Extracorporeal Circulation and Myocardial Protection

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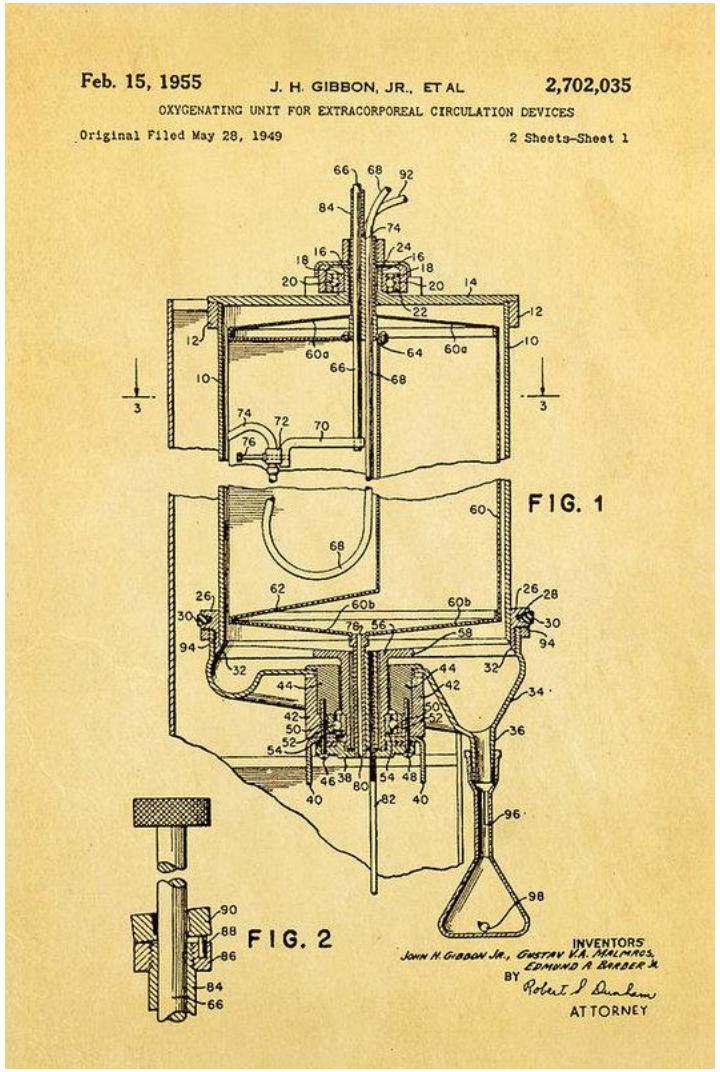
Extracorporeal Circulation

1st Cardiopulmonary Bypass

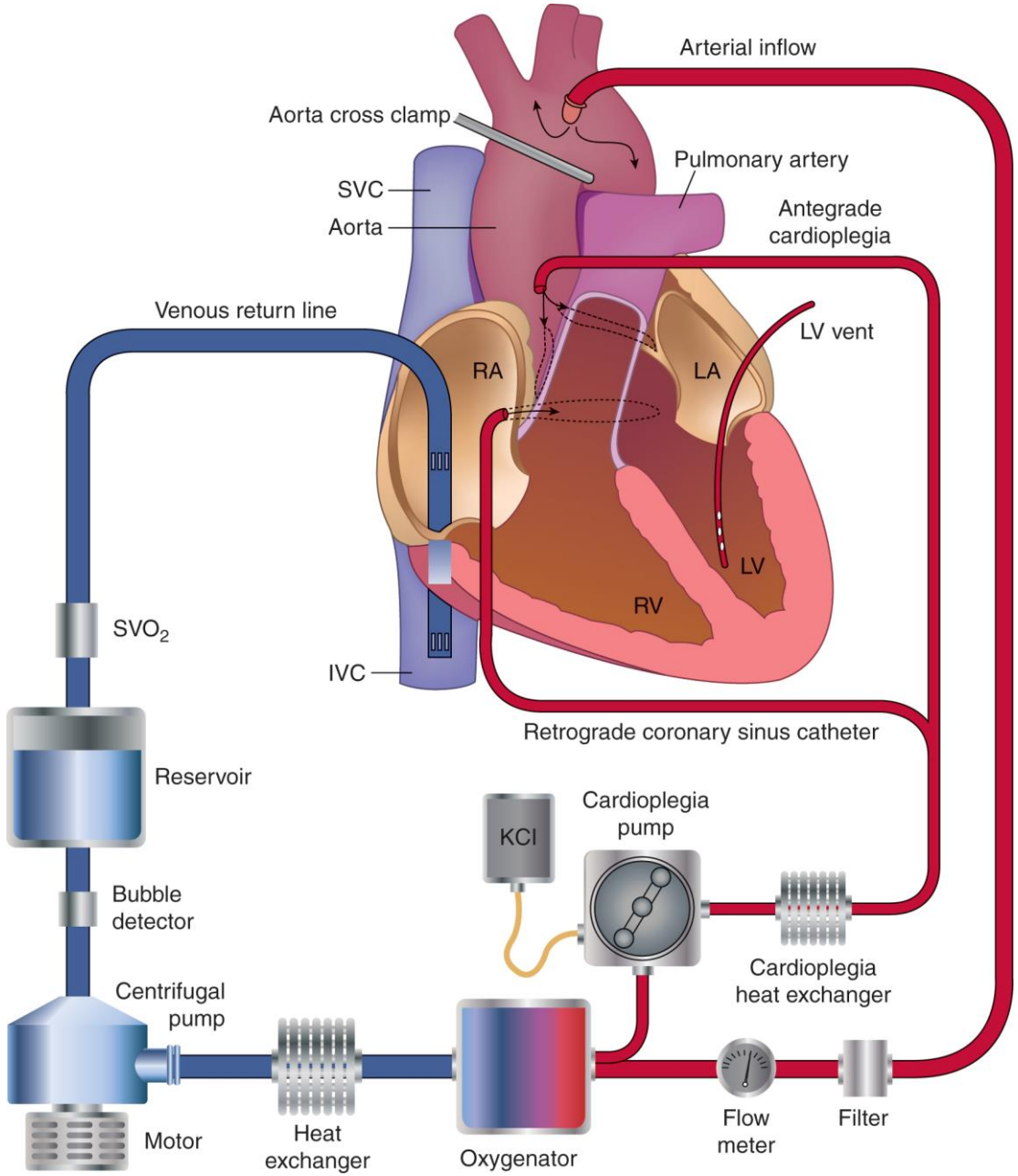
- ***John Gibbon*** - IBM engineer

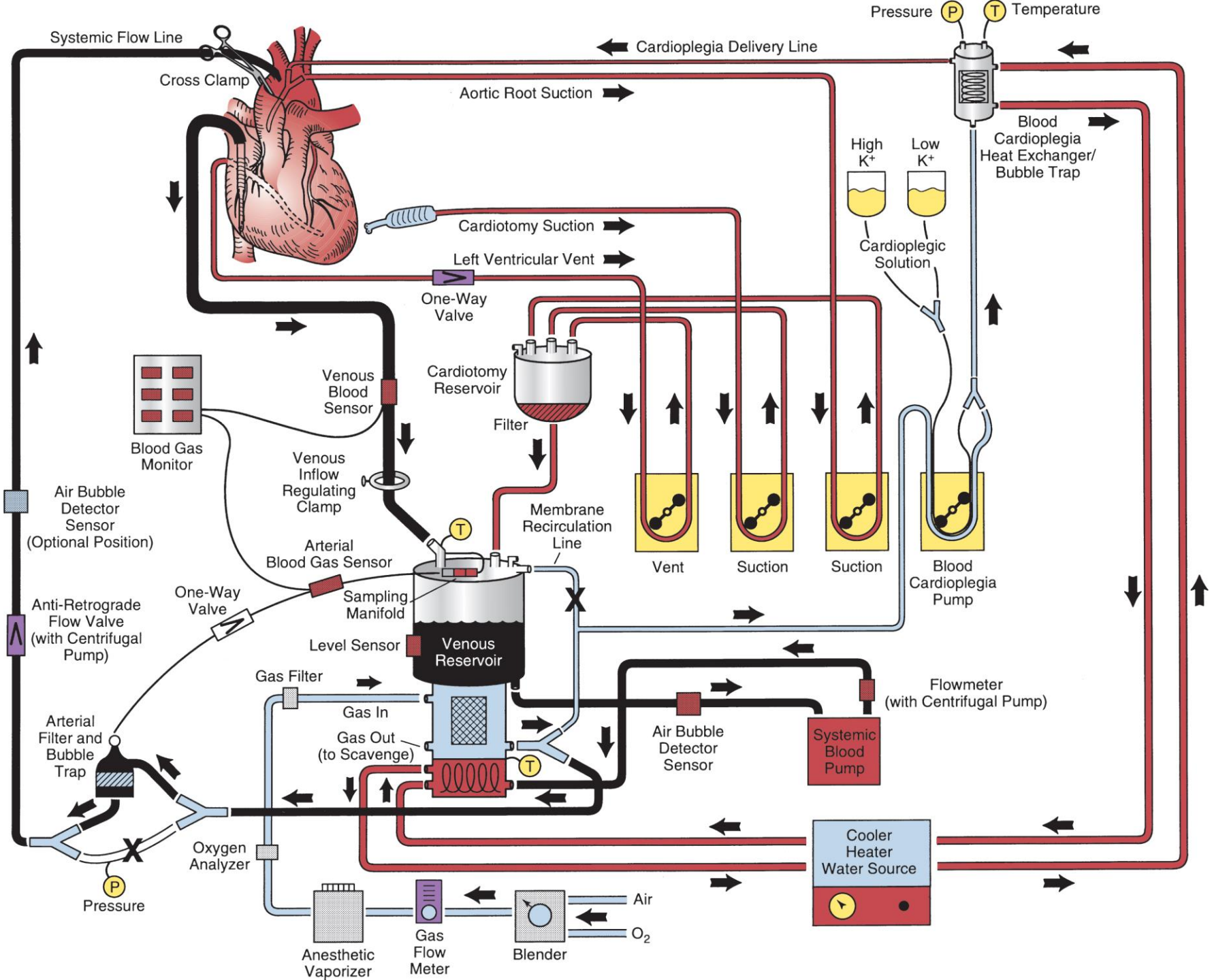


One of the most important biomedical inventions

Perfusion Systems

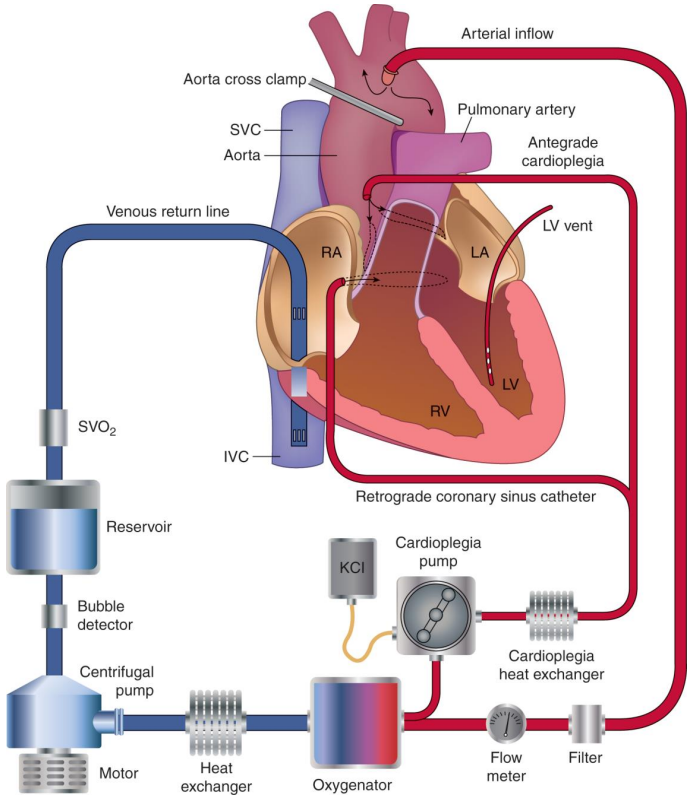
- Venous and arterial cannulation
- Venous reservoir
- Oxygenators
- Heat exchangers
- Pumps
- Filters and bubble traps
- Tubing and connectors
- Heparin-coated circuits
- Cardiotomy reservoir and field suction
- Venting
- Cardioplegia delivery systems
- Hemoconcentrators (Hemofiltration/ultrafiltration)
- Monitors and safety devices




