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Extracorporeal femoral to carotid artery perfusion in selective brain cooling for a giant aneurysm

Case report

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✓ Giant partially thrombosed intracranial aneurysms are a challenge to treat surgically, and they are also unsuitable for coil embolization. The current options for treatment include extracranial–intracranial bypass followed by parent artery occlusion or direct surgical occlusion in which deep hypothermic circulatory arrest is used.

The authors report the use of another approach in the treatment of a giant anterior circulation aneurysm: selective brain cooling accomplished by extracorporeal perfusion. This facilitated direct surgery on a 4.2-cm, partially thrombosed aneurysm of the middle cerebral artery (MCA). A brain temperature of 22˚C was achieved after 20 minutes of perfusion with blood cooled using an extracorporeal technique of femoral–common carotid artery perfusion. This was followed by a 20-minute period of surgical trapping of the MCA, then evacuation and clip occlusion of the aneurysm. During the period of selective brain cooling the patient's core body temperature was maintained above 35˚C.

This technique of selective brain cooling may be a useful alternative to currently available surgical and endovascular methods of treatment for giant aneurysms.

Key Words • **giant aneurysm** • **cerebral protection** • **extracorporeal circulation** • **hypothermia** • **circulatory arrest** • **selective brain cooling**

In surgery for giant aneurysms, it is recognized that complete neck occlusion is obtained most consistently and safely by using measures to relieve pressure in or collapse the aneurysm sac.[1] This requires a period of parent artery occlusion or trapping, which must be undertaken within certain time limits to avoid ischemic stroke.[5,11]

For giant aneurysms of the proximal ICA, it is helpful to decompress the sac by retrograde suction through the CA in the neck during temporary trapping.[2,17] In such cases, robust collateral flow to the cerebral hemisphere can be provided by the circle of Willis above the point of trapping. Nevertheless, for giant aneurysms of the distal ICA or of the MCA, the leptomeningeal collateral supply is often feeble.[4] If there is a thrombus within the aneurysm sac, a longer period of temporary occlusion may be needed to remove it before clip placement. Such aneurysms may be daunting for direct surgery within the time limits of temporary occlusion. Indirect methods are often used, particularly extracranial–intracranial bypass surgery combined with parent artery occlusion.[4,8]

For some giant aneurysms, deep hypothermia is regarded as an effective form of cerebral protection during prolonged surgical ischemia. In particular, closed-chest deep hypothermia has permitted successful surgery in a bloodless field during prolonged periods of circulatory arrest.[7–9,15] This method, however, entails a period of complete cardiac standstill, with risks that include myocardial infarction, sepsis, and pulmonary embolus.[7,15]

In this report we detail a technique of selective brain cooling that eliminated the disadvantages of systemic hypothermia and total circulatory arrest, while preserving the advantage of working in a bloodless but protected field. This technique was used in a patient with a 4.2-cm-diameter, partially thrombosed MCA aneurysm.

Case Report

History and Examination. This 66-year-old woman presented with right temporal headaches and two episodes of left arm weakness. An admission CT scan demonstrated an embolic stroke in the territory of the right MCA and a 2.7-cm-diameter, centrally enhancing mass in the right temporal lobe (Fig. 1 *left*). Cerebral angiography revealed a giant aneurysm of the right MCA bifurcation (Fig. 2 *left*). Follow-up imaging 10 months later revealed enlargement of

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Abbreviations used in this paper: ACT = activated clotting time; CA = carotid artery; CCA = common CA; CT = computerized tomography; ECA = external CA; FA = femoral artery; ICA = internal CA; MCA = middle cerebral artery.

