Edema and Ultrafiltration in ECLS Patients

THE MISSOURI PERFUSION SOCIETY 23rd Annual Scientific Meeting Embassy Suites Country Club Plaza Kansas City, Missouri June 1 & 2, 2018

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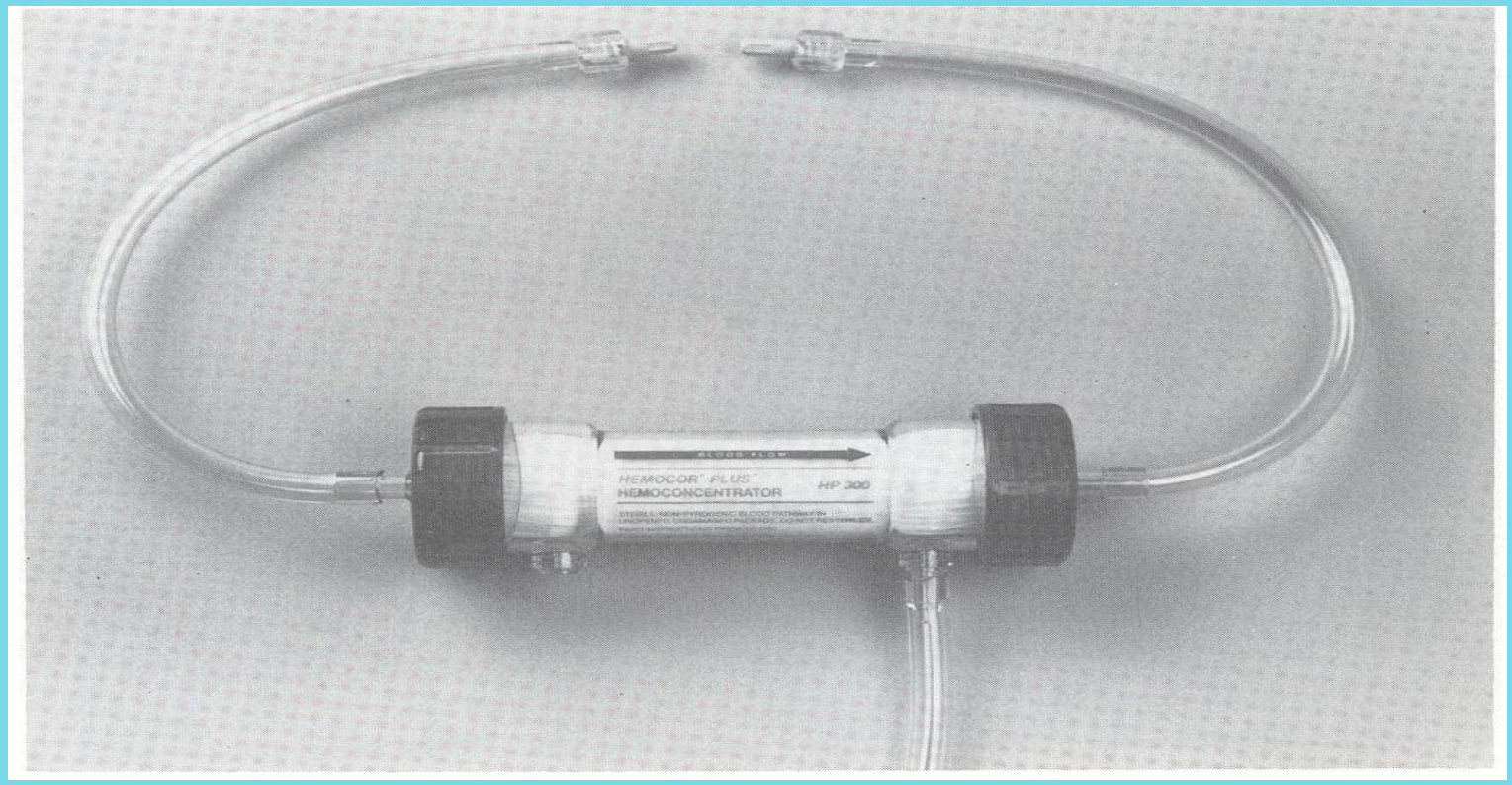
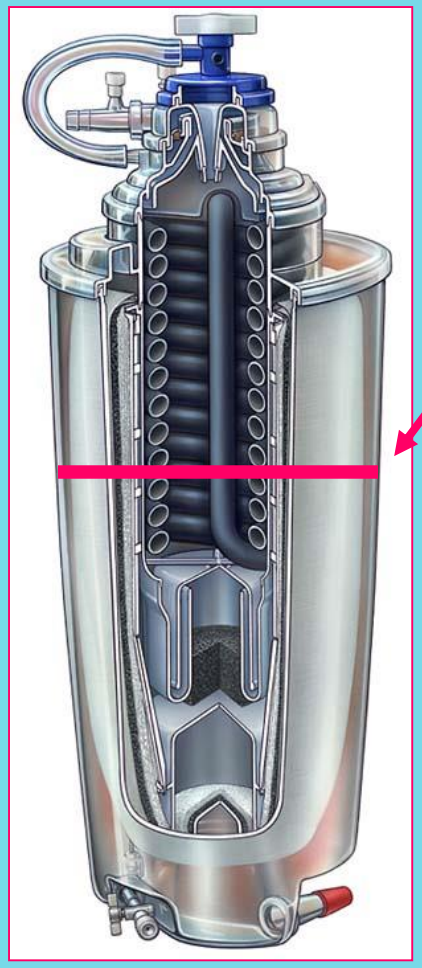
No disclosures

