The brain, the spinal cord, selective antegrade cerebral perfusion and corporeal arrest temperature – are we reducing the margin of patient safety in aortic arch surgery?

Keywords: Spinal cord; Aortic arch; Neuroprotection; Selective antegrade cerebral perfusion

Neurological injuries, stroke and paraplegia are the most devastating complications of aortic surgery. Historically, these two complications have been considered separately; investigation and discussion of arch surgery has concentrated on the risk of injury to the brain while discussion of descending and thoraco-abdominal aortic surgery has concentrated on the risks and avoidance of spinal cord injury (SCI). The report from Professor Griepp’s laboratory in this issue of the journal [1] clearly demonstrates that this convenient compartmentalisation of neurological injury by site of surgery is an oversimplification and that for aortic arch surgery, protection of the spinal cord as well as the brain is an important concern.

The reason that this concern has manifested itself is the increasingly popular trend towards the performance of aortic arch surgery at warmer temperatures. Confidence in the ability of selective antegrade cerebral perfusion (SACP) to protect the brain, together with an effort to reduce some of the purported disadvantages of hypothermia and longer cardiopulmonary bypass (CPB) times has meant that arch surgery is now being performed at almost any temperature between 15°C and 37°C. This means that the period of corporeal (and thus spinal cord) ischaemia is endured by the patient at higher temperature. Consequently, there is a potential increased risk of SCI.

Aortic arch surgery requires temporary interruption of the cerebral, spinal and corporeal circulation. To prevent brain injury, a number of neuroprotective measures have been studied. Profound cooling of the whole patient to temperatures of 15–20°C reduces cerebral blood flow and oxygen consumption, thereby increasing the ischaemic tolerance of both the brain and every other tissue cooled, including the spinal cord. The extension that such cooling gives to the safe duration of brain circulatory arrest is however limited and human data suggest that the safe duration of hypothermic circulatory arrest (HCA) may be as low as 20 min at 20°C and 30 min at 15°C. Not surprisingly, clinical arrest times greater than 25 min at deep hypothermia carry an increased risk of transient neurological deficit and arrest times greater than 40 min are associated with an increased risk of stroke and mortality [2]. However, the spinal cord is less vulnerable to ischaemia than the brain [3] and, consequently, there are very few reports of SCI in series of arch surgery using deep HCA alone or with retrograde cerebral perfusion.

The advent of SACP allowed surgeons to undertake arch surgery with the confidence and reassurance that brain protection would be enhanced for the periods necessary for total arch replacement to be completed. In Bachet’s original description of cold cerebroplegia, the carotid arteries were cannulated soon after bypass was established and carotid perfusion continued with blood at 6–12°C while the corporeal temperature was set at 25–28°C. Corporeal arrest durations at these temperatures for a mean of 22 (range 10–51) min were well tolerated and no SCI was reported [4].

Simultaneously, Kazui et al. were establishing SACP as a major protective technique in arch surgery. The Kazui technique involves SACP and corporeal arrest at 22°C with cannulation and perfusion of the innominate artery (IA) and left common carotid artery (LCCA) [5]. Additional cannulation and perfusion of the left subclavian artery (LSA) is reserved for those cases in which right vertebral artery flow is jeopardised. The use of these techniques has been associated with low mortality and stroke rates and no mention of SCI.

Similar outcomes, with an absence of SCI, have been reported by European authors even in the presence of quite prolonged corporeal arrest periods. Di Bartolomeo et al. reported 96 consecutive patients undergoing SACP (IA + LCCA) with LSA occlusion at 22–26°C corporeal arrest temperature for SACP durations of 18–220 min (mean 52 min); 43% of patients had corporeal arrest times longer than 45 min and 30% had times longer than 60 min. The stroke rate was 1% and no SCI was reported at this degree of hypothermia [6]. From these clinical reports, it could be inferred that at temperatures approximating 22–25°C, corporeal arrest and the consequent spinal cord ischaemia is well tolerated for the durations necessary to undertake arch replacement surgery. These findings are corroborated by experimental evidence that at 20°C SACP, spinal cord ischaemic durations of 90 min do not induce SCI. The temperature of SACP may also be important. Colder temperatures (15–20°C) have experimentally been shown to confer superior protection whilst a higher brain reperfusion temperature at the end of cold SACP may be deleterious.
So, how does spinal cord ischaemia occur in the context of SACP? During SACP with corporeal circulatory arrest, SACP may continue to provide oxygenated blood flow to the spinal cord through the basilar and anterior spinal arteries. Experimentally, colder is better in this situation. Such flow might be expected to be less if the left subclavian artery is not occluded during SACP as this creates a steal effect via the circle of Willis and left vertebral artery. The flow may be greater during perfusion of all supra-aortic vessels but this effect has only been demonstrated for visceral perfusion, not for the spinal cord [7]. However, whether the left subclavian artery is occluded, open or perfused does not address a further perfusion steal phenomenon, which occurs through the intercostal arteries and continues throughout SACP. This spinal cord perfusion situation during SACP is analogous to that which occurs during proximal aortic clamping with distal exsanguination in descending aortic surgery. In this situation, open back-bleeding intercostals arteries create a steal phenomenon as blood is shunted from spinal arteries to intercostals without providing a nutritive supply to the cord as effective perfusion pressure is zero. Because of this, the spinal cord is in jeopardy during the corporeal arrest period of arch repair and thus its ischaemic tolerance at different temperatures of SACP becomes very relevant; this was the question addressed by Etz et al. in the current study [1].

