Surgical strategies for neuroprotection during ascending aortic and arch surgery

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Applied Cardiopulmonary Pathophysiology 13: 219-223, 2009

An anastomosis to the aortic arch represents an unique surgical challenge because it classically requires temporary interruption of blood flow to the cerebral vessels – at least for a short moment. The brain, however, is the organ with the least ischemic tolerance. In addition, atherosclerotic debris and air trapped during surgery may be embolized. Thus, ascending aortic surgery with an open distal anastomosis and aortic arch surgery – in the following collectively referred to as "arch surgery" – carry a higher risk of global as well as focal ischemic brain injury than other cardiac surgical procedures.

A focal neurologic deficit postoperatively is usally easily recognized clinically and can be confirmed by computed cerebral tomography. As a consequence, its incidence following arch surgery has been examined by many groups and averages around 4-9 %. Global ischemic deficits are much more difficult to assess, and the range of incidence in the literature varies widely from 5-70% [1]. The clinical spectrum includes varying degrees of confusion and agitation, or impaired alertness and parkinsonism. Because these symptoms on first glance appear to vanish with time, they are often referred to as "temporary neurologic dysfunction" [TDN]. However, patients with postoperative TDN have impaired neurocognitive function – especially regarding memory – during subsequent follow-up and impaired quality of life [2,3,4]. Therefore, TDN must not be taken lightly. Instead, TDN should be viewed as a clinical marker for insidious but significant neurological injury associated with measurable long-term deficits in cerebral function.

This article reviews the surgical strategies in aortic arch surgery implemented to avoid focal or global neurologic deficits – whether permanent or transient. The article does not deal with the indications for surgery or pharmacological approaches for perioperative neuroprotection. It does also not discuss technical details of the surgical procedure (the interested reader may instead access [5,6,7,8,9]).

In reviewing the surgical approaches to neuroprotection during arch surgery, two fundamentally different strategies have to be recognized: one that surrounds a period of circulatory arrest of varying length and the replacement of the diseased aortic segment with an open anastomosis; and another strategy that involves interventional endovascular treatment with prior debranching of the arch vessels.

Classic surgical approach

In today's clinical practise, many of the techniques described below are used together in institutional protocols. There is a complete lack of large-scale randomized trials comparing different protocols which makes it extremely difficult to draw definite conclusions regarding the best practise.

Hypothermia

Hypothermia decreases oxygen consumption and is the mainstay of neuroprotection during aortic arch surgery. Following the landmark studies of Bigelow [10] and the clinical application of hypothermia in the early days of cardiac surgery as the sole method for organ protection, a renewed interest in hypothermia and its combination with extracorporeal circulation developed in the 1960s [11,12]. However, only after experimental studies suggested that a period of 30 minutes of circulatory arrest in deep hypothermia (18°C) is safe [13], this concept gained popularity [14].

In many departments, deep hypothermic circulatory arrest [DHCA] is the basis for arch surgery until today. However, there are questions and problems associated with DHCA. The two most important questions are: What is the maximal safe duration of circulatory arrest? and How deep is deep enough? Newer studies that directly measure oxygen consumption in humans suggest that a period of 29 minutes at 15°C of circulatory arrest is safe [15]. Thus, shorter intervals and lower temperatures than those widely used may be necessary to assure adequate cerebral protection.

Problems associated with DHCA arise from the fact that cooling and rewarming require time. Prolonged use of extracorporeal circulation as well as cooling and rewarming themselves, however, cause more pronounced activation of inflammatory cascades and mechanical trauma to blood components which may lead to significant non-neurologic morbidity [16] and bleeding problems [17]. Thus, slow cooling to deep temperatures and slow rewarming – which are considered to be of uppermost importance if neuroprotection relies on hypothermia alone [5] – are not necessarily advantageous from a "whole-body" point of view. In addition, DHCA causes vascular endothelial dysfunction in many organs, including the cerebral microvasculature [18].

Perfusion

Inducing deep hypothermia raises a number of questions regarding the configuration of the heart-lung-machine and the conduct of extracorporeal circulation. Although numerous studies were published, no definite conclusions can be drawn, especially regarding the need for special tubing or non-occlusive pumps.

It appears reasonable that cooling is performed slowly and that the target temperature has been maintained for quite some time before circulatory arrest is started in order to achieve uniform cooling of the complete brain. It appears also reasonable that rewarming is performed slowly in order to avoid situations in which oxygen demand will exceed oxygen supply [19,20].

Theoretical considerations also suggest that cooling using the pH-stat method (hypothermia-induced hypocapnia and alkalosis is corrected to a normal pH by increasing oxygenator flow of CO_2) results in cerebral vasodilatation with more complete cooling of the brain; and that rewarming using the alpha-stat method (hypothermia-induced hypocapnia and alkalosis is not corrected: pH is allowed to raise) avoids "luxury perfusion" (which may increase the risk of embolization immediately after surgical manipulation) by maintaining autoregulation of cerebral blood flow. However, there is inadequate evidence from clinical studies to firmly recommend one perfusion method over the other.

Selective antegrade cerebral perfusion

Antegrade normothermic cerebral perfusion involving several pumps and cannulation of both carotid and subclavian arteries was the method used for the first attempts in arch surgery [21]. However, this technique was quickly abandoned because – at that time – problems prevailed, but interest in the idea grew again when it became clear that DHCA may not be safe in all situations, especially those requiring long durations of circulatory arrest.

