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Cerbral Protection Strategies for Aortic Arch Surgery

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1. Introduction

Surgical therapy for aortic arch disease involves partial or complete replacement of the aortic arch with reimplantation of the great vessels while the cerebral blood flow is temporarily altered. Patients undergoing this mandatory period of circulatory arrest during arch replacement are at an increased risk for adverse neurologic outcomes, and strategies for cerebral protection must be implemented to achieve successful results. The optimal strategy for management of the circulation during aortic arch surgery remains controversial. Arch reconstruction has historically been associated with significant morbidity and mortality due to global ischemic end-organ damage occurring during the circulatory arrest period. As surgical techniques have evolved, survival has improved; however, neurologic dysfunction due to cerebral ischemia remains a significant concern.

Profound hypothermia was the initial method of cerebral protection utilized during the period of circulatory arrest. The first successful series of arch reconstructions using deep hypothermic circulatory arrest (DHCA) with body temperatures of 18°C was reported in 1975 (1). Further efforts to improve cerebral protection during arch reconstruction have led to the development of antegrade cerebral perfusion (ACP) and retrograde cerebral perfusion (RCP). Both techniques provide continuous blood flow to the brain and are used in conjunction with hypothermic circulatory arrest (HCA). The optimal method of cerebral perfusion (antegrade vs. retrograde) is a controversial topic and has yet to be determined. In the this chapter, the indications for aortic arch surgery will be delineated, and the various methods of cerebral protection strategies and their results will be reviewed.

2. Pathology/indications for aortic arch surgery

The most common indication for arch replacement is the presence of aneurysmal disease. The most common type of arch aneurysm is a degenerative aneurysm. The media of the aortic wall in degenerative aneurysms develops cellular necrosis which results in a loss of smooth muscle cells that are replaced by cystic spaces filled with mucoid material. Dr. Cooley coined the phrase cystic medial necrosis to describe this characteristic histologic pattern found in degenerative aneurysms (2). These aneurysms also have a significant reduction in elastin content due to a poorly understood increase in elastin fragmentation.

The second most common cause of arch aneurysms is atherosclerosis. The development of invasive atheromas is thought to destroy the elastin fibers and smooth muscle cells of the

aortic media resulting in aneurysm formation.(3). Inherited genetic connective tissue disorders such as Marfan syndrome, Ehlers-Danlos and Loeys-Dietz syndrome are less common causes of arch aneurysms. Familial arch aneurysms are a subtype of heritable aneurysms which do not express a recognizable phenotype of a known connective tissue disorder, and do not have a specific gene or product which has been identified (3). Bicuspid aortic valve (BAV) disease is a congenital anomaly occurring in 0.9-2% of the population which is associated with an intrinsic aortopathy that leads to the development of proximal arch aneurysms. BAV aneurysms are thought to be due to an abnormal extracellular matrix of the aortic wall. Infection is a rare cause of (mycotic) arch aneurysms and requires replacement with aortic homograft.

The presence or absence of symptoms is the most important factor in the management of patients with arch aneurysms. Most patients with arch aneurysms are asymptomatic, and the aneurysm is discovered incidentally on radiographic imaging obtained for another purpose. Patients with symptomatic arch aneurysms typically experience chest or back pain. However, symptoms can also include compression or stretching of surrounding anatomic structures. Tracheal compression can cause stridor, esophageal compression may result in dysphagia, superior vena cava compression can cause plethora, and aneurysmal stretching of the recurrent laryngeal nerve produces hoarseness. The sudden onset of pain is considered an ominous warning sign of imminent rupture or dissection, and urgent surgery is indicated for all patients with symptomatic arch aneurysms (4). Operative therapy for asymptomatic arch aneurysms is performed for prophylactic replacement of the aorta in order to prevent rupture or dissection, and thereby improve patient survival. Total aortic arch replacement for an isolated arch aneurysm should be performed at sizes ≥ 5.5cm. Rapid expansion of the aneurysm at a rate ≥0.5cm/year is another indication for surgery. Concomitant proximal (hemi-) arch replacement is recommended at the time of ascending aortic replacement if the proximal arch is enlarged (4).