Systemic Flow Line
Cross Clamp
Cardioplegia Delivery Line
Pressure
P
T
Temperature
Aortic Root Suction
Blood Cardioplegia Heat Exchanger/ Bubble Trap
High K+
Low K+
Cardioplegic Solution
Cardiotomy Suction
Left Ventricular Vent
One-Way Valve
Cardiotomy Reservoir
Filter
Venous Blood Sensor
Blood Gas Monitor
Venous Inflow Regulating Clamp
Air Bubble Detector Sensor (Optional Position)
Membrane Recirculation Line
Arterial Blood Gas Sensor
Vent
Suction
Suction
Blood Cardioplegia Pump
One-Way Valve
Anti-Retrograde Flow Valve (with Centrifugal Pump)
Sampling Manifold
Level Sensor
Venous Reservoir
Gas Filter
Gas In
Gas Out (to Scavenge)
Flowmeter (with Centrifugal Pump)
Air Bubble Detector Sensor
Systemic Blood Pump
Arterial Filter and Bubble Trap
Oxygen Analyzer
Cooler Heater Water Source
Pressure
Anesthetic Vaporizer
Gas Flow Meter
Blender
Air
O_2

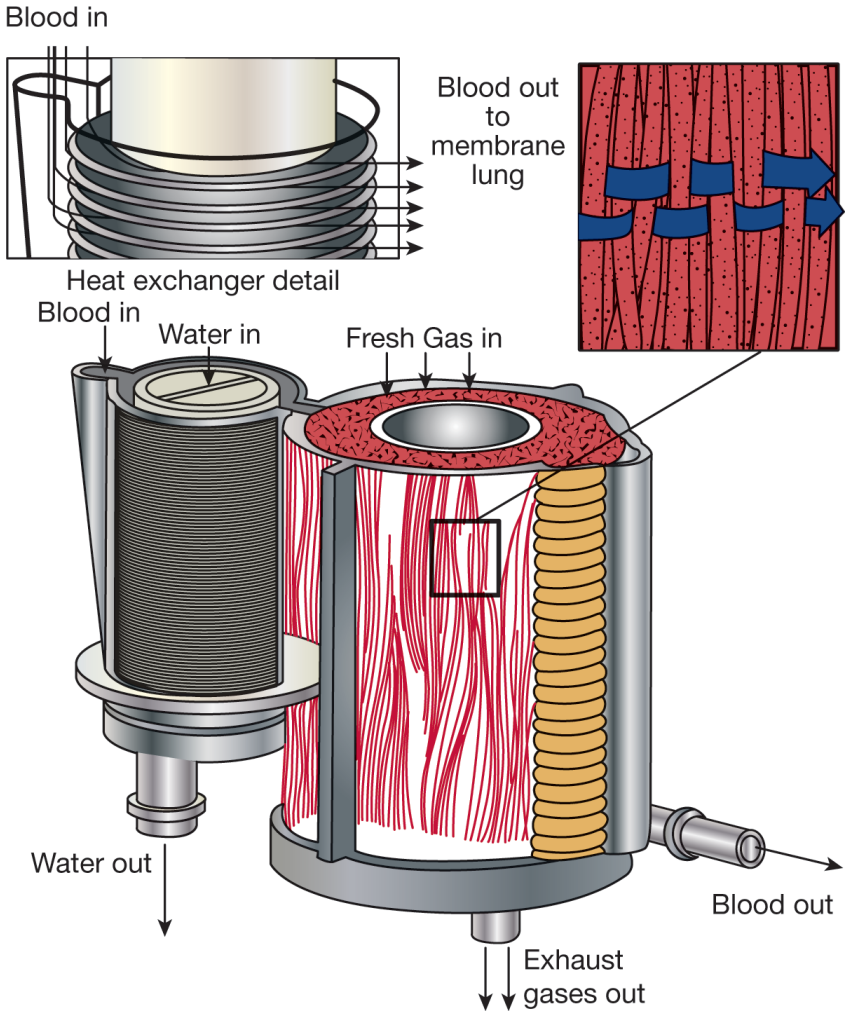
Venous Reservoir

- 1~3L of blood
- Store excess blood
- Bubble trap
- Access for drugs, fluids, or blood



- To provide time for the perfusionist to act if venous drainage is sharply reduced or stopped

Oxygenators



Recommendations for selection of an oxygenator

Recommendations	Class[a]	Level[b]	Ref[c]
Microporous membrane oxygenators are recommended as the first choice for use in CPB.	I	B	[78]
Polymethylpentene membrane oxygenators are not recommended when volatile anaesthetics are used during the procedure.	III	B	[84, 86]

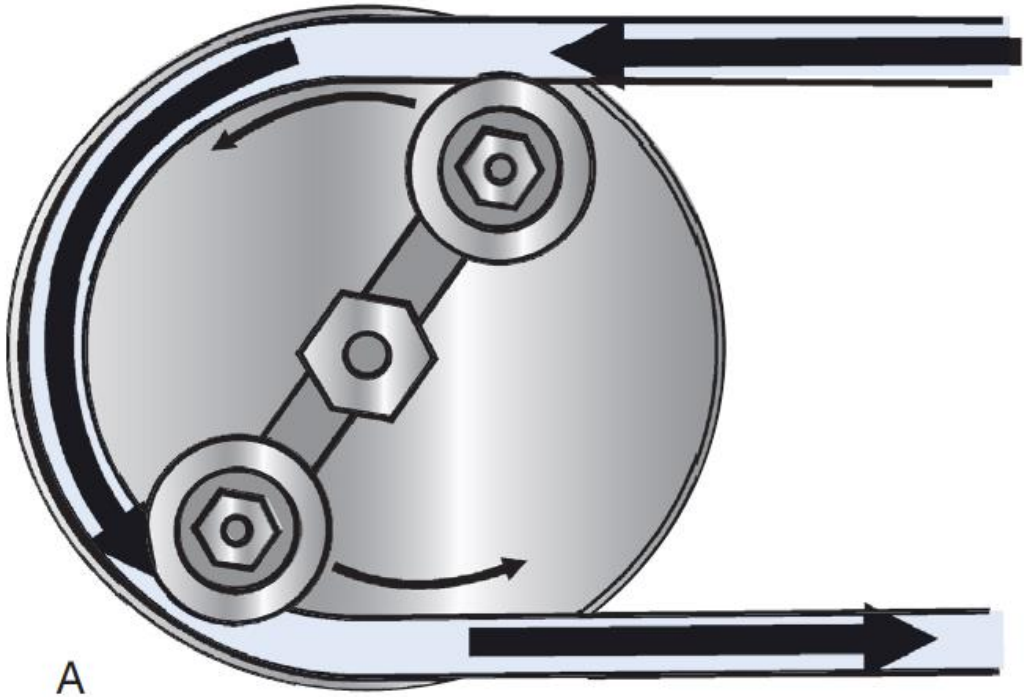
[a]Class of recommendation.
[b]Level of evidence.
[c]References.
CPB: cardiopulmonary bypass.

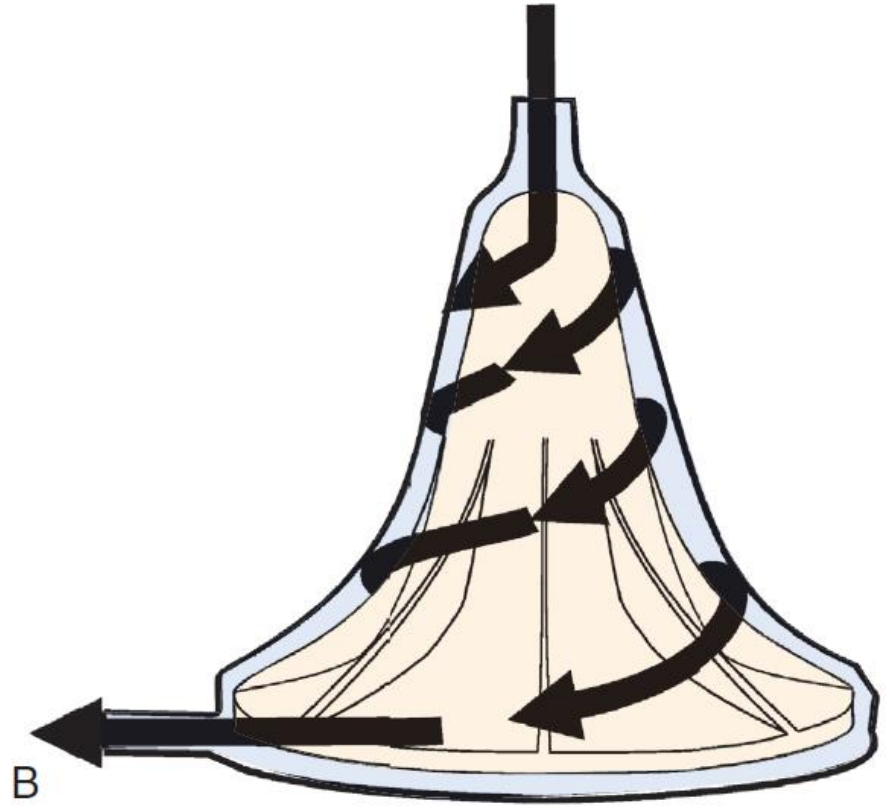
Eur J Cardiothorac Surg 2020;20:210-51

Heat Exchangers

- Heated temperature < 40 °C
- Temperature gradient between body and circuit < 10 °C

Types of Pump





Roller vs Centrifugal Pumps

	Roller pump	Centrifugal pump
Description	Nearly occlusive Afterload independent	Nonocclusive Afterload sensitive
Advantages	Low prime volume Low cost No potential for backflow Shallow sine-wave pulse	Portable, position insensitive Safe positive and negative pressure Adapts to venous return Superior for right or left heart bypass Preferred for long-term bypass Protects against massive air embolism
Disadvantages	Excessive positive and negative pressure Spallation Tubing rupture Potential for massive air embolism Necessary occlusion adjustments Requires close supervision	Large priming volume Requires flowmeter Potential passive backward flow Higher cost

Centrifugal Pump and Roller Pump in Adult Cardiac Surgery: A Meta-Analysis of Randomized Controlled Trials

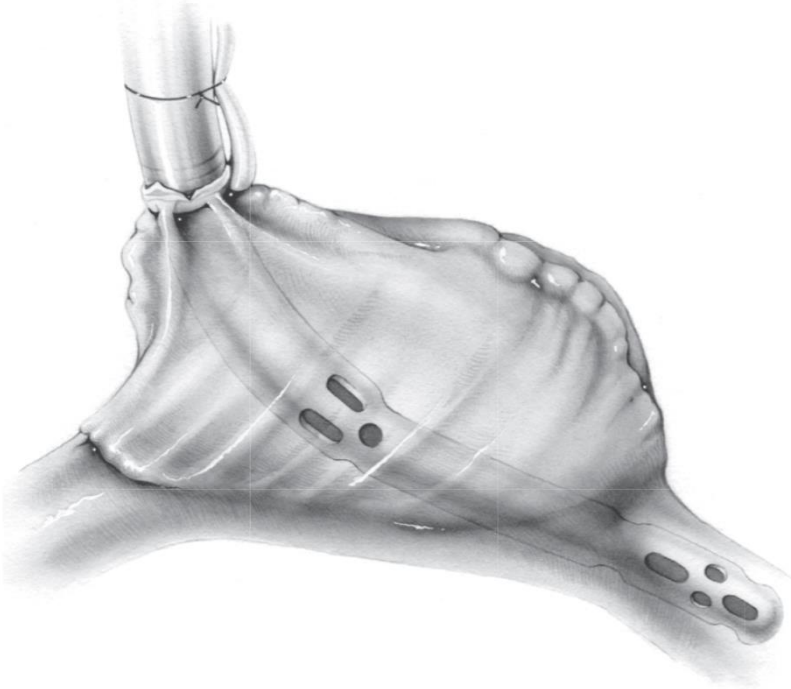
Richard Saczkowski, Michelle Maklin, Thierry Mesana, Munir Boodhwani, and Marc Ruel