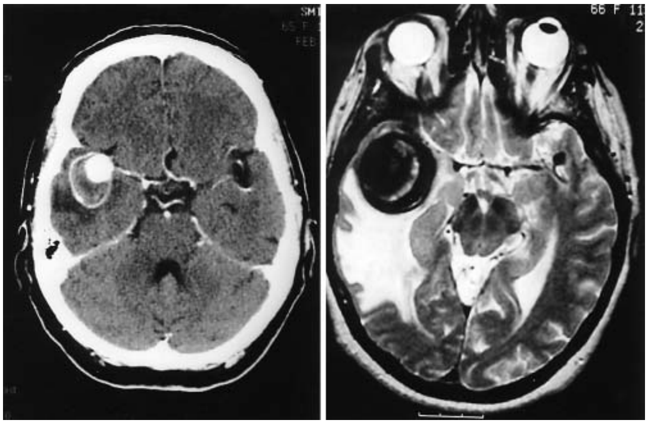

FIG. 1. *Left:* Contrast-enhanced axial CT scan revealing a 2.7-cm-diameter centrally enhancing mass in the right temporal lobe with mild surrounding edema. *Right:* Axial T_2-weighted magnetic resonance image obtained 10 months later, demonstrating enlargement of the mass to a 4.2-cm diameter, with marked increase in surrounding edema and compression of the right cerebral peduncle.

the aneurysm to 4.2 cm, with increased mass effect and cerebral edema (Fig. 1 *right*). The aneurysm had a saccular appearance with a wide neck, indicating that surgical reconstruction with clips might be feasible after evacuation of the intraluminal thrombus. If the attempt at clip occlusion failed, the second option was proximal MCA occlusion with extracranial–intracranial bypass.

Management Procedures.

Anesthetic Agent. A standard general anesthetic technique was used; induction was performed with remifentanil and propofol, and anesthesia was maintained with remifentanil infusion and desflurane in an air/O_2 mixture. Rocuronium was used for muscle relaxation, and ventilation was controlled to maintain a $PaCO_2$ of 33 to 35 mm Hg. In addition to standard monitoring, radial and pulmonary arterial pressures were measured. Scalp electroencephalography readings were obtained using a 12-lead (bihemispheric) montage. A transesophageal echo probe was used in case cardiopulmonary bypass became necessary. Body temperatures were measured using nasopharyngeal and rectal probes as well as the pulmonary artery catheter. The operating room temperature was kept at 20 to 22˚C and the patient was placed on a water-heating mattress preset to 38˚C. After lumbar drain insertion and patient positioning, a forced-air heating blanket covered in a sterile plastic drape was laid over the patient's prepared chest and upper abdomen and another was placed over her legs.

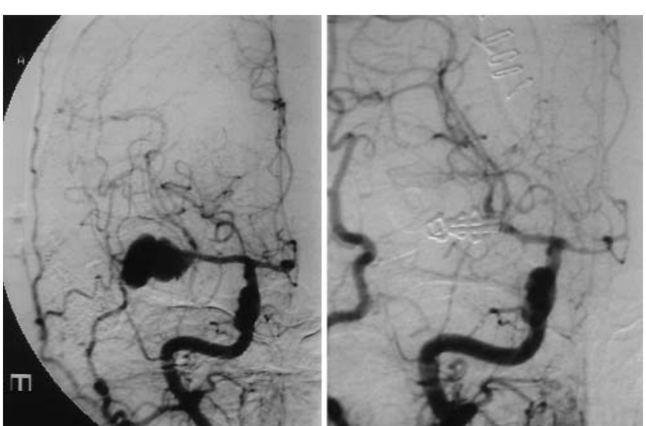

FIG. 2. *Left:* Right CCA angiogram, anteroposterior Towne projection, demonstrating filling of the central lumen of the MCA bifurcation aneurysm and displacement of M_2 and M_3 branches away from the lumen by the thrombosed portion of the aneurysm mass. *Right:* Postoperative right CCA angiogram, same projection, demonstrating satisfactory clip occlusion of the aneurysm with preservation of both divisions of the MCA.

