Cold to the Core: Clinical Considerations of Deep Hypothermic Circulatory Arrest (DHCA) Management

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Learning Objectives: To review the following anesthetic considerations and management strategies for DHCA

1. Neurologic monitoring modalities that can be used during DHCA
2. Cerebral perfusion adjunctive modalities during DHCA
3. Neuroprotective pharmacologic selections during DHCA

Case Presentation:

A 75 year old male patient presents for repair of an ascending aortic aneurysm, measuring 5.5 cm at the level of the isthmus, requiring graft replacement utilizing DHCA. His past medical history includes: coronary artery disease, requiring a two vessel CABG thirteen years ago, hypertension, obstructive sleep apnea and non insulin dependent diabetes mellitus. Two years ago, he suffered a transient ischemic attack. A current ultrasound reveals carotid disease with bilateral 45 percent stenosis. Routine laboratory work is unremarkable except for a mildly elevated creatinine of 1.4 mg/dL.

Questions:

1. Discuss perioperative risk factors for this patient
2. Discuss the indications for DHCA
3. Explain the physiological effects of hypothermia on cerebral tissue
4. At what temperature should cooling occur and for how long?
5. Where should temperature be measurement?
6. Discuss the different forms of neurological monitoring for DHCA
7. Is cerebral preservation sufficient using DHCA alone?
8. What are the pharmacological agents often used to promote neuroprotection?
9. The NIRS (cerebral oximetry) monitor decreases 50 percent from baseline on the left side fifteen minutes after initiation of DHCA. Discuss the differential diagnosis and management
10. Discuss alpha-stat versus pH-stat management and recommend a strategy for this patient
11. An intraoperative blood glucose is measured at 200 mg/dL. Discuss the effects of hyperglycemia during DHCA and intraoperative management
12. What are the concerns regarding post bypass coagulopathy following DHCA? Should lysine analog antifibrinolytic agents be used with DHCA?
13. Discuss rewarming methods and the desired temperature
Discussion:
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Indications for deep hypothermic circulatory arrest (DHCA)

Deep hypothermic circulatory arrest (DCHA) is utilized during the following procedures: congenital cardiac, aortic arch repairs,1 neurosurgical2 and pulmonary enarterectomies.3,4 Aortic arch aneurysms and atheromas, preventing aortic cannulation or cross clamp placement,5 may require cessation of cerebral blood flow or low-flow selective perfusion to provide a bloodless and motionless field. DHCA theorizes that temperature reduction will sufficiently inhibit cerebral metabolism allowing for circulatory arrest, while minimizing ischemic induced postoperative neurologic dysfunction.

The physiological effects of hypothermia on cerebral tissue

Cerebral tissue depends on aerobic glycolysis and oxygen supply depletion is associated with ischemic cell injury. Hypothermia decreases the cerebral metabolic rate of oxygen (CMRO₂).6 Q₁₀ (the ratio of two CMRO₂ measurements differing by 10°C) varies throughout temperature ranges (2.19 to 4.54).7,8 Although hypothermia decreases brain energy expenditure, a limit in cerebral metabolism reduction exist. At 25°C CMRO₂ is 37 percent of baseline; while at 15°C, CMRO₂ decreases to 16 percent.9 Hypothermia also alters autoregulation causing an “uncoupling” and decreasing the effective range from 50-150 mmHg to 30-40 mmHg.10

Length and temperature of cooling

Preservation of cerebral tissue is dependent on obtaining homogenous hypothermia and relies on high cerebral blood flow and slow cooling. Since hemoglobin oxygen affinity increases with hypothermia, cerebral tissue hypoxia may occur with rapid cooling. The final temperature and the length of cooling remains controversial, but 15-25°C is clinically acceptable. At 15°C, the cerebral metabolism is 16 percent of baseline.7 Electroencephalogram (EEG) activity is present at 18°C but silence at 13°C and 8°C.12 With a nasopharyngeal temperature of 18°C and/or cooling time of 30 minutes, only 60 percent of patients demonstrate electrocerebral silence.11 Cooling longer than 50 minutes and/or to a nasopharyngeal temperature of less than 12.5°C are the only absolute predictors of isoelectric activity.13

Variances in temperature measurements based on location

Core body temperatures differ from peripheral measurements (2°C to 4°C).14 Although the tympanic membrane (TM) is in close proximity to cerebral tissue, these measurements are unreliable during hypothermic conditions.15-17 A temperature gradient of 2°C exist between core (bladder) and the cerebral tissues.18 Jugular venous bulb temperature is comparable to cerebral tissue.19 Jugular venous bulb versus nasopharyngeal temperature measurements provide precision but bias varies especially during rewarming (up to 3.4°C).20 Underestimation via nasopharyngeal temperature may risk destructive cerebral hyperthermia.21

