

## Notes

### Myocardial Protection

#### 1. Myocardial Perfusion

- Normally, subendocardial flow exceeds subepicardial flow
- Myocardial perfusion, however, is altered by cardiopulmonary bypass
- Narrow pulse pressure and variable mean pressure affects coronary perfusion pressure
- Wall tension is increased in the empty, smaller heart
- Ventricular fibrillation also increases wall tension
- Regulatory and inflammatory factors are released which affect coronary resistance
- Microemboli from the circuit and hemodilution impair oxygen delivery
- Endothelial and myocardial edema further affect perfusion
- Subendothelial vulnerability is increased by hypertrophy, coronary disease, fibrillation, cyanosis, shock, and chronic heart failure
- The acutely ischemic heart may have poor reflow to the injured area

#### 2. Myocardial Ischemic Injury

##### A. Acute ischemic dysfunction

- Global myocardial ischemia
- Reversible contractile failure, mostly from change in perfusion pressure
- Immediate recovery as oxygen supply is restored

##### B. Stunning

- Reversible systolic and diastolic dysfunction, no myocardial necrosis
- Begins in subendothelium and progresses outward
- May be accompanied by endothelial dysfunction
- Results from ischemia-reperfusion insult, mediated by increased intracellular calcium accumulation

- Recovery occurs within hours to weeks

##### C. Hibernation

- Reversible chronic contractile depression
- Related to poor myocardial blood flow
- Recovery occurs within weeks to months

##### D. Necrosis

- Irreversible ischemic injury with myocardial necrosis
- Hypercontracture occurs first in the subendothelium and is more rapid in the hypertrophied heart
- Typically results in contraction band necrosis, rarely "stone heart"
- Osmotic and ionic dysregulation produce membrane injury and myocyte lysis

### 3. Cardioplegia

- Studies in animals have inconsistent correlation with clinical results due to species differences, extent of disease, and perioperative events that precipitate, extend, or enhance myocardial damage
- The goals of cardioplegia are to protect against ischemic injury, provide a motionless and bloodless field, and allow for effective post-ischemic myocardial resuscitation
- Cardioplegic techniques vary according to perfusate (blood vs. crystalloid), duration (continuous vs. intermittent), route (antegrade vs. retrograde), temperature (warm vs. cold), and additives
- Special consideration is required for the acutely ischemic heart and the neonate

### 4. Mechanisms of Cardioplegic Protection

- Mechanical arrest (potassium-induced) will reduce oxygen consumption by 80%
- Hypothermia will reduce consumption by another 10-15%
- Aerobic metabolism can be maintained with oxygenated cardioplegia

- Hypothermic arrest is sustained with readministration every 15-30 minutes
- Retrograde delivery protects the left ventricle more completely than the right ventricle
- Prevent myocardial rewarming with systemic hypothermia, aortic and ventricular vents, and caval occlusion
- In acute ischemia, use warm induction with substrate enhancement (glutamate, aspartate)
- Reperfusion should be controlled, using warm, hypocalcemic alkaline cardioplegia
- This approach combats intracellular acidosis and rapid calcium infusion injury
- Retrograde or low-pressure antegrade perfusion is preferred for reperfusion
- Ensure uniform warming

### 5. Neonates and Children

- Children older than 2 months have similar myocardial physiology to adults
- The neonatal myocardium, however, is different in several ways
- Hypoxia is more easily tolerated
- There are greater glycogen stores and more amino acid utilization
- ATP breakdown is slower due to deficiency in 5' nucleotidase
- Multidose cardioplegia is disadvantageous
- Cyanosis may worsen resistance to ischemia
- Amino acid substrate enhancement is beneficial

### 6. Cardioplegia Composition

- Blood has the advantage of oxygen carrying capacity, histidine and hemoglobin buffers, free radical scavengers in RBCs, and metabolic substrates
- Blood also has improved rheologic and oncotic properties, which may lessen myocardia edema
- Buffers such as THAM, histidine, and NaHCO<sub>3</sub> form a slightly alkaline solution for reperfusion that can counteract intracellular acidosis
- Small amounts of calcium (0.1-0.5 mM/L) restores calcium that has been chelated by citrate
- Potassium concentrations range from 10-25 mM/L, with the first dose being the highest
- Other substrates are being evaluated, including allopurinol, SOD, deferoxamine, adenosine, nucleoside transport inhibitors, and potassium-channel openers

## CARDIOPULMONARY BYPASS

### 1. The Circulatory Environment

- Cardiopulmonary bypass is an abnormal circulatory state
- Non-pulsatile flow, hemolysis, hemodilution, foreign surface exposure, general stress response, and the inflammatory response all contribute

#### A. Mechanical Components

- Roller pumps are slightly non-occlusive, resistance-independent, and may cause less blood trauma
- Centrifugal pumps are dependent on inflow or outflow resistance; will cease flow at very low inflow resistance and very high outflow resistance
- Venous drainage can be active or siphoned
- Active drainage requires vacuum through the venous reservoir or negative pressure from the pump

#### B. Heat Exchanger

- The cooling or warming gradient is usually within 10-14 degrees of the patient's temperature
- This minimizes the tendency for gas to come out of solution and risk of air embolism
- Mixed blood temperature should be less than or equal to 38.5C
- The water bath should stay between 15 and 42C to prevent organ damage (too cold) and hemolysis (too warm)