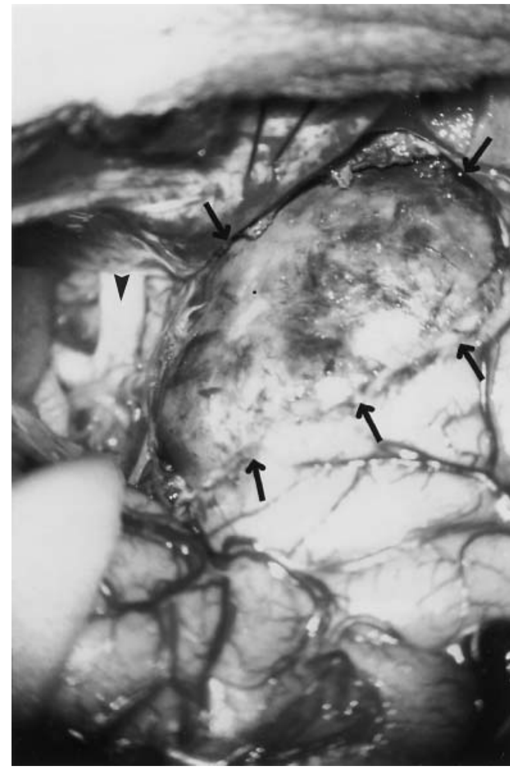

FIG. 3. Intraoperative photograph showing the aneurysm, which is demarcated by *arrows*. The *arrowhead* designates the right optic nerve.

Neurosurgical Method. Exposure was accompished through a standard right frontotemporal craniotomy. After opening the dura, two malleable strip temperature probes were placed on the brain in the subdural space posterior to the craniotomy. A needle temperature probe was inserted into the temporalis muscle. The right CA in the neck was exposed through a standard endarterectomy incision.

The sylvian fissure was opened with the aid of an operating microscope, and the aneurysm mass was visible (Fig. 3) after retraction of the undersurface of the frontal lobe. It was evident that evacuation of the thrombus would be required. To accomplish this, a prolonged period of MCA occlusion was anticipated.

Perfusion. A standard cardiopulmonary perfusion circuit was set up using a blood cardioplegia apparatus (Cardiotherm; Medtronic, Inc., Mississauga, ON, Canada). The apparatus consisted of 0.25-in tubing for both inflow and outflow circuits, and the priming solution was Ringer lactate

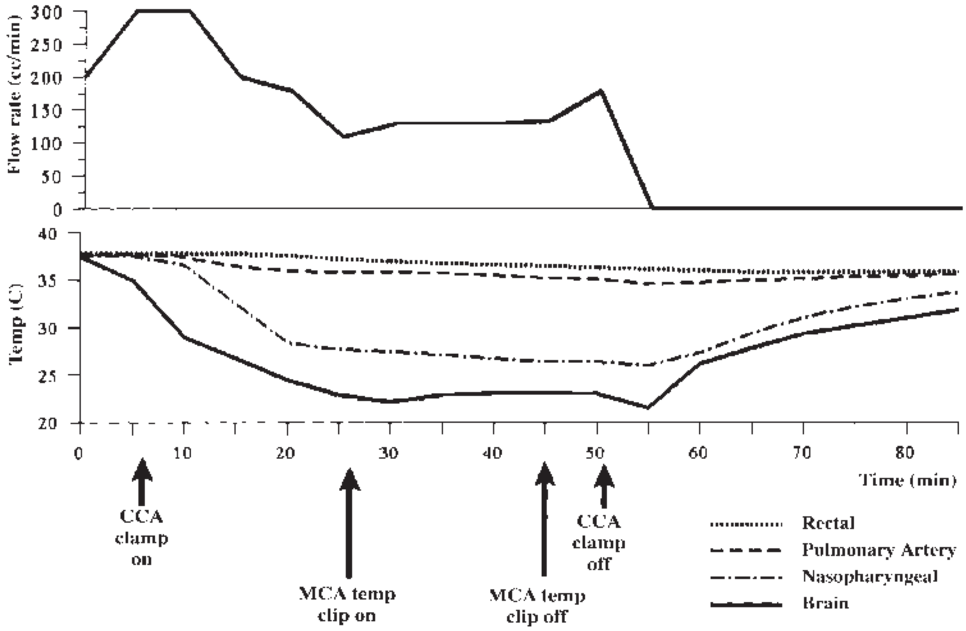

FIG. 4. Graphs depicting extracorporeal flow rate *(upper)* and temperature (Temp; *lower*) at four points of measurement (brain, rectum, nasopharynx, and pulmonary artery) compared with time.

