3 MINUTES REVIEW:
CARDIOPULMONARY BYPASS ESSENTIALS

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SUMMARY

- When you study CPB you need to know :

The Circuit

The Circuit components

-Arterial cannulae (Site, Types)
-Venous cannulae (Site, Types)
- Oxygenators
- Reservoirs
- Pumps
- Tubes

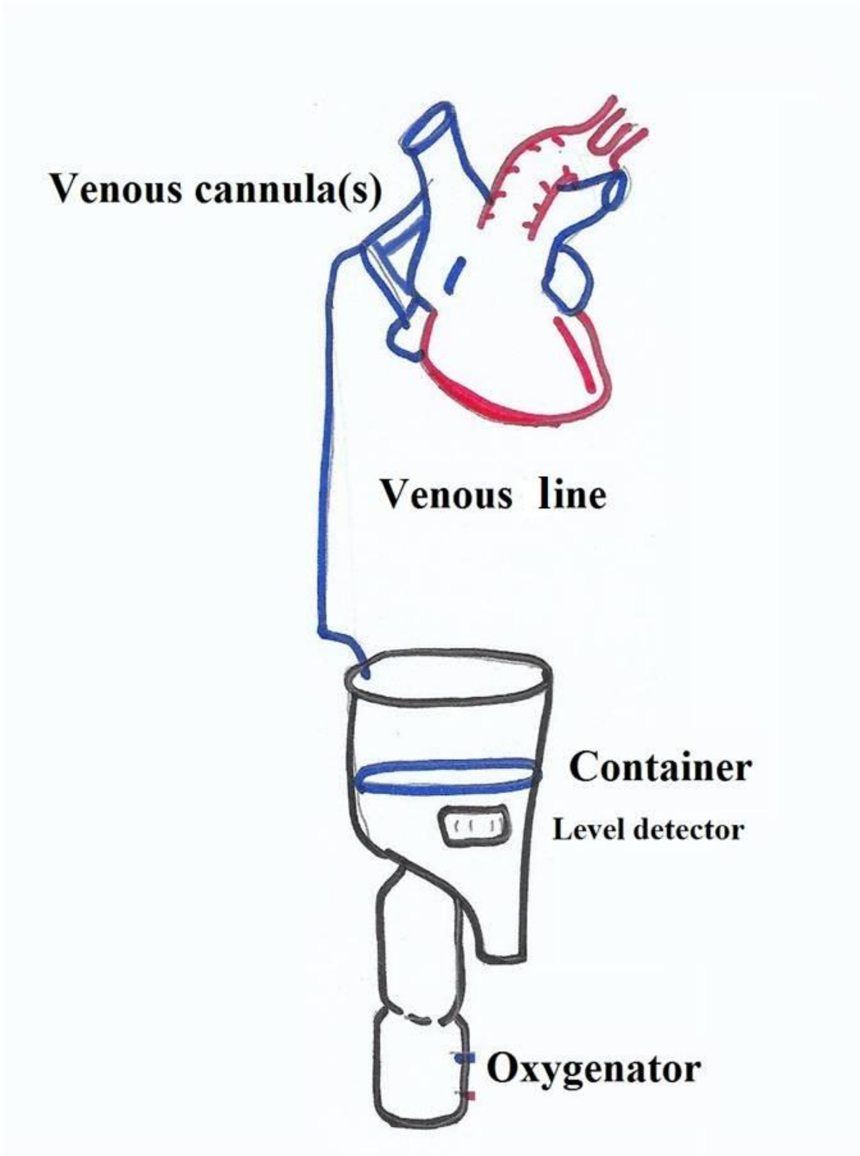
Conduct of CPB (4 steps)

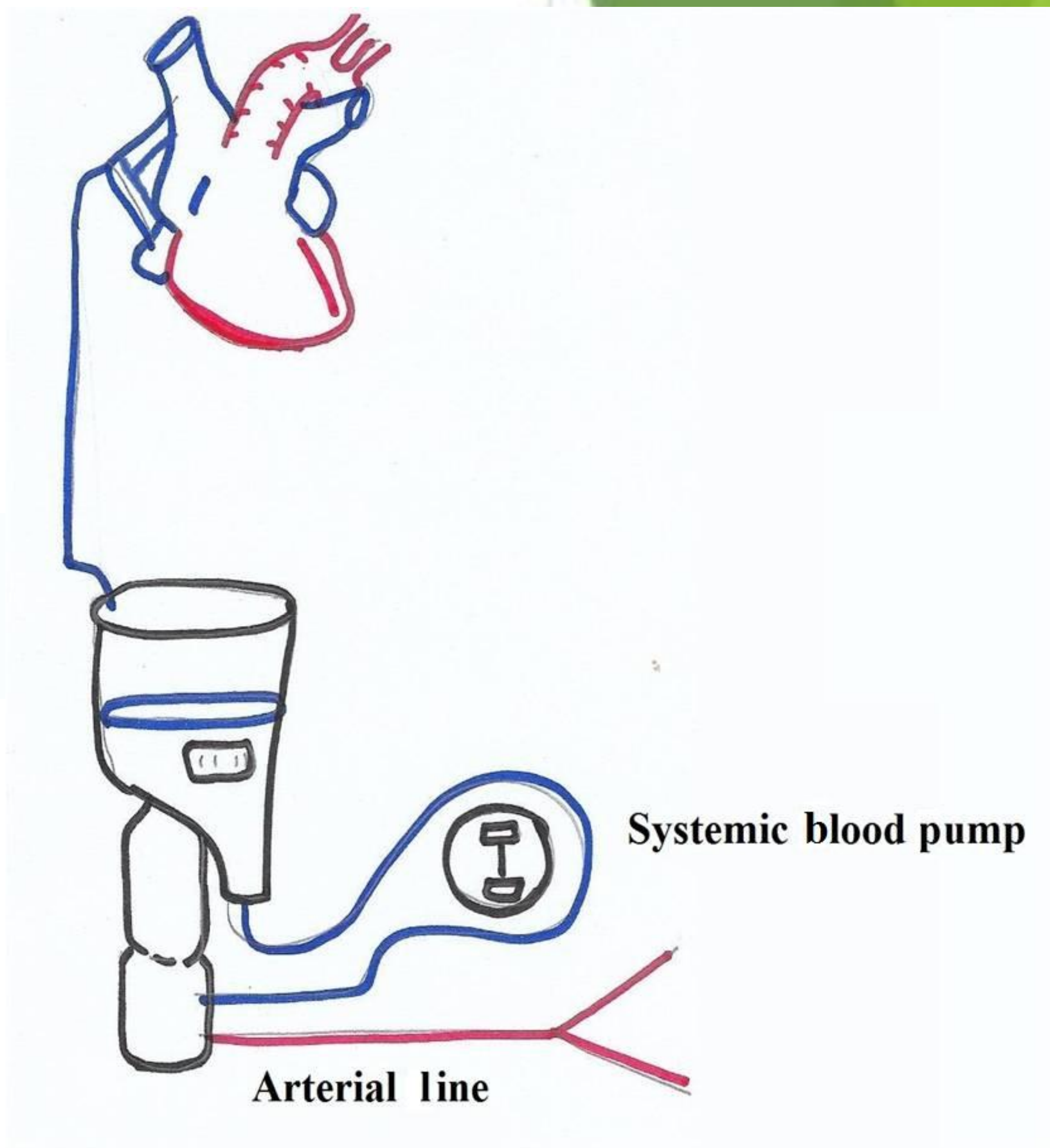
Weaning from CPB (4 steps)

