Review

Review of Deep Hypothermia and Circulatory Arrest Techniques For Surgical Repair of Giant Cerebral Aneurysms

Linda B. Mongero BS, CCP, Joseph J. Sistino MPA, CCP

Columbia-Presbyterian Medical Center, Milstein Hospital, New York, New York

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ABSTRACT

Early experience in the 1960s with the repair of giant cerebral aneurysms utilizing cardiopulmonary bypass (CPB) with deep hypothermia and circulatory arrest was reviewed. However, due to the complications associated with CPB, its use was abandoned in the early 1970's. Surface cooling alone with open chest cardiac massage was then employed successfully in a series of neurosurgical patients.

Reintroduction of bypass techniques for core cooling using peripheral cannulation combined with neurosurgical advances has decreased the morbidity associated with this technique in the 1980s. However, some centers continue to perform these procedures with open chest cardiopulmonary bypass. Although there are advantages to the open chest technique, it is no longer necessary in most patients. With a long thin-walled venous cannula advanced from the femoral vein to the right atrium, combined with a centrifugal pump in the venous line, adequate venous return and cardiac decompression can be achieved without the need for a sternotomy. Advances in perfusion techniques and anesthetic monitoring are the hallmarks of the successful outcome in neurosurgical repairs of giant cerebral aneurysms in the 1990s.

Address correspondence to:
Linda B. Mongero, CCP
Columbia-Presbyterian Medical Center
Milstein Hospital
Building 4-350
New York, NY 10032-3784

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LITERATURE REVIEW

Profound hypothermia as described by Drew (1) in 1959 proved it was possible to cool a dog to 8°C and rewarm it without harm or evidence of neurological damage. To achieve profound hypothermia, it was necessary to take over the function of both ventricles mechanically, especially when asystole occurs. Cooling to 8°C was accomplished with blood draining from the left atrium to a reservoir, then pumped through a cooling coil and back to the dog via the femoral artery. A separate circuit for right heart bypass with cannulation of the right atrium and the pulmonary artery was used. This other circuit did not cool the venous blood. Thirty minutes were necessary to cool to 8°C while rewarming took slightly longer. Measurement of brain temperature proved that this organ was not excluded from the cooling process. There were no electrolyte imbalances nor postoperative lung complications. The 100 feet of plastic tubing in the heat exchanger was a considerable resistance to blood flow and was replaced with stainless steel tubes in later experiments.

Woodhall (2) and associates made further developments with the use of pharmacological agents for control of cardiac arrhythmias during induced hypothermia below 24°C. Their observation was that administration of quinidine during cooling prevented ventricular fibrillation. The method of achieving cardiopulmonary bypass and hypothermia utilized a modified DeWall-Lillehei pump-oxygenator containing two Brown-Harrison heat exchangers coupled in series. Venous return from both the left internal jugular vein and the sapho-femoral bulb into the inferior vena cava drained blood to the circuit for oxygenation. The blood was returned to the patient via the femoral artery. After 44 minutes of cardiopulmonary bypass the perfusate temperature was 4°C and the brain temperature attained a final level of 11°C. The heart fibrillated at 23°C esophageal temperature and cardiac asystole ensued at 18.9°C. The flow was reduced to 2000 ml per minute to prevent overdistention of the heart. The period of circulatory arrest was 10 minutes for surgical repair by the neurosurgeon at which time the pump remained off. The extracorporeal circulation was restarted and promptly rewarmed the patient in 74 minutes. The heart spontaneously defibrillated to normal sinus rhythm at an esophageal temperature of 16°C.

Several potentially valuable refinements were suggested to improve the technical factors that controlled repair of this intracranial condition. Venous outflow of the brain may have been obstructed due to cannulation of the internal jugular vein which would tend to increase the intracranial pressure. Because this may have been already elevated due to the lesion, an infraclavicular approach would have been preferable. Long periods of cardiac asystole with lack of extracorporeal perfusion may cause tissue necrosis. Short intermittent periods of flow would not impair the neurosurgeon's view and are actually valuable to check hemostasis. Rewarming should be conducted more slowly than demonstrated so as not to develop cardiac muscle temperature gradients and changes in metabolic tissue demand.