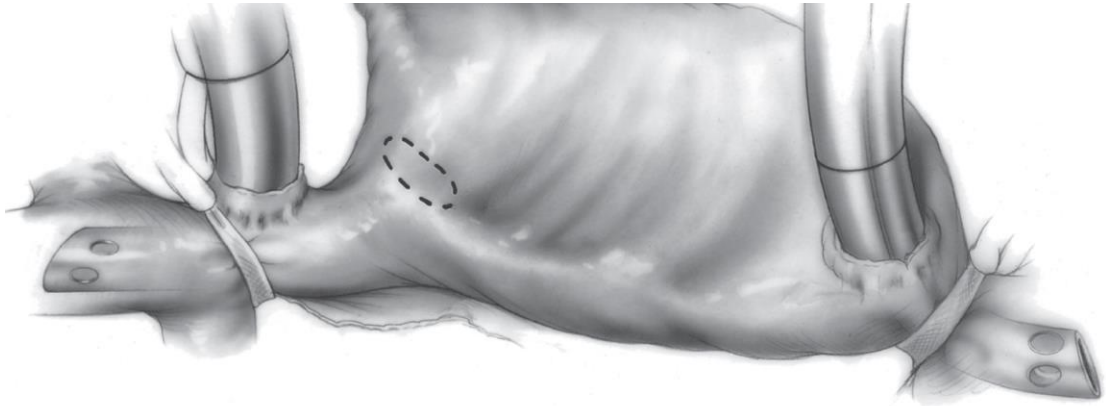
Department of Cardiac Surgery, Royal Columbian Hospital, New Westminster, British Columbia, Canada

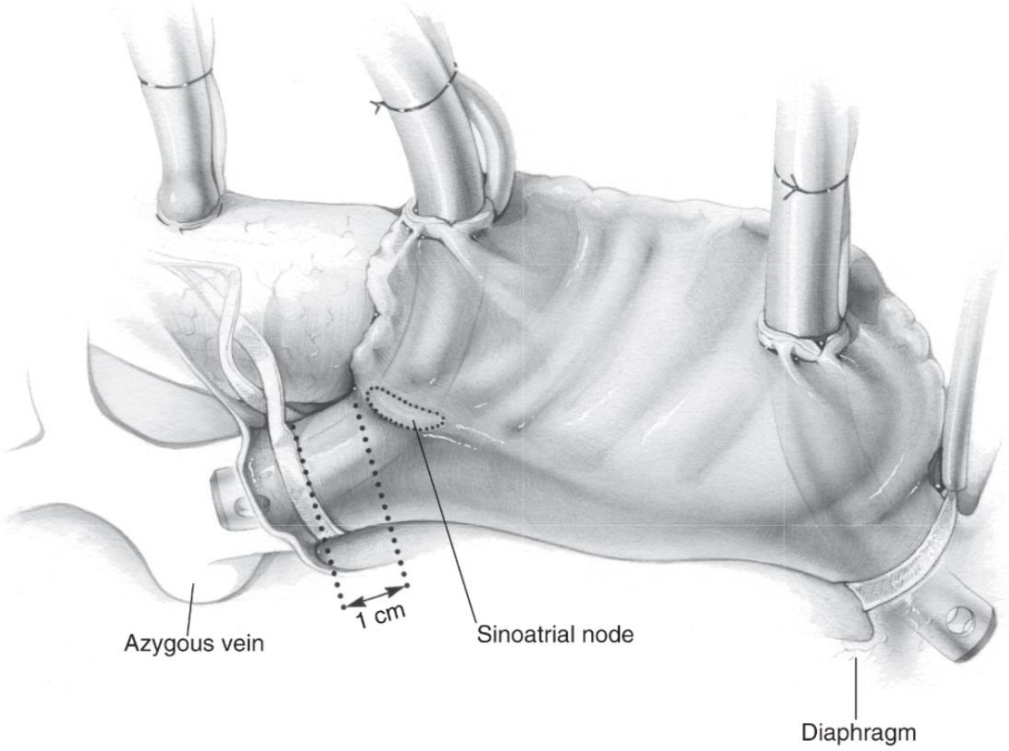
- 18 randomized controlled trials with 1868 patients
- Predominantly isolated CABG
- **No significant difference** for hematological variables, postoperative blood loss, transfusions, neurological outcomes, or mortality

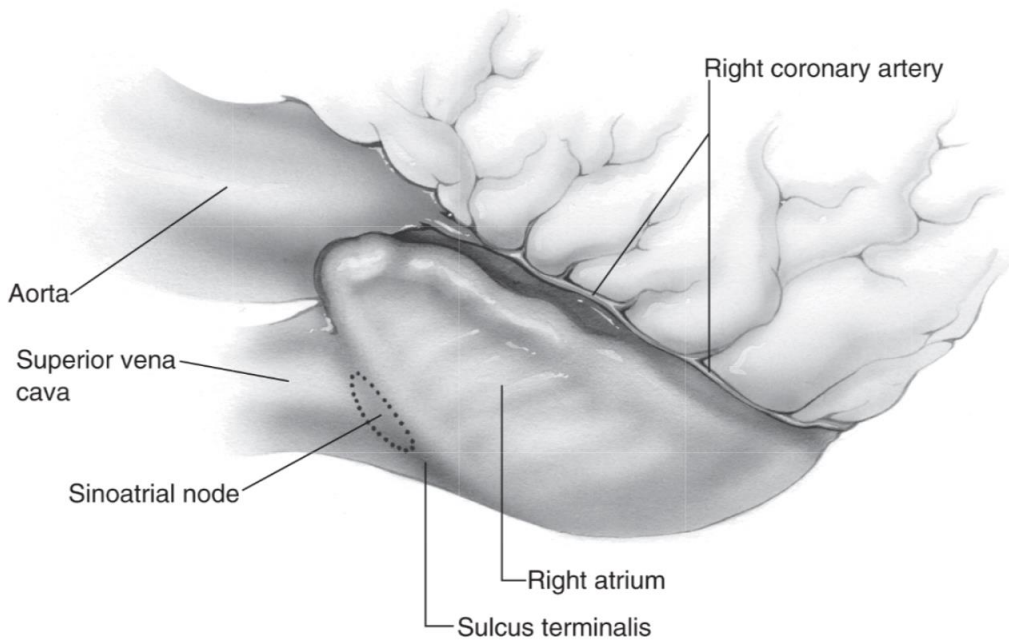
Artif Organs 2012;36:668-76

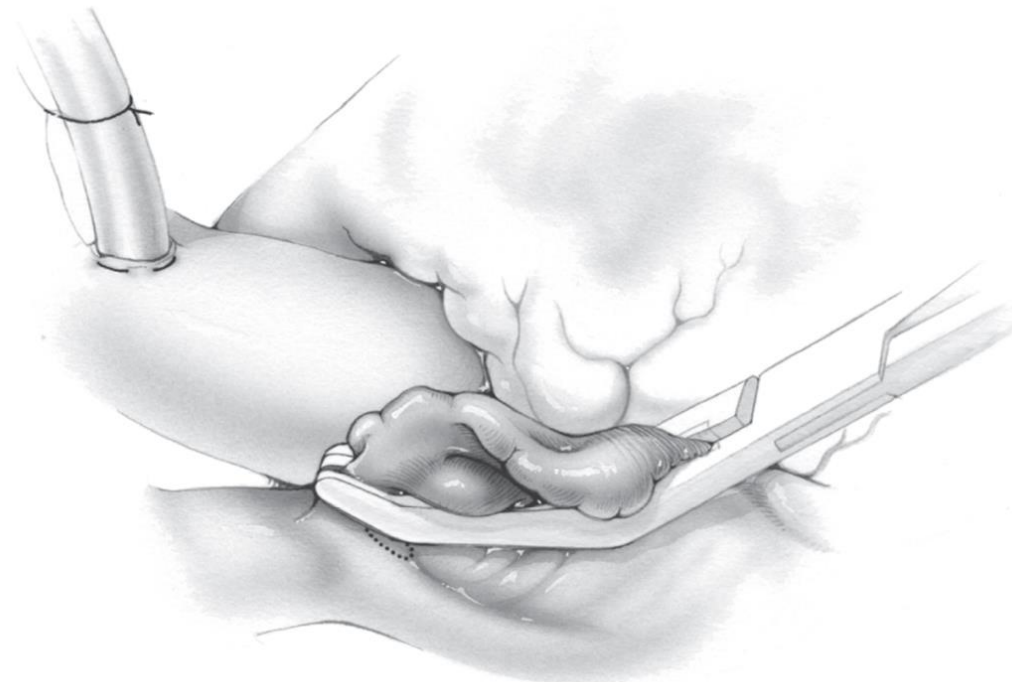
Venous Cannulation








Right coronary artery
Aorta
Superior vena cava
Sinoatrial node
Right atrium
Sulcus terminalis

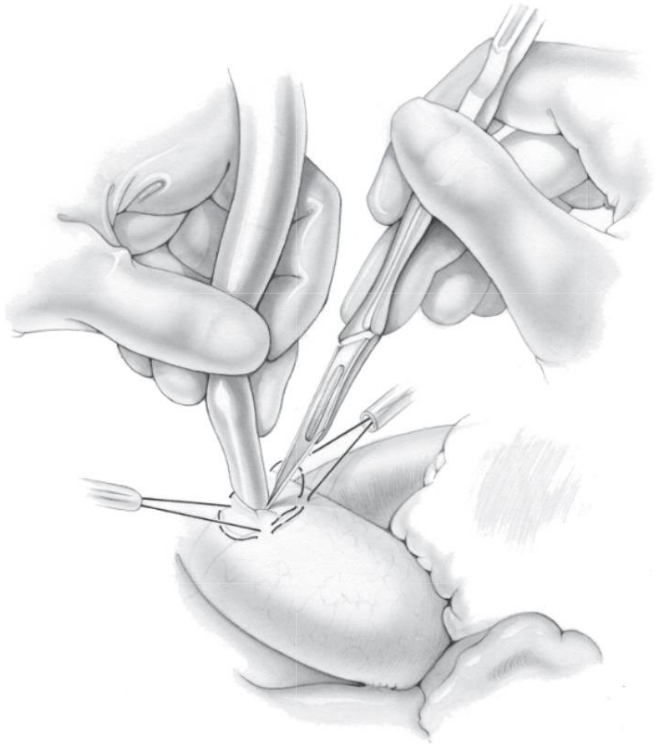


Causes of Low Venous Return

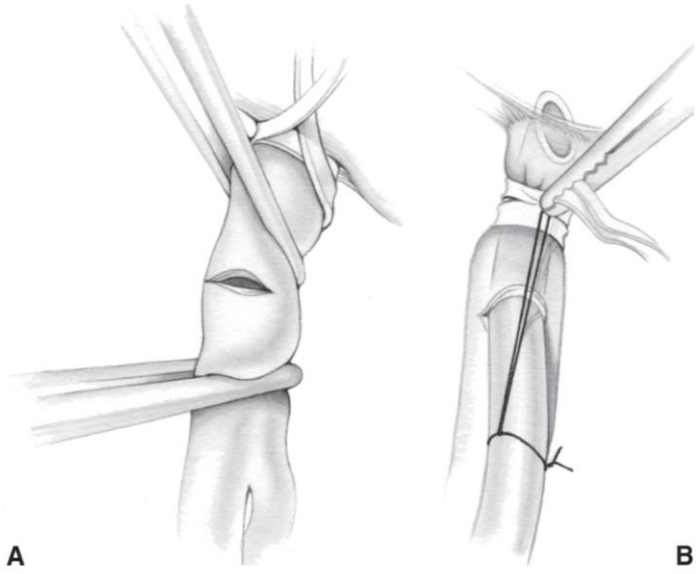
- Low venous pressure
- Hypovolemia
- Drug- or anesthetic-induced venous dilatation
- Inadequate height between the heart and the reservoir
- Inadequate cannula size
- Cannula obstruction or kinking, air-lock