The rationale for selective antegrade cerebral perfusion [SACP] is simple: If there is no – or only a very limited – interval in which the perfusion to the brain is arrested, no problems can result from cerebral ischemia. It is widely accepted today, that SACP is safe and able to improve neuroprotection during arch surgery [5,22]. However, SACP can be performed in many different ways, and many questions remain unsettled. While some experts advocate the use of SACP in addition to DHCA [5], other authors doubt that deep hypothermia is required if the period of circulatory arrest is short and different degrees of moderate [23,24,25,26] or even mild [27] systemic hypothermia are used. In addition, the temperature of the blood perfusing the brain may be either deeply hypothermic (6-12°C "cold cerebroplegia" [27]), moderately hypothermic (26-28°C [28]), or even warmer (30-32°C [29]). The required hematocrit, flow rates to the brain and perfusion pressures may vary with each combination of temperatures, and the optimal strategy has not been established.

Generally spoken, the higher the systemic temperature, the smaller the safety margin. If – for any reason – SACP cannot be established in the planned way and surgery has to be performed during circulatory arrest, higher temperatures are less protective and probably may result in cerebral ischemia and neurological complications. It should also not be forgotten that the descending aorta is usually not perfused during SACP; therefore, higher systemic temperatures at the time of circulatory arrest jeopardize the protection of other end-organs, especially spinal-cord and kidney. (Distal perfusion, however, can be achieved relatively easy [30].)

SACP may be achieved either using conventional cannulas; in this case, backbleeding is avoided by snaring the vessel from the outside; or it can be achieved with small perfusion catheters with inflatable ballons that occlude the vessel from within; or SACP can be achieved using a vascular prothesis that is sewn to the vessel that is to be perfused. Especially with the first two possibilities, the operative field can become quite narrow and obstructed thereby increasing the surgical complexity. Thus, keeping the cannulas/perfusion catheters for SACP out of the main operative field would be beneficial.

Cannulation site

When performing arch surgery, direct cannulation of the ascending aorta or the aortic arch will often not be possible (e.g. in typ A dissection) or not be wise (e.g. in heavily atheromatous or porcellain aortas). If the ascending aorta or the arch is cannulated, a cannula should be used that has little "sandblasting" effect [31] and hence reduces the risk of embolization.

The femoral artery is usually not the first choice for cannulation because it is often calcified and atherosclerotic and because of the resulting unphysiologic retrograde perfusion pattern and its inherent risks, especially embolism.

Nowadays, the right axillary artery is often used for cannulation. This has several advantages: The axillary artery is usually soft and not diseased (either by atherosclerosis or dissection). In addition, axillary cannulation offers the opportunity to achieve SACP to the right hemisphere (simply by clamping the brachiocephalic trunk and reducing the flow at the time a bloodless arch is required) without having a bothersome cannula within the main operative field.

Another cannulation site for SACP is the carotid artery, whether uni [32]- or bilateral [27]. With this technique, again, cannulas within the main operative field are avoided increasing the ease of the arch procedure.

It has not been firmly established whether unilateral cerebral perfusion – either from the right axillary artery or from a carotid artery – provides sufficient flow to the other cerebral hemisphere. While some reports suggest that unilateral perfusion offers excellent neuroprotection [32,33], anatomical data call for caution. In a recent autopsy study, an insufficient circulation to the contralateral hemisphere was noted in 14-17% [34]. If in doubt during surgery, the other hemisphere can be perfused using cannulation from within the main operative field as described before. It is also not known whether the left subclavian artery needs to be clamped.

Retrograde cerebral perfusion

During retrograde cerebral perfusion [RCP] the veins of the head are perfused with cold blood, usually via the vena cava superior. There are three theoretical reasons why RCP may provide some degree of neuroprotection: (1) providing nutritive cerebral blood flow; (2) flushing embolic material (either air or debris) out of the cerebral circulation; (3) maintaining cerebral hypothermia.

RCP gained widespread popularity before it was experimentally validated. Meanwhile, however, most – but not all – studies indicate that RCP is unable to provide blood flow sufficient to meet the metabolic needs of the brain. Some studies indicate that RCP might even be harmful by inducing cerebal edema [35]. As a consequence, most groups nowadays appear not to rely on neuroprotection by RCP, but use SACP instead. However, a short period of RCP is used by many surgeons at the end of the circulatory arrest in order to flush out embolic material from the cerebral vessels.

Hybrid approach

While all of the techniques described have been developed to support replacement of the aortic arch (or parts of it) and facilitate a hand-sewn open anastomosis, a completely different strategy has evolved with the advent and progress of endovascular therapy. With this strategy, the arch is excluded from the circulation using an endovascular prosthesis. Thus, no extracorporeal circulation and no circulatory arrest is needed at all [36,37,38,39]. This will – theoretically – reduce the invasiveness of the procedure and its risk, not only regarding neurological problems.

However, before the arch can be excluded by an endovascular prosthesis, the supraaortic vessels, of course, need to be connected to the blood stream in a new way, e.g. by sewing vascular prostheses to both carotid arteries and connecting them to the ascending aorta. This procedure is often called "debranching" and can also be performed "off-pump". Whether or not the left subclavian artery also needs to be bypassed, is an individual decision based on the given anatomy.

Although this new strategy sounds simple and free of risks, it is neither the one nor the other. Significant neurologic morbidity can result from the debranching procedure itself, especially if the carotid arteries and/or the ascending aorta exhibit severe atheromatous wall abnormalities.

Until today, only a limited number of patients have been treated using the off-pump hybrid approach. Its general feasibility has been demonstrated, and techniques need to be refined. However, we hardly don't know anything about the long-term results of hybrid arch repair. Special concerns relate to endoleaks, migration of the endovascular prosthesis, and damage to surrounding structures. Thus, it is much too early to judge on the value of this new strategy in the treatment of aortic arch diseases, but it might be applicable for carefully selected patients with an unusually high risk from a conventional procedure.

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