Aortic Arch Surgery with Deep Hypothermic Circulatory Arrest (DHCA)

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The two most common indications for aortic arch replacement are aortic dissection and aneurysm. Surgery involving the aortic arch requires interruption of blood flow to the cerebral vessels. However, the brain and central nervous system are extremely vulnerable to ischemia, and prolonged brain ischemia can be catastrophic. To minimize the risk of cerebral ischemic injury, these repairs have traditionally been accomplished with deep hypothermic circulatory arrest (DHCA). On CPB, the patient is cooled, typically to a core temperature of 16-18°C, to protect the brain and other organs from ischemia during circulatory arrest.

### Contents

1. Effects of Hypothermia
2. Pharmacologic Cerebral Protection Agents
3. Anesthetic Technique
4. Hemodynamic Monitoring
5. Bypass Management – Cooling Period
6. Bypass Management – Circulatory Arrest Period
7. Bypass Management – Rewarming Period
8. Post-Bypass Management
9. Conclusion
10. References

#### Effects of Hypothermia

- Decreases metabolic rate and oxygen consumption
- Decreases excitatory neurotransmitter release
- Decreases free radical production
- Causes loss of autoregulation of cerebral blood flow, leading to pressure-dependent flow at lower temperatures

Once the patient has been adequately cooled, the CPB pump is arrested. Circulatory arrest provides a motionless and bloodless surgical field for aortic arch repair. It is generally felt that the safe duration of circulatory arrest with adequate cooling may only be 30 minutes. [REF 1,2] Efforts to provide greater cerebral protection for arch surgery have involved two approaches; pharmacologic therapies, and selective cerebral perfusion during the period of circulatory arrest.
Pharmacologic Cerebral Protection Agents

- High-dose barbiturates
- High-dose steroids
- Lidocaine
- Magnesium
- Nimodipine
- Mannitol

Many institutions may still administer one or more of these agents prior to the circulatory arrest period. However, there is no conclusive evidence that these agents provide any additional cerebral protection when the patient is adequately cooled prior to circulatory arrest. Many of these agents have undesirable side effects as well. For example, barbiturates can inhibit oxidative metabolism which may worsen reperfusion injury, and also cause cerebral vasoconstriction which can impair brain cooling. High-dose steroids lead to hyperglycemia and impair wound healing.

There is evidence that suggests that straight DHCA, without selective cerebral perfusion or pharmacologic adjuncts, provides effective brain protection for arch surgery. [REF 2] Retrograde cerebral perfusion (RCP) received the most attention initially. With RCP the flow to the brain is delivered via the venous system, typically the superior vena cava. Blood travels ‘backwards’, from the venous to the arterial vessels. Review of the literature concludes that RCP may not improve cerebral outcomes, and that antegrade cerebral perfusion (ACP) likely provides superior brain protection. [REF 3, 4]

Antegrade cerebral perfusion is delivered into the arterial circulation, perfusing the brain in a forward direction. Flow can be delivered by a variety of means, and the optimal perfusion strategy is still debated. At the initiation of circulatory arrest, the arch vessels are occluded at their origin to direct flow to the brain and away from the surgical field. If the right axillary artery is cannulated for bypass, ACP can be delivered to the right cerebral vessels without additional cannula placement. Perfusion of the left brain with this technique requires an intact Circle of Willis, which is not present in all patients. To ensure blood delivery to the left brain, the left carotid artery can be selectively cannulated from the surgical field. Many centers selectively cannulate bilateral carotid arteries with dual-lumen cannulas which can deliver flow and measure pressure simultaneously.

Anesthetic Technique

The anesthetic goals for aortic arch surgery are similar to most other cardiac surgical procedures. Agents that provide hemodynamic stability for induction and maintenance should be selected. Hypertension increases the risk of rupture and/or further dissection, and should absolutely be avoided in these patients.
Because of the prolonged bypass duration, and profound hypothermia and metabolic changes, these patients are not considered ‘fast-track’ candidates.

After induction of anesthesia, begin passive cooling by keeping room temperature low and not turning on fluid warmers or forced-air warming blankets until the rewarming period. Because of limited surface area available for warming blankets above the patient, an under-body forced-air warming blanket should be considered, and placed beneath the patient prior to induction. Under-body water heating blankets have been associated with severe patient burns, and are not recommended.