Arterial Cannulation

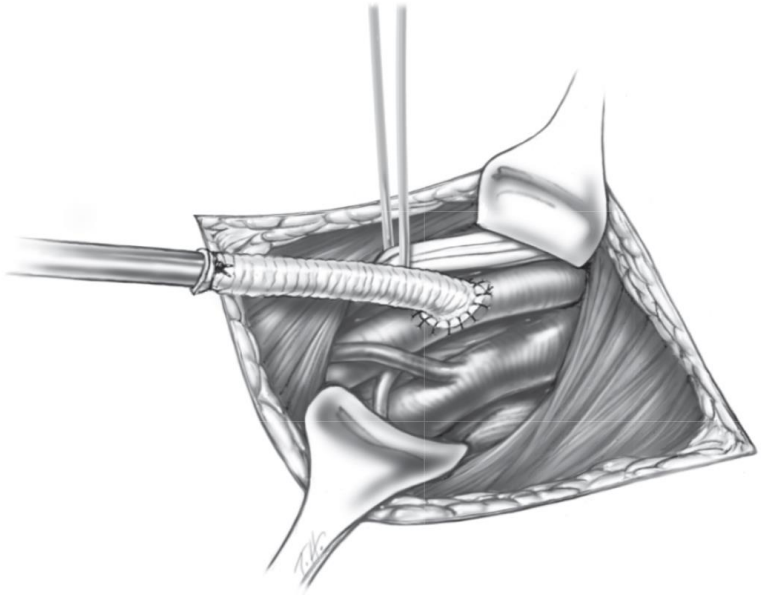
- Optimal arterial BP during cannulation
  - MAP 70~80mmHg, **sBP 100~120mmHg**



