Introduction to Cardiopulmonary Bypass

TSDA Boot Camp

July 26-29, 2012

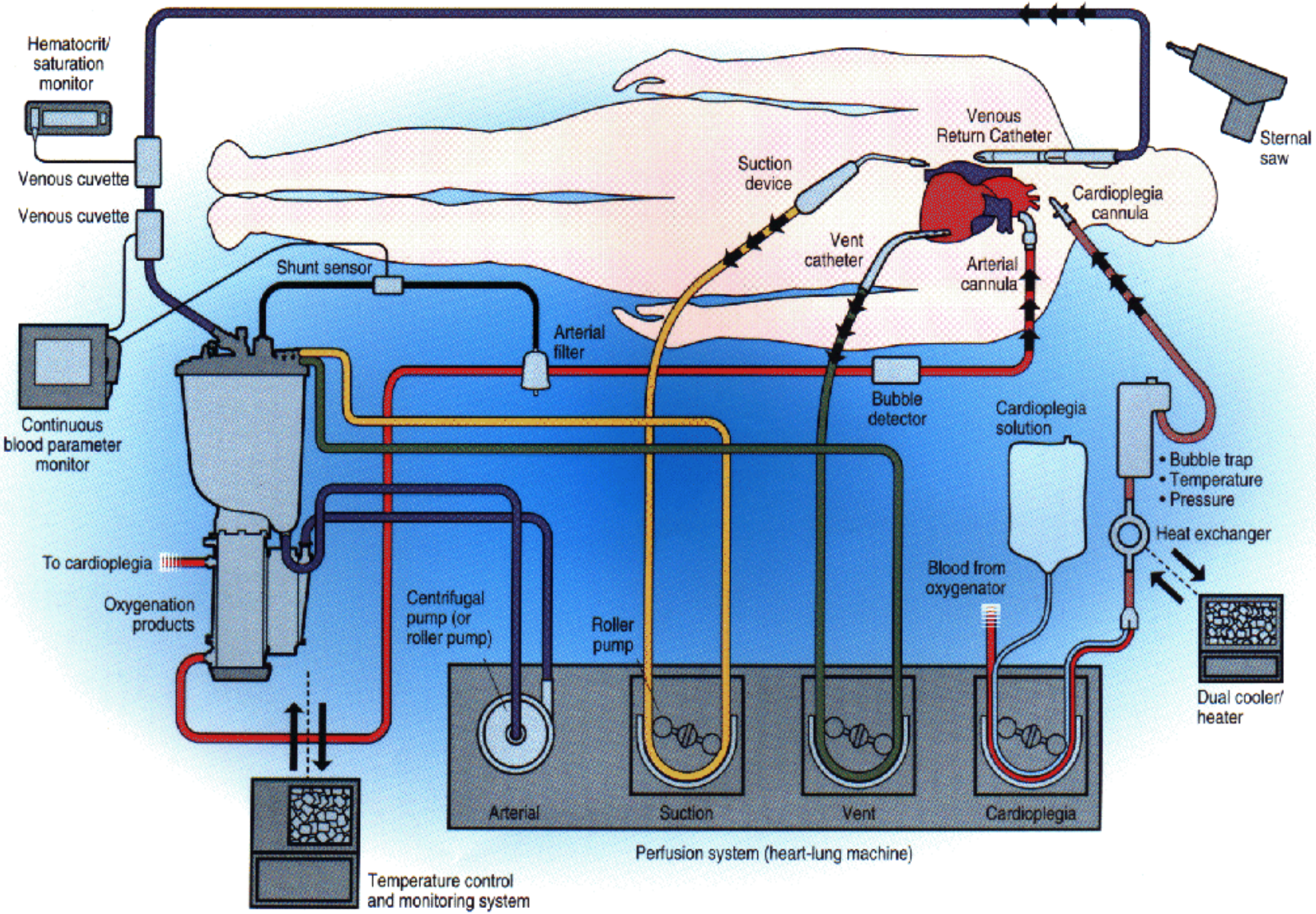
Chapel Hill, NC

Boot Camp Cardiac Faculty

- John Alexander, MD
- Brian Bethea, MD
  Jim Fann, MD
- Dave Fullerton, MD
- Eugene Grossi, MD
- George Hicks, MD
- John Ikonomidis, MD
- William Jakobleff, MD
- Ahmet Kilic, MD
- Rick Lee, MD
- Frank Manetta, MD
- Walter Merrill, MD
- Nahush Mokadam, MD
- William Northrup, MD
- Richard Prager, MD
- Sara Shumway, MD
- Jennifer Walker, MD
- Pyongsoo Yoon, MD