The other common indication for surgical intervention on the aortic arch is acute Type A aortic dissection. Surgical treatment of acute Type A aortic dissection requires resection of the primary tear, restoration of aortic valve competency, aortic replacement, and obliteration of the false lumen at the proximal and distal anastomoses. The distal extent of aortic replacement depends upon whether the arch is involved in the dissection. Arch involvement requires hemi-arch or total arch replacement under circulatory arrest using an open distal anastomosis. Total arch replacement in the setting of acute Type A aortic dissection is recommended when the arch is aneurysmal or there is extensive destruction or leakage (4). Nevertheless, it should be emphasized that total arch replacement significantly increases the risk of stroke and death during repair of an acute Type A dissection and should only be performed by experienced surgeons.

3. Cerebral protection strategies

3.1 Deep hypothermic circulatory arrest

In 1952, John Lewis used systemic hypothermia at 28°C and inflow occlusion to perform the first successful atrial septal defect repair in a 5 year old girl (5). Systemic hypothermia was gradually phased out with the introduction of the cardiopulmonary bypass machine, but was rediscovered and used by separate investigators in isolated reports of aortic arch replacement in the 1960's (6,7). Dr. Griepp reported the first successful series of total arch replacements in adults in 1975, using deep hypothermic circulatory arrest) at 18°C for cerebral protection (1).

The technique of DHCA for aortic arch replacement involves placing the patient on cardiopulmonary bypass and initiating systemic hypothermia to a core temperature of 18°C. Once this core temperature has been achieved, cardiopulmonary bypass is interrupted and the systemic circulation is arrested. The aortic arch is resected and reconstructed, deairing maneuvers are performed, and cardiopulmonary bypass is resumed. The exact mechanism of cerebral protection afforded by deep hypothermia is not completely understood, but its main beneficial effect is the suppression of cerebral metabolism. This is important because it enables an extension of the period of cerebral ischemic tolerance required for arch replacement.

Systemic hypothermia at 20°C has been shown to reduce the cerebral metabolic rate by 76% (8) (Table 1). It has also been postulated that there is an uncoupling of cerebral blood flow and cerebral metabolism at approximately 22˚C, likely due to a loss of autoregulation in the cerebral vasculature. The ratio of cerebral blood flow to cerebral metabolism increases from 20:1 at normothermia, to 75:1 with deep hypothermia (9). Once the period of DHCA has been completed and cerebral reperfusion has been initiated, severe cerebral vasoconstriction occurs. There is also an accumulated cerebral oxygen debt from the ischemic period which must be "paid back", and therefore, normal levels of cerebral metabolism are maintained by increased oxygen extraction (10, 11, 12). During the period following DHCA, the brain is at high risk for both ongoing ischemic injury due to low cerebral blood flow, and reperfusion injury. There has also been experimental data to suggest that following DHCA, there is an increase in intracranial pressure due to cerebral edema which negatively impacts neurophysiologic recovery (13).

Temperature (°C)	Cerebral Metabolic Rate (% of baseline)	Safe Duration of HCA (min)
37	100	5
30	56 (52–60)	9 (8–10)
25	37 (33–42)	14 (12–15)
20	24 (21–29)	21 (17–24)
15	16 (13–20)	31 (25–38)
10	11 (8–14)	45 (36–62)

Calculations based on assumption that there is a 5-min tolerance for circulatory arrest at 37°C. Values in parenthesis are 95% confidence intervals. HCA = hypothermic circulatory arrest.

Table 1. From McCullough JN, Zhang N, Reich DL et al. Cerebral metabolic suppresion during hypothermic circulatory arrest in humans. Ann Thorac Surg 1999; 67:1895-1921.

Cerebral injury following procedures requiring circulatory arrest is manifested clinically as post-operative transient or permanent neurologic injury. Permanent neurologic dysfunction (PND) appears as a focal neurologic deficit or stroke, which is thought to be the result of embolic phenomena. The incidence of PND following arch reconstruction has been shown to be directly related to the site of arterial cannulation (14). Transient neurologic deficit (TND) is defined as postoperative confusion, delirium, obtundation, or transient focal deficits (resolution within 24 hours) with negative brain computed tomography or magnetic

resonance imaging scans. TND is a reversible, diffuse, subtle injury which is an indicator of global cerebral injury due to inadequate cerebral protection. TND following arch reconstruction using DHCA alone has been shown to occur in approximately 25% of all cases, and a linear relationship has been demonstrated between the incidence of TND and the duration of DHCA (15, 16, 17).