- **Role of CPB**
- **Pathophysiology of CPB**

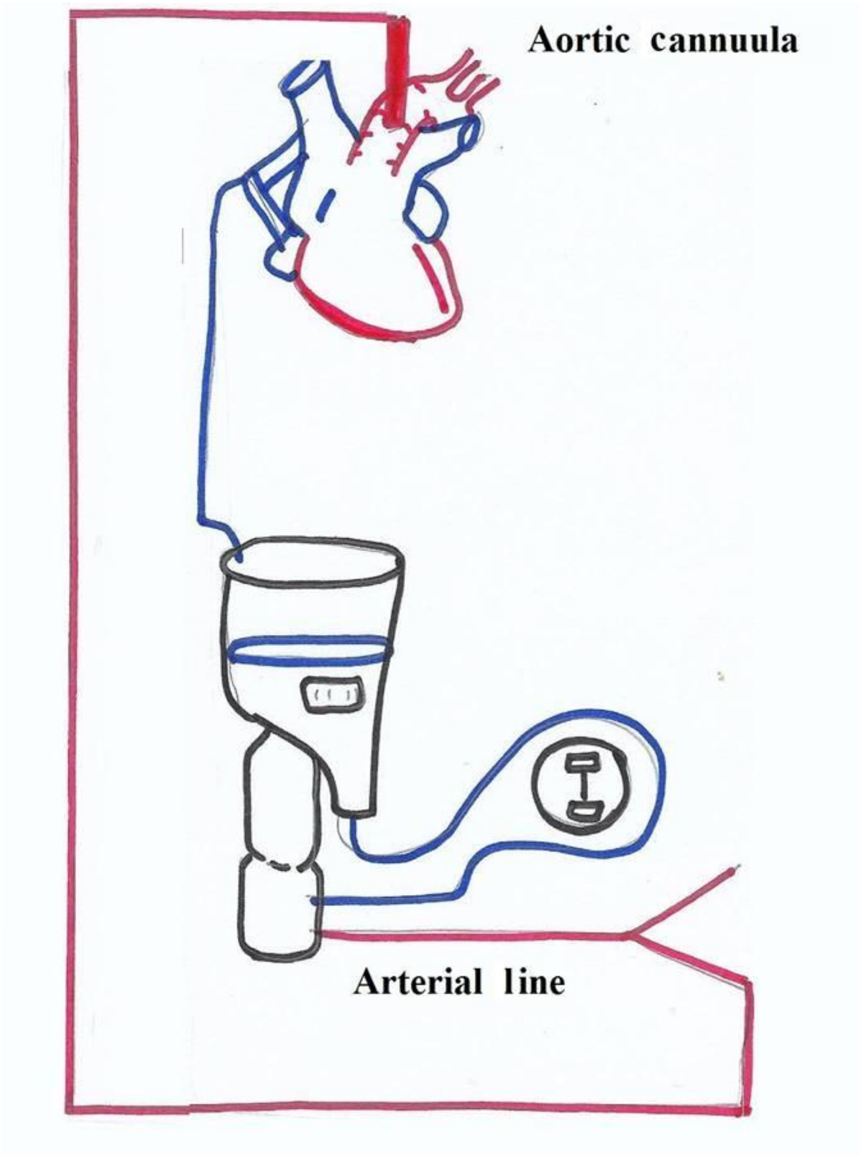
Further reading: History, emergency bypass scenarios, ECMO, DHCA

