electroencephalographic monitoring and was particularly helpful when blood pressure by auscultation was unobtainable during hypothermia. Review of electroencephalograms following total occlusion gave supporting evidence to the safe limit for occlusion at this temperature.<sup>11,12</sup> If the period of occlusion

lasted about 5 minutes or less, the return to the low amplitude fast activity present just prior to occlusion occurred in a minute or two. Eight patients in this series had inflow tract occlusion varying from 8-11 minutes. These longer periods of occlusion resulted in a more gradual restoration of the preocclusive pattern. An occlusion of 8 minutes might result in an abnormal electroencephalogram for about 1 hour. All of these patients were awake at the time of tracheal extubation.

Blood pressure has been obtained by auscultation only. With careful blood replacement and by monitoring the electroencephalogram, we have not believed it necessary to monitor the intra-arterial pressure. In only a third of our cases has a blood pressure been heard throughout the procedure. Usually the blood pressure is abruptly lost to auscultation during the cooling period when the temperature is between 33 C. and 34 C., although the range has extended from 29 C. to 36 C. An audible blood pressure reappears rather surreptitiously with a narrow pulse pressure and over a wide temperature range. Five patients at the time of tracheal extubation, who were ventilating adequately and were awake, had inaudible blood pressures. Return of blood pressure occurred in the recovery room with gradual rewarming.

Blood replacement was no problem. The average amount of citrated blood transfused during surgery was 600 ml. per patient. Only 3 patients required a third unit of blood. The amount of blood transfused depended more upon the ease or difficulty in repairing the cardiac defect than upon the size of the patient. There were no unusual bleeding problems.

#### COMPLICATIONS

Ventricular fibrillation occurred in two patients. One patient whose circulation was occluded for 11 minutes developed ventricular fibrillation shortly after the occlusive period, but responded to potassium chloride arrest, massage to the responsive phase and then 50 per cent glucose intravenously.<sup>13</sup> The other patient, whose circulation was occluded for 13 minutes, developed ventricular fibrillation 2 minutes following occlusion and could not be converted to normal rhythm. Both of these

cases occurred early in the series. At that time, blood for coronary perfusion was venous blood obtained from a warmed donor arm.<sup>14</sup> Samples of blood used in each case were found to be only 60 per cent saturated. Because of the variability in oxygen saturation by this method, it was abandoned in favor of the present method of using the patient's own arterial blood.

During the occlusive period, the needle used for coronary perfusion became impinged on the posterior wall of the aorta in two patients. Cardiac cyanosis and bradycardia reminiscent of the isolated, nonperfused hypothermic heart followed in each instance. Good color and tone quickly reappeared with manipulation of the needle and restitution of coronary perfusion.

Postoperative complications were predominantly pulmonary and were most likely related to the bilateral anterior thoracotomy and the difficulty in effecting proper ventilator function. Bronchoscopy was required for two patients because of inability to mobilize mucous plugs. Pleural effusion of significant degree occurred in two patients, but resolved spontaneously. Bronchopneumonia developed in two patients. More recently, the use of a right lateral thoracotomy incision for atrial defects or a longitudinal sternal splitting incision for pulmonary valvulotomies appeared to reduce postoperative difficulties.

Gastric dilatation developed in two children in the recovery room, seriously interfering with proper pulmonary ventilation. It occurred rapidly and there was marked improvement on decompression. No neurological sequelae, burns or fat necroses occurred in this series. One child required 2 weeks of physiotherapy to the elbow because of an extensive hematoma occurring during a blood infusion.

#### MORTALITY

Two deaths occurred in this series. An 11 year old child with a large ostium secundum defect occluded for 13 minutes developed ventricular fibrillation 2 minutes following occlusion, and attempts at resuscitation were unsuccessful. The temperature at the time of occlusion was 29.5 C. The other death was a 38 year old woman with an atrial septal

defect. Operation was uneventful. Postoperatively, she initially did well, but then became agitated, uncooperative and psychotically depressed. Freidlanders pneumonia followed by staphylococcal pneumonia, in spite of vigorous treatment, resulted in her death 3 weeks postoperatively.

### RESULTS

Of the eleven patients with pulmonary valvular stenosis, who were subjected to postoperative cardiac catheterization, all showed a reduction of the systolic gradient across the pulmonary valve to an absolute level of 20 mm. of mercury or less. All patients were asymptomatic after operation and showed major regression of evidences of right ventricular hypertrophy. One patient showed hemodynamic evidence of pulmonic insufficiency, but was not a clinical problem.

Of the 17 patients with auricular septal defects, who survived, all have had cardiac catheterization as well as clinical evidence of complete closure of their septal defects, with the exception of one patient. This patient shows clinical evidence of a continued left to right shunt, which has been verified by cardiac catheterization. The shunt has been reduced by approximately 50 per cent and the patient has had a significant clinical improvement since operation.

### DISCUSSION

It is becoming increasingly evident that hypothermia when limited to 28 C. or above can be a relatively benign adjunct to anesthesia and operation.<sup>9, 11, 12</sup> Although it has been called an elaborate, time-consuming technique, requiring a specially trained team,<sup>18</sup> our experience has not borne this out. Utilization of a standard technique permits adequate temperature prediction and control. Children usually require less than 30 minutes of additional anesthesia time to be cooled to the desired temperature. Although the presence of two anesthesiologists is of value during induction of anesthesia and cooling, one can adequately manage a case thereafter.

Ventricular fibrillation remains the greatest single danger of open heart surgery under hypothermia. The perfusion of the coronary

arteries with warmed, oxygenated, heparinized blood, however, has been demonstrated experimentally to protect the heart from ventricular fibrillation during and after periods of venous inflow tract occlusion.<sup>16, 17, 18</sup> Experiments in our laboratory indicate that perfusion rates approximately one-half normal coronary blood flow rates can prevent significant myocardial anoxia. Its value has also been demonstrated clinically by Maloney, Spencer and Grow.<sup>19, 20, 21</sup>

A growing awareness of the need for open heart surgery at the community hospital level is evident.<sup>2</sup> The anesthetic and operative management of patients with atrial and pulmonary valvular defects, as described above, imposes no undue burden on community hospital facilities. A large "cardiac team" is not required and blood requirements are minimal.

### SUMMARY AND CONCLUSION

The management of 30 consecutive cases undergoing open heart surgery for auricular defects and pulmonary stenosis employing hypothermia and coronary perfusion has been discussed. Hypothermia has proved to be an easily managed and predictable technique. Coronary perfusion with the patient's own arterial blood during the time of occlusion and cardiotomy maintains or restores good myocardial tone and beat. The feasibility of this method of open heart surgery on the community hospital level has been emphasized.

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