Hemoconcentrators



RESIDUAL OXYGENATOR BLOOD VOLUME: THEN AND NOW



BUBBLE OXYGENATOR WITHOUT ULTRAFILTRATION: RESIDUAL VOLUME ~ 1000 MLS

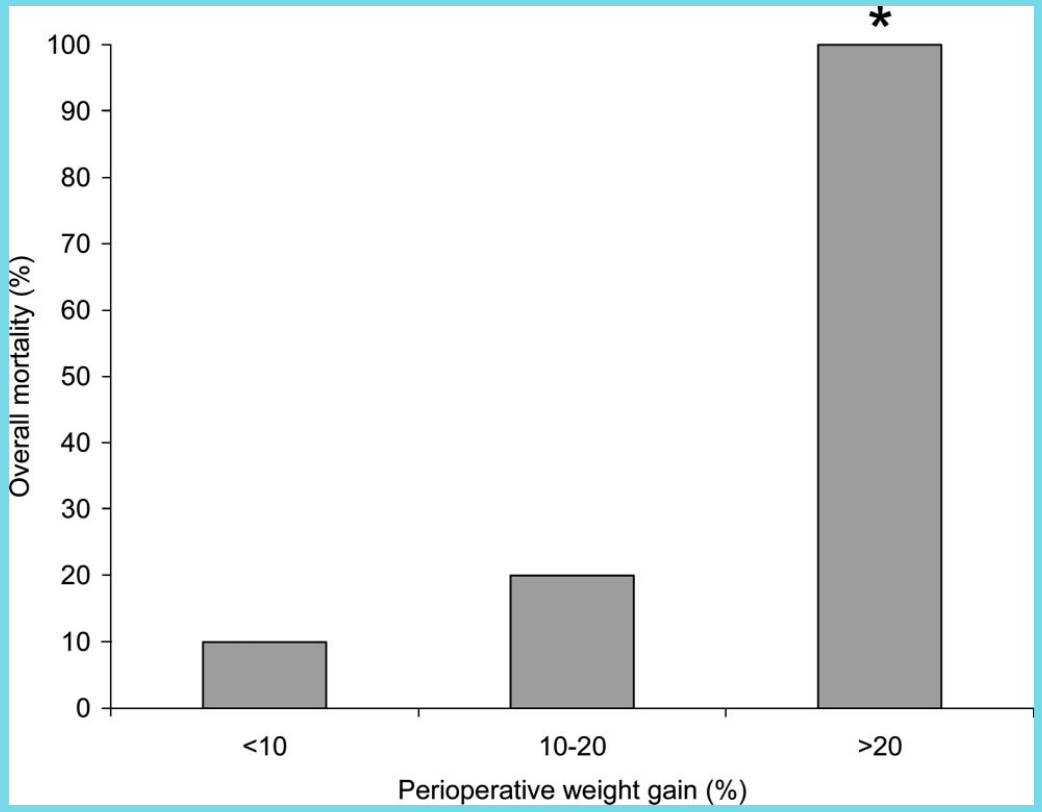
HOLLOW FIBER MEMBRANE OXYGENATOR WITH ULTRAFILTRATION: RESIDUAL VOLUME ~ 10 MLS

Likely causes, frequent consequences and preventative treatments for edema in ECLS patients

Likely Causes	Frequent Consequences	Preventative Treatments
1. Congestive heart failure 2. Preoperative fluid resuscitation 3. Crystalloid hemodilution 4. Hypothermia 5. Altered blood flow 6. Vascular tone changes 7. Pediatrics a. low body weight b. immaturity 8. Systemic Inflammatory response syndrome a. increased foreign surface exposure b. increased CPB time c. increased capillary permeability	1) Edema (adults) averages +14% of body weight 2) Edema (neonates) 37-54% incidence a) delayed chest closure 3) Increased blood transfusion 4) Increased length of stay 5) Impaired tissue oxygenation 6) Prolonged ventilation 7) Need for circulatory support 8) Myocardial edema 9) Pulmonary edema 10) Organ dysfunction 11) Acute respiratory distress syndrome	1) Reduce prime volume a) retrograde autologous priming b) mini circuits 2) Increase the oncotic/osmotic pressure in the blood a) mannitol b) albumin c) plasma protein fraction d) fresh frozen plasma e) dextran f) hydroxyethyl starch g) hypertonic saline 3) Steroids to reduce inflammatory response a) dexamethasone b) methylprednisolone 4) Continuous ultrafiltration 5) Modified ultrafiltration 6) Vasopressors 7) Diuretics

Information derived from Hirleman and Larson, 2008

Perioperative Fluid Balance And Survival



n = 48 surgical ICU patients

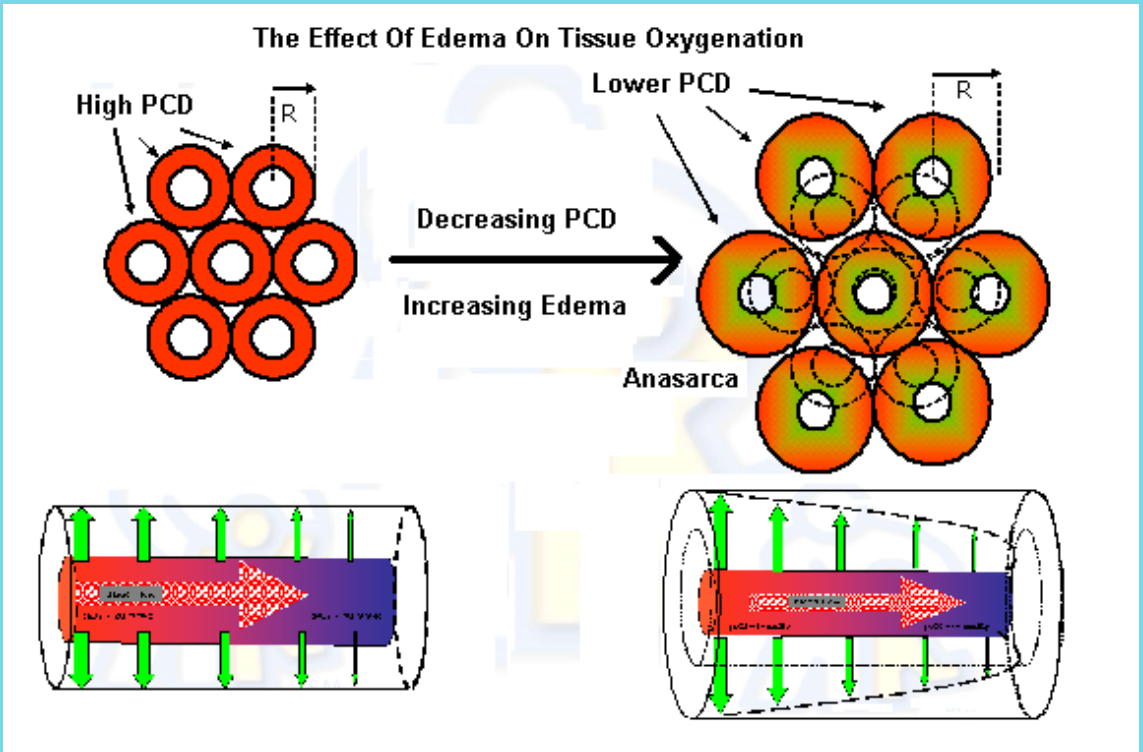
D. Chappell et al. Anesthesiology, V 109, No 4, Oct 2008

A. Lowell et al. Crit Care Med. 1990 Jul;18(7):728-33

- Native Reservoir
- Adult TBW 58%
  - 19% ECW
    - 4% intravascular (plasma)
    - 15% interstitial.
- Neonates TBW 79%
  - 44% ECW
    - 6% intravascular (plasma)
    - 38% interstitial
- Interstitial fluid protects against dehydration/acute blood loss
- Loss of native reservoir fluid > hypotension/organ failure.
  - Heat stroke

- Ready Reservoir
- 33% of all peds cardiac pts have CHF
- Many adult pts coming to surgery have excess fluid from CHF.
- All pts coming to OR receive IV rehydration after fasting.
- A few pts have received IV resuscitation prior to surgery.
- Safe to remove ready reservoir fluids to prevent edema.