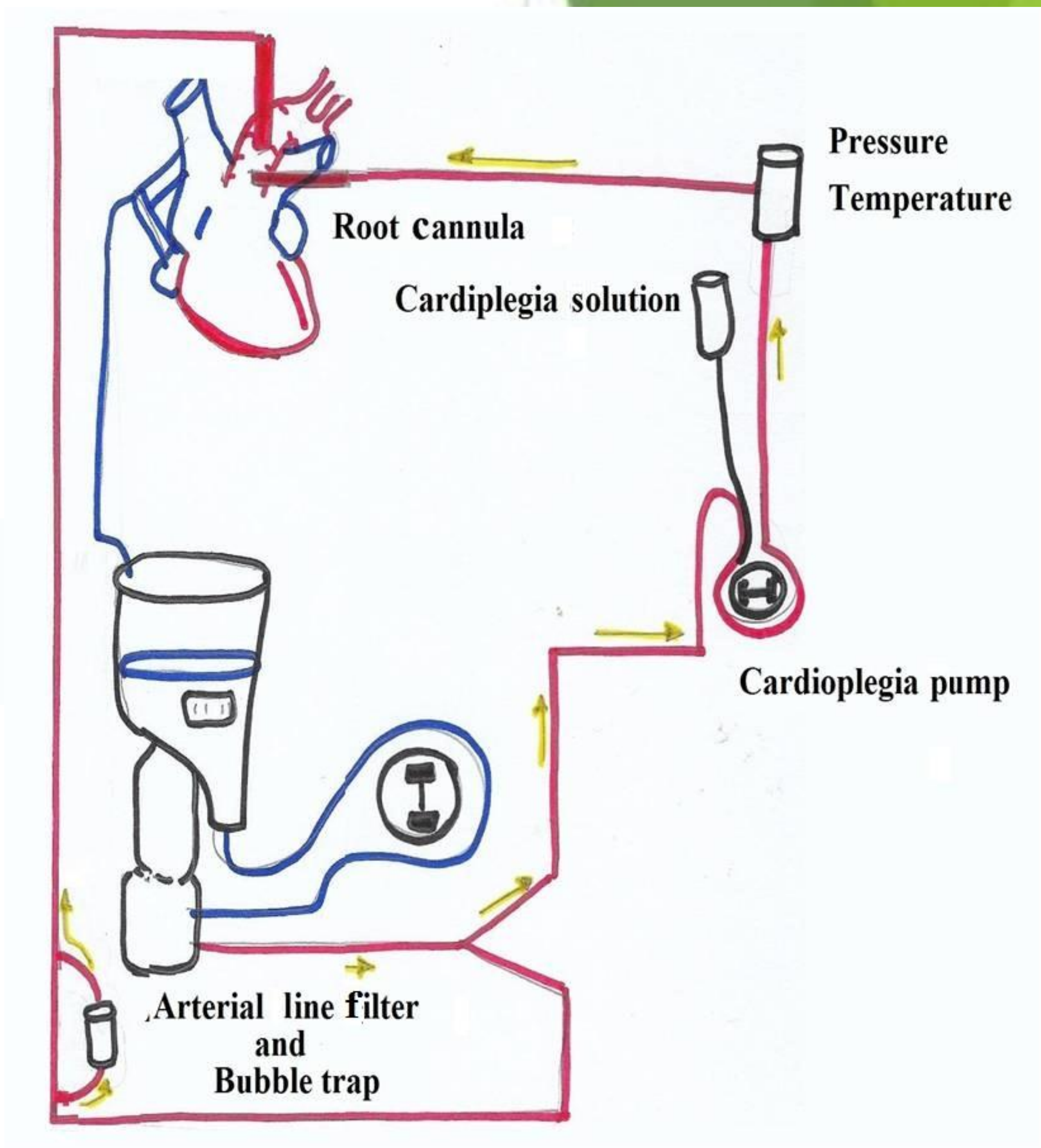
THE CIRCUIT


Venous cannula(s)
Venous line
Container
Level detector
Oxygenator

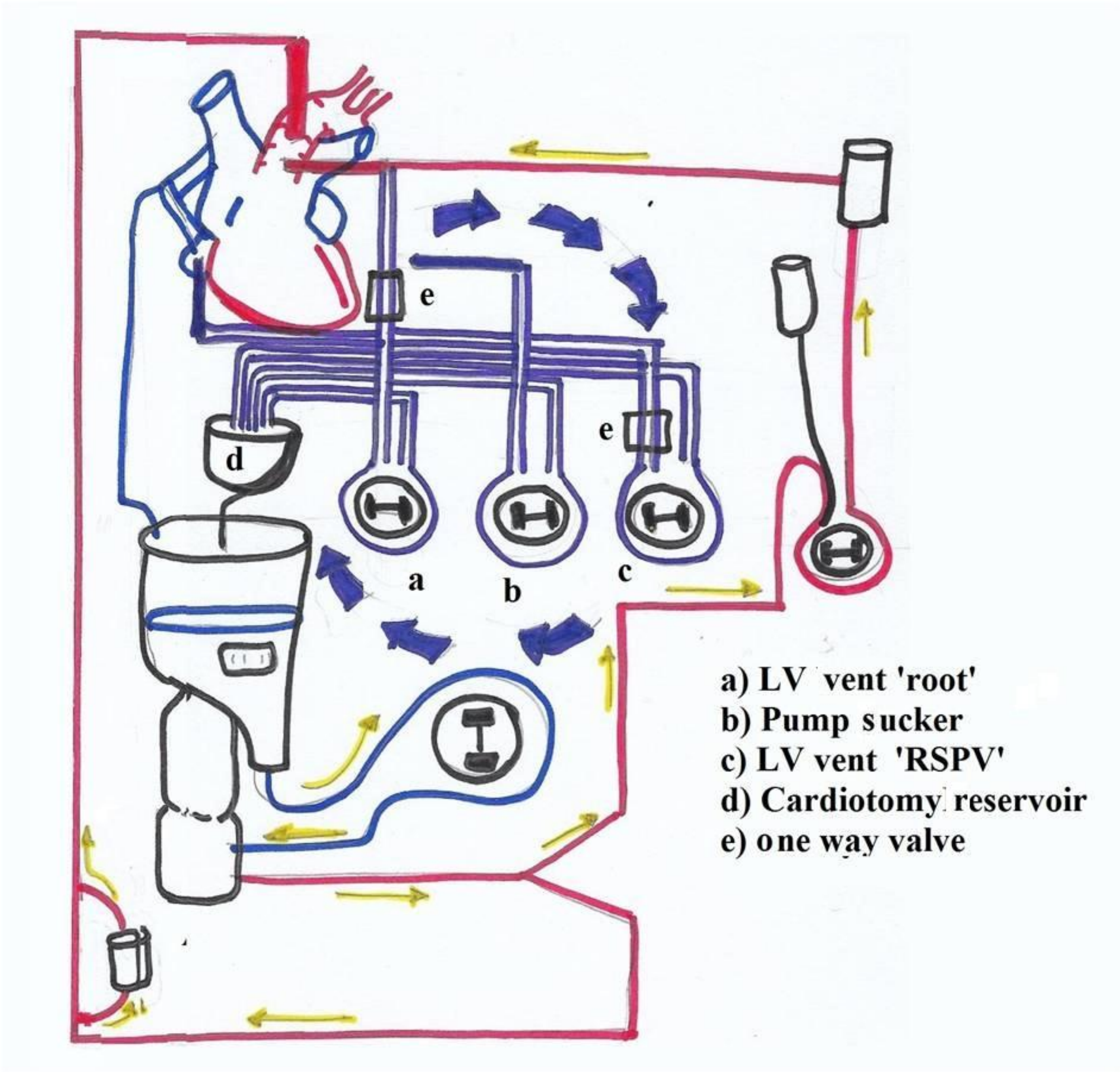

Systemic blood pump
Arterial line

THE CIRCUIT

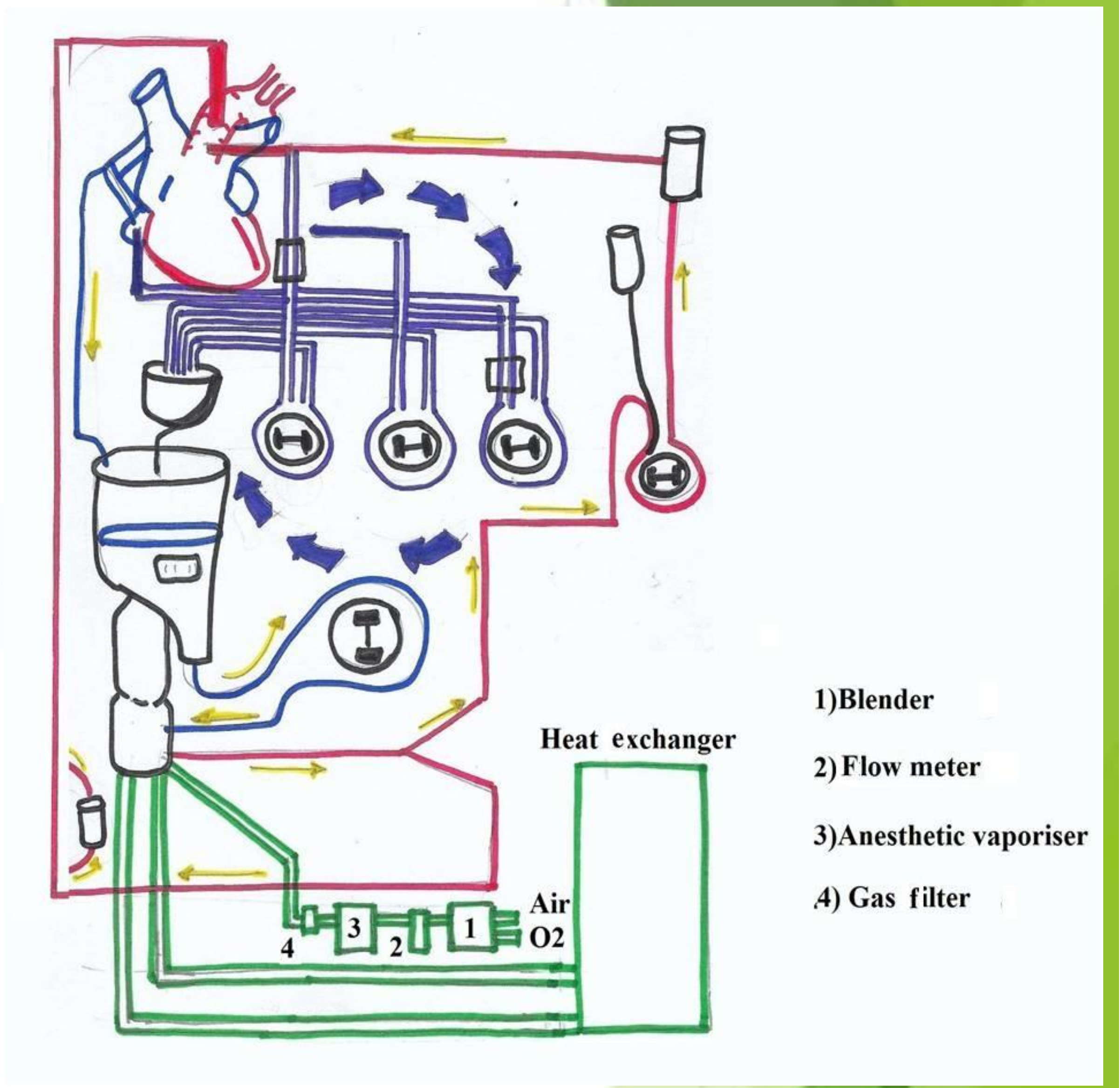

Aortic cannuula
Arterial line


Pressure
Temperature
Root cannula
Cardiplegia solution
Cardioplegia pump
Arterial line filter
and
Bubble trap

THE CIRCUIT



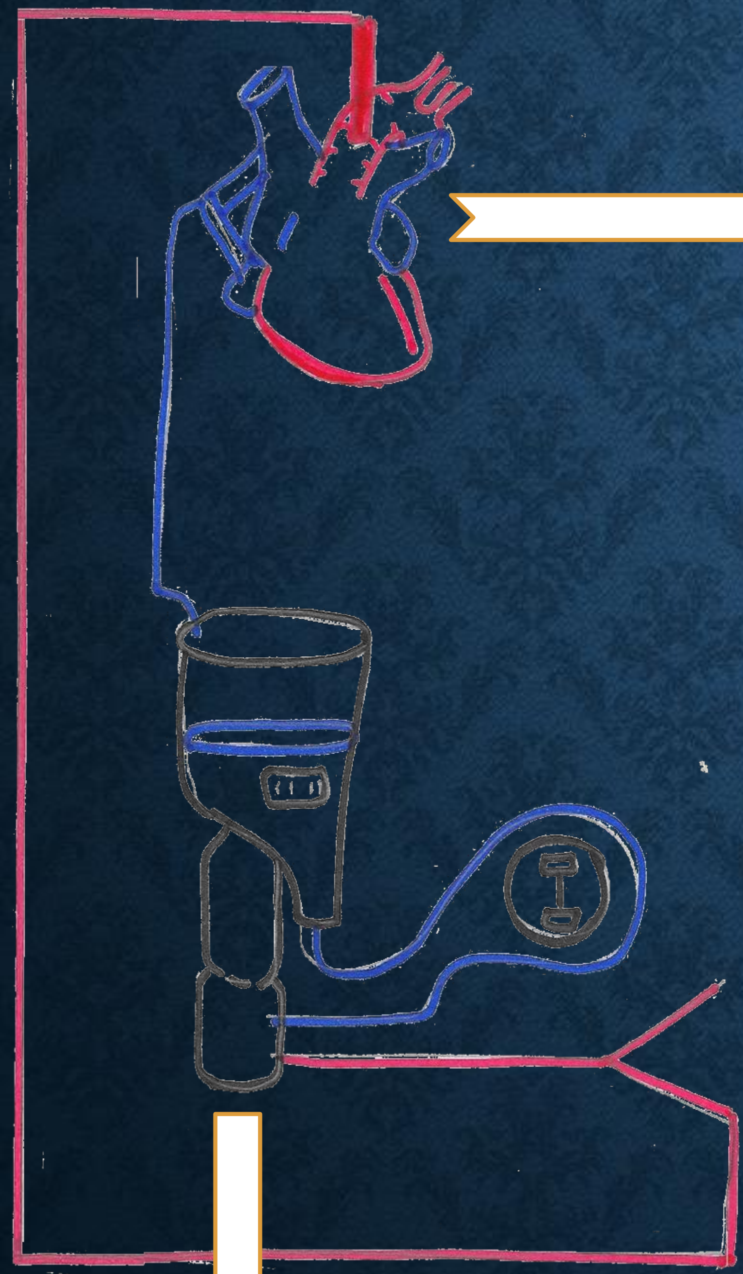
a
b
c
d
e
e
a) LV vent 'root'
b) Pump sucker
c) LV vent 'RSPV'
d) Cardiotomy reservoir
e) one way valve



Heat exchanger
1)Blender
2) Flow meter
3)Anesthetic vaporiser
4) Gas filter
Air
O2
1
2
3
4

ROLE OF CPB

The role of cardiopulmonary bypass could be summarized in the following bullet points:

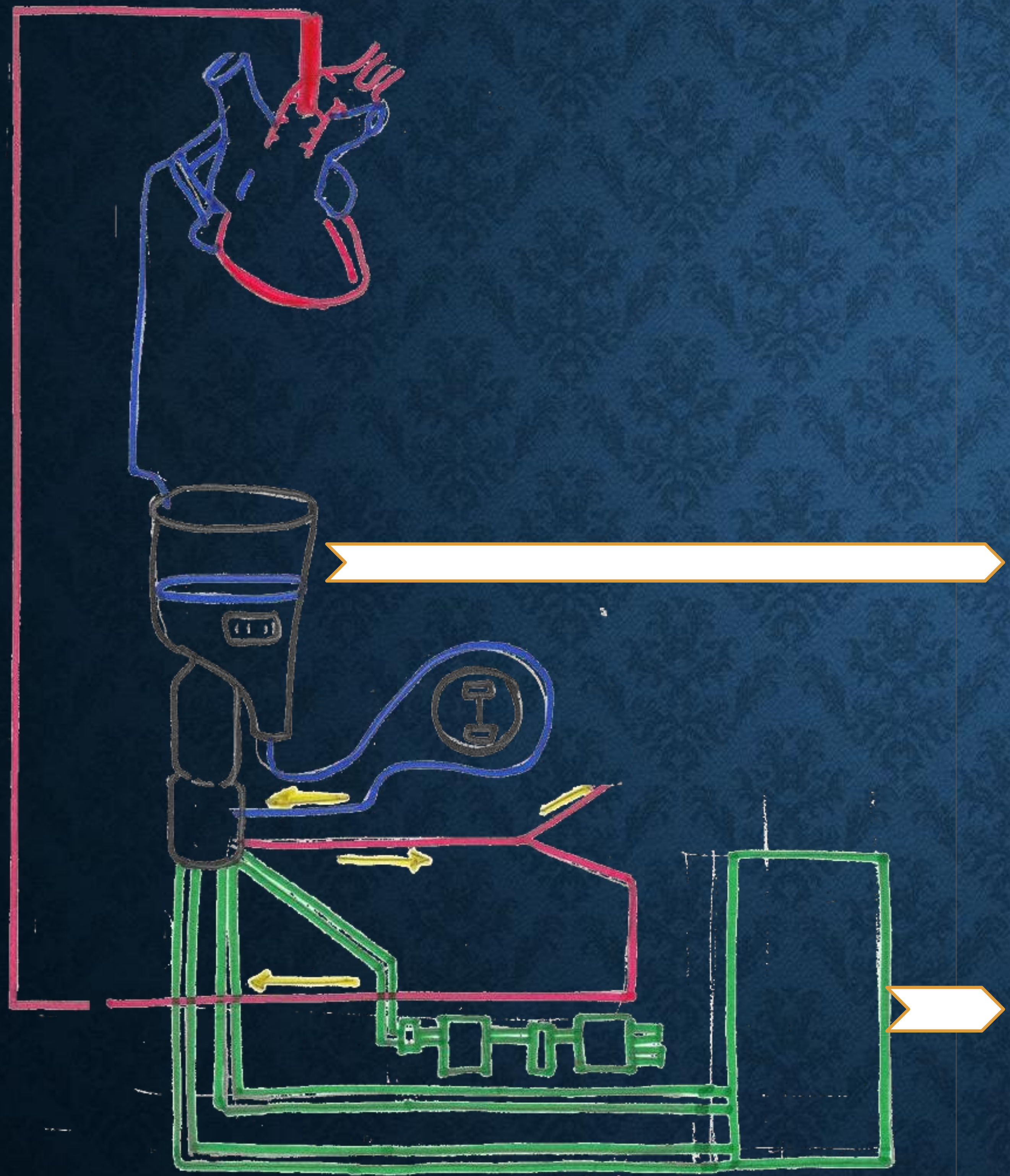


1) **Empty the heart**:
Drain all the blood out, achieved via **venous cannulas**

2) **Oxygenate blood**:

Replace the function of the lungs which can thence be stopped, achieved via oxygenators

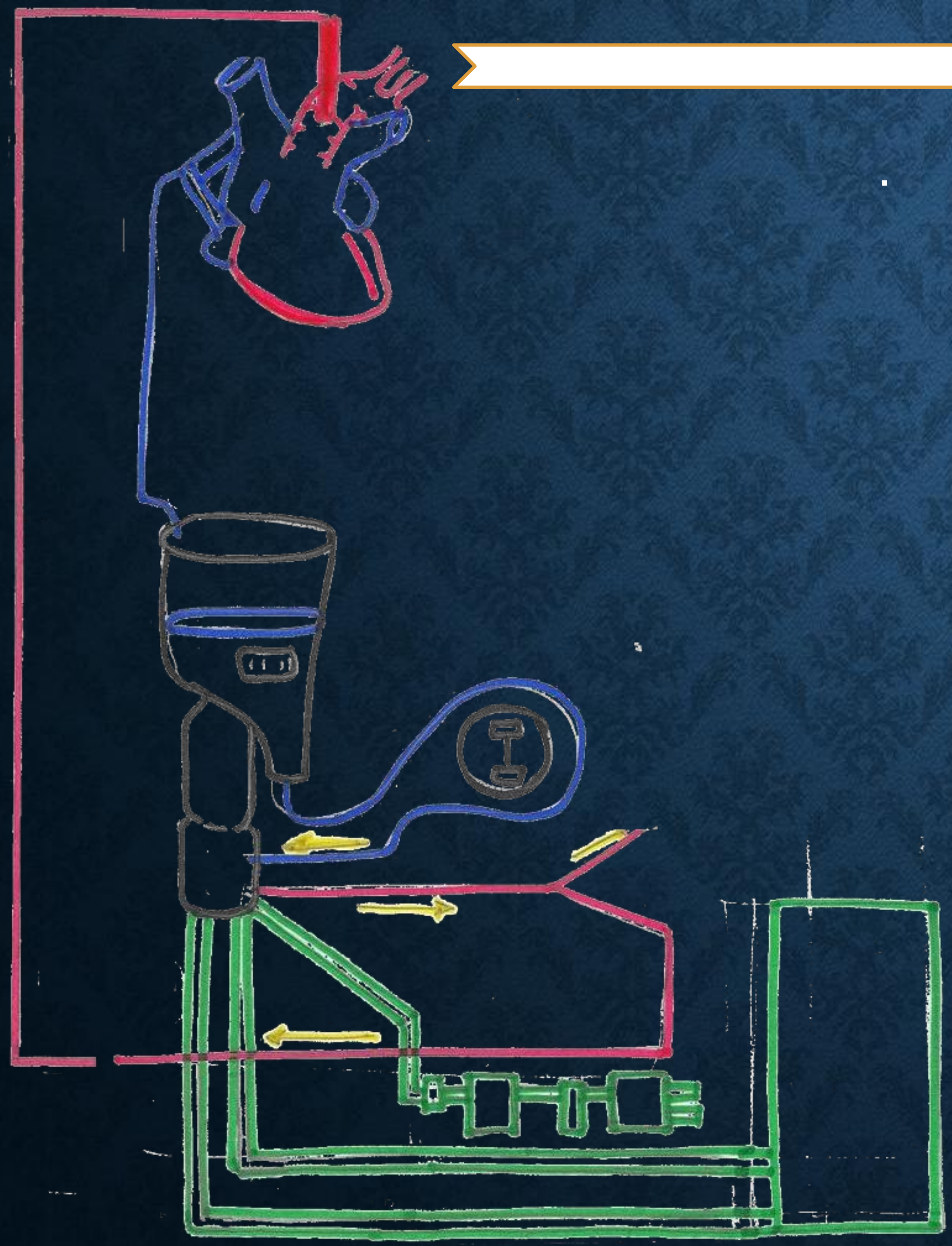
ROLE OF CPB



3) Adjust its chemical and electrolyte contents: achieved via a reservoir along its **sampling ports.**