#### C. Oxygenator

- Largest foreign surface contact area
- Membrane oxygenators can be microporous, hollow fiber, or silastic (true membrane)
- Gas flow is titrated to maintain PaO<sub>2</sub> between 85 and 250mmHg to avoid O<sub>2</sub> toxicity
- PCO<sub>2</sub> is regulated by gas and blood flow through the membrane
- pH is controlled by adjusting the PaCO<sub>2</sub>
- alpha stat adjusts the pH to 37C, with the goal of providing optimal enzymatic function during hypothermia
- pH stat corrects the pH to the temperature of the patient's blood, with the goal of relative hypercarbia to increase cerebral blood flow

### 2. Mechanisms of Injury

#### A. Mechanical

- The foreign surfaces of the bypass circuit (boundary layer of oxygenator, heat exchanger, filters, tubing) interact with the blood
- Shear stresses include the pump, cardiotomy suction, and cannulae
- Microemboli can form as particles from the oxygenator, platelet aggregate, or fibrin aggregates, and are greatest within the first 15 minutes of bypass

**B. Humoral**

- Factor XII (Hageman factor), the alternative complement cascade (C3a), kallekrein, and plasminogen are activated in various degrees
- Other factors interrelate and amplify the inflammatory reaction, including the arachidonic acid cascade, interleukins, TNF, and PAF

**C. Cellular**

- Neutrophils play a major role in humoral activation and are sequestered in the lung, releasing cytotoxin and free radicals which increase vasoreactivity and vascular permeability
- Monocytes and mast cells also participate, although their role is unclear
- Lymphocytes have a minor role, if any
- Platelets are activated and elaborate GPIB, IIB, and IIIA
- Absolute number of platelets is reduced by 40% by the end of bypass, and the number of receptors is also decreased
- Endothelial cells are affected by abnormal flow, humoral factors, and local ischemia
- A wide variety of substances are expressed by the en-

dothelium, including prostaglandins, thromboxanes, leukotrienes, and interleukins.

**3. Miscellaneous**

- Circulatory arrest with profound hypothermia (18-20C) is generally safe up to 45 minutes
- Over 60 minutes is associated with increased incidence of neurologic deficit
- The period between 45 and 60 minutes is unclear, as histologic injury seems to be greater than functional injury
- Maintain a gradient of 4-6C, as rapid cooling produces uneven cerebral cooling
- Retrograde and low flow cerebral perfusion are currently being evaluated
- Pulsatile flow has not been shown to be superior to non-pulsatile flow
- Lower ACT of 300-350 seconds is not associated with greater complications compared to standard ACT of 450
- Aprotinin will elevate the ACT (600-800), neutralizes the kallikrein cascade, and protects platelet receptors
- Protamine reactions occur through the classical component pathway and cause direct myocardial depression



# Quiz

**DIRECTIONS:** Select the most appropriate of the five answers.

**1. The utilization of blood versus crystalloid potassium cardioplegic solutions differs in which of the following ways?**

- A. The volume and frequency and pressure at which the cardioplegic solution is delivered
- B. Superiority of a specific potassium ion concentration
- C. Alleged superiority of a blood vehicle because the heart is arrested in an oxygenated environment
- D. Necessity for adjuvant use of calcium channel blocking agents
- E. None of the above.

**2. The most sensitive index for assessing the presence of postoperative myocardial necrosis following coronary revascularization is:**

- A. The development of new Q waves on the electrocardiogram.
- B. The requirement for isotropic support in the perioperative period.
- C. Presence of new "hot-spot" images by technetium 99m pyrophosphate myocardial scintigraphy.
- D. Elevation in serum of MB-band creatine phosphokinase.
- E. The development of complete left bundle branch block on the initial postoperative electrocardiogram.

**DIRECTIONS:** There are four choices for the answer to each of the following questions; one or more may be correct. Use this code to select the most appropriate response: A: (1) B:(1&3) C:(2&4) D:(4) E:(1-4)

**3. Maintenance of uniform myocardial hypothermia during aortic cross-clamping**

**is enhanced by:**

- 1. Perfusion of cardioplegic solutions through completed distal coronary anastomoses.
- 2. Separate vena caval cannulation and use of occlusive caval tapes.
- 3. Topical iced saline lavage.
- 4. Decreasing the systemic flow rate.

**4. Optimal myocardial protection afforded by hypothermic potassium cardioplegia is achieved when:**

- 1. The myocardial temperature is kept to less than 20°C.
- 2. The potassium concentration of the cardioplegic solution is greater than 40 mEq per liter.
- 3. There is absence of electrocardiographic activity throughout the aortic cross-clamp period.
- 4. Steroids are added as adjuvants for membrane stabilization.

**5. Intraoperative myocardium protection utilizing intermittent hypothermic potassium cardioplegia has been shown to be efficacious in:**

- 1. Preserving myocardial high-energy phosphate compounds during ischemic periods of 60 minutes.
- 2. Preserving preoperative left ventricular ejection fraction when measured one week following coronary revascularization.
- 3. Decreasing the incidence of perioperative infarction following coronary revascularization.
- 4. Decreasing the incidence of postoperative supraventricular arrhythmias.

Answer Key:

These questions and the answers reprinted from Self-Education (Self-Assessment Syllabus in Thoracic Surgery (SESATS) by CCCETS.

1.E  
2.D  
3.E (1-4)  
4.B (1&3)  
5.A (1-3)