

Perfusion and cannulation strategies for neurological protection in aortic arch surgery

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Submitted Mar 05, 2013. Accepted for publication Mar 21, 2013.

doi: 10.3978/j.issn.2225-319X.2013.03.12

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Introduction

The surgical treatment of the aortic arch includes unique obstacles compounding the typical challenges faced by traditional cardiac surgery. Owing to the exquisite sensitivity of neurologic tissue to ischemic injury, the vital importance of safely protecting the brain during inevitable interruptions normal cerebral perfusion cannot be understated. Over the years, substantial efforts have been devoted to clinical and laboratory research in an effort to elucidate the optimal techniques for protecting the brain during aortic arch surgery.

Neuroprotective techniques

The three main types of neuroprotection - hypothermic circulatory arrest, antegrade cerebral perfusion, and retrograde cerebral perfusion - have been well documented in this issue. While our group initially believed that cerebral circulatory arrest for up to an hour at profound hypothermia was safe, prolonged patient awakening times led us to question the veracity of this belief. Measurement of cerebral metabolic rates in 37 patients undergoing arch surgery narrowed the theoretical safe duration of circulatory arrest to 25-30 minutes at profoundly hypothermic temperatures, with further decreases correspondent to increases in arrest temperature (1). Complemented by other studies and ancillary data (2,3), this led us to believe that hypothermic circulatory arrest for more than 30 minutes is not entirely safe.

In light of this limitation, neuroprotective measures such as retrograde cerebral perfusion (RCP) gained prominence in the early 1990s. This simple technique

did not interfere with the surgical procedure, and held out the theoretical promise of venous perfusion of the cerebral microvasculature. Despite initial enthusiasm, our experimental studies led us to doubt the utility of RCP in providing metabolic substrate. By introducing microspheres into the perfusate and assaying various sources of returned blood for the presence of microspheres, we ascertained that only 0.01% of blood infused into the superior vena cava traverses the capillaries of the brain (4). The vast majority (90%) returned through veno-venous shunts to the inferior vena cava. Based on these results, we conclude that while RCP can cool the brain and wash out air and non-impacted particulate emboli from large and small arteries, it does not provide nutrient flow to the brain parenchyma. Furthermore, elevated perfusion pressures during RCP can also occasion significant cerebral edema (5,6).

Selective antegrade cerebral perfusion (SACP) has now superseded RCP as a neuroprotective adjunct. Performed correctly, this method overcomes many of the limitations associated with RCP. A comparison of all three cerebral protection techniques (HCA alone, HCA + RCP, HCA + SACP) in comparable patients who underwent 40-80 minutes of circulatory arrest yielded some interesting results (7). While stroke rates were similar between groups, half of the patients in the HCA group and HCA + SACP group recovered symptomatically from discrete focal neurological deficits, while none of the patients in the HCA + RCP group did. This suggests that perhaps smaller strokes were made larger when retrograde perfusion was utilized as cerebral protection. Indeed, while the incidence of temporary neurological function (TND) was quite high in all groups, it was significantly lower with antegrade

perfusion (odds ratio 0.3), suggesting the superiority of SACP over the other methods.

Technical strategies in antegrade cerebral perfusion

As cerebral metabolic rate is contingent upon brain temperature, cooling to sufficient levels is of critical importance in aortic arch surgery. In a study of hypothermic cerebral perfusion at 10, 15, 20, and 25 °C in four groups of animals, we observed a significant difference in neurological function between groups perfused at 10 and 15 °C than at 20 and 25 °C (8). These results indicate the positive benefits of cooler temperatures.

In addition, several studies from our group have further elucidated other technical aspects of cerebral perfusion. We have shown that cerebral perfusion at 50 or 70 mmHg provides cerebral protection superior to perfusion at 90 mmHg (9). Some degree of auto-regulation is lost at colder temperatures, which means that higher perfusion pressures may potentially cause excess perfusion. Additionally, while perfusion with pH-stat management doubles cerebral blood flow compared to alpha-stat management, equivalent cerebral protection is observed (10), thus, excess flow with pH management appears to confer little benefit. Clinically, since the probability of embolization is in part related to the flow volume, a high flow rate would probably be detrimental. Finally, perfusion with a hematocrit of 30 provides superior cerebral protection than with a lower hematocrit (11). This improvement is not due to oxygen carrying capacity since adequate oxygen is carried even at a hematocrit of 20 at low temperatures.

Therefore, our experiences suggest that the optimal parameters for antegrade cerebral perfusion include perfusate temperature between 10 and 15 °C, a pressure of 50 to 70 mmHg, alpha-stat acid-base management, and a hematocrit above 30.