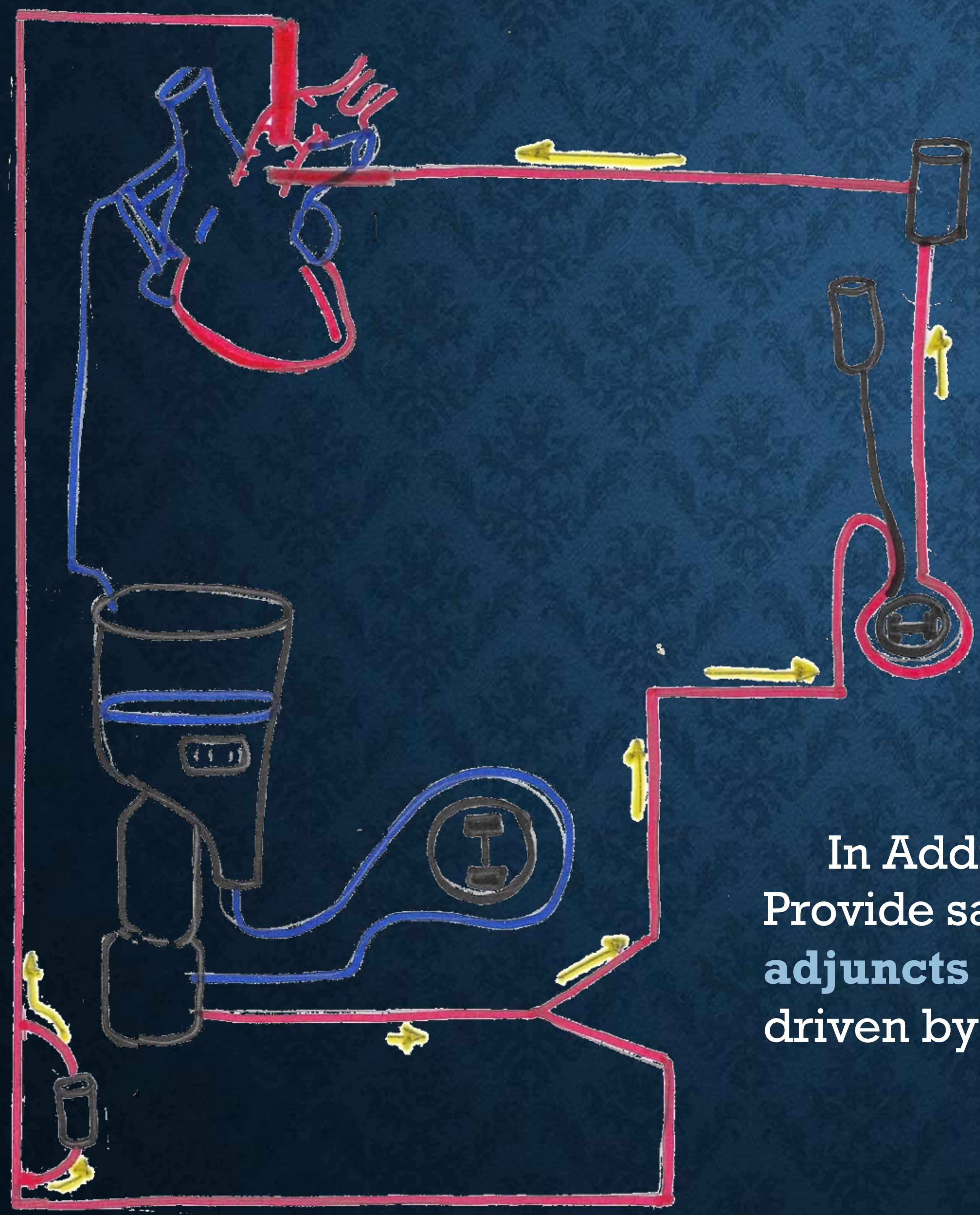
4) Adjust its temperature: achieved via **heat exchanger machine**

ROLE OF CPB



5) Return it to the patient:
Achieved via **arterial cannulas**.

ROLE OF CPB

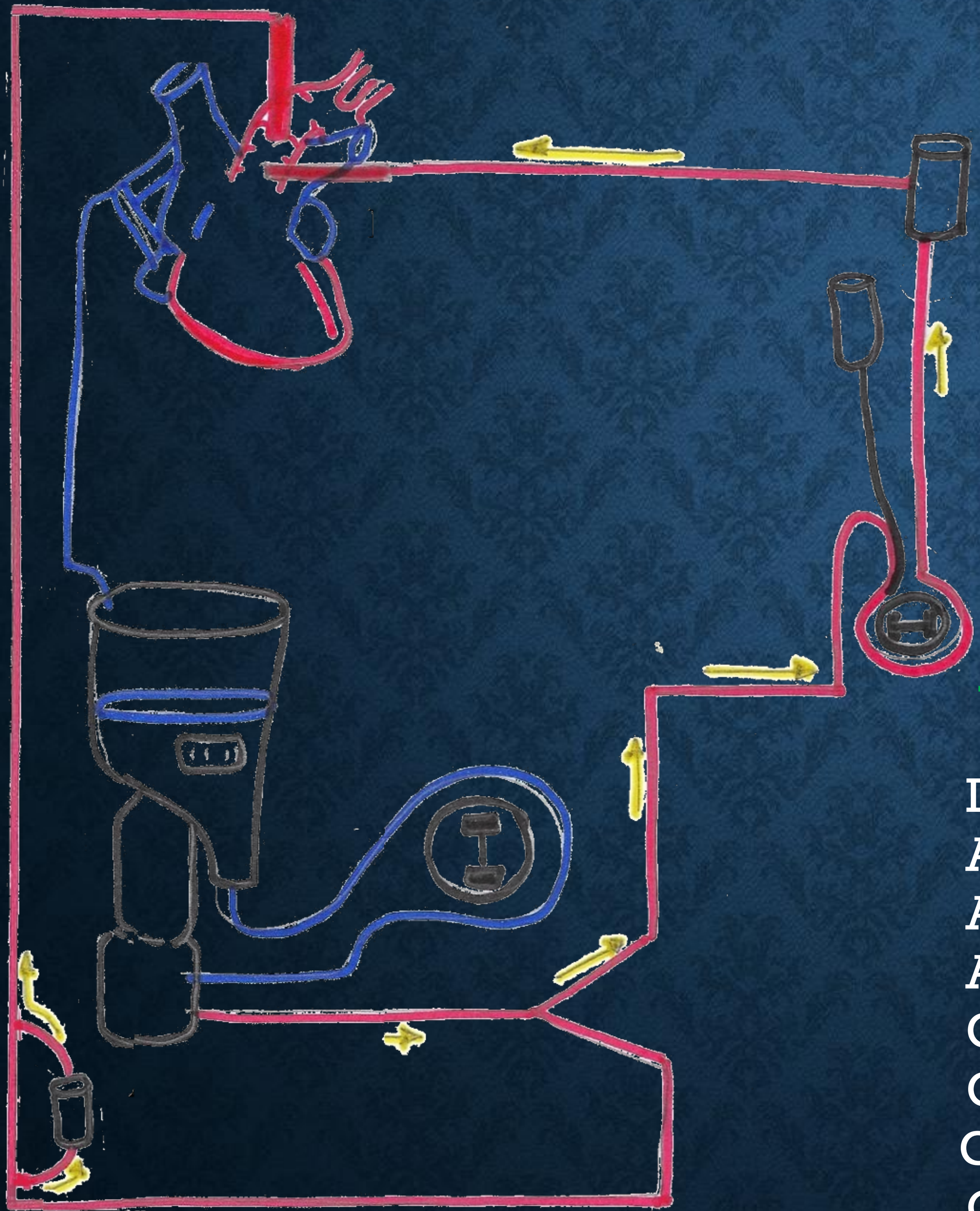


6) Deliver cardioplegia
and provide myocardial protection

In Addition
Provide safety nets and standby pathways, **safety adjuncts** this is all achieved via a closed circuit driven by **pumps** and connected by **tubes**

ROLE OF CPB

Accordingly, the components of the cardiopulmonary bypass circuit are:



- Venous cannula
- Arterial cannula
- Oxygenator
- Reservoir
- Pumps
- Tubes
- Heat Exchanger
- Cardiotomy suckers
- Cardiac Vents

Adjuncts:

- Level detector.
- Arterial line pressure meter.
- Arterial line bubble trap.
- Arterial line particle filter.
- Cardioplegia line pressure meter.
- Gas line filter.
- Gas flow meter.
- One way valve on LV vent.

CIRCUIT COMPONENTS

ARTERIAL CANNULAE :

Types

- **Right angled:** prevents perforating the posterior wall of the aorta, *however,* can selectively perfuse an arch branch.
- **Straight:** prevents selective arch vessel perfusion, *however,* can perforate the posterior wall of the aorta.
- **Beveled tip:** easier insertion, however, higher pressure gradient delivered at the tip.
- **Diffusion tip:** less pressure gradient, allow better perfusion of arch branches *however* slightly more difficult insertion(relative).
- **Wire reinforced:** allows higher flow for a smaller size cannula. Also longer tip inside the aortic lumen, hence more secure perfusion in case of dissection.
- **Flanges:** hemostatic as well as acts as anchor points for the purse strings

SITES

Central Cannulation	Peripheral cannulation
Advantages	Disadvantages
• One incision for the surgery and cannulation • No added risk for limb ischemia • Can use bigger cannula sizes • Always forward flow in vessels • Less prone to cannulation site complications	• Two incisions • Risk present • Smaller cannula • Forward or backward • More prone
Disadvantage	Advantages
Less suitable for aortic arch, aneurysm, dissection, minimal invasive and redo surgeries.	Suitable

CIRCUIT COMPONENTS

VENOUS CANNULAE:

Types

- Ross Basket: least likely to cause IVC tear, maximum drainage, used for right atrial venous cannulation
- 2-stage: used in cavo-atrial venous cannulation
- 1-stage: used in selective bicaval cannulation, indirect.
- 1-stage right-angled: used in selective bicaval cannulation, direct (avoids back wall abutting and block)