In order to limit adverse neurologic outcomes, many investigations have focused upon determining a "safe" duration of DHCA. Based upon direct measurements of cerebral metabolism in adults, the safe period of DHCA has been estimated to be 30 minutes at 15°C, and 40 minutes at 10°C. Cellular anoxia occurs when these time periods are exceeded. (8). In a series of 656 patients undergoing arch surgery with DHCA alone, Svensson and colleagues reported a 10% mortality rate, and a 7% incidence of transient or permanent stroke. In a multivariate analysis, these authors demonstrated an increased risk of stroke following a period of DHCA > 40 minutes, and an increased mortality rate following a DHCA period >65 minutes (18). Griepp's group reported a 22% incidence of TND in 443 patients undergoing hemi-arch replacement with DHCA alone. In a multivariate analysis, these authors showed a DHCA time >30 minutes was an independent risk factor for TND (19). Using neuropsychologic tests, these investigators also demonstrated in a separate study that a DHCA duration > 25 minutes is a risk factor long-term deficits in neurocognitive function (20).

DHCA was the first successful cerebral protection strategy used in aortic arch surgery. Over the past three decades, aortic surgeons have improved their techniques for arch replacement and novel strategies for circulation management and cerebral protection have evolved. However, for short circulatory arrest times ≤ 30 minutes, there are still many surgeons who achieve excellent outcomes with DHCA alone as their sole method of cerebral protection during arch reconstruction. For more complex, extended arch reconstructions that require circulatory arrest times > 30 minutes, there is a consensus that DHCA alone is an inadequate cerebral protection strategy. In the current era, most experts in the field of aortic surgery use either antegrade or retrograde cerebral perfusion as an adjunctive method of cerebral protection in addtion to deep or moderate hypothermic circulatory arrest. (21).

3.2 Retrograde Cerebral Perfusion

Retrograde cerebral perfusion (RCP) was first described by Mills and Ochner as a method of treating a massive air embolus during cardiopulmonary bypass (22). RCP is employed by cannulating and snaring the superior vena cava, and infusing blood up the superior vena cava to perfuse the brain in a retrograde direction during the period of circulatory arrest. Flow rates are adjusted to achieve an SVC pressure of 20-25mm Hg. It is well recognized that RCP is a highly effective method of flushing embolic material from the cerebral circulation, and it maintains cerebral hypothermia by continuously bathing the brain in cold blood. There is a theoretical benefit that RCP can provide sufficient cerebral blood flow to support cerebral metabolism and remove toxic metabolites and waste products (9).

Although there was initial enthusiasm for RCP's ability to support cerebral metabolism, this hypothesis has subsequently been disproved. Multiple animal studies in different species have demonstrated minimal or no cerebral blood flow with the use of RCP (23, 24, 25). Although cerebral perfusion can be improved with higher retrograde perfusion pressures and occlusion of the inferior vena cava, there is a concomitant increase in cerebral edema with histologic evidence of cerebral injury (26).

Many groups adopted the use of RCP in conjunction with DHCA in the 1990's as their routine strategy for circulatory management during arch reconstruction with excellent

outcomes. Bavaria and colleagues demonstrated a significant improvement over previous reported series of Type A aortic dissection repairs using DHCA and RCP. In their series of 104 patients, these investigators reported a 9% mortality rate and 5% stroke rate with a mean duration of DHCA+RCP of 42 minutes in 104 consecutive patients undergoing emergent repair of Type A aortic dissection (27). In a series of 479 patients undergoing arch surgery with DHCA for aneurysmal disease or dissection, Coselli compared the results using DHCA alone vs. DHCA+RCP. The subgroup who received DHCA+RCP had significantly reduced mortality (DHCA+RCP 3.4% vs. DHCA 14.8%, $p<0.001$) and stroke rates (DHCA+RCP 2.4% vs. DCHA 6.5%, $p<0.05$) (28).