Experience at the Mayo Clinic in 1960 by Alfred Uihlein (3), on 14 patients with intracranial lesions for surgical repair under deep hypothermic circulatory arrest using the Drew Method reported no increases in brain damage. Cardiovascular and pulmonary complications were absent in all but two patients. Three patients died three days postoperatively due to hemorrhage. Use of a warming blanket was reported to keep the patients' temperatures from drifting downward after cardiopulmonary bypass.

A second group of patients (n=66) having 67 intracranial aneurysms underwent deep hypothermia using extracorporeal circulation by either the open-chest or the closed chest method at the Mayo Clinic and was reported by Uihlein (3). Seventeen patients were operated on by the methods described by Drew (1). Four of these open-thorax procedures were unsuccessful. Forty-nine patients underwent the closed-thorax perfusion method of Woodhall (2) and associates, with 11 patients having an unsuccessful outcome. Alterations in blood clotting characteristics constituted the major deterrent to deep hypothermia for surgical repair of these lesions. Aminocaproic acid was administered intravenously at the time of craniotomy before bypass to help prevent bleeding. After neutralization of heparin, several units of freshly acquired platelets were administered. Although this study justifies the use of deep hypothermia for successful repair of intracerebral aneurysms using the closed chest technique, most of the unexpected complications were blamed on the extracorporeal circulation techniques used at this time.

Patterson and Ray (4) did an elaborate study on mongrel dogs and later applied those techniques to humans. Experiments were performed on 120 dogs connected to the extracorporeal circuit with venous cannula inserted through the jugular vein into the right atrium and the femoral vein into the inferior vena cava. Blood was drained via gravity from a table that could be raised and lowered to control the rate of venous return to a Kay-Cross disc oxygenator ventilated with 100% oxygen. The blood was pumped from the oxygenator through a Brown-Harrison heat exchanger and a bubble trap to the right femoral artery. The extracorporeal circuit was primed with 1750 ml of ACD heparinized blood. Flow rates ranged from 75-100 ml/kg but as cooling progressed decreased to 30-50 ml/kg. If venous return was poor, a small amount of transfused blood greatly improved the flow and pressures. During craniotomies when blood is drained from the animal to aid in exposure of the aneurysm, there is a danger of an air embolus through an open vein. This occurred on two occasions, as reported by Patterson, and the air was introduced through an open manometer connected to a venous pressure catheter. Cooling these animals was rather uneven until a reported rapid decline of the esophageal temperature below 25°C. This was paralleled by a rapid fall in temperature within the upper aorta which occurred when the heart slowed and cardiac output fell. It appeared that the cold blood returning to the femoral artery did not reach the upper aorta during partial bypass. Only when the animal's cardiac output fell, did blood from the pump flow up the aorta to sufficiently cool the thoracic aorta.

Patterson and Ray's (4) clinical experience on seven patients required certain modifications. The disc oxygenator used in the dog model was increased from nine inches in dogs to 18 inches for humans and the extracorporeal circuit was primed with 3250 ml of fresh heparinized blood. Also, a millipore filter was used to sterilize the gas introduced to the oxygenator. They concluded that the time spent cooling and rewarming could be shortened by using a more efficient heat exchanger and the brain could be cooled more rapidly than the rest of the body by introducing cold blood into the upper aorta instead of into the femoral artery. Otherwise, this is a safe technique used for repair of intracranial aneurysms. An addendum to the laboratory and clinical findings of this group was the reported use of low molecular weight dextran to prime the extracorporeal circuit. This improved the perfusion flow rates and resulted in faster cooling.

