EDITORIALS

CEREBRAL PROTECTION DURING AORTIC ARCH SURGERY*

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In this issue of the *Journal*, Kazui and associates¹ report an outstanding series of patients with aortic arch operations, with an exceptionally low mortality and incidence of neurologic complications. This is the latest in a series of reports by Kazui, who has been a pioneer championing the use of antegrade cerebral perfusion during these operations. He is to be congratulated for his independence, ingenuity, and skill, documenting ever-improving results of aneurysm operations in this elderly, high-risk population and providing exemplary leadership in devising improved techniques for cerebral protection during aortic surgery.

In the hands of most aortic surgeons, results of aortic arch surgery have been improving gradually, although few can claim results quite so good as Kazui's. Neurologic damage is a frequent cause of death and complications after these operations, as a result either of focal thromboembolic episodes or of global ischemia during arrest of antegrade cerebral circulation. Various approaches are currently being used throughout the world to try to reduce the incidence of both kinds of neurologic complications. In addition to clinical studies, such as that of Kazui, laboratory investigations have also contributed to an understanding of how best to protect the brain during surgery that requires interruption of normal cerebral perfusion. What follows is a discussion of the benefits and possible drawbacks of each of the techniques for cerebral protection currently used clinically. Some specific precautions to avoid embolization during these procedures are also suggested.

Hypothermic circulatory arrest

Hypothermic circulatory arrest (HCA) was the first technique to gain wide acceptance for use in surgery of the aortic arch.² It has the virtue of simplicity, permitting

a field essentially free of blood and cannulas, allowing thorough inspection of the aneurysm and a careful open distal anastomosis. However, awareness of a relatively high incidence of neurologic complications after aortic arch surgery with HCA led to the gradual recognition that the safety of HCA depends on very careful implementation and that HCA cannot be relied on to protect the brain completely during prolonged procedures.

Because the rationale for the use of HCA depends on the ability of hypothermia to reduce metabolic rate, adequate cooling is mandatory. Cooling should be carried out until a temperature of 10°C to 13°C has been reached in the esophagus and the oxygen saturation in the jugular venous bulb is more than 95%, indicating maximal metabolic suppression.³ Cooling should be thorough—lasting at least 30 minutes—to prevent a gradual updrift of temperature during the interval of HCA, and the intracranial temperature should further be protected from rising during HCA by packing the head in ice. Scrupulous attention during rewarming after HCA is also indicated to avoid the possibility that oxygen demand will outstrip supply: gradual rewarming and avoidance of high perfusate temperatures are essential. Inappropriate cerebral vasoconstriction has been documented after HCA,⁴ mandating careful attention to maintaining stable hemodynamics to assure optimal oxygen delivery during this vulnerable interval, which extends for at least 8 hours postoperatively.

Even with meticulous attention to cooling and warming techniques, as well as careful monitoring, a duration of HCA exceeding 25 minutes has been shown to produce symptoms characterized as temporary neurologic dysfunction (prolonged obtundation, disorientation, and Parkinson-like movements) in a significant minority of patients, especially in elderly patients.⁵ Severe temporary neurologic dysfunction has, in turn, been correlated with persistent loss of cognitive function lasting at least 6 weeks postoperatively.⁶ A deterioration in postoperative cognitive testing occurs significantly more frequently in patients with more than 25 minutes of HCA. The idea that the safe duration of HCA may be limited to 30 minutes or so is also supported by recent metabolic studies in dogs, pigs, and human beings, which all suggest that cerebral metabolic suppression at clinical levels of deep hypothermia is less complete than had been assumed previously.³

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Retrograde cerebral perfusion

As recognition of the probable limits of safe HCA was becoming more widespread, the technique of retrograde cerebral perfusion (RCP), first advocated by Ueda and colleagues,⁷ was being enthusiastically embraced by a number of investigators and clinicians. The idea of supplying the brain with blood retrogradely, via the superior vena cava, had appeal not only as a possible way of delivering nutrients to the brain during a prolonged period of HCA, but also as a possible way of flushing out cerebral emboli.

Initial laboratory results and clinical reports were encouraging. However, on closer examination, many of the studies that reported improved outcomes after aortic surgery with RCP used historical controls and short durations of circulatory arrest. There were also some disturbing studies, using various techniques in several different animal species, reporting that no flow to the brain during RCP could be demonstrated.^{8,9} In other experimental studies, the most effective conditions for retrograde flow were under circumstances—including clamping of the inferior vena cava and use of high perfusion pressures—that resulted in disturbingly high rates of fluid sequestration, significant cerebral edema, and mild cerebral histopathology: these sequelae were seen even after relatively short intervals of RCP.¹⁰ Studies in our laboratory in which cerebral blood flow was quantitated not only by collecting aortic arch return but also by counting the number of microspheres trapped in the brain have demonstrated conclusively that too little capillary flow occurs during RCP (even with occlusion of the inferior vena cava) to confer any meaningful metabolic benefit even during deep hypothermia.*

Careful analysis of clinical results has now also shown that long durations of RCP are associated not only with high rates of temporary neurologic dysfunction, but also, in some studies, with an increased risk of stroke and death after aortic surgery. In our own institution, we were unable to demonstrate any improvement in clinical outcome with the use of RCP, and we no longer use this technique.¹¹ We think its major benefit in the hands of others is in providing continued cerebral cooling via veno-arterial and veno-venous anastomoses during HCA, and that an updrift in temperature during HCA can more safely be prevented by thorough cooling and packing the head in ice.