These patients commonly experience excessive coagulopathy after bypass, and infrequently have massive hemorrhage from rupture prior to repair. For these reasons, good intravenous access is mandatory. Strongly consider placing a second central venous sheath for volume administration if peripheral access is limited. Fluid warmers are useful for maintaining temperature post-CPB. In most cases a rapid infusing device is not needed.

In an attempt to attenuate CPB-induced fibrinolysis, and post-CPB coagulopathy, administration of an antifibrinolytic agent should be considered. There remains some controversy about the safety of these agents in DHCA, with case reports of undesired thrombosis with use of aprotinin and the lysine analogues (tranexamic acid and ε-aminocaproic acid). The lysine analogues are generally felt to be safe, although their use requires further investigation. [REF 5]

Hemodynamic Monitoring

Unless there is a contraindication, TEE is performed in all cases. TEE is extremely valuable in determining extent of aortic pathology, which may influence the location of bypass cannula placement, and whether there is involvement of the aortic valve or not. It is also useful for monitoring ventricular function, and identifying other valvular pathology, or the presence of an intra-cardiac shunt or pericardial effusion.

Invasive lines are placed for monitoring of central venous and systemic arterial blood pressures. Myocardial dysfunction and arrhythmias may be more common after DHCA. Ensure there are an adequate number of ports for delivering vasoactive and antiarrhythmic medications into the central venous circulation. Additional placement of a PAC may facilitate post-CPB hemodynamic management, especially when there is preexisting ventricular dysfunction, or valvular pathology.

The site(s) of arterial monitoring must be determined on a case-by-case basis, knowing planned sites of bypass cannulas, and extent of aortic pathology. The radial arteries are readily available, and are the most commonly used sites. The right radial artery is in continuity with the right axillary artery and is often requested by surgeons for monitoring perfusion pressure during ACP. At full-CPB flow rates and even during ACP, the right radial artery pressure may read much higher than the actual perfusion pressure of the systemic circulation, or right cerebral circulation. A right radial arterial line should not be the only site monitored in cases utilizing right axillary cannulation. The left radial artery will not be in continuity with the
ACP circuit, but will more accurately represent systemic perfusion pressure when the right axillary artery is used for arterial inflow during full CPB.

Following the prolonged bypass period, there may be a large discrepancy between the radial artery pressure and central aortic pressure. This may persist for several hours after bypass. Measurement of the femoral artery pressure is more accurate during this time, and is strongly advocated for patients undergoing DHCA. Before considering placement, one must know if the surgeon plans to reserve either groin for cannulation of femoral vessels. The femoral arteries should also be avoided if there is extension of dissection into the pelvic vessels, or in the presence of severe peripheral vascular disease or previous femoral artery revascularization procedures.

Patient temperature should be monitored in at least 2 locations. One temperature probe is placed in the nasopharynx (NP) or esophagus, to reflect cerebral temperature. The second temperature is measured from the urinary bladder or rectum, reflective of the patient’s core temperature.

Some centers utilize a full electroencephalogram (EEG) to determine adequacy of cerebral cooling on bypass. Circulatory arrest is not performed until the EEG shows electrical silence. Processed EEG devices commonly used as awareness monitors are used by some centers during DHCA. However, there is limited data regarding the ability of these devices to predict electrical silence in patients undergoing DHCA.

The optimal hematocrit (HCT) for bypass involving DHCA is not known. Traditional thinking felt that blood with a lower HCT was ‘thinner’, less viscous, and would more uniformly perfuse all organs during profound hypothermia. Many recent studies in animal models and in pediatric patients have shown that maintaining a higher HCT (~30%) during bypass with DHCA results in less neurologic injury. Based on the current evidence, a reasonable HCT would be 24-30%. If the predicted HCT on bypass is higher than desired, intraoperative autologous hemodilution (IAH) may be performed. The perfusionist can also remove blood during bypass to achieve the desired HCT prior to DHCA.

**Bypass Management – Cooling Period**

Prior to cannulation, heparin (300-400 units/kg) is typically administered to achieve an activated clotting time (ACT) of 450-500 seconds. Because of the extended duration of CPB (up to 3-4 hours) additional heparin is often required. This can be given empirically after a certain time period, or can be given based on measurement of heparin concentrations while on CPB. It is important to remember that the ACT may remain prolonged because of hypothermia and hemodilution, even in the presence of inadequate heparinization.