The spinal cord is more tolerant to ischaemia than the brain and demonstrates a similar increasing ischaemic tolerance with reducing temperature [3]. Strauch, in Griepp’s laboratory, demonstrated that in pigs normothermic ischaemia can be tolerated for 20 min but not longer. At 32 °C, ischaemic tolerance sits exquisitely close to 50 min. Ischaemic periods beyond this result in paraplegia. In the current study [1], by extrapolation of the findings of Strauch, the authors anticipated that at 28 °C, spinal cord ischaemic tolerance would be at least 90 min and therefore compared the spinal ischaemic tolerance of two groups of animals undergoing SACP at 28 °C for 90 or 120 min. The results were not as anticipated. Over half the animals in the SACP 90 min 28 °C group died of multi-organ failure within 24 h (suggesting adverse effects of corporeal visceral ischaemia) and 40% developed paraparesis. All animals displayed histological SCI. The 120-min period of 28 °C SACP was uniformly harmful with a higher than 60% 24-h mortality, uniform histological SCI and uniform paraplegia. In keeping with the likely phenomenon of steal through open intercostal arteries, spinal cord blood flow diminished as soon as SACP was commenced and was absent throughout SACP below the T4 region. These data suggest that the margin of safety for SCI at moderate hypothermia is less than has been assumed.

Preliminary reports have suggested that warmer corporeal and carotid perfusion temperatures are clinically safe for the brain but these reports mainly included patients with arrest periods of less than 30 min duration and have incorporated distal aortic perfusion to provide corporeal protection. Minatoya et al. reported outcomes of aortic arch surgery in 229 cases, at three different temperatures; 20 °C, 25 °C and 28 °C used in sequential eras [8]. Permanent and transient neurological deficit rates were similar at all three temperatures and there were no cases of SCI. However, in the warmest group, there was a subtle acknowledgement of the increased risk of SCI as, in these patients, triple supra-aortic vessel SACP was performed and several also had earlier corporeal reperfusion through the femoral artery [9]; thus, it cannot be assumed that each temperature had similar safety in preventing spinal cord ischaemia. Other authors have also advocated continuous distal perfusion during warm aortic arch surgery with aortic balloon occlusion but whether such techniques are superior is undetermined as comparative studies have not been performed. Even normothermic arch replacement has been undertaken but all such reports include the balloon occlusion of the descending aorta with flow to the lower body, effectively avoiding corporeal arrest.

Pacini et al. reported outcomes for 305 patients undergoing SACP and corporeal arrest at 25 °C (n = 189) or lower than 25 °C [10]. No differences were demonstrable in mortality, stroke or transient neurological deficit rates between the two temperature groups and no episodes of paraplegia were reported.

Kamiya et al. in another retrospective review of patients undergoing aortic arch repair with HCA and SACP, subdivided patients into those undergoing surgery with moderate (25–28 °C) and deep (20–24.9 °C) hypothermia using propensity matching [11]. In general, there was little difference in mortality or complication rates between groups. However, sub-group analysis of patients with arrest times more than 60 min, suggested an increased mortality and paraplegia rate in the warmer group.

Each of these studies has been retrospective and there are no randomised trials of surgery at different temperatures. However, the evidence so far suggests that moderate hypothermia certainly appears safe for limited corporeal arrest durations but that the margin of safety for times greater than 60 min may be limited. In experienced centres, subtle changes are made to the perfusion circuit when there is concern that arrest periods may be prolonged and the cord may be in jeopardy, for example, LSCA cannulation, balloon descending-aorta occlusion and perfusion through the femoral artery [8].

One of the reasons for performing warmer surgery is to reduce the incidence of hypothermia-related complications. In fact, studies so far suggest little difference in complication rates between moderate and deeply hypothermic aortic arch surgery. While bypass times may be shorter, this has not always translated to reduced complication rates. The risk of bleeding in such surgery is more likely to be related to operation extent rather than temperature differences alone and the published retrospective studies have actually not identified statistically significant differences in elements of morbidity that are likely to be temperature related with the exception of a possible increase in the risk of bleeding with colder techniques [11].

As aortic arch surgery traversed from the eras of hypothermic circulatory arrest alone to the incorporation of SACP, the margin of safety for the brain increased. This appeared measureable by the crude indicators of mortality, stroke rate and transient neurological deficit incidence. More aortic procedures were performed with better outcomes. As we now move to an era of warmer temperature aortic surgery, we are, as Griepp’s report indicates, reducing the safety margin if not for the brain, for the spinal cord and viscera. If technical difficulties occur during the conduct of an arch replacement at 28 °C that would increase corporeal
arrest time significantly, there is little room for manoeuvre to increase the protection for the viscera or cord. Although occlusion of the descending aorta and perfusion is sometimes possible, this bail-out manoeuvre has to be available and incorporated in surgical and perfusion planning; and, therefore, is this change in temperature and more complicated perfusion management really better for the patient? Such questions lend themselves well to (multicentre) randomised controlled trials with appropriate stratification for aortic pathology and likely extent of repair. This would reduce our reliance on the scrutiny of retrospective reports with missing data, era effects, learning curves and non-human experimental studies. It is hoped that aortic surgery will progress through this scientific methodological route. At the present time, surgeons should remain acutely aware that a prolonged period of SACP at moderate hypothermia may not afford adequate spinal cord protection and that bail-out strategies to maintain protection should be instantly available if this situation arises.

References


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Available online 17 September 2009