SITES

	Selective Bicaval , Direct	Selective Indirect	Cavo-atrial
Decompressing of right heart (i.e. Preventing distention, rewarming, coronary backflow via coronary sinus)	Best referred to as total CPB	+ / _ Could achieve total drainage if snares applied	Least Can't achieve total CPB
Drainage right heart (i.e. draining the cardioplegia return via coronary sinus)	Not Possible	+/ _ Could drain CP if snares released	Best
Potential kinking (i.e. when lifting the heart during mitral surgery, CABG)	Least likely	+ / _ Highly dependent on heart anatomy case dependent	Most likely especially SVC cannula
Technique difficulty (i.e. ease of learning)	Most difficult	Moderate	Easiest

CIRCUIT COMPONENTS

Oxygenators

	Membrane Oxygenator		Bubble Oxygenator
Pros	1) Less SIRS (with time, plasma proteins coats the circuit and creates biological membrane reducing the SIRS effect) 2) Better control of gases (pO_2, pCO_2, SO_2) 3) Less incidence of micro-emboli	**Cons**	1) More SIRS (continuous blood gas interface with every bubble leading to higher SIRS) 2) Poor control 3) More prone to micro-emboli formation
Cons	1) More expensive	**Pros**	1) Cheaper

Reservoirs

	Open reservoir		Closed reservoir
Pros	1) Cheaper 2) Easier priming and managing drainage 3) Easier control via sampling ports, sideways	Cons	1) Expensive 2) More difficult 3) Not possible
Cons	1) More SIRS effect	Pros	1) Less SIRS

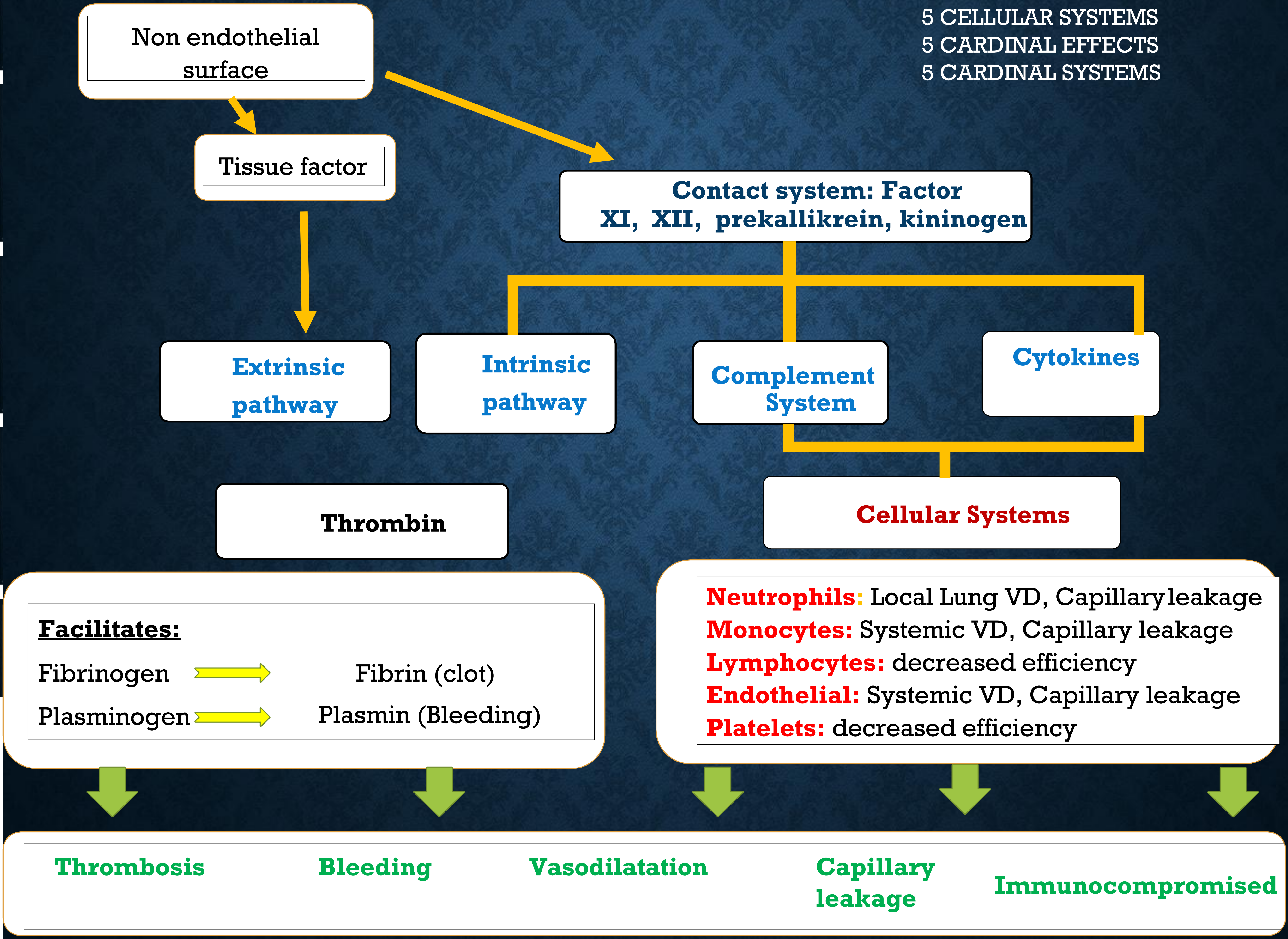
Pumps

	Roller pump		Centrifugal pump
pros	1) Not dependent on afterload pressure Thus 1) Backflow is not possible 2) Pulsatile flow possible	pros	1) Dependent on afterload Thus 1) Backflow is possible 2) Pulsatile flow is impossible
cons	1) Occlusive circuit (possible mechanical break of tubes, hemolysis, possible air embolism)	cons	1) Non occlusive circuit

Tubes: Needs to be Non-toxic, Non-Immunogenic, Non-mutagenic, Non-Carcinogenic, transparent
The material of choice is PVC (polyvinyl chloride)

PATHOPHYSIOLOGY

5 PLASMA PROTEINS
5 CELLULAR SYSTEMS
5 CARDINAL EFFECTS
5 CARDINAL SYSTEMS



PATHOPHYSIOLOGY

Thrombosis	Bleeding	Vasodilatation	Capillary leakage	Immunocompromised

CVS	RESP	RENAL	NEURO	GIT
CARDIAC • -ve contractility DUE TO • Myocardial edema • Arrhythmias • Myocardial stunning VASCULAR • Capillary leakage • Vasodilation • Bleeding tendency	DEAD SPACE • IP shunts open • Lung collapse • -ve ventilation OBSTRUCTIVE • Mucus plug • Bronchospasm RESTRICTIVE • Pulmonary edema	FLUID OVERLOAD • 2L priming solution • Renin-angiotensin • Stress Cortisol INTRAVASCULAR DEPLETION • Capillary leakage • Vasodilation • Plasma proteins depletion	STROKE • Micro-emboli • Hypoperfusion	Paralytic ileus Reduced mobility GUT ISCHEMIA Microemboli ULCERS Stress ulcers