SYSTEMIC CAPILLARY EDEMA FORMATION DURING RESUSITATION, CPB OR ECMO: FLUID SETTLES IN THE ORGANS AND PERIPHERY



Angioedema

PULMONARY CAPILLARY EDEMA FORMATION DURING RESUSITATION, CPB OR ECMO: FLUID SETTLES IN THE LUNGS

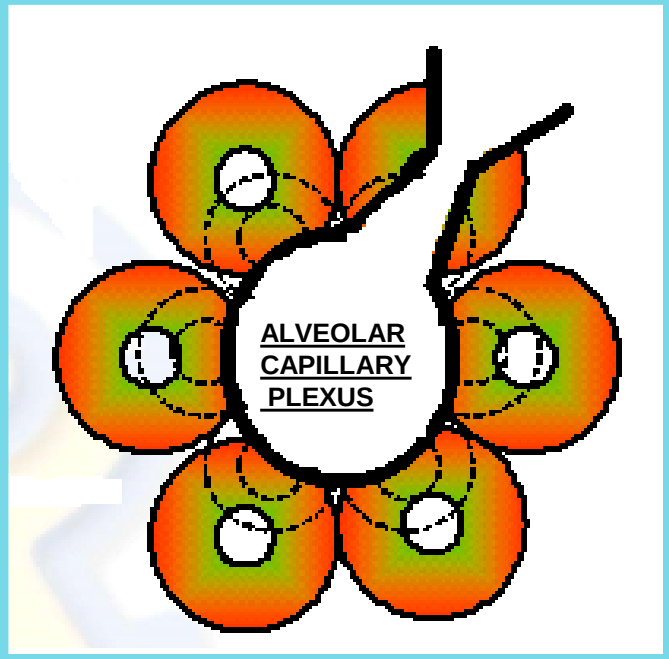
↑ INTERSTITIAL EDEMA

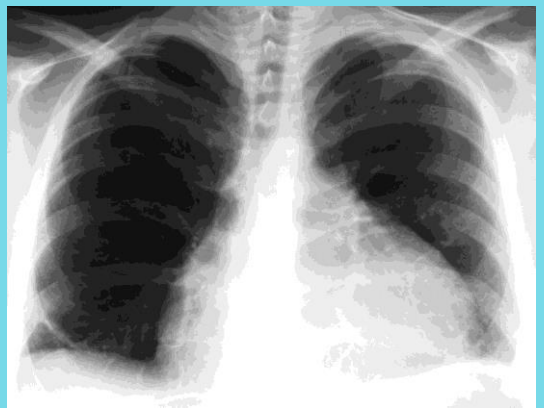
↑PVR

↑RV FILLING PRESSURE

↓ LV PRELOAD

↓ MAP

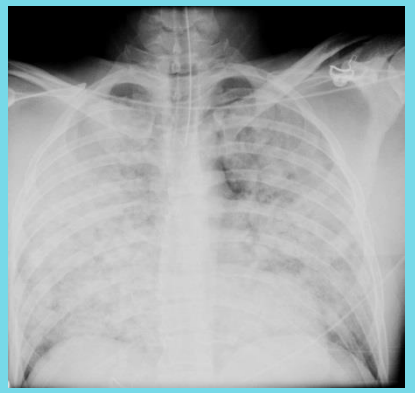




↑aADO2

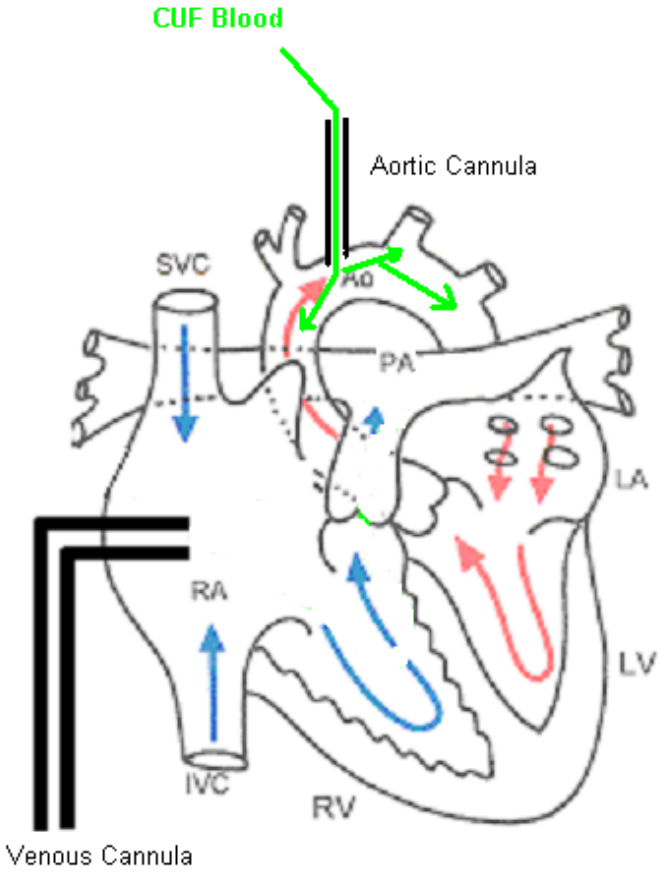
↑AIRWAY RESISTANCE

↓PULMONARY COMPLIANCE

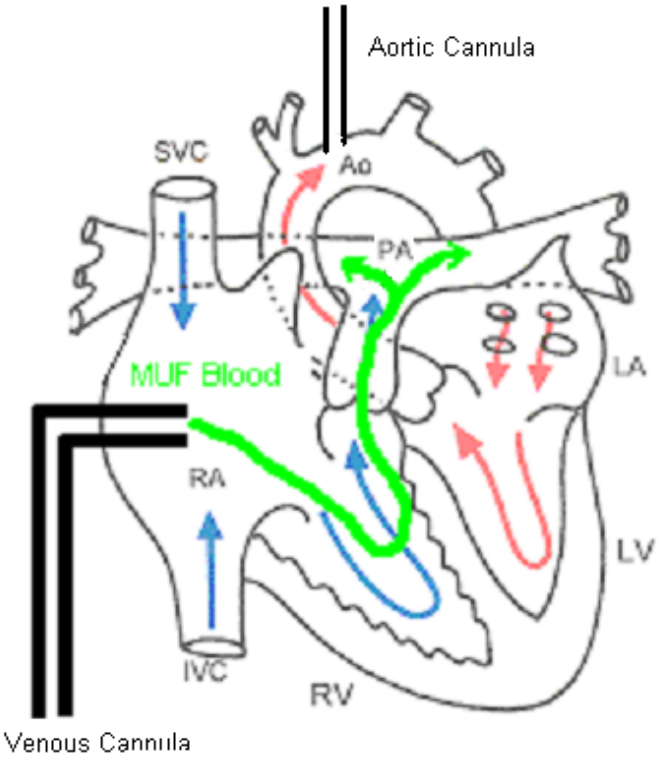


Capillary Targets:

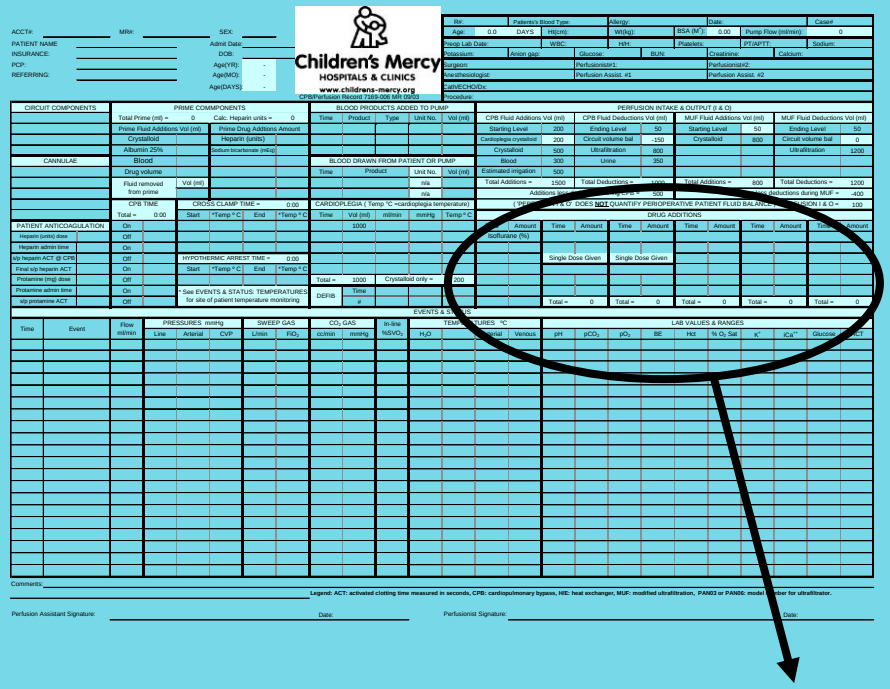
Continuous ultrafiltration (CUF) during CPB or VA ECMO
Modified ultrafiltration (MUF) after CPB or VV ECMO

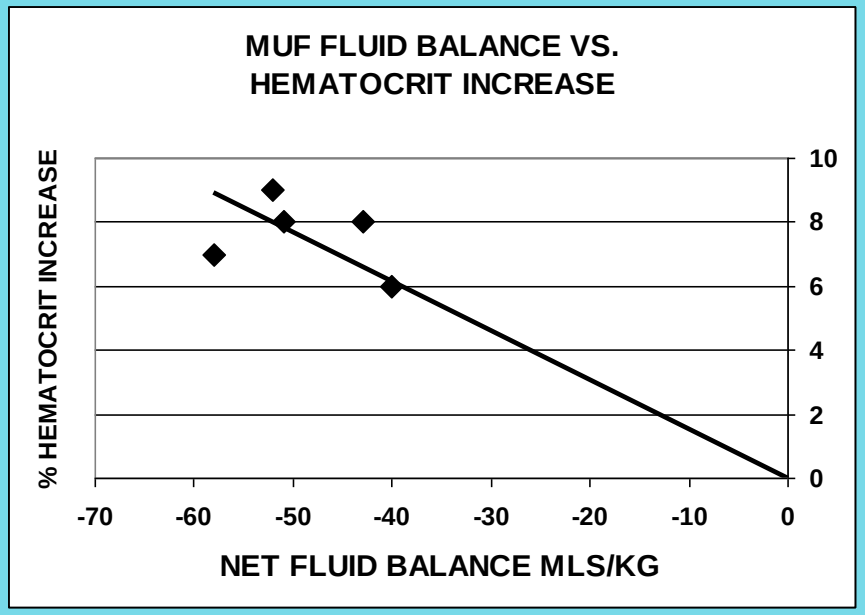


CUF blood pumped to systemic capillaires



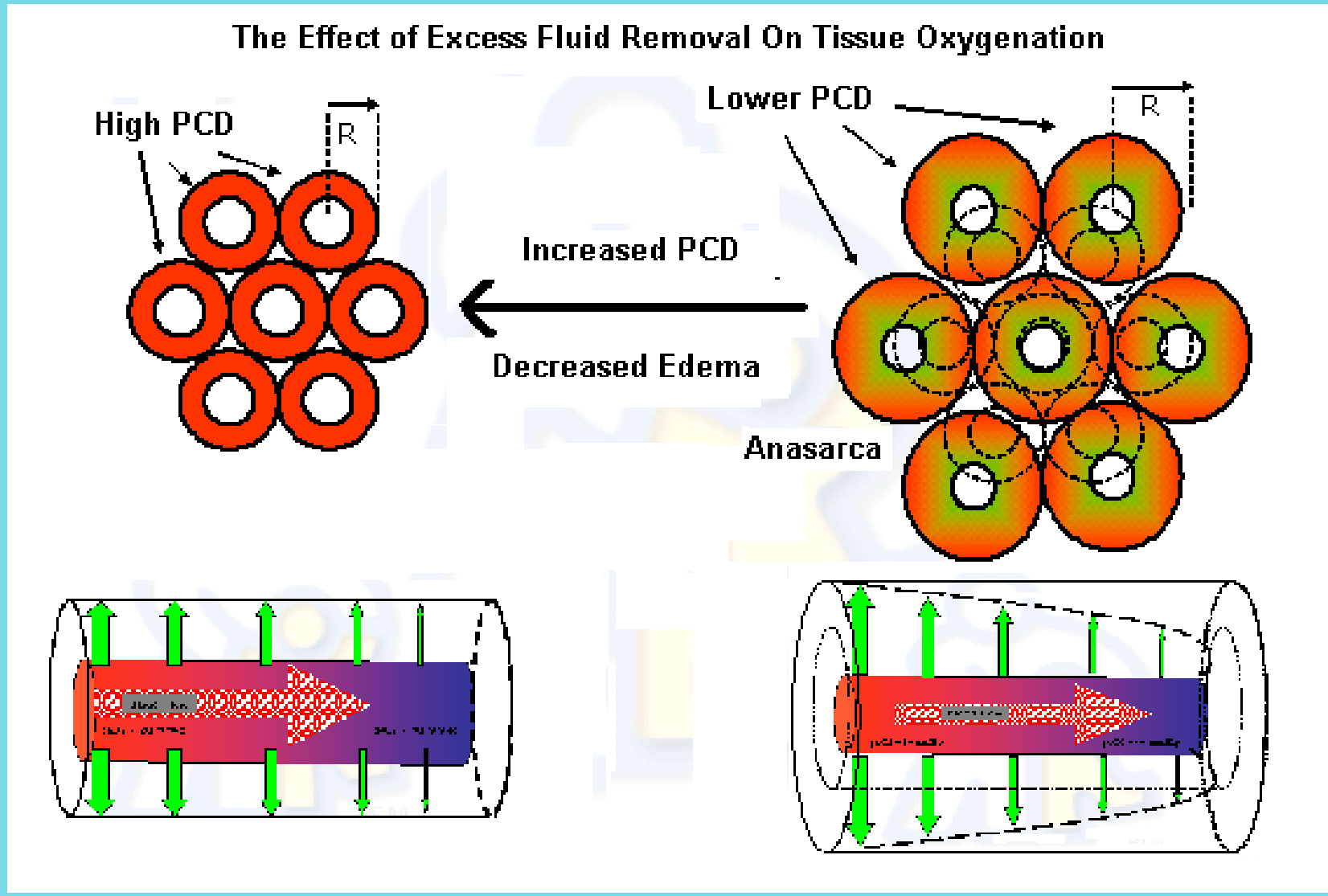
MUF blood pumped to pulmonary capillaries