Michenfelder (5) and associates from the Mayo Clinic in 1963 indicated the usefulness of profound hypothermia and total circulatory arrest in the repair of cerebral aneurysms in 15 patients using the closed chest technique. A Mayo-Gibbon pump-oxygenator was used for perfusion of the patient. Priming of the circuit consisted of 1500 ml of ACD blood, 1500 ml of 5 percent dextrose in water, and 240 ml of serum albumin. The flow rates ranged from 1.3 to 1.7 l/min/m2. During cooling and rewarming when the temperatures are more than 25°C and the cardiac action is suitable, the systemic flow is aided by the patient's own output. To minimize the possibility of left ventricular distention once the heart fibrillated, they maintained low venous and right atrial pressures, gradually cooled to prevent premature fibrillation, and defibrillated early during rewarming. The amount of blood administered in the operating room including priming volume ranged from 2500 to 6500 ml per patient. Possibly the flow rates of 1.3 to 1.7 l/min/m^2 were not adequate because metabolic acidosis occurred in several patients the first postoperative evening. Michenfelder (6) found there was relatively little difference between his patients and others previously reported with the open- chest technique in postoperative hemodynamic, metabolic, and pulmonary function.

Although the use of deep hypothermia and circulatory arrest facilitated superb exposure of cerebral aneurysms in 10 cases by Drake (7), the results were not rewarding. The operative mortality was 30% and overall mortality 50%. The open-chest method was performed by Drake with cannulation of the right atrium to facilitate venous return and a standard femoral artery cannula for return from the pump oxygenator. A 12°C gradient was maintained between the core and perfusing blood to minimize the risk of gaseous microemboli. The three postoperative deaths were attributed to the use of extracorporeal circulation due to inadequate perfusion and uncontrollable bleeding. Drake felt that this technique created enough additional hazards that it was probably not warranted in cases where the aneurysm could be obliterated by more conventional methods.

Due to the major complications associated with cardiopulmonary bypass, the technique of deep hypothermia and circulatory arrest for repair of giant cerebral aneurysms was not reported again for some years. The technique, however, continues to be utilized for certain cardiovascular procedures (8).

In 1974, in an attempt to avoid the use of cardiopulmonary bypass, McMurtry, Housepian, Bowman, et al (9), reported a technique to aid in the surgical treatment of patients with basilar artery aneurysms. Twelve patients under moderate hypothermia (28°C) induced by surface cooling for approximately 3.5 hours, reached a core temperature of 32°C. While active cooling was continued, the patient was transferred to the operating room. The head, neck, and chest were prepped and draped. The neurosurgical team began the craniotomy and placement of the operating microscope before the cardiac surgeon performed the sternotomy. At this time the core temperature had reached 28°C, ventricular fibrillation was induced and the aneurysm was repaired within 4 minutes. If more time is needed, manual cardiac systole was performed for 60 seconds. This was repeated for as long as 28 minutes. After the aneurysm was treated, normal sinus rhythm was restored. The authors preferred this open-chest technique to the closed-chest technique because there is a longer time available for safe arrest. Also, loss of control of cardiac rhythm and post-arrest hypertension are obviated by the open method.

Reappraisal of cardiopulmonary bypass with deep hypothermia and circulatory arrest for complex neurosurgical operations continued in 1983 by Baumgartner (9). Because of the refinements in extracorporeal bypass techniques as well as improved neuroanesthesia management, elective neurosurgical procedures were performed on 14 patients over a four year period. All patients underwent cardiovascular evaluation to rule out significant cardiac disease. The femoral cannulation technique included both femoral veins to insure adequate venous drainage to the pump and arterial infusion was through the right femoral artery. Cardiopulmonary bypass was initiated at flow rates of 40 to 50 ml/kg/min. At a temperature of 20°C nasopharyngeal, total circulatory arrest was begun. Positioning of the patient's head above the level of the heart facilitated venous drainage of the cranial vessels when the venous lines were opened. It required an average of 67 minutes to rewarm the patients to 36°C with flows ranging from 40 to 50 ml/kg/min.

To achieve hemostasis after protamine sulfate was administered, 6 units of platelets, 4 units of fresh-frozen plasma, 1 to 2 gm of calcium chloride, the patient's own fresh blood (removed before bypass), and 2 units of factor IX complex were given in each instance.

There was zero mortality reported in this group, however; morbidity consisted of ten postoperative neurological complications, of which seven were transient and three were permanent. The major disadvantage of the technique was the effect on the coagulation system and the associated platelet dysfunction due to foreign surface contact. The closed chest technique was preferred to thoracotomy because of its simplicity and reduction in surgical trauma. Baumgartner was encouraged by the results obtained in this series and felt it justified reappraisal of hypothermia with circulatory arrest for repair of these otherwise inoperable lesions.