CONDUCT AND WEANING FROM CPB

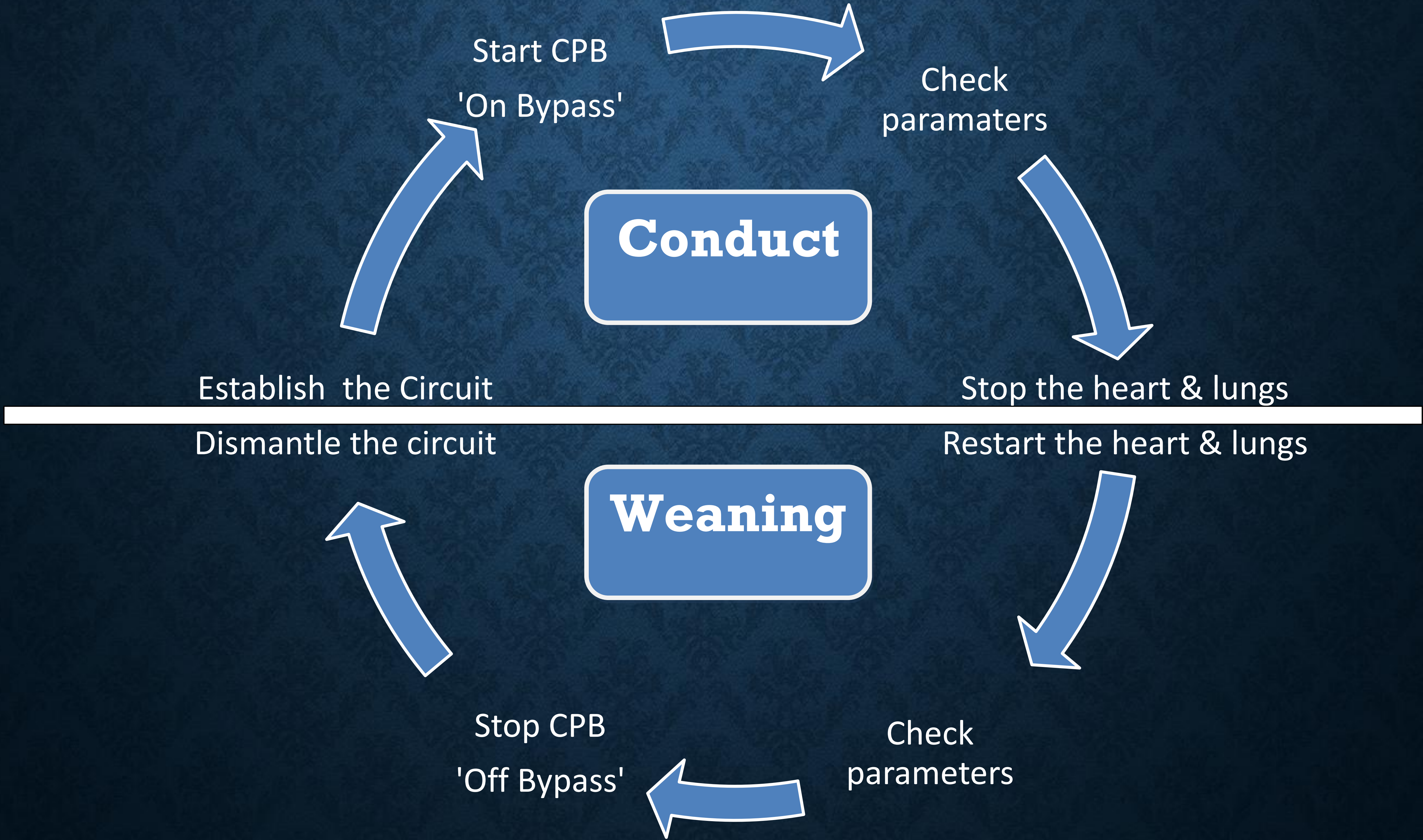
Conduct 'four steps'	Weaning 'four steps'
1) Establish the circuit • Set up • Priming • Heparinization	1) Restart the heart • Rewarming • Deairing • Pacing
2) Start CPB " ON BYPASS "	2) Checking parameters
3) Checking parameters	3) Stop CPB " COME DOWN"

If satisfactory

If satisfactory

4) Stop the heart	4) Dismantle the circuit

CONDUCT AND WEANING FROM CPB



CONDUCT OF CPB

STEP 1: SET UP THE CIRCUIT

(PRIMING, HEPARINIZATION)

- Set up the circuit (see slides 2-4) and carry on priming and heparinization.

- **Priming :**

- **Value:** Initially the tubes of the venous (inflow) and arterial (outflow) are in continuity. This is to allow the perfusionist to fill the circuit with fluid from the reservoir and run the main head pump, to expel all air out of the tubes and keep air confined to the top bit of the reservoir. This creates what we refer to as the 'LEVEL,' below which no air must be detected because this will be the connection between the patient and the heart-lung machine. If air exists on the arterial side, it causes 'air embolism,' and if it exists on the venous side, it creates 'airlock.'

- **Priming solution constituents:** One of the common protocols is: 1L crystalloid, 500 mL Colloid, 250 mL mannitol or 0.5mg/Kg(studies shown to reduce the incidence of kidney dysfunction post-operative). Another protocol sometimes used is replacing the crystalloid with blood, this could be cross-matched stored blood from the blood bank, or from the patient's blood, in that case, referred to as autologous retrograde priming.

CONDUCT OF CPB
STEP 1: SET UP THE CIRCUIT
(PRIMING, HEPARINISIATION)

- **Heparinization :**
- **Value :**
- Cardiopulmonary bypass is a non-endothelial circuit.Blood is prone to massive clotting if not well anticoagulated.Accordingly, before starting IV heparin in a specific dose is given
- **Protocol :**
- (300units /Kg or 3g/Kg).The sufficient level of anticoagulation is judged via checking ACT in theatre.
- ACT > 300 s is safe for Cannulation
- ACT > 400 s is safe for going on bypass
- ACT > 480 s is safe for going on DHCA
- (ACT is checked every 30 min during the operation if it falls below 480 s extra 500 units are given)
- At the end of the operation, heparin is reversed by giving protamine (1g /100 units of heparin)

CONDUCT OF CPB

STEP 2: GOING ON CPB

"ON BYPASS "

- **Before dividing lines**

- **The surgeon must confirm two things with the perfusionist:**

- Pump is off

otherwise, the pump will push against a closed clamp leading to machine breakage

- Venous line clamped

Otherwise, the fluid in the venous line will all siphon back into the reservoir.

- **Before connecting the lines to the cannulas**

- **The surgeon instructs the perfusionist to:**

- Arterial cannula

To push some fluid to de-air the connection completely
'*to come around.*'

- Venous cannula

To pull back fluid to reduce the length of tubes and also make sure it sits nicely. 'take back.'

- **After connecting the arterial line to the aortic cannula**

- **Two features to confirm :**

- Good swing

Indicates the cannula is in continuity with the bloodstream, i.e., inside the aorta

- Good pressure

Indicates the cannula is not on an inappropriate site. (e.g., back wall, dissection lumen)

CONDUCT OF CPB

STEP 3: CONFIRMING SATISFACTORY CPB:

- To confirm satisfactory cardiopulmonary bypass, certain parameters must be checked. Collectively can be grouped into Drainage and Perfusion

Drainage:

Patient:

CVP: 0-2 mmHg

Pump:

Reservoir level: 600-1200 mL

Heart

Right Atrium: Fully decompressed

THE HEART

Perfusion:

Patient

MAP: 50-70mmHg

O2 sat: 95-100%

Pump

A-line pressure ≤ 300mmHg

Main pump flow 2.2-2.4 L/m2

Heart

Aorta No evidence of Dissection

Inappropriate Drainage:

Cannula
- Small size
- Inappropriate position

Heart
- Under-filled (Low CVP to start)
- Inappropriate position

Misc.
- Table Position
- VAVD (0 to 60 mmHg)

Disaster: IVC tear

Inappropriate Perfusion:

Cannula Hit
- Atheroma plaque
- Abut posterior wall

Cannula perfusing
- Arch branch
- Outside aorta

Disaster: Aortic dissection

CONDUCT OF CPB

STEP 4: STOPPING THE HEART AND THE LUNGS:

- If all well, the surgeon stops the heart via proper myocardial protection strategy (described in a different chapter) and stops the lungs by simply switching off the ventilator.

WEANING FROM CPB

STEP 1: RESTARTING THE HEART (REWARMING, DEAIRING, AND PACING)

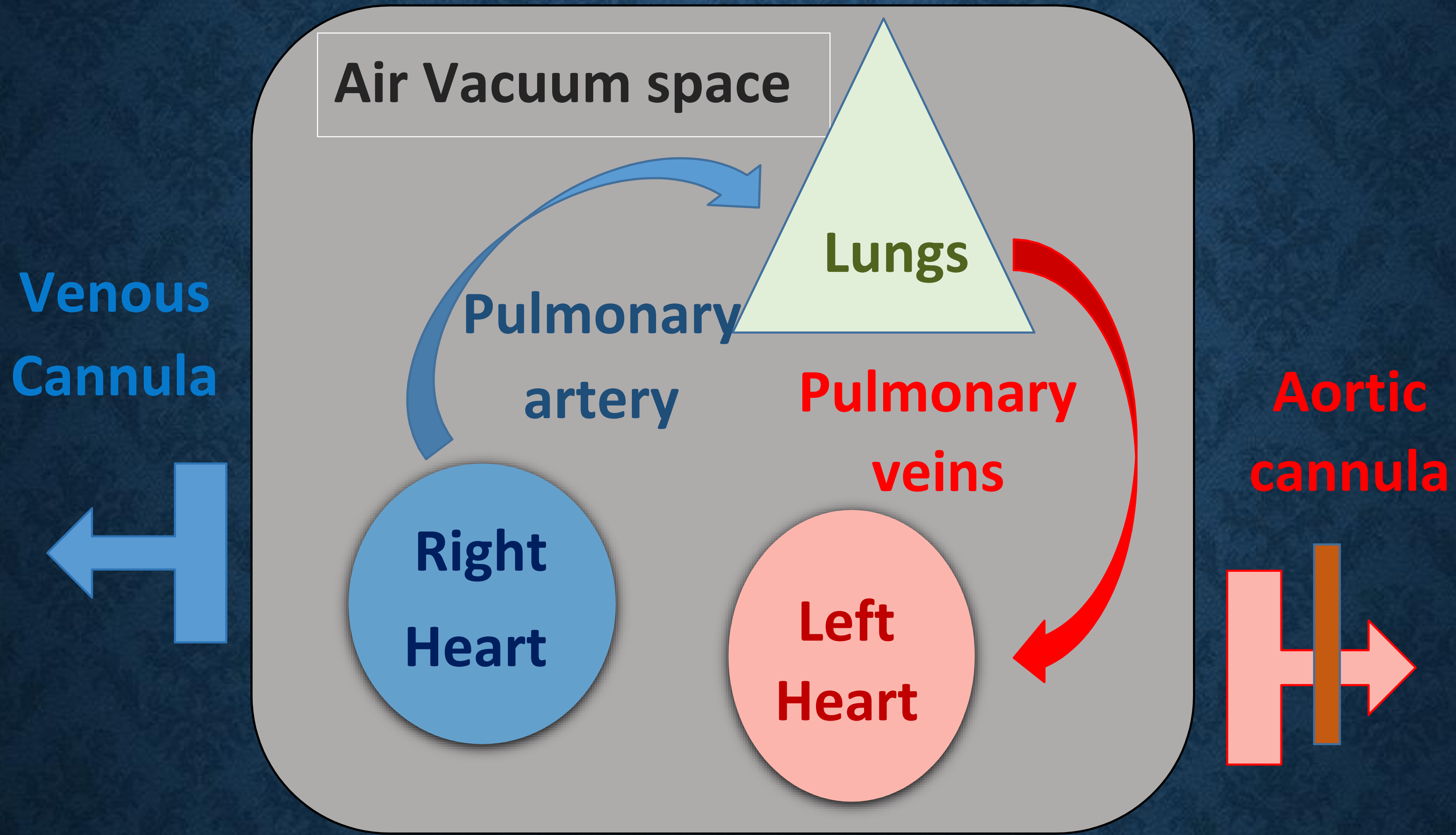
- The surgeon restarts the heart and the lungs allowing both to function while the pump still running. Restarting the heart by Rewarming, Dearing and installing epicardial pacing (discussed in a separate chapter). Restarting the lungs simply by re-ventilating.