PERFUSION INTAKE & OUTPUT (I & O)							
CPB Fluid Additions Vol (ml)		CPB Fluid Deductions Vol (ml)		MUF Fluid Additions Vol (ml)		MUF Fluid Deductions Vol (ml)	
Starting Level	200	Ending Level	50	Starting Level	50	Ending Level	50
Cardioplegia crystalloid	200	Circuit volume bal	-150	Crystalloid	800	Circuit volume bal	0
Crystalloid	500	Ultrafiltration	800			Ultrafiltration	1200
Blood	300	Urine	350				
Estimated irrigation	500						
Total Additions =	1500	Total Deductions =	1000	Total Additions =	800	Total Deductions =	1200
		Additions less deductions during CPB =	500			Additions less deductions during MUF =	-400
('PERFUSION I & O' DOES **NOT** QUANTIFY PERIOPERATIVE PATIENT FLUID BALANCE)						PERFUSION I & O =	100

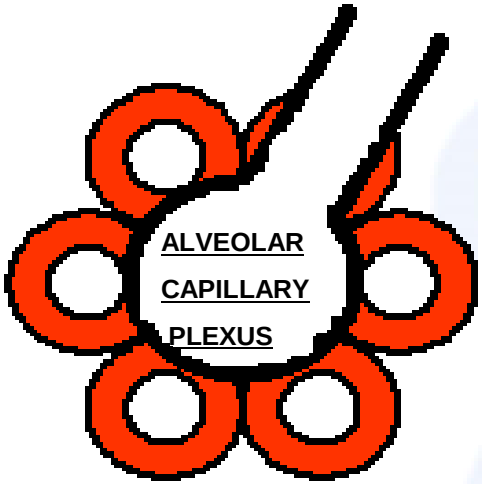
ULTRAFILTRATION OR DIURESIS REVERSES EDEMA TO IMPROVE TISSUE OXYGENATION: SYSTEMIC CAPILLARIES