Ascending aorta

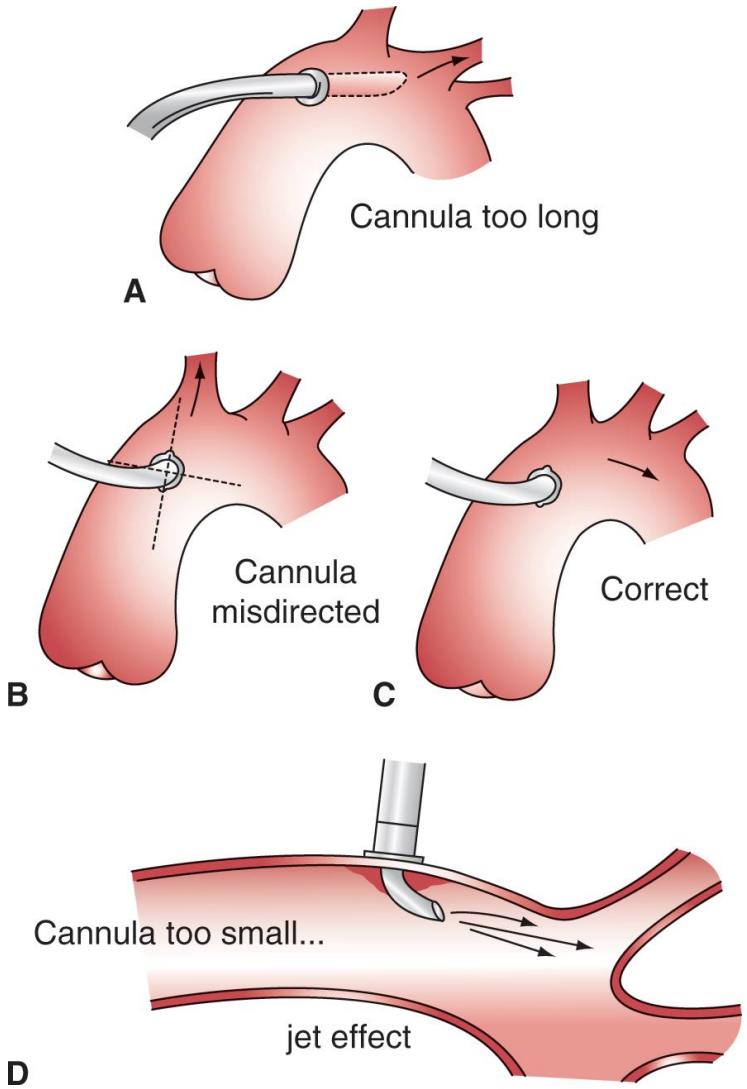


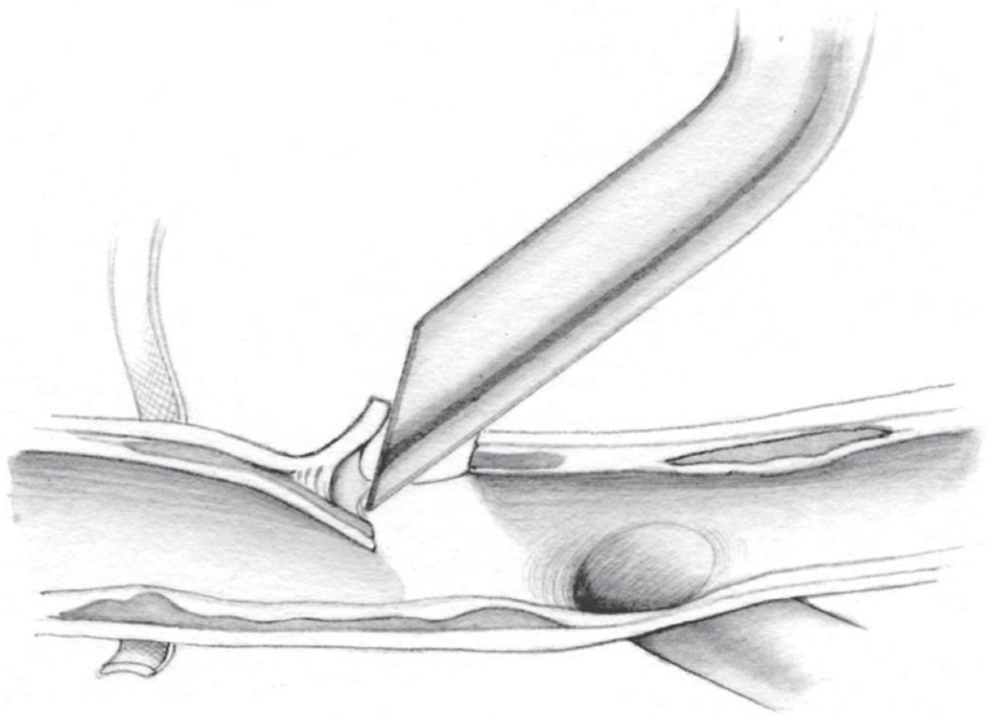
Femoral artery



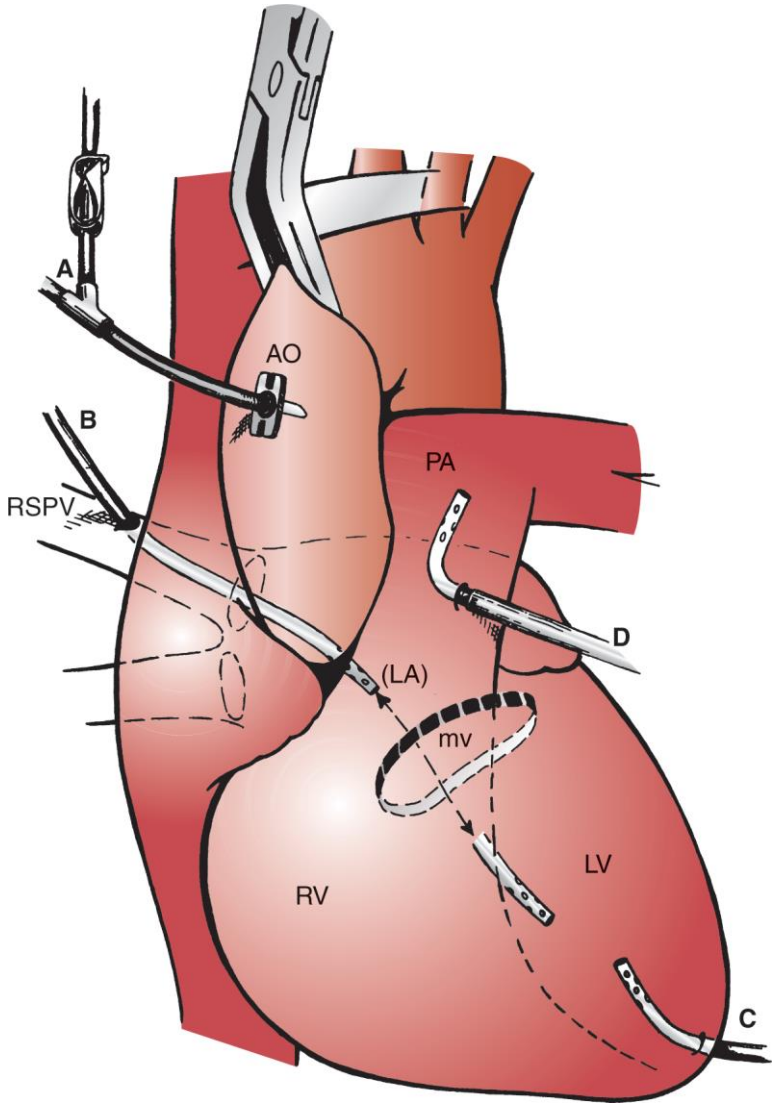
Axillary artery

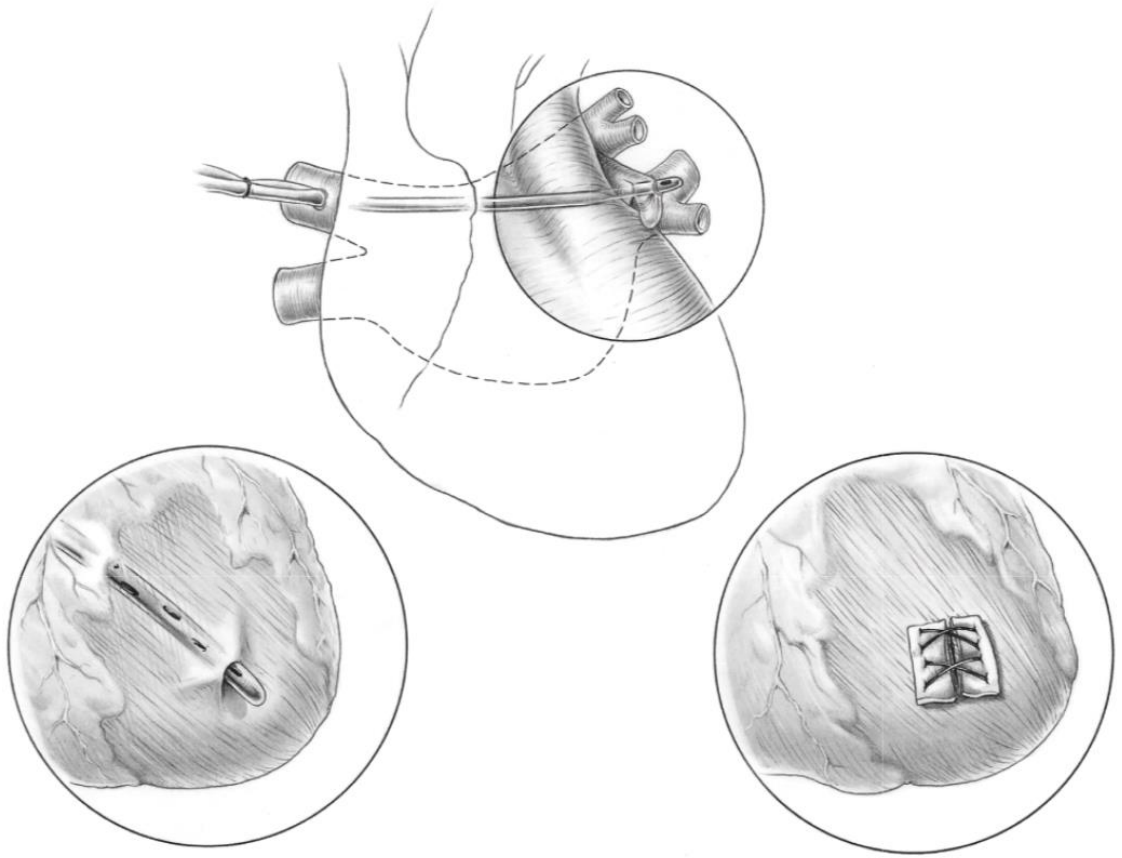
Aortic Cannulation Problems





Sites for Venting LV





Determinants of Safe Perfusion

- Blood flow rate

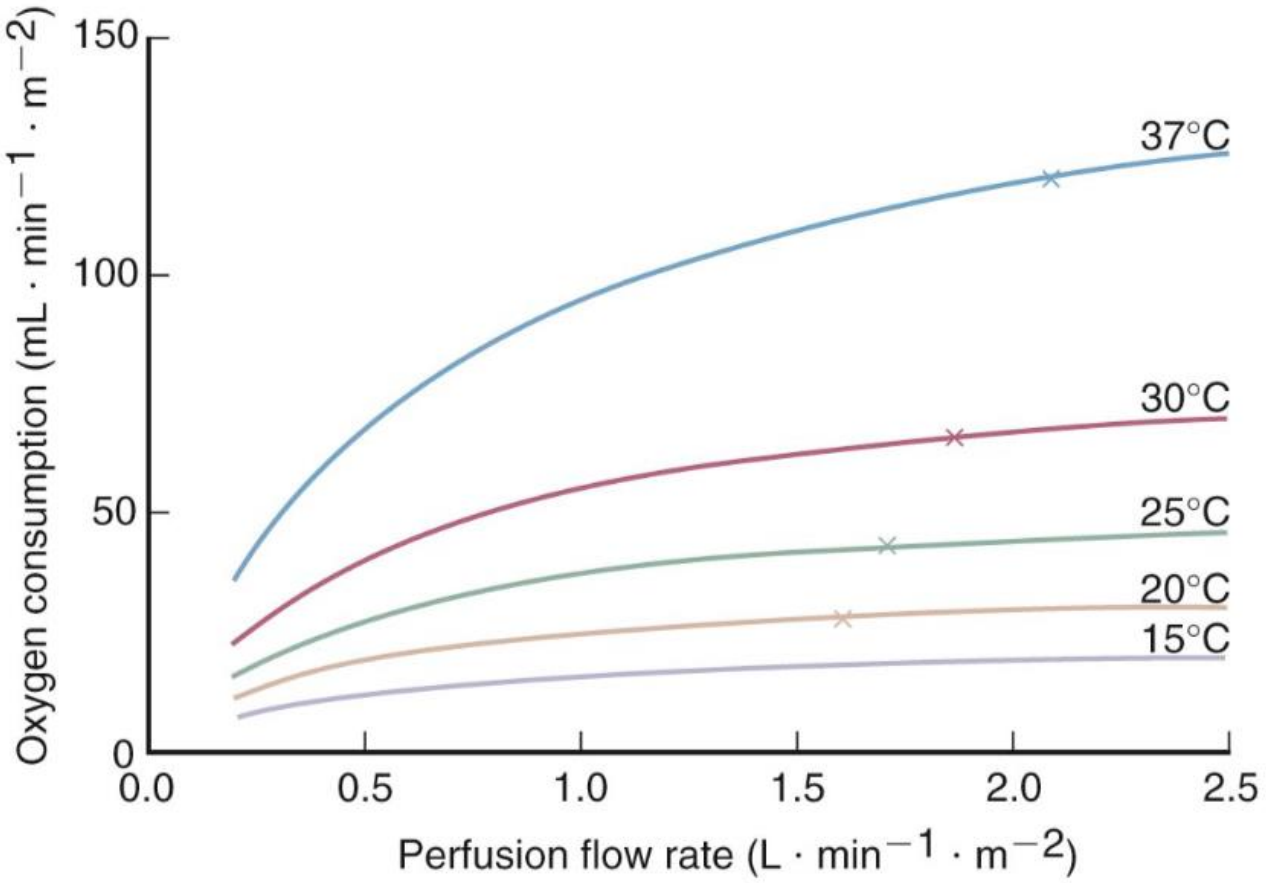
- Arterial pressure

- Hematocrit

- Temperature

- Acid/Base management

Blood Flow Rate



Accepted flow rate : 2.2~2.5L/min/m^2 at 35~37°C, Hct 25%

Arterial Pressure

- Mean arterial pressure
  → near **70mmHg**

- Older patients with vascular disease or hypertension
  → **70~80mmHg**

Pressure Monitoring

Recommendations for control of mean arterial blood pressure during cardiopulmonary bypass

Recommendations	Class[a]	Level[b]	Ref[c]
It is recommended to adjust the MAP during CPB with the use of arterial vasodilators (if MAP >80 mmHg) or vasoconstrictors (if MAP <50 mmHg), after checking and adjusting the depth of anaesthesia and assuming sufficiently targeted pump flow.	I	A	[186, 187]
The use of vasopressors to force the MAP during CPB at values higher than 80 mmHg is not recommended.	III	B	[186, 191, 199]
It is recommended that vasoplegic syndrome during CPB be treated with α1 adrenergic agonist vasopressors.	I	C	
In patients with vasoplegic syndrome refractory to α1-adrenergic agonist vasopressors, alternative drugs (vasopressin, terlipressin or methylene blue) should be used, alone or in combination with α1-agonists.	IIa	B	[194, 196, 197]
Hydroxocobalamin may be used to treat vasoplegic syndrome during CPB.	IIb	C	

[a]Class of recommendation.
[b]Level of evidence.
[c]References.
CPB: cardiopulmonary bypass; MAP: mean arterial pressure.

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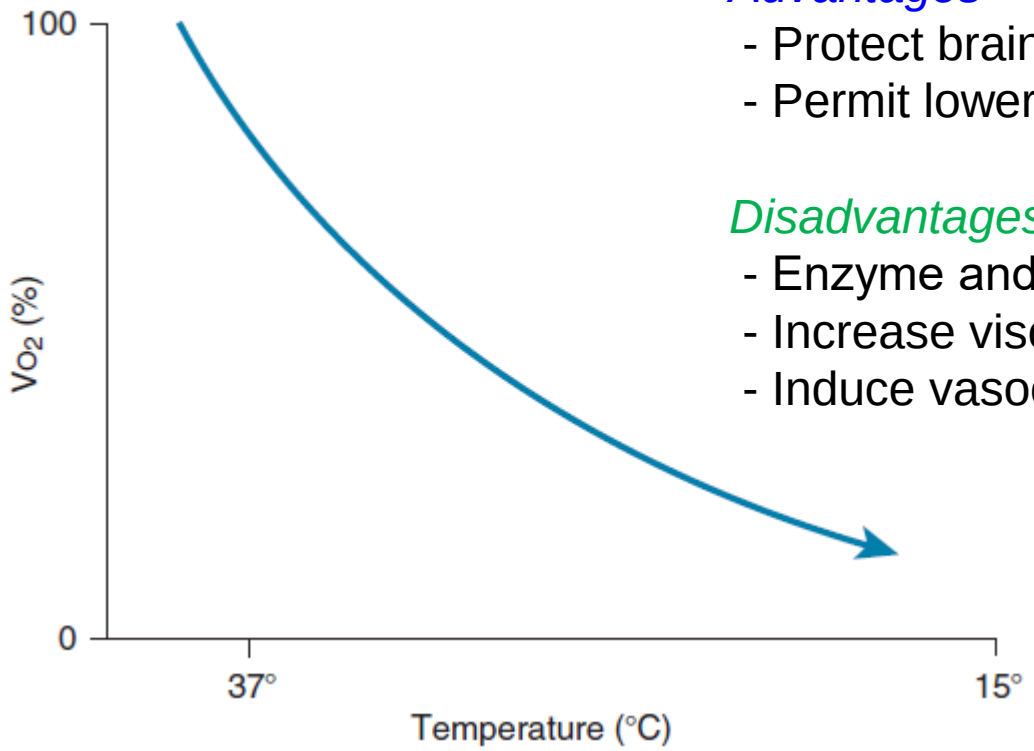
Hematocrit

- Ideal hematocrit : controversial, but **usually 20~25%** during CPB

- Low hematocrit
  - Reduce blood viscosity and hemolysis
  - Reduce oxygen-carrying capacity
  - Increase cerebral blood flow

- Viscosity remains stable when percent Hct and blood temperature are equal (ex. Same viscosity : 37°C 37% Hct = 20°C 20% Hct)

Temperature



Hypothermia

Advantages

- Protect brain
- Permit lower flow perfusion and lower hematocrit

Disadvantages

- Enzyme and organ dysfunction (bleeding↑, SVR↑, delayed cardiac recovery)
- Increase viscosity
- Induce vasoconstriction

O2 consumption decreases by 50% for every 10°C drop in temperature

Acid/Base Management

- 1°C ↓ → pH 0.015 units ↑
- Alkalosis and hypocarbia → cerebral blood flow↓
- **pH-stat strategy**
  - Addition of CO_2 during hypothermia
  - Preferable in children
- **α-stat strategy**
  - No active correction of pH with hypothermia
  - Preferable in adult

Heparin and Protamine

- Heparin dose : 300U/kg
- Target activated clotting time (ACT) : 400~480 sec
- Protamine dose : 1mg/100U of heparin
- The most common problem related to protamine
  - Heparin rebound
  - Hypotension
  - Anaphylactoid reactions
  - Pulmonary vasoconstriction
  - Direct antiplatelet effect

Recommendations for periprocedural anticoagulation management

Recommendations	Class[a]	Level[b]	Ref[c]
Heparin management			
ACT above 480 s during CPB should be considered in CPB with uncoated equipment and cardiotomy suction. The required target ACT is dependent on the type of equipment used.	IIa	C	
Individualized heparin and protamine management should be considered to reduce postoperative coagulation abnormalities and bleeding complications in cardiac surgery with CPB.	IIa	B	[165, 166, 169]
In the absence of individual heparin dosing tools, it is recommended that ACT tests be performed at regular intervals based on institutional protocols, and heparin doses have to be given accordingly.	I	C	
Protamine management			
Protamine overdosing should be avoided in order to reduce postoperative coagulation abnormalities and bleeding complications in cardiac surgery with CPB.	IIa	B	[172]
Alternative anticoagulation			
In patients with contraindications to heparin and/or protamine usage and in need of an operation requiring CPB, anticoagulation with bivalirudin should be considered.	IIa	B	[174, 176]
In patients with contraindications to heparin and/or protamine usage, in need of an operation requiring CPB and significant renal dysfunction, anticoagulation with argatroban may be considered.	IIb	C	

[a]Class of recommendation.
[b]Level of evidence.
[c]References.
ACT: activated clotting time; CPB: cardiopulmonary bypass.

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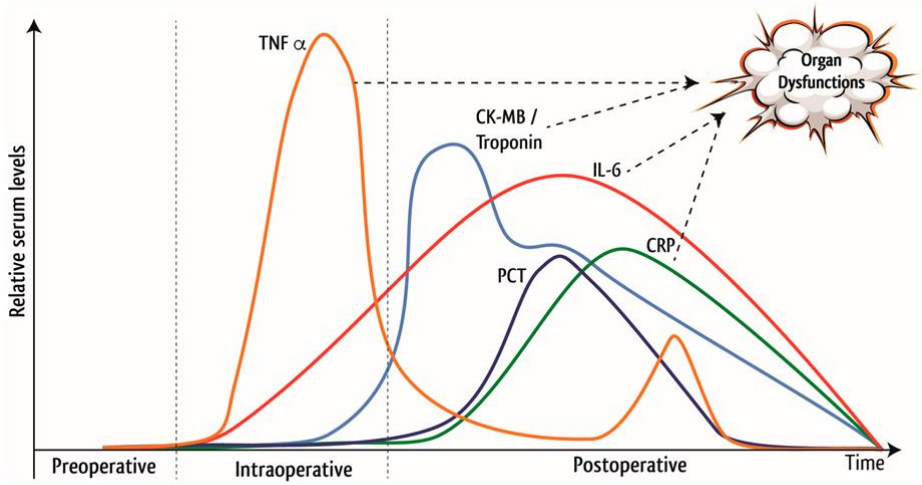
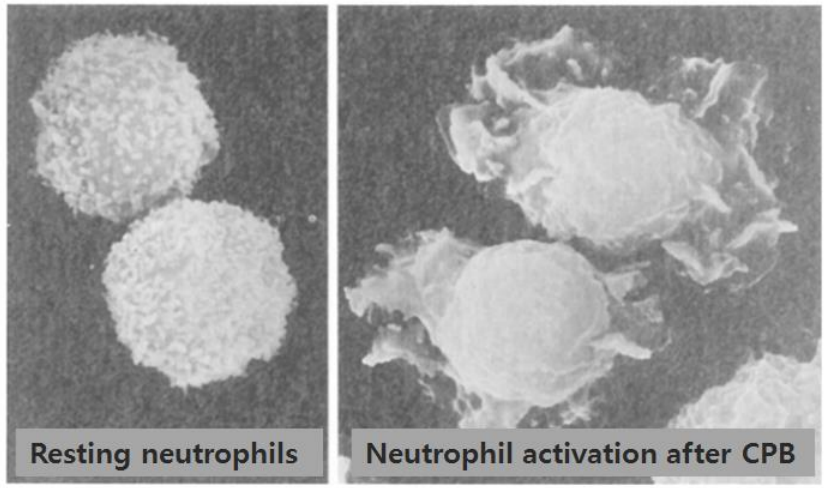
Inflammatory Responses to CPB



Aileen H., et al. Nutrients 2018



Baggiolini M. Nature 1998; 392:565.