The British Journal of Neurosurgery published an article by Richards (11) describing the experience in 1987 of the management of repair of intracranial aneurysms on cardiopulmonary bypass. Eleven patients underwent computerized axial tomography scanning and four vessel angiography before their method of treatment was decided. Perioperative risk factors were decided by a cardiologist and only one patient that was hypertensive suffered complications while convalescing and suddenly died of myocardial infarction.

The patients were positioned with the left chest prepped and draped in case of emergency thoracotomy for acute left ventricular distention. Both femoral veins and the femoral artery on one side were cannulated. The perfusion apparatus utilized a membrane oxygenator and approximately thirty minutes were necessary to cool the patient from 37°C to 15°C. The practice of trickle perfusion if the aneurysm was opened prevented air from entering the intracranial circulation. When the aneurysm was secured, the patient was rewarmed and discontinued from cardiopulmonary bypass and hemostasis restored. Fresh frozen plasma and platelets were routinely given and the operation was completed only after the thrombin time returned to normal.

Spetzler (12) reported the repair of giant cerebral aneurysms in several patients in 1986. Monitoring of the electroencephalographic activity (EEG), somatosensory evoke potentials (SSEP), and brain-stem auditory evoked potentials (BAEP) were reported for the first time. EEG recording was used to titrate an effective dose of barbiturates for cerebral protection during the procedure and SSEP to confirm the integrity of the sensory conduction. BAEP was used when the procedure threatens brain-stem structures. The benefits of monitoring this way were illustrated on a patient that was found to have a subdural hematoma perioperatively which was evacuated and the patient recovered uneventfully.

Surface cooling was initiated and hemodilution to a hematocrit of 28% performed by running the patient's blood into an anticoagulant solution while replacing the blood volume with cold saline. Femoral-femoral cannulation was used with the closed-chest method for cardiopulmonary bypass. When the heart began to fibrillate below 28°C, a bolus of potassium chloride was given to prevent myocardial ischemic injury. Post cardiopulmonary bypass, autologous blood with fresh platelets and clotting factors were administered to control bleeding.

Seven patients underwent this neurosurgical procedure using these techniques for cardiopulmonary bypass and circulatory arrest. The outcome was excellent in four procedures, two patients died, and one had fair recovery. The authors feel the long-term results support the use of this technique for repair of giant cerebral aneurysms.

A 1989 case report from the departments of Neurosurgery, Cardiothoracic Surgery, and Anesthesia at the Yale Medical School (13) was strongly in favor of the open-chest method. Total cardiopulmonary bypass was instituted after median sternotomy via cannulation of the right atrium and aorta. Once the flow was established, cooling was begun. The cooling time was 30 minutes to a temperature of 16°C rectal, at which time the pump was turned off and cold (4°C) potassium cardioplegia given into the aortic root. After the aneurysm was clipped and bypass reinstituted, the patient was rewarmed to a core temperature of 34°C in 55 minutes.

Chyatte (13) believes that the open-chest method has several distinct advantages over the closed-chest technique. Venous return is always ensured with optimal bypass flows. Total bypass times, neurological damage, and coagulopathies associated with prolonged bypass time can be minimized. Myocardial protection with cardioplegia aided by direct observation upon rewarming eliminates the risk of overdistention of the left ventricle. In addition, trauma to the femoral veins is avoided and this decreases the risk of deep venous thrombophlebitis and pulmonary embolism. These conclusions were drawn from their experience with this single procedure.

CONCLUSION

Although there are advantages to the open chest technique, it is no longer necessary in most patients. With a long thin-walled venous cannulae advanced from the femoral vein to the right atrium, combined with a centrifugal pump in the venous line, full bypass and cardiac decompression can be achieved without the need for a sternotomy (13). Advances in perfusion techniques and anesthetic monitoring are the hallmarks of the successful outcome in neurosurgical repairs of giant cerebral aneurysms in the 1990s.

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