Pulmonary Edema Reversal by MUF or SCUF

Edema Formation Impairs Heart & Lung Function

FLUID FROM CHF, IV CRYSTALLOID & PUMP PRIME SETTLES IN LUNG DURING CPB OR ECMO, DECREASING PCD



↑ PULMONARY EDEMA

↑PVR

↑RV FILLING PRESSURE

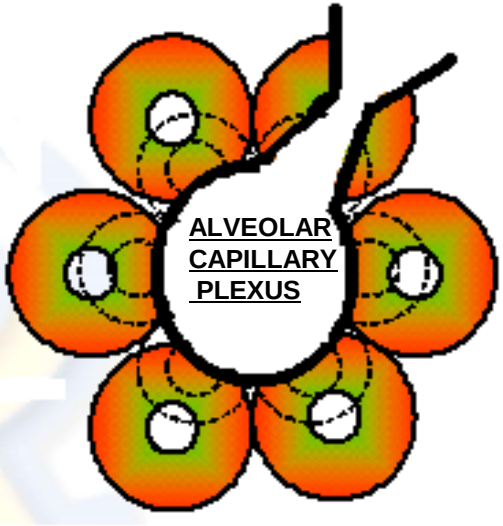
↓LV PRELOAD

↑aADO2

↑AIRWAY RESISTANCE

↓PULMONARY COMPLIANCE

CVP = 16, MAP = 40



FLUID REMOVED FROM LUNG DURING MUF OR SCUF INCREASES PCD

Net fluid balance after CPB/MUF = - 32 ± 55 ml/kg

↓PULMONARY EDEMA

↓PVR

↓RV FILLING PRESSURE

↑LV PRELOAD

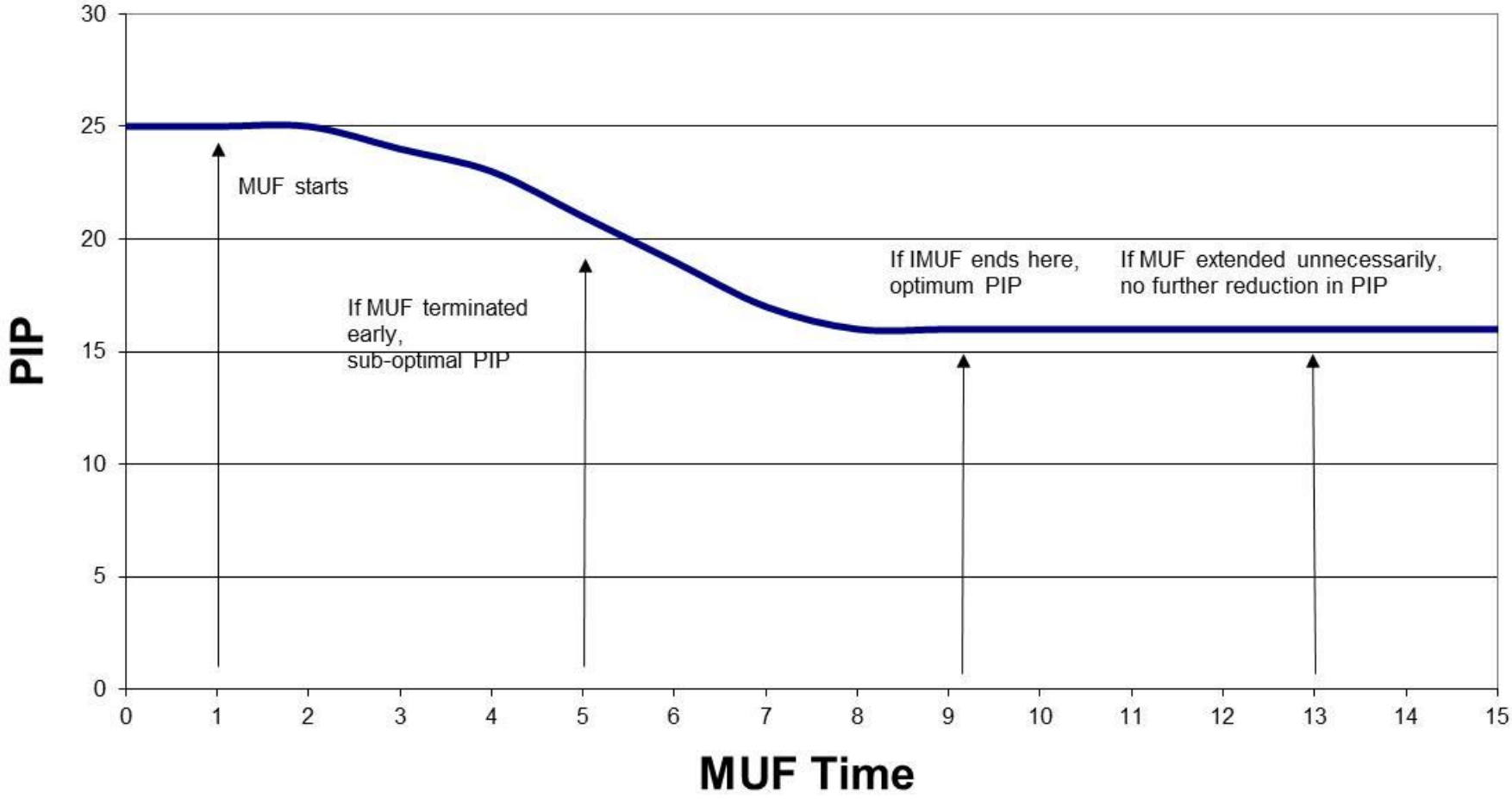
↓aADO2

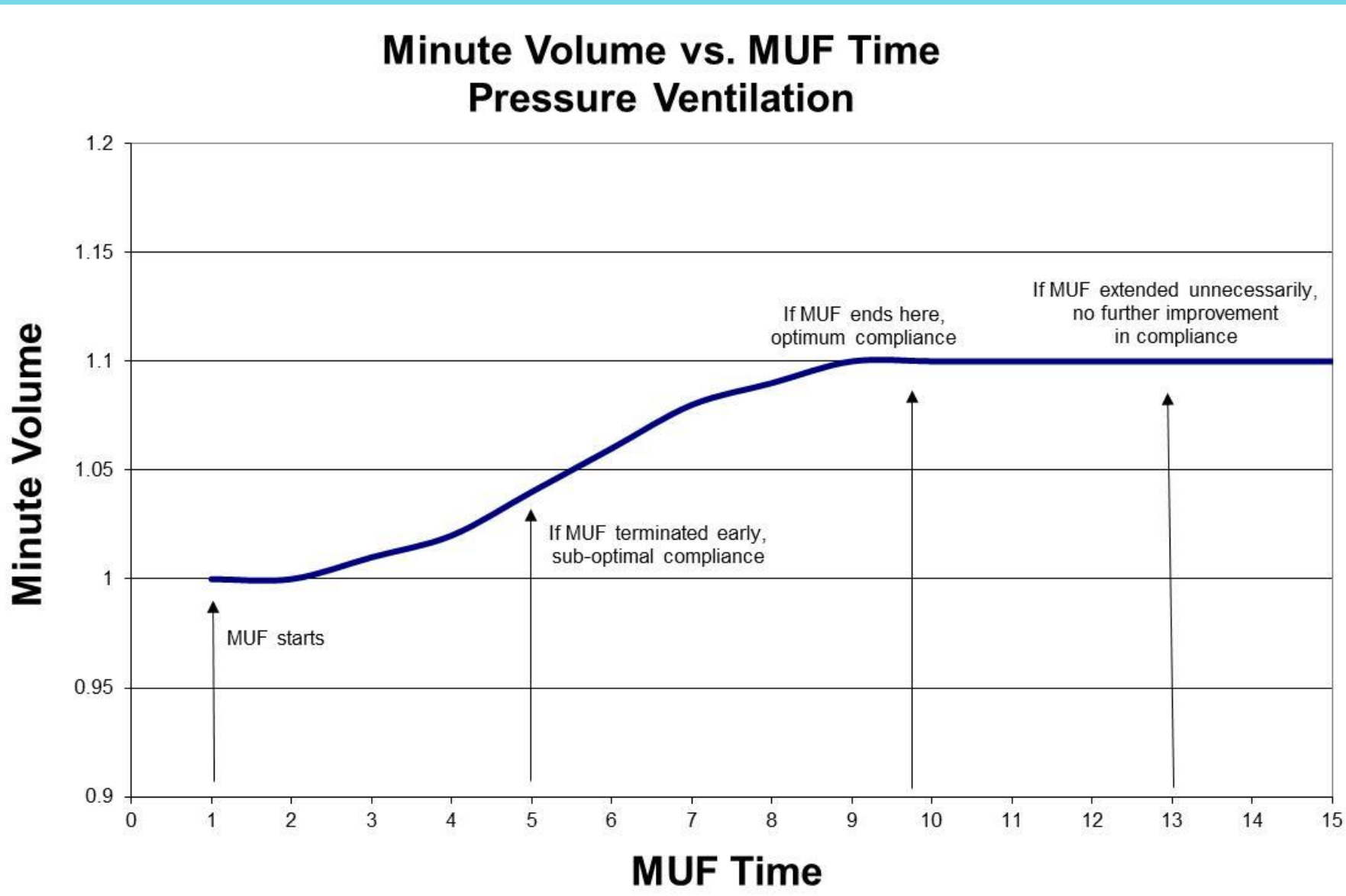
↓AIRWAY RESISTANCE

↑PULMONARY COMPLIANCE

CVP = 8, MAP = 80

PIP vs. MUF Time
Volume Ventilation




Minute Volume vs. MUF Time
Pressure Ventilation
Minute Volume
1.2
1.15
1.1
1.05
1
0.95
0.9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
MUF Time
MUF starts
If MUF terminated early,
sub-optimal compliance
If MUF ends here,
optimum compliance
If MUF extended unnecessarily,
no further improvement
in compliance