Boot Camp Cardiac Faculty Support

- Edward Darling, MS, CCP
- Daniel Coore, PhD
- Paul Ramphal, FRCS, DM

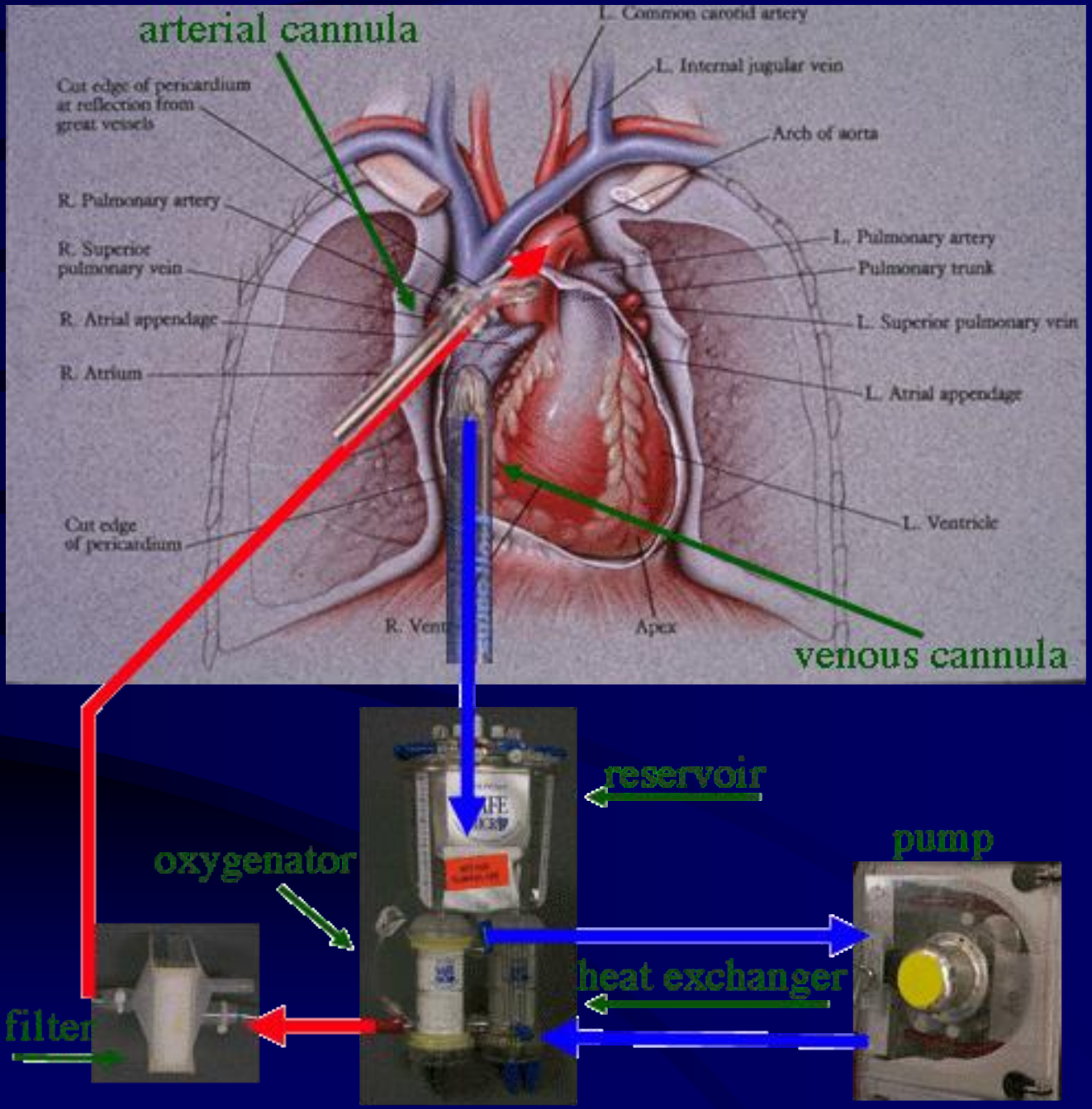

Hematocrit/
saturation
monitor
Venous cuvette
Venous cuvette
Shunt sensor
Continuous
blood parameter
monitor
Arterial
filter
Venous
Return Catheter
Sternal
saw
Suction
device
Cardioplegia
cannula
Vent
catheter
Arterial
cannula
Bubble
detector
Cardioplegia
solution
• Bubble trap
• Temperature
• Pressure
Heat exchanger
Dual cooler/
heater
To cardioplegia
Oxygenation
products
Centrifugal
pump (or
roller pump)
Roller
pump
Blood from
oxygenator
Arterial
Suction
Vent
Cardioplegia
Perfusion system (heart-lung machine)
Temperature control
and monitoring system