Moderate hypothermia

There has been substantial interest in the past decade in using SACP with a higher perfusate temperature (12-16). Mortality rates in these studies are in the low teens or in single digits, with stroke in low single digits as well. Of particular note, among patients who had lower body HCA durations of more than 60 minutes using moderate hypothermia, mortality increased to 27%, and 18% of

patients experienced paraplegia. The predominant reason for utilizing higher perfusion temperatures - in addition to shortening the duration of the operation - is the belief that perfusion at higher temperatures reduces coagulopathy postoperatively. However, use of profound hypothermia at 16 degrees certainly did not result in any increase in the incidence of bleeding, suggesting that the issue of coagulopathy is not solely contingent on arrest temperature, and that one need not avoid profound hypothermia solely because of an enhanced risk of coagulopathy.

Our group has further examined the issue of spinal cord protection with SACP at higher arrest temperatures in the laboratory (17), with the observation of a reduction in blood flow as one descends the spinal cord. In these animals, flow during SACP is essentially non-existent below T8. Histologically, the upper spinal cord (cervical and thoracic) showed no histological damage, but substantial histological injury was observed in the lower cord. All animals were paraplegic when cerebral perfusion was implemented at 28 °C for 120 minutes, with the majority clinically paraplegic when perfused for 90 minutes. Thus, moderate hypothermia should be used with caution when prolonged durations of SACP are anticipated.

Perfusion site

Perfusion site has emerged as an important issue in cardiac surgery in general, and is particularly significant in aortic surgery. Our group made a switch to axillary artery cannulation in the late 1990s, and now uses a right angle cannula and distal occlusion of the right subclavian artery. In contrast, there are some who feel that an end-to-side graft is the preferred technique. Our opinion is that it is the utilization of the technique, rather than the technique itself, which is important in minimizing embolic risk. A review of nearly 900 patients in our institute over 16 years revealed a reduction of adverse events from 12% (aorta cannulation) and 20% (femoral) to 3% with the use of axillary cannulation in patients with atherosclerotic aneurysms (18).

Unilateral vs. bilateral perfusion

Significant debates still exist regarding the appropriate number of perfusing vessels. Regardless of the method, we believe that if a vessel is not to be perfused, it should be clamped to prevent steal. There is further debate regarding whether to use balloon-tipped catheters, which may shorten the interval of hypothermic circulatory arrest due to the

ease of their use, but carry some increased risk of particulate embolization.

Our preference is for an alternative technique: rapid connection of the arch vessels to a trifurcated or multiple-branched graft with hypothermic circulatory arrest, followed by perfusion of the graft via a catheter placed within the graft itself or via the axillary artery. We feel that perfusion of all arch vessels with a single input provides several advantages. Firstly, it simplifies pressure monitoring: usually a catheter in the contralateral radial artery is sufficient, obviating the need for pressure or flow monitoring in individual balloon-tipped catheters. Secondly, the risk of hypo- or hyper-perfusion of a single cerebral hemisphere is negated, and one does not necessarily need to monitor perfusion with near-infrared spectroscopy or transcranial Doppler to ensure perfusion of both hemispheres.

Conclusions

Our understanding from several decades of work in the surgical treatment of aortic arch disease has improved significantly since the early days of arch surgery. We believe that data at the present time support the position that axillary artery cannulation is mandatory in atherosclerotic aneurysms, and is probably preferable in other aneurysm types. With regard to perfusion, we believe that experimental and clinical evidence strongly support the idea that HCA is not advisable for more than 30 minutes. While there certainly are situations in which the surgical situation demands prolonged arrest periods, we believe that HCA should not be the sole neuroprotective mechanism in these cases. Retrograde cerebral perfusion, at least in our opinion, is primarily of historical interest at the present time, as it can only help with cooling but not oxygenation. Like the majority of surgeons, we prefer antegrade cerebral perfusion, as well as using perfusion parameters that have been established by laboratory studies. We also believe that three vessel perfusion is safer than perfusing only one or two vessels. Finally, we caution surgeons to carefully consider the risks of spinal cord ischemia when utilizing prolonged ACP at moderately hypothermic temperatures.

Prevention of ischemic injury to the central nervous system during aortic arch surgery represents a substantial challenge in arch surgery. After several decades of experimental and clinical research, the basic parameters of optimal cerebral protection have been defined and validated. Utilizing the principles discussed herein, surgery of the aortic arch can now be performed with results that

are beginning to approach those of routine cardiac surgery.

Acknowledgements

The authors would like to thank David Tian for assistance in editing this manuscript.

Disclosure: The authors declare no conflict of interest.

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Cite this article as: Griep RB, Griep EB. Perfusion and cannulation strategies for neurological protection in aortic arch surgery. *Ann Cardiothorac Surg* 2013;2(2):159-162. doi: 10.3978/j.issn.2225-319X.2013.03.12