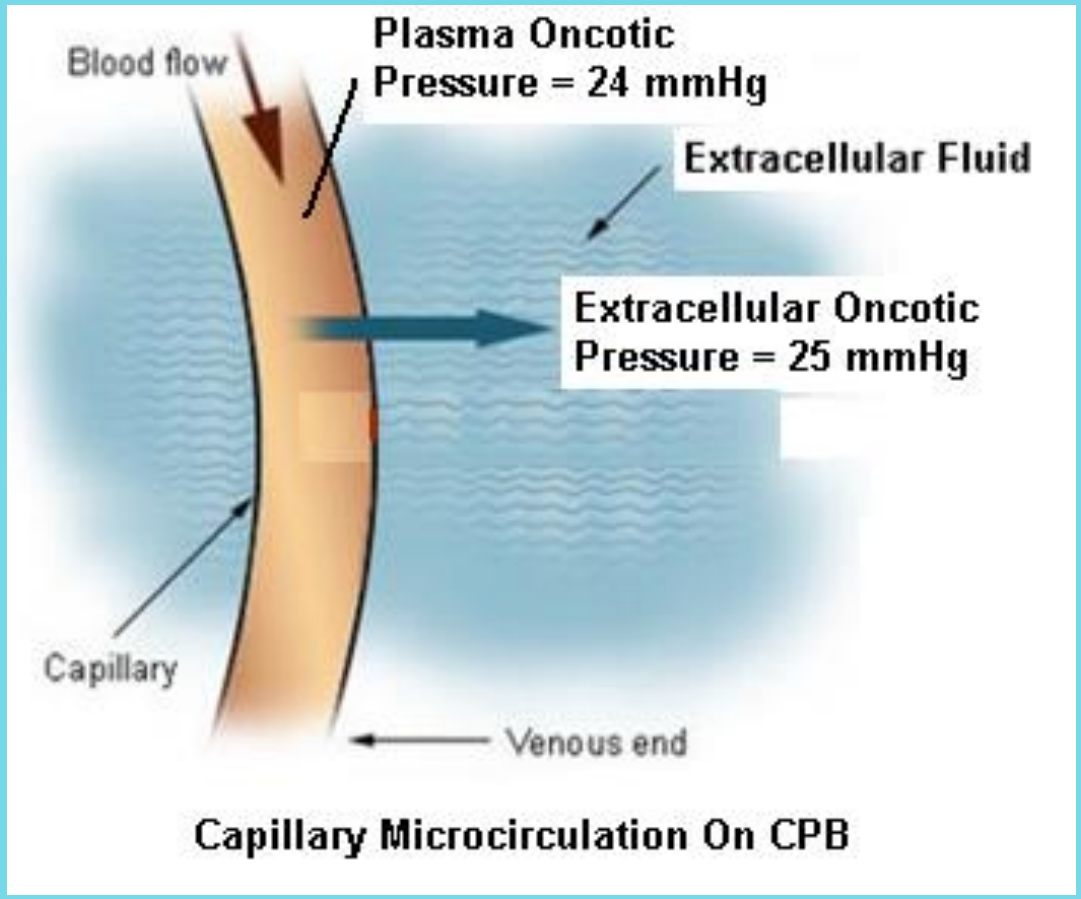
Oncotic vs. Osmotic Pressure

- Oncotic (colloid osmotic pressure, COP)
- Pressure exerted by larger molecules (proteins) in plasma

- Osmotic
- Pressure exerted by smaller molecules (glucose, ions) in plasma

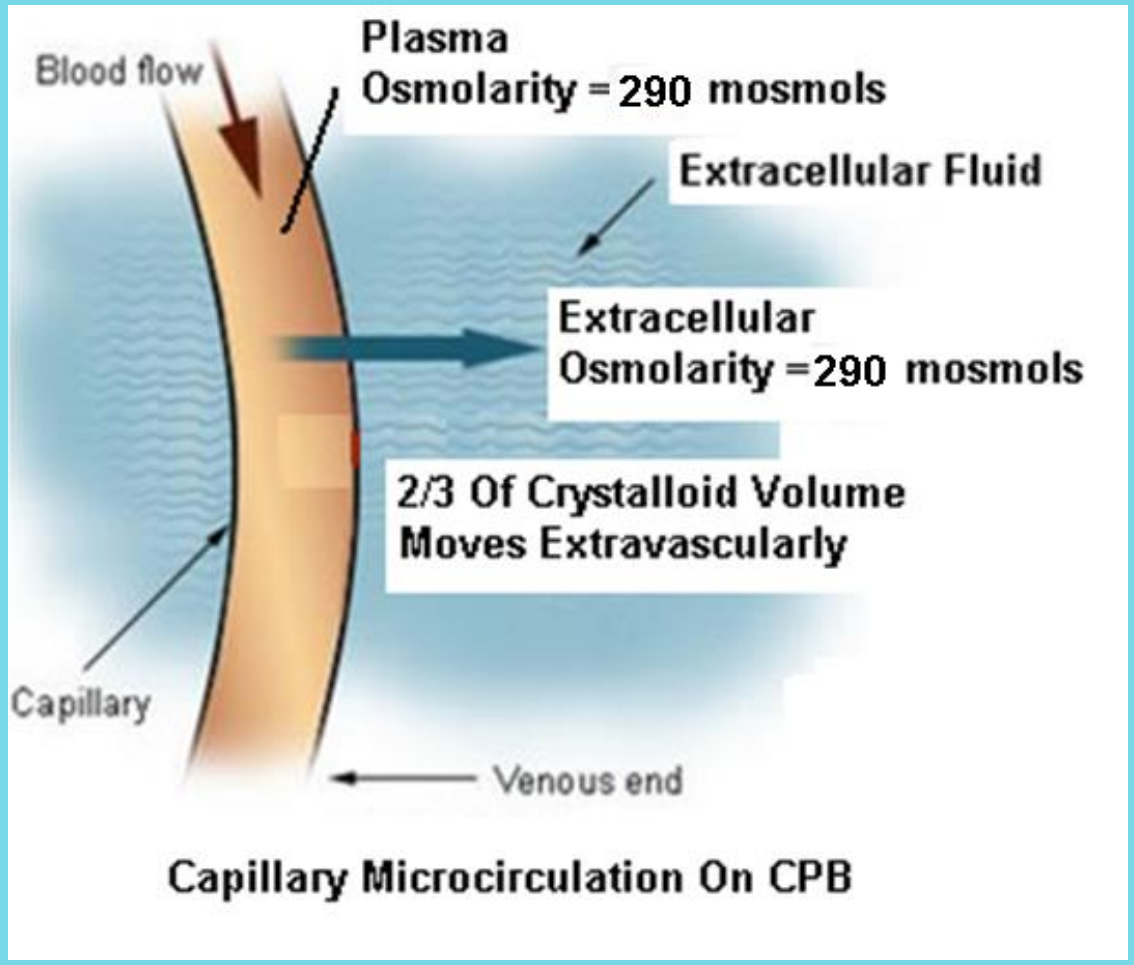
Hemodilution And Colloid Oncotic Pressure (COP)