Neurological monitors during DHCA

EEG: The electroencephalogram (EEG) provides continuous recording of spontaneous cortex electrical activity.22 Benefits include detection of ischemia from under perfusion, hypotension and initiation of CPB. With EEG silence, the CMRO₂ decreases by approximately 50 percent.23 If electrical activity monitoring is not used, the only means of insuring electrical silence is by cooling for 50 minutes and/or to a temperature of 12.5 °C, which may prolong CPB time.13 Electroencephalogram (EEG) activity is present at 18°C but silence at 13°C and 8°C.12 With a nasopharyngeal temperature of 18°C and/or cooling time of 30 minutes, only 60 percent of patients demonstrate electrocerebral silence.11 Cooling longer than 50 minutes and/or to a nasopharyngeal temperature of less than 12.5°C are the only absolute predictors of isoelectric activity.13

BIS: The Bispectral monitor (BIS), allows for integration of various EEG descriptors into a single variable.24 Hayashida et al. observes during DCHA the BIS decreasing to 0, with cooling to 17 °C, and increasing with rewarming to baseline.25 Ziegeler et al. reports a linear BIS response with initiation of DCHA and a rate of recovery depending on the duration.26

SjVO₂: Jugular bulb oxygen saturation (SjVO₂) allows the measurement of mixed venous sampling of the brain, reflecting the global balance of oxygen supply and demand.27 As CMRO₂ decreases, less oxygen is extracted from hemoglobin and SjVO₂ increases. A value above 95% represents sufficient suppression of metabolism to allow DHCA for 50 minutes.28,29

Transcranial Doppler Ultrasound: Transcranial doppler ultrasound is a noninvasive way of monitoring cerebral blood flow utilizing the middle cerebral artery. Retrograde cerebral perfusion and potentially optimal pressures may be monitored.30

NIRS/ rSO₂: Near-infrared spectroscopy (NIRS), or cerebral oximetry (rSO₂), is based on absorption of light using two receptors.31,32 The deeper brain signal is calculated by subtracting the superficial signal from the total signal (normal range 47% to 83%). NIRS provides information regarding local oxygenation, perfusion and effective measurements from non-pulsatile flow associated with cardiopulmonary bypass and circulatory arrest. NIRS monitoring may be useful in ensuring a maximum rSO₂ prior to the onset of DHCA and optimal duration.33,34
The safe duration of DHCA

Gerbils undergoing DCHA display significant cerebral tissue histological changes with 45 minutes of DCHA. In a human clinical study, the predicted safe duration of DHCA at 37°C is 5 minutes and at 13°C is only 29 minutes. A retrospective analysis of 394 patients undergoing DHCA reports an “acceptable” incidence of stroke if the DHCA time was less than 40 minutes. The incidence increases to 13.1 percent when greater than 40 minutes. In comparison, Svensson et al. reports a direct relationship between duration and stroke incidence (45 minutes of circulatory arrest, 10.7 percent incidence; 60 minutes, 14.6 percent). Considering cognitive function, a small study of 29 patients undergoing DHCA at 19°C and a mean time of 31 minutes, reports preservation of the cognitive demands of high level professionals.

The sufficiency of DHCA alone, with respect to cerebral preservation

Although pharmacological agents along with perfusion methods are beneficial, DCHA alone provides adequate cerebral preservation. Straight DCHA at 19°C with the head packed in ice is associated with full cognitive preservation. Gega et al reports DCHA alone, provides adequate cerebral protection as determined by preservation of cognitive function and a low seizure and stroke incidence.

Neuroprotective pharmacologic agents

Although commonly used during DHCA cases, pharmacological agent administration varies widely among anesthesia providers and lacks standardization. Pharmacologic agents may inhibit any residual cerebral activity existing even at temperatures less than 18°C therefore minimizing oxygen consumption. The barbiturate, thiopental, decreases cerebral tissue energy requirements. With the CMRO2 reduction, CBF is also decreased, so administration, prior to complete cooling, may prevent uniform cerebral preservation. Recently, the solo pharmacological manufacture of thiopental, Hospia, ceased production of the drug. An investigation utilizing propofol, reports effective EEG burst suppression but fails to show neuroprotective benefits. Etomidate may have a neuroprotective advantage, as seen in rats undergoing cerebral ischemia. The volatile anesthesic agent, isoflurane, provides EEG suppression but does not decrease CBF. Steroids provide an anti-inflammatory effect with CPB along with neuroprotective effects following spinal cord injury, but no benefits during DHCA have been reported. Calcium channel blockers, beta blockers, lidocaine and mannitol and other agents may also be used.