Estrera and colleagues also reported excellent results with the use of DHCA+RCP in both elective and emergent arch repairs. These investigators reported a mortality rate of 10.4% and a 2.8% stroke rate in a series of 1107 patients in which 907 (82%) patients received DHCA+RCP. However, the incidence of TND was 15.5% with relatively short mean RCP times of 26 minutes (29). Although this is lower than the 25% incidence of TND associated with arch reconstruction using DHCA alone (17), it is still a significant incidence of inadequate cerebral protection. Other groups have also reported a significant incidence of TND with the use of DHCA+RCP (30, 31, 32). The high incidence of TND and the recent popularity of antegrade cerebral perfusion has led to decreased utilization of RCP by most aortic surgeons (21). Nevertheless, RCP remains an important adjunctive cerebral protection strategy to DHCA is still used by many high volume aortic centers with excellent outcomes (33, 34). It is a highly effective anti-embolic technique which is especially useful for arch reconstruction in patients with carrying a heavy atherosclerotic burden.

3.3 Antegrade Cerebral Perfusion

Debakey and Cooley were the first to successfully describe the use of antegrade cerebral perfusion (ACP) in the surgical repair of an arch aneurysm (35). In their initial report, cannulas were placed into the right femoral artery and both carotid arteries, and a separate pump from the main cardiopulmonary bypass machine was used to perfuse normothermic blood into the carotid arteries. Despite its initial success, this method was considered complex and cumbersome, and was subsequently abandoned in favor of DHCA + RCP. The use of ACP began to reappear in reports of arch reconstructions in the late 1980's. Bachet reported a 2.1% PND rate and a 4.3% TND rate with the use of ACP with "cold cerebroplegia" via bilateral carotid cannulation in a series of 54 patients (36). A year later, Kazui published excellent neurologic outcomes in a series of arch reconstructions by introducing catheters into the innominate and left common carotid arteries and providing ACP at a rate of 10mL/Kg/min during the period of DHCA. This perfusion rate was considered 50% of physiologic levels based upon experimental data, and has subsequently become the standard perfusion rate of ACP by most groups using this technique (37). During the 1990's most centers performing a significant volume of aortic arch surgery began using either ACP or RCP as an adjunctive form of cerebral protection in addition to DHCA.

It should be recognized that the utilization of ACP changes the paradigm of circulatory arrest. Circulatory arrest, as originally described, refers to the total arrest of the circulation and the absence of perfusion to all organs (except the heart via cardioplegia). The addition of ACP changes this concept from total body circulatory arrest to lower body circulatory arrest, as the brain, arms and the spinal cord (via collateral circulation) are being perfused. Therefore the legs and the abdominal visceral are the only truly ischemic organs during the circulatory arrest period with the use of ACP.

Different methods and nomenclature are used in the literature to describe ACP techniques. It is most commonly referred to as selective antegrade cerebral perfusion (SACP), because many surgeons introduce individual cathethers or cannulae into the orifices of the innominate and left common carotid arteries, thus selecting out the individual great vessels for cerebral perfusion. This is also referred to as bilateral selective antegrade cerebral perfusion (bSACP). Another modality is unilateral SACP (uSACP), which can refer to two different sites of cannulation. One method is to directly cannulate or sew a graft on to the base of the innominate artery to provide antegrade cerebral perfusion up the right common carotid artery. A different technique is to directly cannulate or sew a graft on to the right axillary artery. At the time of circulatory arrest, a clamp is placed across the base of the innominate artery, and blood is forced up the right common carotid. Both methods are considered uSACP.

The hypothesis of ACP is that antegrade cerebral blood flow is more physiologic than no blood flow (HCA) or retrograde blood flow (RCP), and should therefore provide superior cerebral protection. Data from experimental animal models of DHCA comparing ACP and RCP have confirmed this hypothesis. Hagl and colleagues showed in an acute porcine model that a strategy of DHCA+ACP compared to DHCA alone is associated with improved neurophysiologic recovery, lower intracranial pressure, less cerebral edema, and reduced tissue acidosis following the circulatory arrest period (38). In a porcine model of circulatory arrest and reperfusion, Filgueiras and colleagues showed that near normal cerebral metabolism was maintained with DHCA+ACP, based upon pH measurements and levels of cerebral metabolites. The pigs who underwent DHCA+RCP or DHCA alone demonstrated a significant drop in cerebral pH during the protocol (39). In a separate study using the same model, these same investigators demonstrated preserved cell structure upon histopathologic analysis with HCA+ACP compared to HCA+RCP (40)