Activation of inflammatory mediator and alteration of immune function

Coagulopathy Related to CPB

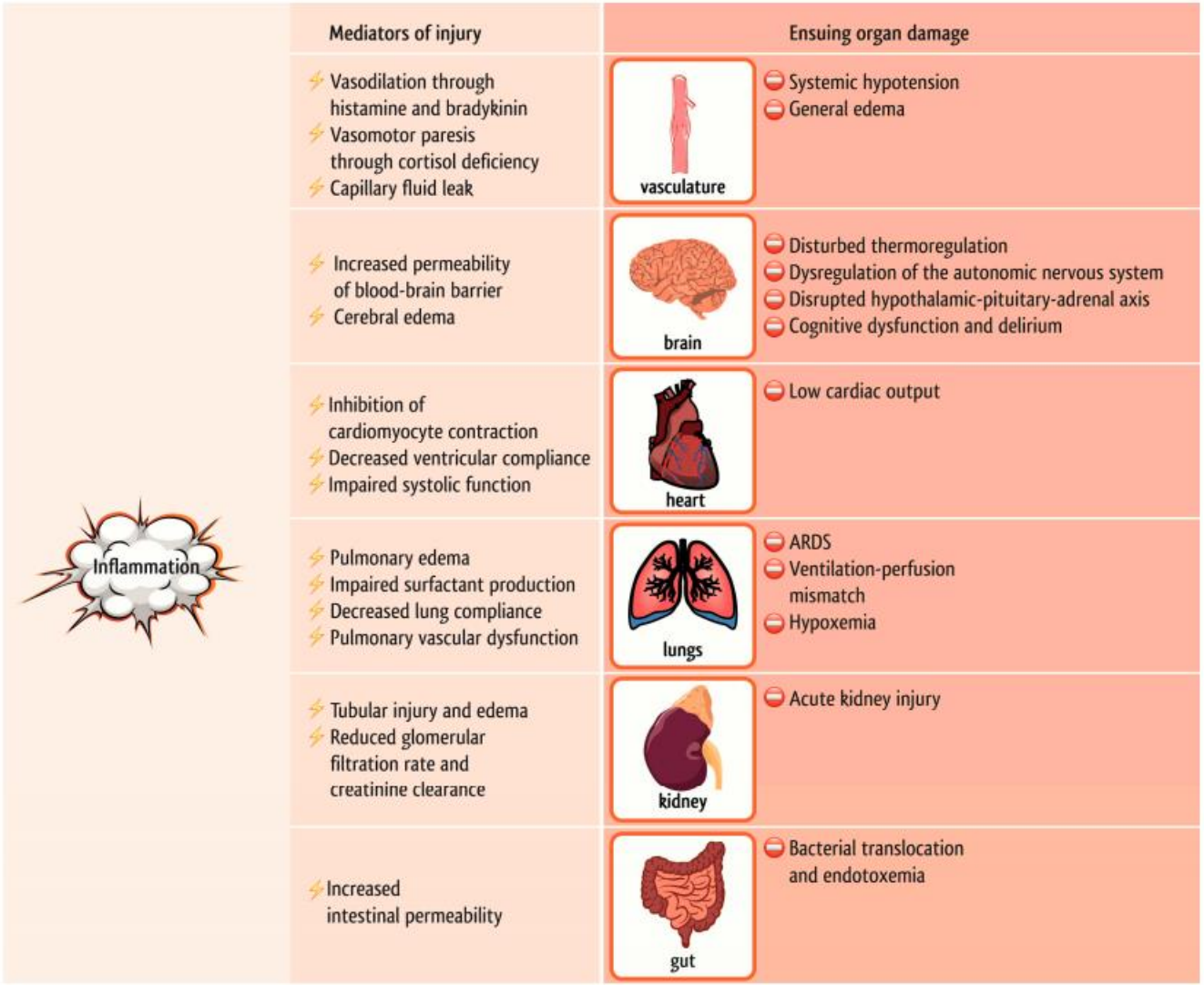
- Hemodilution
- Hypothermia
- Hemolysis
- Heparinization
- Activation of the coagulation system

Endocrine and Electrolytes Responses to CPB

- Antidiuretic hormone (vasopressin)↑
- Adrenocorticotropin↑
- T3 and T4 responses to TSH↓
- Adrenal responses↑
- Hyperglycemia and hypoinsulinemia
- Hypomagnesemia

Organ Damage Related to CPB

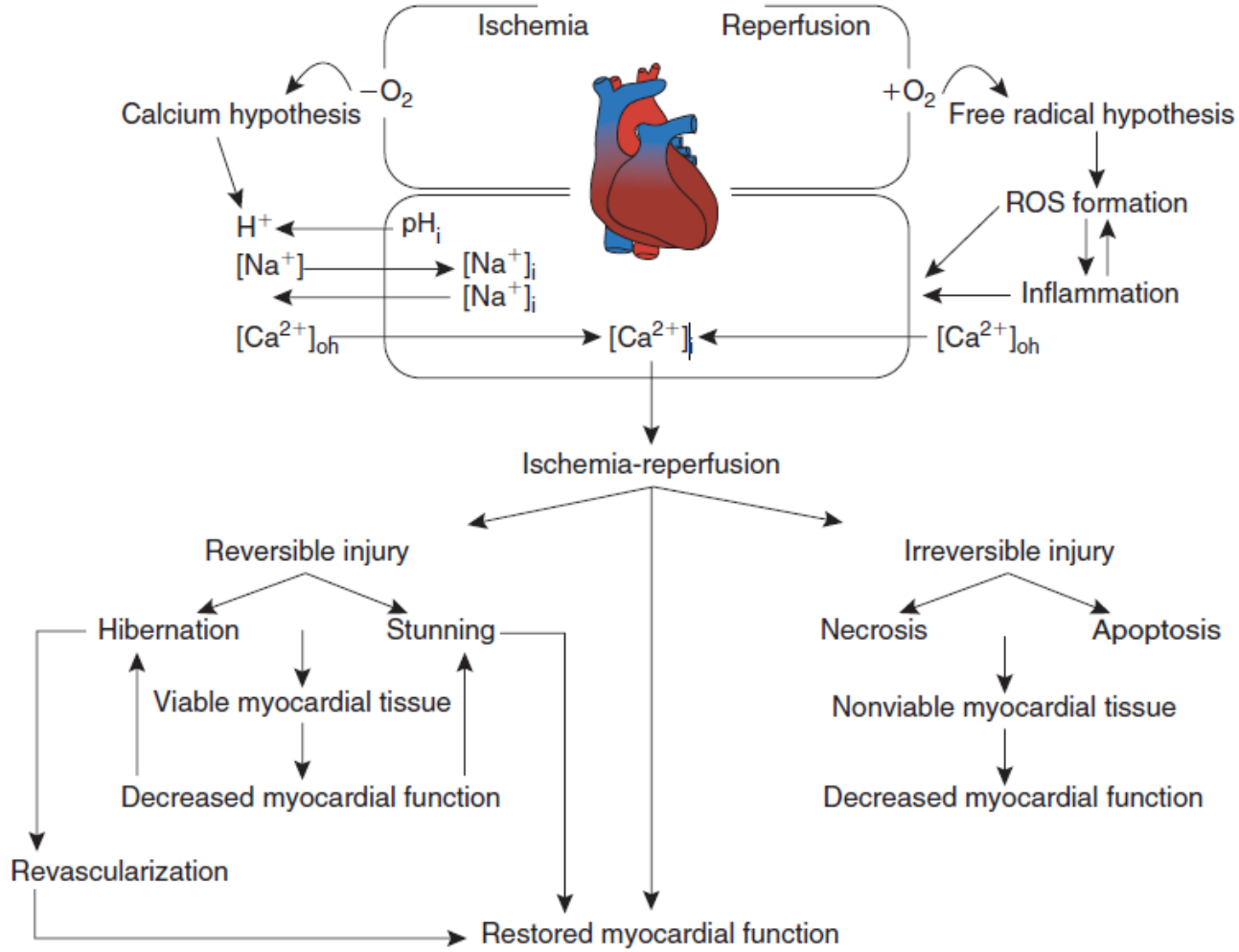
- Neurologic injury
  - Stroke
  - Delirium
  - Cognitive decine
- Lung injury
  - Atelectasis
  - ARDS
- Renal injury



Nutrients 2018;10:597

Myocardial Protection

Ischemia-Reperfusion Injury



Cardioplegia

- By *Will Sealy*, 1958, Duke University
  - Cardio- ; heart
  - Plegia ; paralysis, cessation of motion

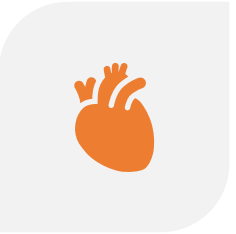
- Maintaining the myocardium in a state of '***reversible injury***' for longer periods

Principles for Myocardial Protection

RAPID INDUCTION OF ARREST

MILD OR MODERATE HYPOTHERMIA

APPROPRIATE BUFFERING OF THE CARDIOPLEGIC SOLUTION



AVOIDANCE OF MYOCARDIAL EDEMA

AVOIDANCE OF SUBSTRATE DEPLETION

Types of Cardioplegia

Crystalloid cardioplegia

Blood cardioplegia

Rationale for Using Blood for Cardioplegia

- Provides an oxygenated environment
- Limits hemodilution
- Affords and excellent buffering capacity and osmotic properties
- Allows for physiologic electrolytes and pH
- Offers endogenous antioxidants and free-radical scavengers
- Less complex to prepare

Components of Cardioplegic Solutions

	Na	K	Mg	Ca	Buffer	pH	Osm	Other components
Intracellular crystalloid CP								
Bretschnieder's no. 3 Bretschnieder's HTK Roe's	12.0 15.0 27.0	10.0 9.0 20.0	4.0 4.0 3.0	0 0 0	Histidine Histidine THAM	7.4 7.3 7.6	320 310 347	Procaine, mannitol Ketoglutarate, typtophan, mannitol Glucose
Extracellular crystalloid CP								
del Nido solution St. Thomas no. 1 St. Thomas no. 2 (Plegisol) Tyer's	140 144.0 110.0 138.0	5 20.0 16.0 25.0	0.75 32.0 32.0 3.0	0 4.8 1.2 1.0	Bicarbonate None Bicarbonate Bicarbonate	7.4 5.5 7.8 7.8	375 285 324 275	Lidocaine, mannitol Procaine None Acetate, gluconate
Blood CP								
Cold induction Warm induction	118.0 122.0	18.0 25.0	1.6 1.6	0.3-0.5 0.15-0.25	±THAM ±THAM	7.6-7.8 7.5-7.6	320-340 340-360	Glucose, oxygen Glucose, oxygen, glutamate, aspartate

* Intracellular type : Absent or low concentrations of sodium and calcium
* Extracellular type : Higher concentrations of sodium, calcium, and magnisium