Why CPB

- To facilitate a surgical intervention
- Provide a motionless field
- Provide a bloodless field

Patient populations

- Coronary Artery Disease (CAD)
- Valve Disease
- Congenital Heart Defects
- Dissections
- Aneurysms
  - aortic, ventricular, giant cerebral
- Transplants
  - heart, liver, lung, trachea
- Other
  - limb cancer, hypothermic rescue


arterial cannula
L. Common carotid artery
L. Internal jugular vein
Cut edge of pericardium at reflection from great vessels
Arch of aorta
R. Pulmonary artery
R. Superior pulmonary vein
L. Pulmonary artery
Pulmonary trunk
R. Atrial appendage
L. Superior pulmonary vein
R. Atrium
L. Atrial appendage
L. Ventricle
Cut edge of pericardium
R. Vent
Apex
venous cannula
reservoir
oxygenator
pump
heat exchanger
filter

Extracorporeal Circuit

- An artificial external blood pathway with artificial organs
- 3.5 - 4 M^2 of plastics and metals

Tubing Characteristics

- Transparent
- Resilient
- Flexible
- Kink resistant
- Blood compatible
- Can be sterilized

Tubing Size vs. Volume

- ID 1/4 inch = 9.65 ml/foot
- ID 3/8 inch = 21.71 ml/foot
- ID 1/2 inch = 38.61 ml/foot
- (8 foot venous line = 309 ml)

Venous Tubing

- Minimum 10 mmHg pressure drop
- 1/4 inch = 0.9 lpm
- 3/8 inch = 4.0 lpm
- 1/2 inch = 7.0 lpm

Arterial Tubing

- Velocities less than 200 cm/sec result in acceptable hemolysis rates
- 1/4 inch = 3.4 lpm maximum flow
- 3/8 inch = 7.0 lpm maximum flow

Cannulas

- Arterial
  - Return blood to the body
    - Aortic
    - Femoral
- Venous
  - Drain blood from the body
    - 2 stage
    - Bicaval
    - Femoral





Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Reservoir

- Allow for large fluid shifts

- Open (Hard Shell)
- Closed (Bag)



Arterial Blood Pump

- Roller
- Centrifugal



Arterial Blood Pump

- Roller
- Centrifugal



Arterial Blood Pump

- Roller
- Centrifugal



Oxygenator

- Artificial Lung
- Micro-porous
  - Hollow Fiber
  - Flat Plate
- True Membrane



Oxygenator

- Artificial Lung
- Micro-porous
  - Hollow Fiber
  - Flat Plate
- True Membrane



Oxygenator

- Artificial Lung
- Micro-porous
  - Hollow Fiber
  - Flat Plate
- True Membrane



Oxygenator

- Artificial Lung
- Micro-porous
  - Hollow Fiber
  - Flat Plate
- True Membrane



Oxygenator

- Artificial Lung
- Micro-porous
  - Hollow Fiber
  - Flat Plate
- True Membrane



Heat Exchanger

- Stainless steel, aluminum, or plastic

- Induce hypothermia
- Return normothermia

- Hyperthermic Isolated limb



Heat Exchanger

- Stainless steel, aluminum, or plastic

- Induce hypothermia
- Return normothermia

- Hyperthermic Isolated limb



Heat Exchanger

- Stainless steel, aluminum, or plastic

- Induce hypothermia
- Return normothermia

- Hyperthermic Isolated limb

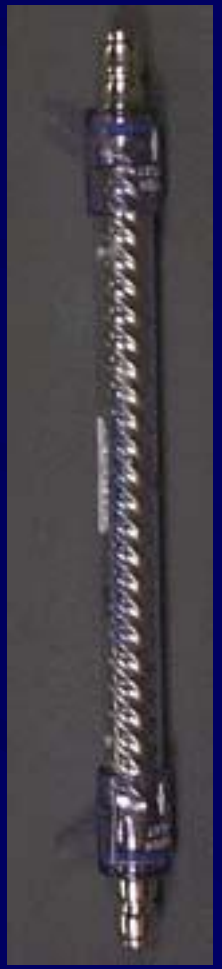


Heat Exchanger

- Stainless steel, aluminum, or plastic

- Induce hypothermia
- Return normothermia

- Hyperthermic Isolated limb



Heat Exchanger

- Stainless steel, aluminum, or plastic

- Induce hypothermia
- Return normothermia

- Hyperthermic Isolated limb



Filter

- Remove emboli
  - 30-40 µ pore size
  - Gaseous
  - Particulate
- Remove leukocytes