Retrograde and antegrade cerebral perfusion

Retrograde Cerebral Perfusion (RCP): RCP was first reported for the management of massive arterial air embolism and was used as an adjunct to DHCA by Ueda et al. in 1990. The technique involves bicaval venous cannulation followed by interruption of antegrade perfusion and arterial line flow divergence through the SVC cannula. RCP is monitored by a superior vena cava or a jugular bulb catheter. Flow rates are usually 500-1000 mL/min, and the pressure in the superior vena cava is maintained at 15-20 mm Hg. RCP allows for the maintenance of intracranial hypothermia, flushing out of embolic debris and metabolic substrates delivery. The benefits remain controversial secondarily to the potential for cerebral edema and worsening neurological outcomes. The efficacy of RCP has been widely studied and continues to be recommended during aortic repairs requiring DHCA. A case series in humans, Cheung et al. suggests oxygen consumption by tissues perfused with RCP. However, whether the oxygen consumed is sufficient to support cellular metabolism and prevent neuronal injury is not known.

Antegrade Cerebral Perfusion (ACP): ACP preserves cerebral oxygenation and energy metabolism to extend aortic arch repair time and improve clinical outcomes. However, ACP requires complicated cannulation techniques and risks embolization of athermanous debris. Right axillary artery cannulation remains the popular approach because of its lower atherosclerotic burden compared to the aortic arch and decreased cannula repositioning. Flow rates are varied between 10-20 mL/kg/min and are manipulated to maintain right upper extremity mean arterial pressure of 40-59 mmHg. Hypothermia is provided by a perfusate temperature of approximately 18°C. However, ACP may be insufficient in 15 percent of patients due to an incomplete Circle of Willis causing inadequate collateral flow to the left brain and prompting bilateral ACP. Bilateral ACP may be especially useful when aortic arch repair time exceeds 40 to 50 minutes. Additionally, ACP with moderate DHCA (25°C) is an adequate technique for aortic arch repair.
The physiology and benefits of alpha-stat versus pH-stat management

In the presence of hypothermic blood, the solubility of O₂ and CO₂ increases, causing a decrease in the partial pressure of O₂ and CO₂. Alpha-stat management consist of maintaining normal pH in temperature corrected (37°C) blood. pH-stat management involves maintaining normal O₂ and CO₂ values in hypothermic blood. During pH-stat, autoregulation and metabolic waste decreases while tissue oxygenation and cerebral blood flow increases. Uniform cooling of cerebral tissue with increased blood flow, and the right shifting of the oxyhemoglobin dissociation curve, improving O₂ delivery, potentially explains the favorable results of pH-stat management. Clinically, pediatric patients benefit from pH-stat management with decreased postoperative ventilator times and troponin levels along with increased blood flow to cerebral vessels in patients with right-left shunts. Worse neurological outcomes have been reported in both adult and pediatric patients undergoing from pH-stat management. In adult patients the increased in CBF, as seen with pH-stat management, may increase cerebral emboli.

Considerations of hyperglycemia in DHCA

Previous literature reports worsening neurological outcomes in hyperglycemic pediatric patients undergoing DHCA. When evaluating cerebral intracellular pH and adenosine triphosphate during circulatory arrest, hyperglycemia is associated with increased intracellular acidosis and the time to return to baseline intracellular pH.

Managing coagulopathy and use of lysine analog antifibrinolytic agents

Hypothermia is closely associated with postoperative coagulopathy, and DCHA cases often require transfusion of platelets and other blood products. Lysine analog antifibrinolytic agents decrease postoperative bleeding in cardiac surgery. Incidences of fatal thrombosis is have occurred in which aminocaproic acid was initiated prior to and maintained throughout DHCA.

Rewarming strategies—Temperature and length of time

According to Grigore et al, neurocognitive function improves when the difference between cardiopulmonary bypass purfusate and nasopharyngeal is maintained less than 2°C during rewarming. Patients with risk factors for cerebral ischemia should be weaned from CPB at 34°C–35°C and hyperthermia avoided (greater than 37°C) during the post-CPB and immediate post operative periords.
References

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