at a total volume of 130 ml. A No. 6 French introducing catheter was placed in the left common femoral vein in case full cardiopulmonary bypass became necessary. The right common FA was exposed and cannulated with a No. 16 French heparin-bonded percutaneous cannula, which was advanced to the distal aorta. Systemic heparinization was instituted with a bolus of 15,000 U, resulting in an ACT of 419 seconds. A second bolus of 5000 U was administered several minutes later to give an ACT of 522 seconds.

Selective Brain Cooling Phase. The brain and systemic temperatures were maintained between 35.5 and 37.5˚C up to the time of brain cooling. The CCA was cannulated with a No. 8 French heparin-bonded cannula. There was palpable atheromatous change at the CA bulb, and this area was avoided. A 26-gauge catheter was inserted into the ICA distally for pressure measurements. Initial extracorporeal perfusion flow was up to 300 ml/minute; this was reduced over several minutes to 150 to 180 ml/minute because of the desire to keep the ICA pressure at a mean of 100 mm Hg or lower (Fig. 4). The CA was clamped proximal to the arterial inflow cannula shortly after the start of extracorporeal perfusion.

Results of Selective Brain Cooling. Within 12 minutes of perfusion with cold (20˚C) blood, the brain temperature had decreased to 26.8˚C. The aneurysm wall was incised and both firm and jelly-like thrombi were removed. After several minutes the aneurysm lumen was entered and bleeding occurred; accordingly, the perfusion flow rate was briefly reduced and a temporary clip was applied to the MCA proximal to the bifurcation. A second temporary clip was applied beyond the aneurysm on the superior division of the MCA. There was no backflow from the inferior division because leptomeningeal collateral supply was absent. The extracorporeal perfusion flow rate was maintained at 130 ml/minute. The brain temperature decreased to 22.5˚C, and was stable between 22.2 to 22.5˚C during 20 minutes of MCA occlusion. The thrombus was evacuated from the aneurysm and the neck of the lesion was clipped. Two periods of temporary M_1 occlusion (17 minutes 15 seconds and 2 minutes 0 seconds) were required to complete the aneurysm evacuation and clipping, resulting in a total temporary trapping time of 19 minutes and 15 seconds. The patient's systemic blood pressure and heart rate showed minimal changes during the period of extracorporeal perfusion. The mean arterial pressure remained above 60 mm Hg without the need for vasopressors or inotropes.

Completion of Selective Brain Cooling. After clip placement, with removal of the temporary clip and no evidence of bleeding or refilling of the collapsed aneurysm sac, the CA was unclamped and decannulated and the brain was allowed to rewarm. The heparinization was reversed with protamine. The total extracorporeal perfusion time was 54 minutes, including the period of MCA occlusion. The brain temperature rose from 21.6˚C at the end of extracorporeal perfusion to 26.2˚C after 5 minutes, and to 31.9˚C after 30 minutes. Pulmonary artery temperature dropped from 37.7˚C to a low point of 34.6˚C at the conclusion of extracorporeal perfusion, then rose to 35.5˚C after 30 minutes of normal circulation. The rectal temperature fell slightly, from 37.8 to 36.2˚C during the period of selective brain cooling, then dropped further to 35.8˚C during 18 minutes of reestablished normal circulation before the temperature stabilized (Fig. 4). There was no alteration in cardiac rhythm, and no untoward bleeding during the cooling or rewarming phase.

Postoperative Course. The patient was extubated on the 1st day postoperatively. She remained neurologically intact and her headaches resolved completely. Postoperative angiography demonstrated satisfactory clip occlusion of the aneurysm (Fig. 2 *right*), and no evidence of new infarction was found on CT scans. Follow-up CT scans obtained at 1 year demonstrated resolution of the edema and mass effect.