Cardioplegia

- Provides myocardial protection
- Motionless and bloodless surgical field
- Uses potassium to stop electrical impulses and contractions
- Cools the heart to decrease oxygen demands

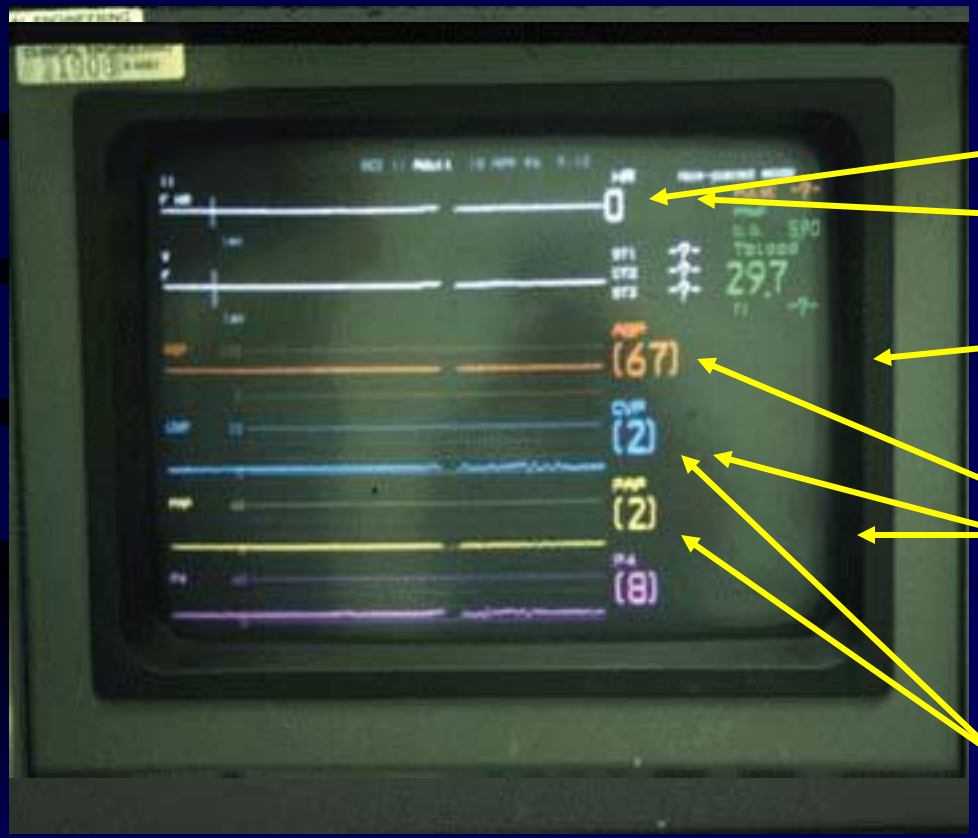
Safety

- Low level alarm
- Air bubble detector
- Arterial line pressure
- Temperature monitor
- Venous oxygen saturation monitor
- FiO_2 gas analyzer
- Battery back up power

Safety

- Checklist
- Clear three-way communication between the surgeon, anesthesiologist and perfusionist