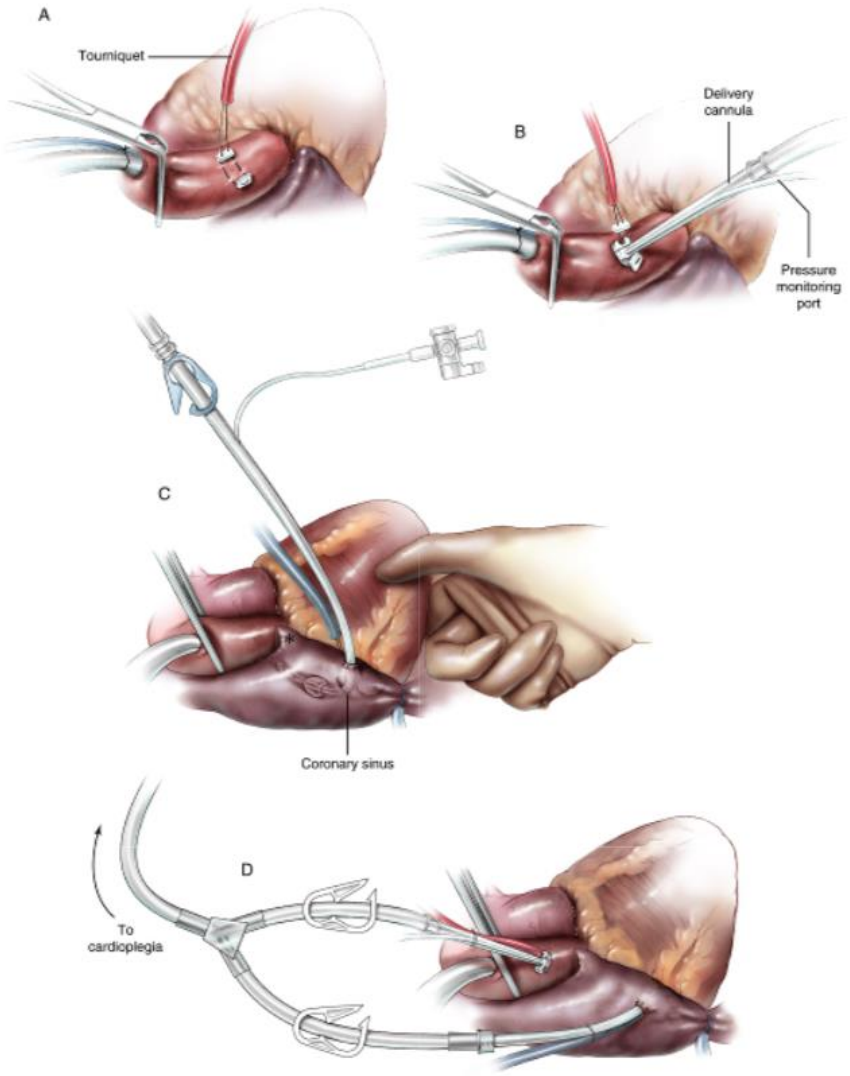
* THAM : tris (hydroxymethyl) aminomethane

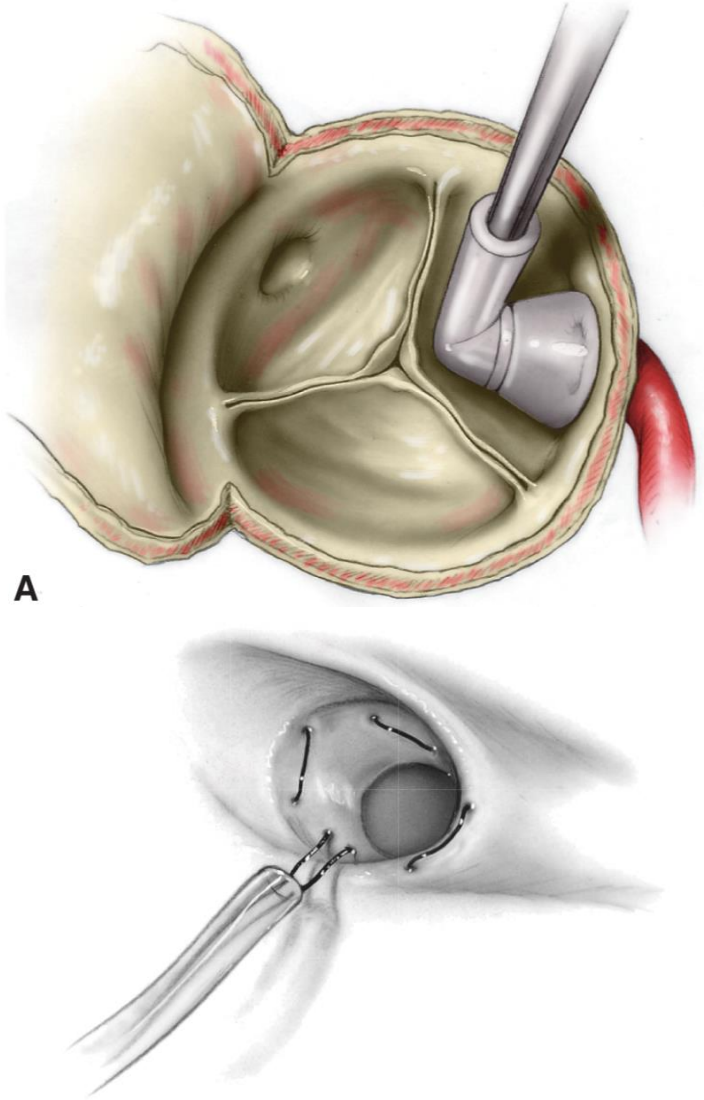
Trend of Cardioplegia Temperature

Cold (5~10°C) Warm (37°C) Tepid (28~32°C)

Delivery Systems

- Antegrade
- Retrograde
- Combined

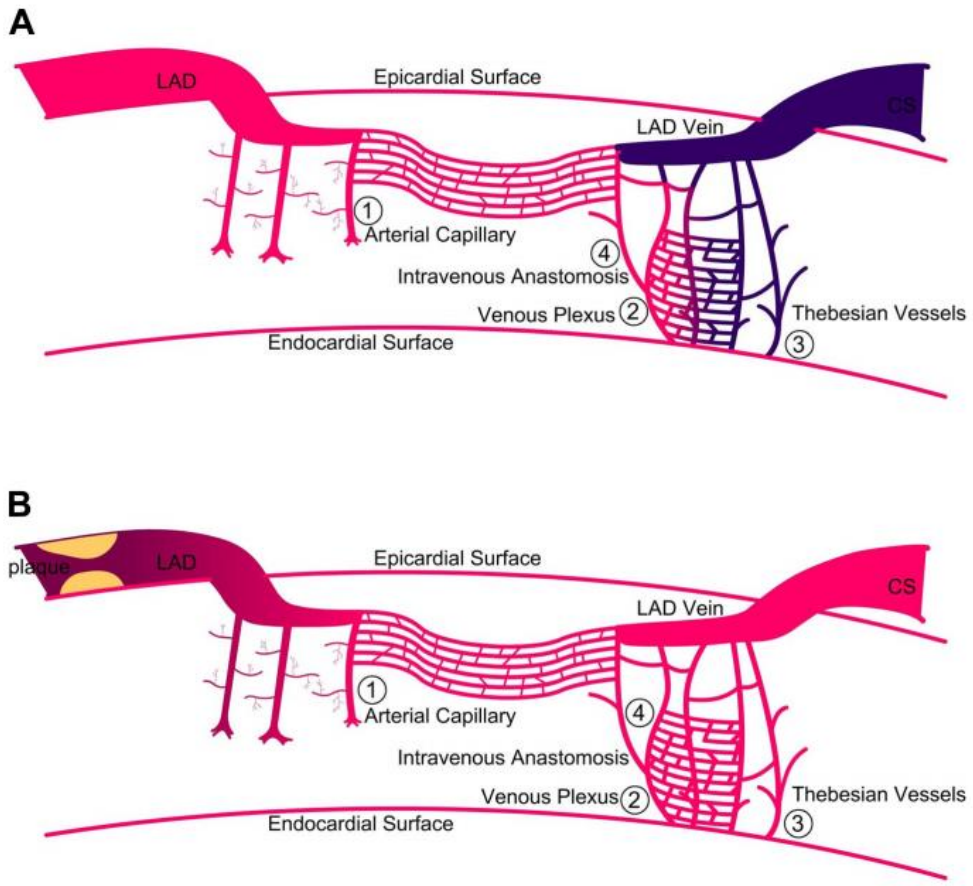




Coronary Circulation

Antegrade

Retrograde

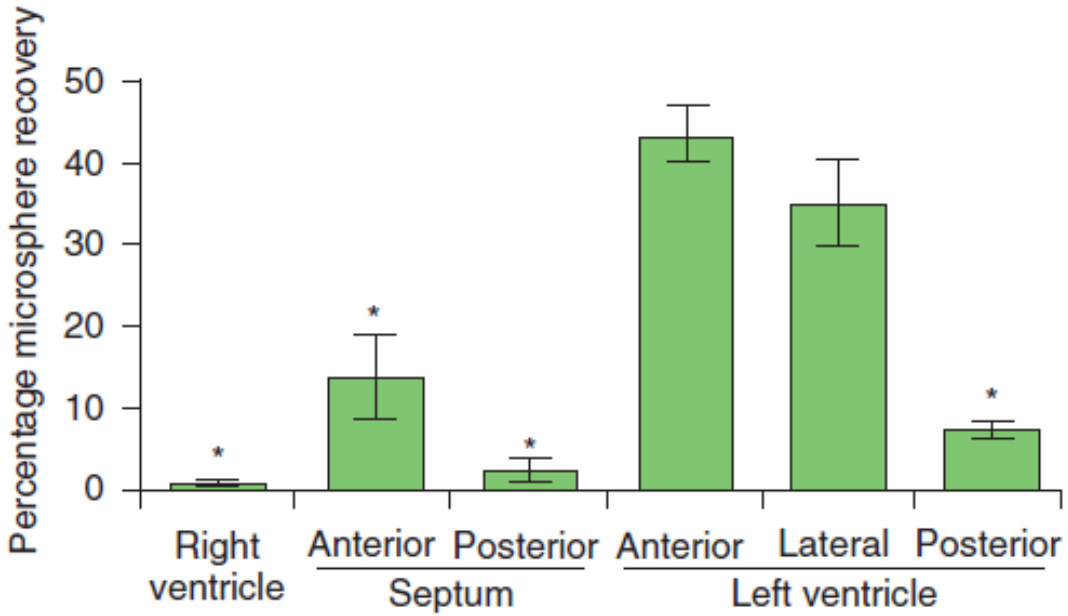


J Appl Physiol 2008;104:1266-72

Antegrade vs Retrograde

- Antegrade
  - Possible aortic injury
  - Limits coronary artery occlusion or aortic insufficiency