The Mount Sinai group under Dr. Griepp has performed extensive laboratory work on the topic of ACP. These investigators determined that hypothermic SACP at 10˚-15˚C provides better cerebral protection than SACP at 20-25˚C based upon post-op behavioral scores in a chronic porcine circulatory arrest model (41). They also showed that a short period of HCA prior to SACP initiation does not impact the level of cerebral protection compared to continuous SACP. This is important clinically because many surgeons will use a short period of HCA alone prior to initiating SACP to keep the field clean while they are performing arch resection in order to reduce the risk of atheroembolization (42). Ye and colleagues compared unilateral and bilateral SACP to determine whether there was any difference in cerebral perfusion and cerebral protection between the two techniques. Using magnetic resonance perfusion imaging, these investigators compared cerebral blood volume and regional cerebral perfusion patterns in pigs undergoing circulatory arrest with uSACP via the right axillary artery to a separate group undergoing bSACP via bilateral carotid artery cannulation. Both methods provided uniform blood distribution to both cerebral hemispheres and preserved normal morphology of the cerebral neurons (43).

Clinical studies have also supported DHCA+ACP as a superior method of cerebral protection compared to DHCA+RCP or DHCA alone. Using transcranial Doppler measurements during DHCA, Tanoue and colleagues demonstrated superior middle cerebral artery blood flow in patients undergoing DHCA+ACP compared to those undergoing DHCA+RCP (44). Neri and colleagues demonstrated that the cerebrovascular autoregulation function was preserved in the immediate postoperative period in patients undergoing DHCA+ACP. However, the autoregulatory function was significantly impaired

in patients undergoing DHCA alone or DHCA+RCP. Based upon the higher incidence of TND in the DHCA and DHCA+RCP groups, this post-operative impairment in cerebral autoregulation was considered to be an expression of CNS injury (45).

Hagl reviewed the neurologic outcomes from the Mount Sinai experience of 717 patients undergoing arch replacement with the three different methods of cerebral protection. The incidence of stroke (PND) and TND was 5.7% and 30%. Due to significant differences in the circulatory arrest times, they were unable to determine whether the method of cerebral protection impacted the stroke rate. However, by using a multivariate analysis, the use of DHCA+ACP significantly reduced the incidence of TND compared to DHCA+RCP or DHCA alone (31). In a randomized controlled trials comparing ACP vs RCP for total arch replacements performed under DHCA, Okita and colleagues showed no difference in stroke between patients undergoing ACP vs RCP, however ACP significantly reduced the incidence of TND (ACP 13.3% vs. RCP 33.3%, p=0.05) (46). These results were also replicated in series of 48 patients undergoing arch reconstruction during type A aortic dissection repair. In this series, Apostolakis and colleagues reported no difference in mortality or PND between patients undergoing DHCA+ACP vs DHCA+RCP. However, the incidence of TND was significantly higher in the DHCA+RCP group (DHCA+RCP 43.5% vs. DHCA+ACP 16%, p=0.04) (47).

In the current era, ACP has become the preferred method of cerebral protection employed by most aortic surgeons at the time of arch reconstruction (21). The lessons learned from the majority of studies comparing the various methods of cerebral protection are: 1)an adjunct form of cerebral protection (ACP or RCP) is superior to DHCA alone and 2)the method of cerebral perfusion (ACP or RCP) has no impact upon the incidence of PND, however ACP significantly reduces the incidence of TND.

3.4 Moderate hypothermia

Since Griepp's initial report of the successful use of DHCA for cerebral protection during arch replacement, profound systemic hypothermia at a core temperature of 18°C has been the standard point of hypothermia at which most surgeons will initiate circulatory arrest. As discussed above, deep hypothermia affords excellent cerebral protection by suppressing cerebral metabolism. Studies in the field of transplantaiton have also demonstrated that hypothermia acts in a similar fashion in the preservation of organs (e.g. lungs, liver, heart, kidneys)(48). However, profound systemic hypothermia has been shown to have adverse effects in multiple organ systems including endothelial dysfunction, neuronal apoptosis, coagulopathy and renal failure (49, 50, 51, 52). The time required to cool and rewarm the body to 18°C leads to prolonged cardiopulmonary bypass which is detrimental to multiple organ system. Furthermore, deep hypothermia has been shown to be a strong risk factor for bleeding requiring re-exploration following arch reconstruction (16). Furthermore, despite the cerebral metabolic suppressive effects of profound hypothermia, a linear relationship has been demonstrated between the incidence of TND and the duration of DHCA alone (53).