Discussion

Concept of Selective Brain Cooling for Aneurysm Surgery

The introduction of total-body hypothermic circulatory arrest to neurosurgery in the 1950s was motivated by the desire to minimize brain injury while working in a completely dry surgical field.[3] To a limited degree, selective brain cooling was also considered at that time. In a study performed in dogs, Verdura, et al.,[18] showed that bilateral CA perfusion with cooled blood resulted in a brain temperature of 15˚C, whereas the core body temperature dropped to no lower than 29˚C. Potential advantages of a selective approach over total-body circulatory arrest included elimination of the need for an oxygenator and a reduced anticoagulation time with the brain being rewarmed by the systemic circulation. Despite these advantages, there was a lack of interest because of the difficulty involved in total arrest of the cerebral circulation at the level of the neck. The techniques were complicated: in one study in which dogs were subjected to selective cooling combined with deliberate profound hypotension, neurological deficits and cardiovascular collapse occurred postoperatively.[10]

In 10 humans with aneurysms or brain tumors, Williams and Turner[19] used selective cooling administered through the CA during surgery. They made infusions at higher than normal pressures in an attempt to obtain whole-brain hypothermia. This was combined with surgical occlusion of the opposite CA and both vertebral arteries to obtain total cerebral circulatory arrest. Although profound brain cooling (to temperatures as low as 11.6 to 19.5˚C) was achieved, these authors discontinued use of the technique because of a high mortality rate resulting from poor control of coagulation and lengthy operating times.

More recently, Schwartz and colleagues[12] have reexamined single CA hypothermic extracorporeal perfusion in baboons. In that study, sustained cerebral hypothermia to less than 19˚C for 30 minutes was achieved with only mild systemic cooling.

Physiological Observations From This Case

Our experience demonstrates that it is physiologically possible to create a prolonged state of selective brain cooling to 22˚C, with preservation of systemic normothermia by using extracorporeal perfusion of cooled blood diverted from a patient's FA. The rate of brain cooling paralleled the rate of extracorporeal perfusion (Fig. 4). During the first 8 minutes, with flow rates at a mean of 280 ml/minute, the right cerebral hemisphere temperature decreased by approximately 1˚ per minute, to 29˚C. With reduction of flow to 200 ml/minute over the next 5 minutes, the brain temperature fell by approximately 1˚ every 2 minutes, to 26.8˚C. A further flow reduction to 130 ml/minute over the next 7 minutes was associated with a slower drop in brain temperature (by 1˚ every 3 minutes) to a stable level of hypothermia at 22.2 to 23.2˚C, which was maintained for 25 minutes before the cessation of extracorporeal cooling.

With the use of warming blankets both over and under the patient, the rate of systemic cooling was very slow. The pulmonary artery temperature dropped slightly, from 37.8 to 34.6˚C over 50 minutes, a rate of 0.06˚C per minute; it began to rise immediately on cessation of extracorporeal cooling. The rectal temperature continued to drop, to 35.8˚C for 15 minutes after the cessation of extracorporeal cooling, stabilizing at that level for the next 15 minutes. Although we had intended to rewarm the brain extracorporeally after the aneurysm clip placement, this was not necessary. With the patient's core temperature at 36˚C, passive rewarming was allowed to occur with the help of the warming blankets over and under the thorax and abdomen, avoiding a potential overshoot in brain temperature.

Technical Considerations

One of our concerns with selective CA perfusion was the potential for overperfusion as has been reported in animal studies.[12] Pressure in the distal ICA was monitored with a 26-gauge catheter, in addition to direct measurement through the arterial inflow line by the clinical cardiac perfusionist. The flow rate of 300 ml/minute that we initially chose for the extracorporeal perfusion was based on phase-contrast magnetic resonance imaging measurements of mean flow rates in the CCAs of healthy female volunteers. These were obtained previously by one of us (D.A.S.) as part of an ongoing, independent study of CA hemodynamics.[16] Initial mean pressure readings at this flow rate were in the range of 110 to 130 mm Hg, and led us to reduce the flow rate to maintain a mean perfusion pressure of 90 to 100 mm Hg.