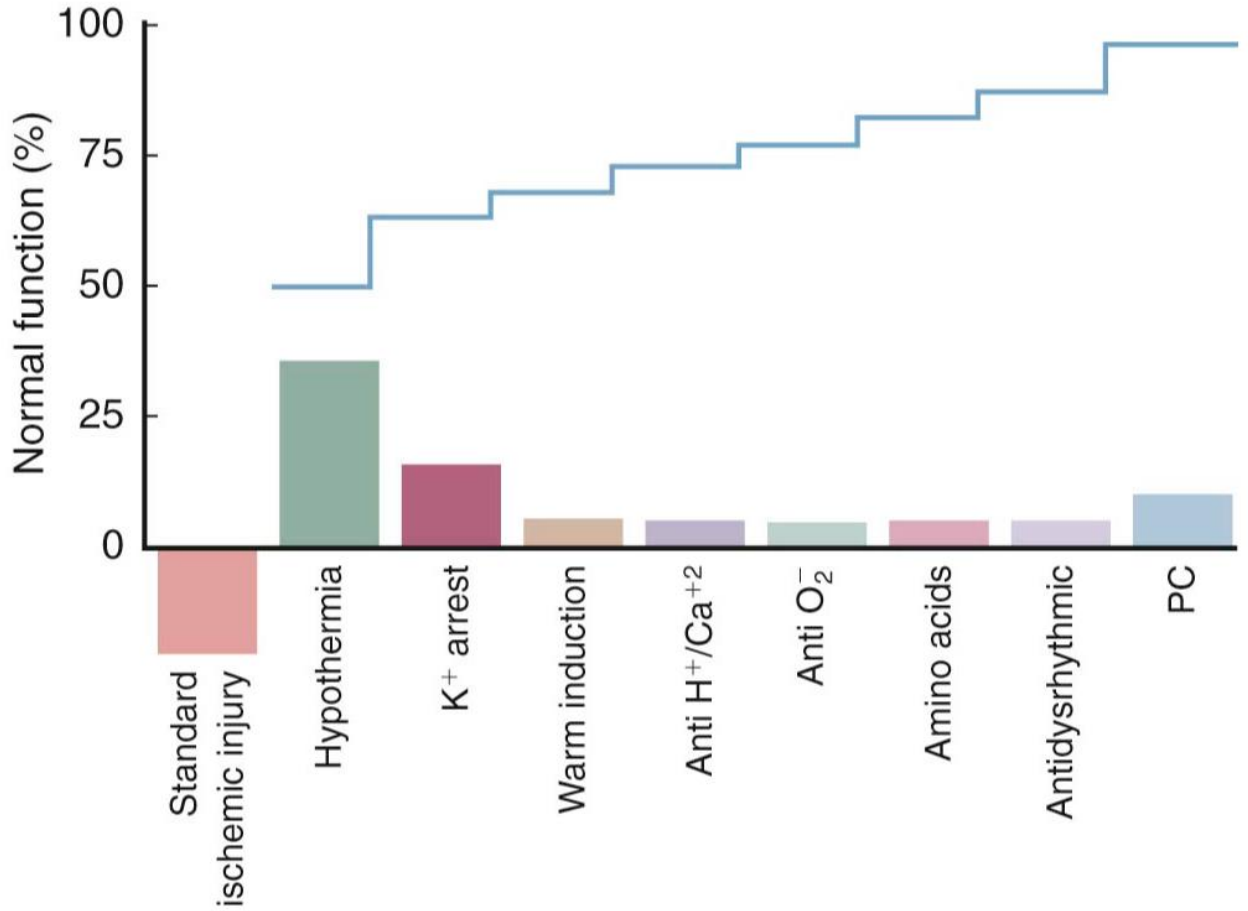
- Retrograde
  - Convenient for mitral valve surgery
  - Provide continuous cardioplegia
  - Prevent coronary thromboembolism
  - Easy dislocation
  - Possible injury of coronary sinus
    - Perfusion pressure < 30~40mmHg
  - Inadequate perfusion of RV



Continuous vs Intermittent

- No differences in patient outcomes
- Most use intermittent cardioplegia in order to have a bloodless field

Incremental Beneficial Effects



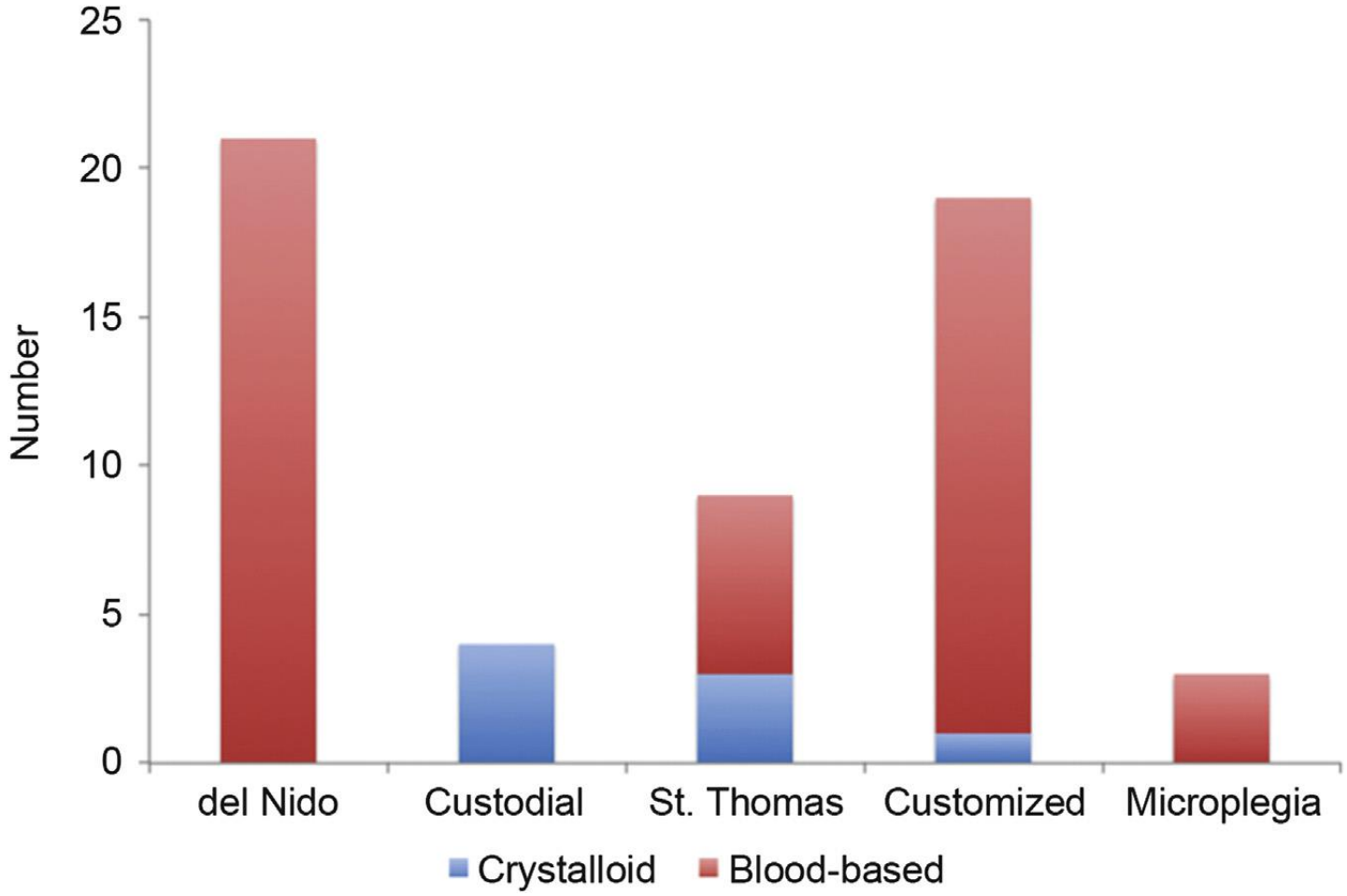
Current Status of Cardioplegic Technique

- Controversy persists
  - Blood cardioplegia vs Crystalloid cardioplegia
  - Ideal temperature ?
  - Best method of delivery ?

- No international consensus regarding the ideal cardioplegic solution or its use

- How to provide optimal myocardial protection is understanding of the various protection techniques

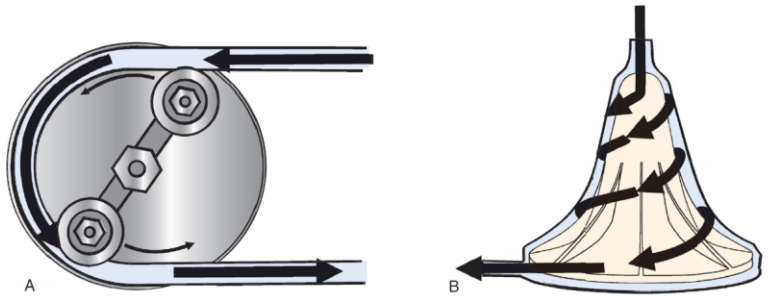
North American Survey



Ann Thorac Surg 2013;96:923-9

Summary

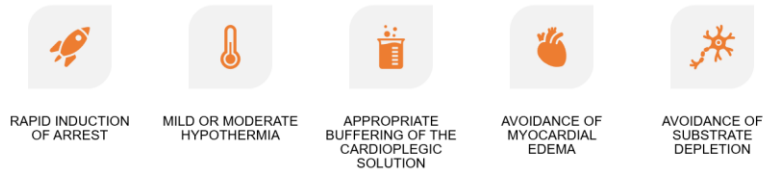
Types of Pump



Determinants of Safe Perfusion

- Blood flow rate
- Arterial pressure
- Hematocrit
- Temperature
- Acid/Base management

Principles for Myocardial Protection



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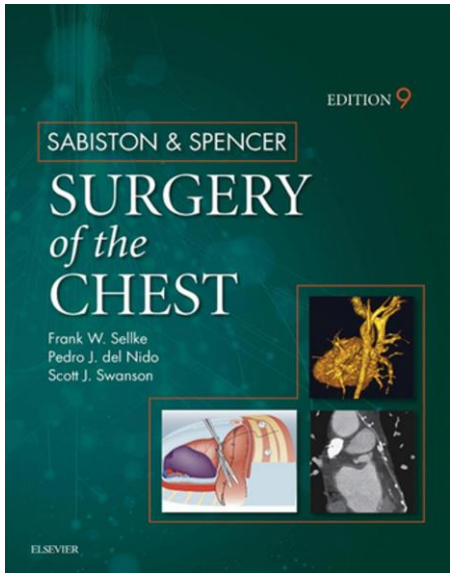
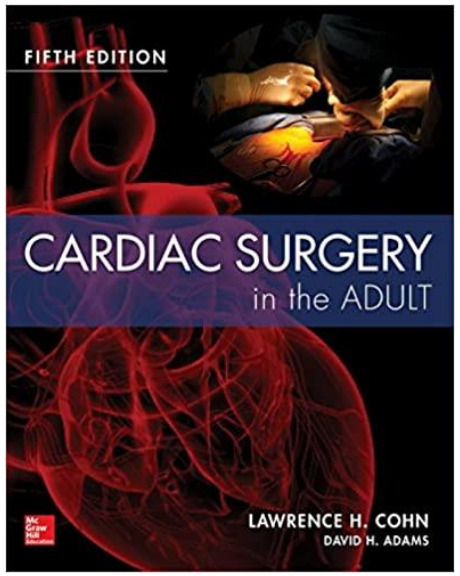
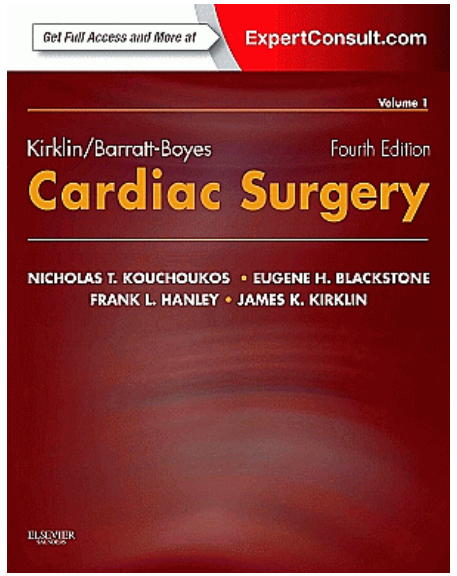
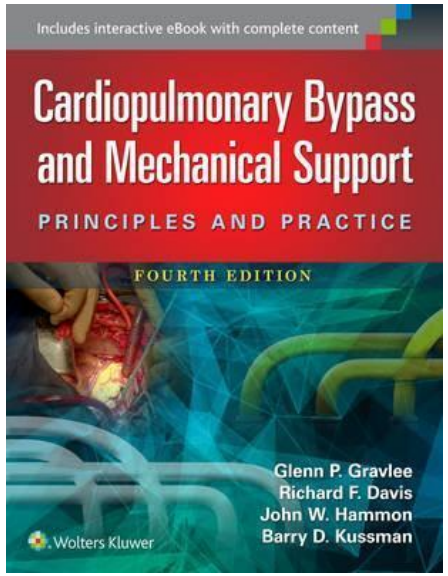
- How to provide optimal myocardial protection is understanding of the various protection techniques

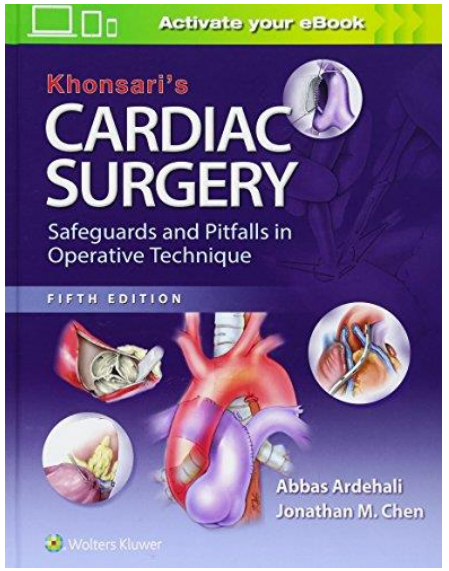
References











Thank you !