In an attempt to avoid the morbidity associated with DHCA, reduce cardiopulmonary bypass times and improve neurologic outcomes there has been a strong initiative from many different high volume aortic centers to begin performing arch replacements under moderate hypothermia circulatory arrest with ACP. This technique still provides maximum cerebral protection because the brain is being perfused with antegrade "cold cerebroplegia" at temperatures ≤ 18°C for ACP. It is the abdominal viscera which are the organs placed at risk with the technique of MCHA+ACP. However there has yet to be a report of increased risk of mesenteric ischemia, liver or renal failure with the use of MHCA.

Bachet's initial description of arch reconstructions using "cold cerebroplegia" at 6˚-12˚C in 1991 was also remarkable for the fact that he performed all of his arch reconstructions under moderate hypothermic circulatory arrest at core temperatures between 25-28°C (36). Using this technique he reported excellent neurologic outcomes with an incidence of PND and TND of 2.1% and 4.3% respectively. Minatoya and colleagues evaluated outcomes of 229 patients who received arch reconstruction with HCA+bSACP at three different temperatures: 20˚C (n=81), 25˚C (n=81), and 28˚C (n=67). 81% of all patients received total arch replacement. There were no significant differences between the three groups with regards to the incidence of mortality, PND or TND (54). The use of MHCA+ACP for arch reconstruction has also been reported by several groups in the setting of acute Type A aortic dissection with results equivalent to those achieved with DHCA (55, 56, 57).

At Emory, MHCA+uSACP is our preferred method of cerebral protection. All circulatory arrest cases are performed by cannulating an 8mm Dacron graft sewn to the right axillary artery. This is based upon a strong belief that axillary artery cannulation reduces the incidence of PND. This is supported by the important analysis by Svensson and colleagues who reviewed their stroke rates in 1336 circulatory arrest cases with different sites for arterial cannulation (ascending aorta, femoral, axillary, and innominate). They determined that cannulating a graft sewn to the right axillary artery resulted in the lowest incidence of PND (14). Although the mechanism of the protective effect of axillary cannulation is unknown, we have two hypotheses. The first is that axillary artery cannulation provides retrograde blood flow down the innominate artery, which may prevent atheroembolic disease from the ascending aorta. The second hypothesis relates to the differences in technique between uSACP and bSACP. In bSACP, there is a risk of cannulation-induced embolic injury from the introduction of cerebral perfusion catheters into the innominate and left common carotid arteries, especially in patients with atheromatous aortic arch disease. With uSACP, the innominate artery is occluded at the time of circulatory arrest and antegrade blood at 16°C is perfused at 10ml/kg/min through the right common carotid artery, right vertebral artery as well as through the left carotid system via intracranial and extracranial collaterals (58). This avoids manipulation of the ostia of the great vessels which are often covered with large, friable atherosclerotic plaques.

In our initial report using this technique, we reviewed 412 arch reconstruction cases (elective and emergent) performed under MHCA with uSACP at core temperature of 25.7°C at the initiation of circulatory arrest. Operative mortality was 7.0%, and the incidence of PND and TND were 3.6% and 5.1% respectively with no cases of paraplegia. There were four (1%) deaths due to mesenteric inschemia, and three of these four patients presented with an acute Type A aortic dissection with preoperative visceral malperfusion. There was a 4.6% incidence of renal failure requiring dialysis. In a multivariate analysis, moderate hypothermia was not found to be an independent risk factor for mortality, PND, TND or renal failure requiring dialysis (55). Since that initial report, our experience has grown and we have continued to perform arch reconstructions at more moderate levels of hypothermia. In our recent study, we compared the outcomes of 257 patients undergoing arch reconstruction at 24.3°C to 265 patients undergoing arch reconstruction using at 28.5 °C. Both groups had adjunctive uSACP. There was no difference in mortality, TND or renal failure requiring dialysis between the two groups. The Stroke rate, cardiopulmonary bypass, cross clamp, post op ventilator times and ICU and hospital lengths of stay were all reduced in the 28.5˚C group (Table 2) (59). We feel that these results add to the growing body of literature which supports the strategy of moderate hypothermic circulatory arrest + uSACP as a highly effective cerebral protection strategy for aortic arch replacement (36, 54, 55, 56).