The perfusionist should maintain ≤ 10°C temperature differences between the perfusate and NP or esophageal temperature to ensure more uniform cooling of the entire body. During cooling, α-stat pH management is commonly employed above 30-32°C, and then switched to pH-stat (CO2 added) to enhance cerebral blood flow and cooling at lower temperatures.
Target a mean arterial pressure (MAP) of 60 mmHg during cooling. Higher pressures can be treated with a vasodilator such as sodium nitroprusside, which may allow the perfusionist to maintain a higher flow rate, and reduce the time required for cooling. Patients will be cooled until their core temperature is 16-18°C. Cooling may take a full hour once CPB is initiated. If electroencephalogram (EEG) is monitored, cooling is continued until an isoelectric state is achieved.

Ice is commonly placed on the head to facilitate cerebral cooling. Care should be taken to avoid direct contact with the eyes and ears.

Blood glucose may elevate from the stress response of surgery and bypass, or from hypothermia alone. Check blood glucose levels prior to circulatory arrest, especially in patients at with additional risk for hyperglycemia (diabetes, steroid administration, etc.). While the optimal glucose level for DHCA is not known, extremes of hyperglycemia and hypoglycemia should be avoided. A reasonable target would be 100-150 mg/dL.

### Bypass Management – Circulatory Arrest Period

As mentioned previously, ACP may be delivered through a right axillary artery cannula, or through cannulas placed into one or both carotid arteries. The arch vessels are occluded at their origin, and flow is initiated between 5-15 ml/kg/min. Pressure transducers should be available to monitor carotid artery pressures if appropriate cannulas are inserted. To avoid cerebral hyperperfusion, the perfusion pressure should be limited to 50 mmHg. The optimal perfusion pressure and cannulation strategy is still debated at this time.

Although there is no literature to support this practice, it is generally felt that antifibrinolytic infusions should be suspended during the period of circulatory arrest to avoid a collection of the potentially procoagulant drug in the static venous circulation.

### Bypass Management – Rewarming Period

Rewarming typically takes longer than cooling, and may last 1-2 hours. Again the perfusate temperature should be no more than 10°C greater than the NP/esophageal temperature, and no higher than 37°C to avoid thermal injury to the brain. Alpha-stat pH management (no CO2 added) should be used throughout the rewarming process to avoid cerebral hyperperfusion.

Room temperature should be increased and the ice removed from the head. Once full bypass has been reestablished the forced-air warming blanket may be turned on, and antifibrinolytic infusion restarted.

Similar to the cooling process, administration of a vasodilating agent may allow the perfusionist to maintain higher flow rates, and shorten the rewarming period. While the NP/esophageal temperature will
normalize first, it is important to ensure adequate core rewarming, reflected by the rectal/bladder temperature (typically 36°C). Separation from CPB prior to adequate core rewarming leads to temperature drift, and may result in significant hypothermia. While rewarming, the perfusionist may be able to raise the HCT with ultrafiltration.

If an aortic valve-sparing procedure was performed, valve competency should be determined once a regular cardiac rhythm has been established. If the aortic valve requires surgical intervention, it can then be performed while the patient is being rewarmed.

**Post-Bypass Management**

Because of the extended bypass duration and temperature changes, patients may be more likely to exhibit ventricular dysfunction, arrhythmias and coagulopathy after bypass. Hemodynamic management is guided by TEE and other available monitors. Coagulopathy should be anticipated, and coagulation laboratory tests obtained after neutralization of the heparin. If surgical sources of bleeding have been excluded, bleeding may be treated with blood component therapy guided by abnormal coagulation parameters and institutional protocol.

After separation from bypass, patient temperature may drift due to temperature equilibration, despite adequate rewarming. Keep the OR warm and actively warm the patient until an adequate core temperature is maintained.

**Conclusion**

Surgery involving the aortic arch carries additional complexity compared to a standard cardiac operation. These cases require greater anesthesiologist involvement, and require close communication with the surgeon and perfusionist, both preoperatively, and intraoperatively. Essential to the operative proceedings are a detailed TEE examination providing information about extent of aortic pathology and aortic valve function, and placement of appropriate monitoring lines.

**References**