Hemodynamics

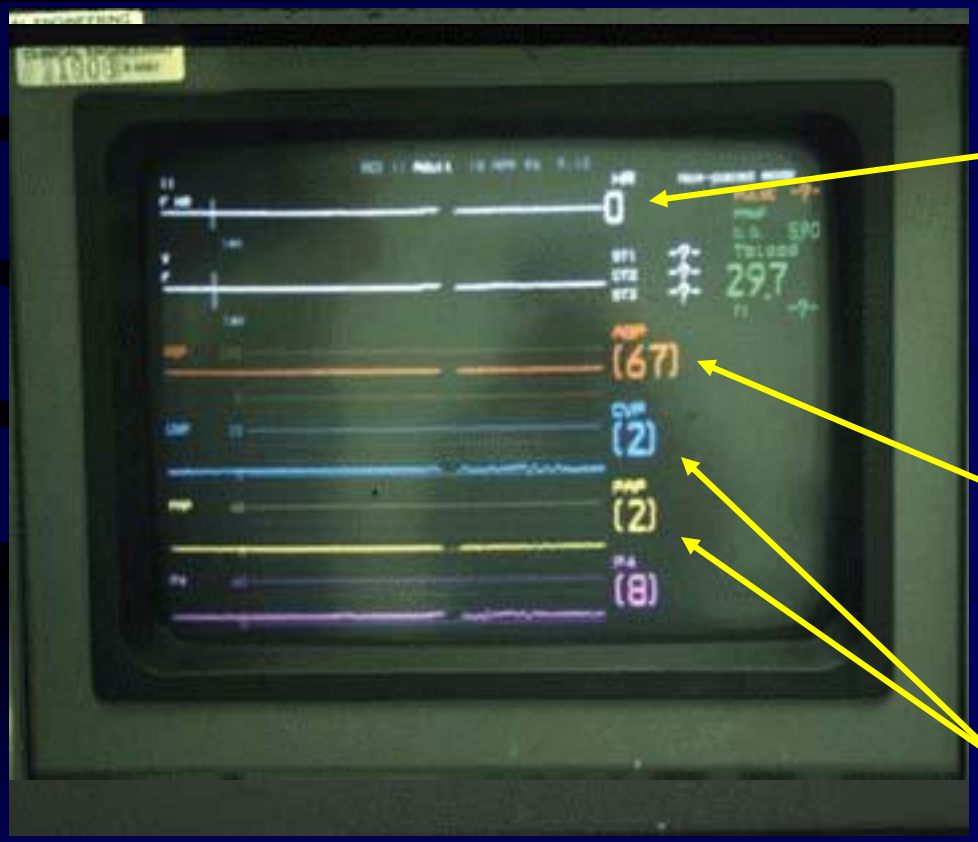


Before CPB there is electrical activity on the EKG,

pulsatile arterial blood pressure,

and positive pressures from blood present in the right side of the

Hemodynamics



On CPB, the hearts electrical activity can be suspended,

Therefore the arterial blood pressure will be nonpulsatile

And the right side of the heart will be empty

CPB Physiology

- Hemodilution
- Hypotension
- Hypothermia
- Blood gas control

Hemodilution

- Decreased viscosity results in increased tissue perfusion
- Routine procedures: Hematocrit > 21%
- Patient Age
- Jehovah Witness

Hypotension

- CPB is “controlled shock”
- Sudden hemodilution with vasodilatation
- Fluid shift increases blood viscosity
- Hypothermia increases blood viscosity
- Released catecholamines = vasoconstriction

Hypothermia

- Reduces metabolism and oxygen demand
- Allows less blood trauma
- Myocardial protection
- Systemic organ protection
- Provides a margin of safety in the event of equipment failure

Hypothermia

Types	Acceptable Circ. Arrest	
Mild 37° - 32°C	< 5 min	32°
Moderate 32° - 28°	< 20 min	28 °
Deep 28 ° - 18 °	< 45 min	18 °
Profound < 18 °	< 60 min	

Hypothermia

- Outgassing
- Occurs at tissue level when cooling
- Occurs at heat exchanger when rewarming
- Maintain a 12°C gradient
- Cool at a rate of 1°C per minute
- Rewarm at a rate of 1°C per three minutes
- Protein denaturation occurs at 42°C

Blood Gas Strategies

- pH stat maintain normal temperature corrected values for pH and $PaCO_2$
- As blood temperature decreases, CO_2 becomes more soluble
- To maintain a constant pH and $PaCO_2$, CO_2 must be added

Blood Gas Strategies

- Alpha stat maintains a constant OH-/H+ ratio
- The fraction of unprotonated imidazole groups (alpha) remains constant
- Total CO_2 remains constant
- pH changes as temperature changes

Seven Steps for CPB

Step One for CPB

- Heparin

Step Two for CPB

- Expose the heart
- Check BP and aorta

Steps for Initiating CPB

- Cardiac Exposure
- Lines up to table
- Pericardial cradle/sutures
- HEPARIN (3mg/kg) ACT>400sec
- Prepare aorta
- Aortic cannulation sutures
  - 2 Concentric 2-0 Ethibond stitches with sliders
  - Outer suture with two pledgets