Rewarming :

- The process of rewarming is essential to re-establish metabolism of the cardiac myocytes.
- This process takes longer (0.3-0.5 °C /min) than the cooling process (0.5-1.5 °C /min) due to physical properties of fluids.
- Cooling is achieved systemically via the heat exchanger and topically via cold crystalloid in the field. Similarly rewarming is achieved systemically via a heat exchanger and topically via warming blanket, commercially referred to as bear hugger.
- Caution during rewarming, not to rewarm quickly to avoid creating microbubbles (*Boyle's law*) also not to over-heat to avoid denaturation of some plasma proteins.

WEANING FROM CPB

STEP 1: RESTARTING THE HEART (REWARMING, DEAIRING, AND PACING)

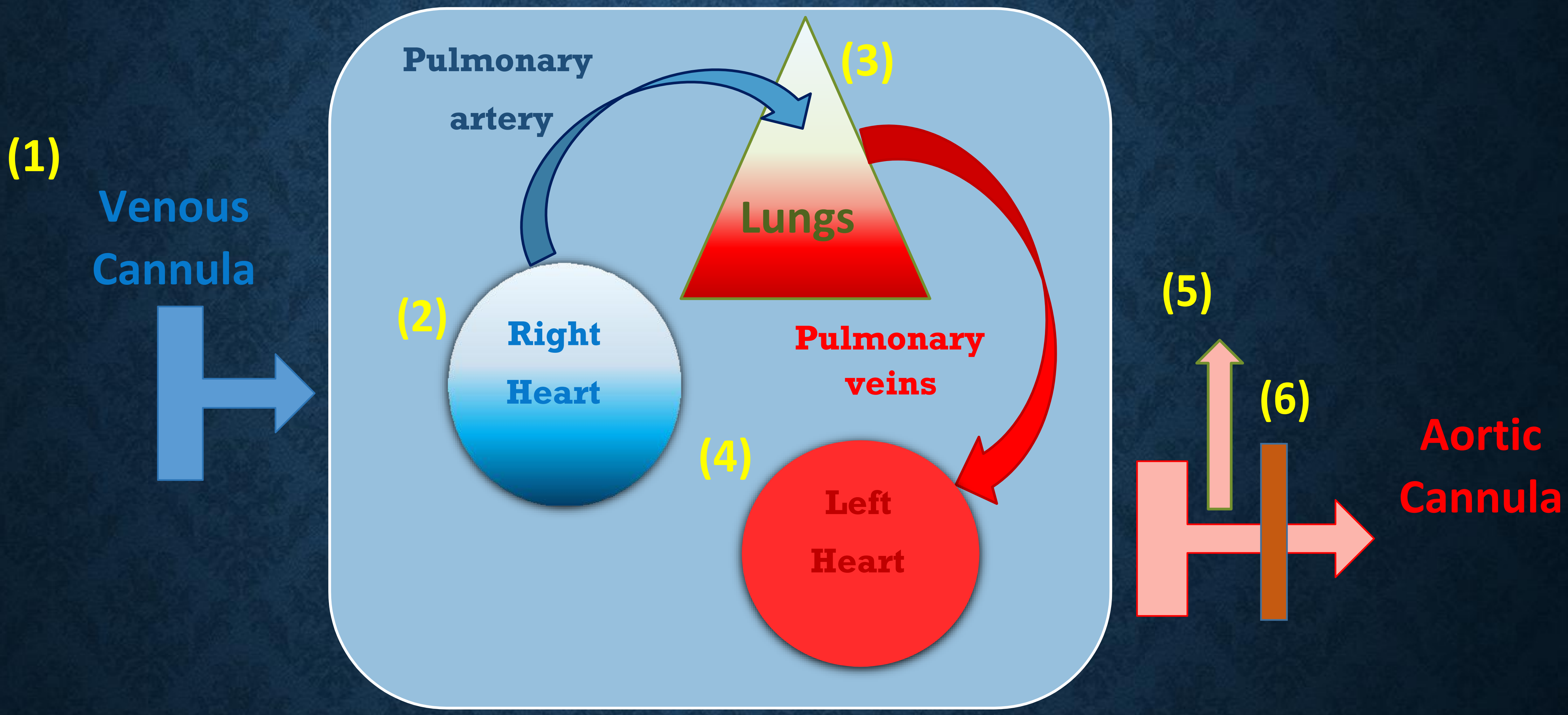


Dearing :

When the heart is fully decompressed, the distance between the venous cannula up to the cross-clamp (including the right heart, pulmonary arteries, lung parenchyma, pulmonary veins and left heart) is supposed to be empty of blood. However, it will contain some air. This air will be exaggerated with any breach created by the surgeon (even as simple as CABG) since it will suck ambient air into this space.Sources of air finding its way to this space during cardiac surgery could be classified as surgical, anesthetic, CPB pump and natural dead space.

WEANING FROM CPB

STEP 1: RESTARTING THE HEART (REWARMING, DEAIRING, AND PACING) :



Dearing :

Dearing process can be started by **(1)** filling the heart through applying a clamp on the venous line **(2)** allow the RV to eject by filling and pacing **(3)** expel air into the pulmonary veins by manually blowing the lungs **(4)** allow the LV to eject by filling and pacing **(5)** run the LV vents at 300 mL/min **(6)** Remove the cross-clamp and continue running the LV vent . Other maneuvers include de-airing through atriotomy, aortotomy, coronary top ends and CO_2 insufflation of the field.

WEANING FROM CPB

STEP 2: CONFIRMING SUITABILITY FOR WEANING :

Before dismantling the circuit, the surgeon must confirm the heart and lungs are ready to resume their functions independently the following is a summary of parameters

- **Two " No "**
  - No conditions requiring CPB, e.g., graft failure, valve leakage, dissection …etc.
  - No residual air further de-airing.
- **Two " satisfactory."**
  - Satisfactory pacing
  - Satisfactory ventilation
- **Two " Physiological"**
  - physiological temp (35-37 ^{o}C)
  - physiological gases (ABG, K^+, PO_2)

WEANING FROM CPB

STEP 3: GRADUAL COME DOWN:

- **Gradual "Come down"**

The perfusionist starts to gradually limit the amount of blood coming back from the patient by applying gradual clamping to the venous line. Doing this alone will lead to more blood going into the patient than coming back, In other words, filling the heart. This is done until a satisfactory contraction is achieved (reaching the highest point of Frank-Starling curve) at such point the perfusionist starts then to slow down the flow of the main head pump as instructed by the surgeon. This will limit the blood flowing back to the heart. This goes on gradually until the venous line is fully clamped and the main head pump is fully switched off.

WEANING FROM CPB

STEP 4: DISMANTLE THE CIRCUIT:

I. Dismantle the circuit

This is done in a stepwise manner in the following order

- Venous cannula out (but leave the purse string intact).
- Root vent out (After TOE confirmation no residual air).
- Aortic cannula out (after giving protamine and satisfactory filling).

Throughout, the surgeon keeps an eye on the heart parameters bearing in mind the situation might necessitate going back on the bypass at any time.To enable that certain precautions are taken.

- Fill the venous line with crystalloid to re-prime it (siphon venous line).
- Perfusionist checks heparinization, occlusion, and reservoir level.
- Surgeon leaves atrial purse strings, ready to reuse if needed.

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