	Mild (>26°C) n=265	Moderate (22-26°C) n=257	P
Temperature (°C)	28.5 ±1.1	24.3 ± 1.3	<0.01
Mortality	5.8%	7.8%	0.37
Stroke	1.5%	4.7%	0.04
TND	3.9%	5.1%	0.49
Dialysis	3.9%	3.9%	0.61
CPB (min)	183 ± 57	209 ± 67	<0.01
Cross Clamp (min)	145 ± 55	162 ± 65	<0.01
HCA (min)	29 ± 14	34 ± 18	<0.01
Ventilator time (hours)	44 ± 101	69 ± 128	0.02
ICU Stay (hours)	102 ± 144	127 ± 149	0.06
Hospital stay (Days)	9.5 ± 7.8	10.8 ± 7.2	0.06

TND=Temporary Neurologic Dysfunction, HCA=Hypothermic Circulatory Arrest,*P<0.05

Table 2. Comparative Analysis of Perioperative Data and Outcomes between Patients undergoing Aortic Arch Reconstruction at Mild vs. Moderate levels of Hypothermia.
From Leshnower BG, Thourani VH, Myung RJ, et al. Aortic Arch Reconstruction at 28°C: A Comparative Analysis of Outcomes using Mild vs Moderate Hypothermia. *Ann Thorac Surg* Submitted.

4. Conclusion

Overall outcomes of patients undergoing aortic arch surgery have significantly improved over the past 3 decades. Advancements in surgical technique, prosthetic grafts and most importantly cerebral protection strategies have all contributed to better results. Despite the evidence presented in the preceding paragraphs, the optimal method of cerebral protection for arch reconstruction remains a controversial topic. All of these data are observational or retrospective studies. Due to surgeon bias and the limited number of arch cases performed, it is unlikely that there will ever be a prospective, randomized, controlled trial to determine the "gold standard" method of cerebral protection.

As we have demonstrated, there are many different methods of cerebral protection which range from simple to complex. The arterial cannulation site, level of hypothermia, and the use of adjunctive cerebral perfusion are factors which have been shown to impact neurologic outcomes following arch reconstruction. It is highly likely that most cardiothoracic surgeons do 1-2 arch reconstructions/year (usually in the setting of Type A dissection) and are most comfortable using DHCA at 18˚C with femoral cannulation as their sole method of cerebral protection (Personal communications). The cerebral protection conferred by deep hypothermia is undisputed, and for short circulatory arrest times (<30 minutes) the addition of RCP or ACP may not significantly impact neurologic outcomes. However it is generally agreed upon that for prolonged circulatory arrest times (>45) minutes, adjunctive ACP or RCP should be utilized. When using MHCA, ACP must be employed as it is the only adjunctive method reported with more moderate levels of hypothermia. Animal studies have demonstrated equivalent bilateral perfusion with the use of uSACP or bSACP, and clinical data has reported excellent neurologic outcomes with either method (43, 54, 55, 57). Surgeons should be familiar with the technical aspects of all

of these different methods of cerebral protection. The arch pathology of each individual patient is different and may dictate the optimal method of cerebral protection on an individual case basis.

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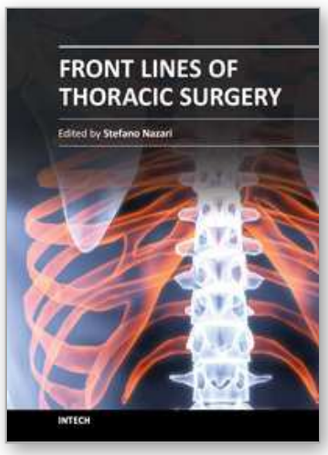

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Front Lines of Thoracic Surgery collects up-to-date contributions on some of the most debated topics in today's clinical practice of cardiac, aortic, and general thoracic surgery,and anesthesia as viewed by authors personally involved in their evolution. The strong and genuine enthusiasm of the authors was clearly perceptible in all their contributions and I'm sure that will further stimulate the reader to understand their messages. Moreover, the strict adhesion of the authors' original observations and findings to the evidence base proves that facts are the best guarantee of scientific value. This is not a standard textbook where the whole discipline is organically presented, but authors' contributions are simply listed in their pertaining subclasses of Thoracic Surgery. I'm sure that this original and very promising editorial format which has and free availability at its core further increases this book's value and it will be of interest to healthcare professionals and scientists dedicated to this field.

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