Step Three for CPB

- Check ACT
- Cannulation of aorta
- Check if aortic cannula is safe

Initiating CPB

- Aortic Cannulation
  - #11 Blade and cannula insertion
  - Snare both stitches securely and tie to cannula
  - Remove all air
  - Connect cannula to arterial line
  - Ask for pulse pressure
  - Ask for perfusion arterial line test
  - Secure aortic cannula (skin stitch and/or towel

Step Four for CPB

- Atrial (venous) Cannulation
- Remove venous clamp
- Command “On bypass”
- Turn lungs off

Initiating CPB

- Venous Cannualtion
  - Single Prolene or Ethibond stitch for RA appendage or body followed by slider
  - Make incision/dilate
  - Insert cannula with hand over the IVC for accurate positioning
- Secure cannula with slider and tie
- Connect ot venous line
- Initiate CPB

Step Five for CPB

- Inspect the heart
- Place cardioplegia cannulae (retro/ante)
- Reduce pump flow/Clamp aorta
- Resume full flow/Check line pressure
- Start cardioplegia
- Set pt temperature with perfusionist

Step Six for CPB

- Release cross-clamp after warm cardioplegia
- Remove all air from heart
- Begin respirations (start lungs)
- Check for be certain there is
  - Good contractility
  - No bleeding
  - Stable heart rhythm
  - Desired patient temperature

Step Seven for CPB

- Wean slowly from CPB
- When stable:
- Clamp venous line and remove
- Remove vent/cardioplegia
- Begin Protamine assessing BP, CVP, BP
- Be alert for hemodynamic reactions
- Remove arterial cannula

Weaning from CPB

- Check list before weaning
  - No bleeding from inaccessible areas
  - Body Temperature (36-37C)
  - Stable heart rhythm
  - Lung function normal in insp/expiration
  - Good myocardial contractility

Weaning from CPB

- Ask perfusionist if he/she is ready
- Reduce CPB to half flow observing preload, afterload and contractility (TEE)
- If no RV/LV dilatation, ask perfusionist to come off CPB
- Add volume to assess ventricular compliance
- Assess need for pharmacologic support depending on preload after load and contractility

Emergencies in CPB

- Massive Air Embolism
- Aortic Dissection with cannulation
- Clotted Oxygenator
- Severe Protamine Reaction
- Inadequate CPB flow
- Inadequate CPB oxygenation

Massive Air Embolism

- Recognition
- Stop CPB
- Place pt in steep head-down position
- Remove aortic cannula from asc. Aorta
- Purge asc. aorta of air and refill arterial line
- Begin retrograde SVC perfusion (20C@1-2l/min for 2-3 min until air is cleared
- Return cannula to aorta for systemic cooling and ?pharmacologic brain protection
- Post-op-Hyperbaric O_2 rx, hyperventilation, ?hypertension

Aortic Dissection- Cannula induced

- Signs
  - Sudden increase in arterial line pressure
  - Profound drop in systemic pressure
  - Decreased venous return to CPB

Aortic Dissection-Cannula Induced

- Stop CPB
- Clamp arterial and venous lines
- Confirm diagnosis (visual or TEE evidence)
  - Flaccid aorta, expanding hematoma, dissection flap
- Rule out kinked or obstructed art line
- Remove arterial cannula to alternate site
- Initiate cooling for DHCA and open aortic repair/replacement

Clotted Oxygenator

- Decreasing PaO_2 with metabolic acidosis
  - Check O_2 supply/blender
  - Rule out oxygenator thrombus
- Emergency oxygenator change-out may be necessary

Severe Protamine Reaction

- Anaphylactic reaction with pulm HTN, edema and systemic hypotension
  - 100%O_2, IV fluids, steroids, antihistamines, vasoconstrictors and bronchodilators
  - Resume CPB if RV failure, severe pulm edema present
  - Epinephrine, vasopressin via LA line

Inadequate CPB Flow

- Directly proportional to venous saturation/acid-base status
- Possible reasons:
  - Inadequate CPB volume
  - Aortic dissection
  - Cannula problems (aortic or venous)
  - Oxygenator thrombus
  - Pump head malfunction

References

- Cardiopulmonary Bypass-Principles and Practice Gravlee GP 2nd Edit Lippincott
- Cardiopulmonary Bypass Mora CT 1995 Springer