Selective antegrade cerebral perfusion

The advantages of selective antegrade cerebral perfusion (ACP) were clearly seen from the start by a number of surgeons, including Kazui and associates.¹² With this technique, which allows a number of variations in implementation, some or all of the cerebral vessels are perfused throughout the duration of systemic circulatory arrest, except for very short intervals. Initial results with normothermic or mildly hypothermic cerebral perfusion were disappointing, but the combination of hypothermia with selective ACP has been very successful in providing cerebral protection both in laboratory studies and in clinical practice. Crittenden and colleagues¹³ were the first to demonstrate experimentally the clear superiority of ACP over any alternative method of cerebral protection, showing in sheep that hypothermic low-flow ACP preserved intracellular pH and energy stores. Bachet,¹⁴ Kazui,¹² and their associates were among the early clinical proponents of cold ACP.

The advantage of this technique is that it allows a much longer interval of safe circulatory arrest, since the supply of nutrients and oxygen at a relatively low flow allows maintenance of appropriate levels of oxygen metabolism at hypothermic temperatures. For optimal implementation, all the cerebral vessels must be perfused, and pressures and flows must be monitored. This makes ACP more time-consuming and cumbersome to initiate than HCA alone, or RCP. Moreover, ACP has the more serious potential disadvantage of requiring manipulation of cerebral vessels, with the risk of dislodging atherosclerotic debris.

The danger of embolization of atherosclerotic debris during ACP can be minimized by attaching separate grafts to each of the cerebral vessels distal to their junction with the aortic arch, where the likelihood of plaque is high: this is the technique used by Kazui and colleagues with such impressive success. Careful aspiration of the arch vessels before the initiation of perfusion is important with any of the variations of ACP. Our preference has been to use a single graft to a cap of arch vessels for selective ACP, but if serious plaques within the arch are present, individual vessel anastomoses are probably safer. We have obtained very good results using ACP even in complex cases requiring prolonged perfusion.

If the total time necessary for aortic arch repair requiring arrest of the antegrade circulation is moderately long, between 40 and 80 minutes, the incidence of temporary neurologic dysfunction, which reflects the adequacy of cerebral protection, is clearly lower with ACP than with any other alternative.¹¹ Thus, ACP is the technique of choice when the need for prolonged arrest of antegrade circulation is anticipated. However, in a large series of patients, even ACP was shown not to be

*Ehrlich MP, Hagl C, McCullough JN, et al. Retrograde cerebral perfusion provides negligible flow through brain capillaries in the pig. Manuscript in preparation.

safe indefinitely: in patients with very prolonged ACP (>80 minutes), an increased duration of ACP was a risk factor for adverse outcome, defined as permanent stroke or death.¹¹

Avoidance of stroke

Clinical experience in many centers suggests that most serious neurologic injury after aortic surgery occurs as a consequence of embolic stroke rather than as a reflection of inadequate cerebral protection from global ischemia, although suboptimal cerebral protection obviously will aggravate focal injury. Avoidance of stroke is consequently of paramount importance in addition to provision of adequate cerebral protection. Toward this end, as first pointed out by Kouchoukos and his colleagues,¹⁵ use of epiaortic scanning is extremely valuable to help deter cannulation of an ascending aorta in an area from which atherosclerotic debris may be dislodged. Many surgeons have noticed decreasing stroke rates since adopting alternate cannulation sites such as the right axillary artery, as also advocated in the current article by Kazui and colleagues.¹

There is no doubt that clamping and retrograde perfusion of the atherosclerotic aorta are major risk factors for stroke and are therefore contraindicated in the presence of significant clot or atheroma. Retrograde arterial perfusion from the femoral artery, with passage of blood that is destined for the cerebral circulation through a severely atherosclerotic abdominal and descending thoracic aorta, unquestionably contributes to cerebral embolic load. Scrupulous avoidance of manipulation of the diseased arch and cerebral vessels except during HCA is absolutely mandatory, as is careful, repeated aspiration of the cerebral vessels after circulatory arrest and before institution of antegrade flow. Fear of air embolism prevents many surgeons from gently aspirating the cerebral vessels during HCA, but with suitable postural maneuvers blood will displace air, and small cerebral air emboli at profoundly hypothermic temperatures are relatively benign.

In summary, the series of arch aneurysms presented in this issue of the *Journal* is a demonstration of the excellent results possible with elective surgery of aortic arch aneurysms if cerebral protection is carried out optimally and embolization is minimized. From what is known at present, our best hope of achieving comparable results in the future would seem to involve using axillary artery cannulation, avoiding manipulation of atherosclerotic vessels before HCA, carefully removing loose debris, restricting HCA to a duration not exceeding 25 minutes, and using selective hypothermic ACP for more complex cases.

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