A second concern was the possibility of premature rewarming of the right cerebral hemisphere during the period of aneurysm trapping and thrombus evacuation. We elected to place the perfusion cannula in the CCA rather than the ICA and to leave the ECA open at the bifurcation. We thought that cooling the scalp, muscle, and dura through the ECA branches would help to cool the brain during the initial phase and also help prevent rewarming of the brain by convection. Extracorporeal flow was continued during the period of aneurysm trapping. Thus, the supraclinoid ICA, proximal MCA, anterior cerebral artery, and ECA were continually oxygenated and cooled. This helped to maintain tissue oxygenation through the collateral circulation,[6,13] and allowed for convective leptomeningeal cooling at the interface of the distal anterior cerebral artery and MCA territories.

Potential Advantages of Selective Brain Cooling Over Circulatory Arrest

The risks associated with prolonged cardiac standstill under deep hypothermia in which closed-chest techniques are used include the following: death due to aortic dissection related to arterial line placement;[1] acute ventricular distension necessitating emergency sternotomy;[7,15] intraoperative air embolus;[15] failure to cardiovert during rewarming, requiring sternotomy and direct cardioversion; and impaired perfusion in other cerebral or vascular territories.[7] Additional risks postoperatively include sepsis, myocardial infarction, deep vein thrombosis, and pulmonary embolus. In two of the larger reported series in which deep hypothermic circulatory arrest was used,[7,15] the mean cardiopulmonary bypass times were 1.5 to 3 hours. The brain temperatures were 15 to 18.3˚C, with a mean circulatory arrest time of 22 minutes. In our case the extracorporeal perfusion time was 54 minutes, the brain temperature was 22˚C, and the temporary trapping time was nearly 20 minutes. For the levels of brain temperature and temporary flow arrest obtained, the perfusion period was shorter than in hypothermic circulatory arrest because of the more rapid brain cooling and the obviation of the need for extracorporeal rewarming. The fact that we did not use systemic cooling also eliminated or reduced the risk of cardiac arrhythmia, aortic dissection, and ventricular distension.

A major concern with the use of deep hypothermic circulatory arrest is its effect on the coagulation system.[7] During the cooling phase, thrombocytopenia may occur. The oxygenator can also impair platelet function, and clotting factors can become diluted. With selective cooling, because the outflow line was from the FA, it was already oxygenated and there was no need to provide an oxygenator in the extracorporeal circuit. As a result, the perfusion setup was simplified. We used a biocompatible circuit but elected to use full anticoagulation, administering a total of 20,000 U heparin to keep the ACT in the range of 419 to 522 seconds.

Limitations and Future Considerations

As adjuncts to neurovascular surgery have improved, there is less need to resort to hypothermic cerebral protection.[1,2,5,8,11] Indeed, some investigators have expressed doubt that hypothermia is ever required for giant anterior circulation aneurysms.[7,14] Although the method described is relatively simple for anterior circulation aneurysms treated via CA exposure, it would be more challenging for posterior circulation aneurysms.

A future consideration relates to our decision to use the blood cardioplegia component from a standard heart–lung machine, in case the need arose to implement full cardiopulmonary bypass. In retrospect, it may have been feasible to use a simpler extracorporeal centrifugal pump system with a biocompatible circuit. This would require less anticoagulation time and would approach a "heparinless" form of extracorporeal perfusion.[6]

Conclusions

We have described the physiological effectiveness of a method of selective brain cooling. This method was used successfully in the treatment of a giant partially thrombosed aneurysm of the right MCA. Selective brain cooling to 22˚C was achieved with preservation of systemic temperatures at 35 to 36˚C, allowing 20 minutes of safe arterial occlusion. This method may be a useful alternative to hypothermic circulatory arrest for giant aneurysms of the anterior circulation.

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