- Hemodilution decreases COP unless albumin or colloid-based volume expanders are added to the prime
  - Normal COP = 20-30 mmHg
  - Normal albumin 3-5 gm/dL
- ↓ COP causes fluid to move from blood into the extravascular space
- ↑ COP causes fluid to move from extravascular space into the blood
- SIRS causes capillary protein leak > edema

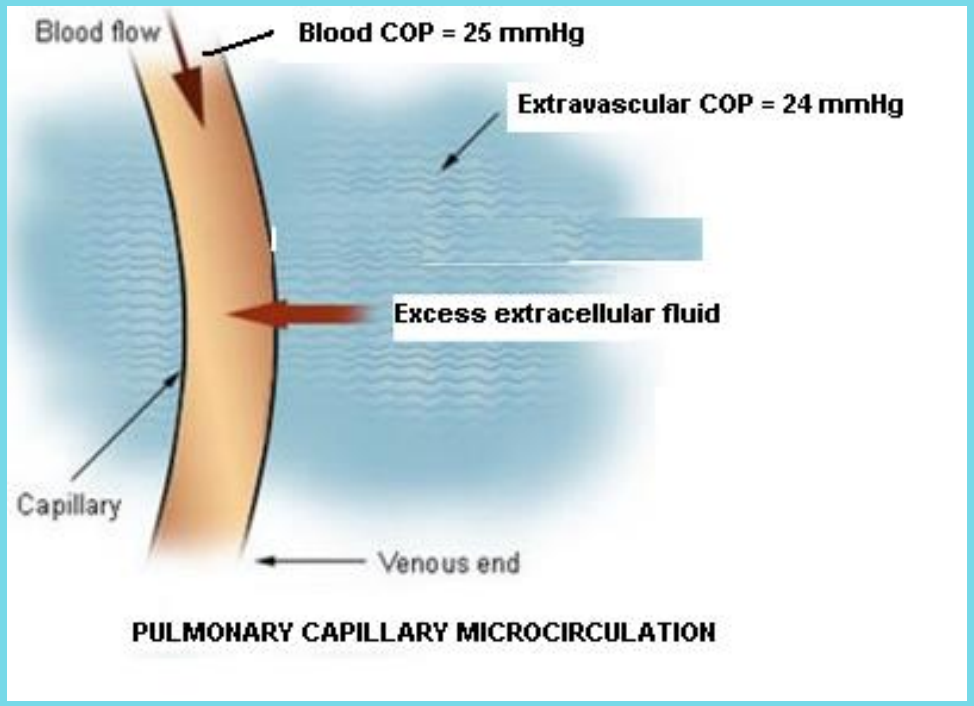


Hemodilution And Osmotic Pressure (Osmolarity)

- Hemodilution does not effect osmolarity
  - Nml = 275-299 mosmols/L
- Low blood osmolarity moves fluid from blood to extravascular space
  - LR = 275 mosmols/L
  - 0.45%NS = 154 mosmols/L
  - D5W = 250 mosmols/L
    - Becomes free water
- High blood osmolarity moves fluid from extravascular space to blood
  - 0.9%NS = 308 mosmols/L
  - Plasmalyte 310 mosmols/L
- 2/3 of crystalloid solutions move across capillary > edema



Capillary Microcirculation On CPB

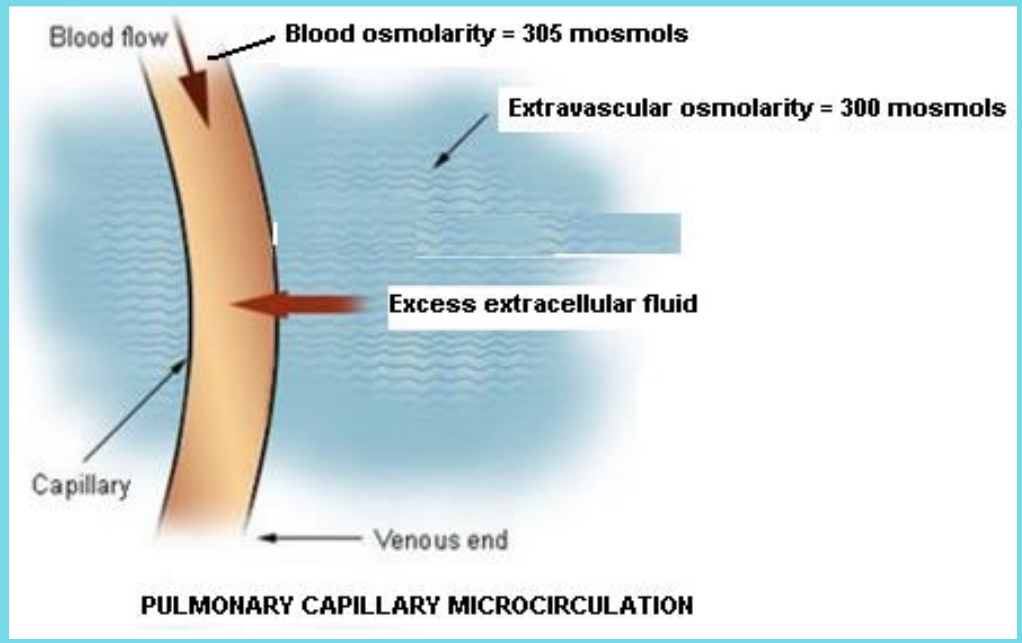


INFANT MUF PULMONARY PHYSIOLOGY

Blood proteins in residual circuit volume are concentrated and directed into lungs

ADULT MUF PULMONARY PHYSIOLOGY

Mannitol 2 gm/L or 50 mEg/L $NaHCO_3$ into residual circuit volume and directed into lungs



FLUID BALANCE VS. MORTALITY

80% NEGATIVE BALANCE, 20% POSITIVE BALANCE [n = 1540]

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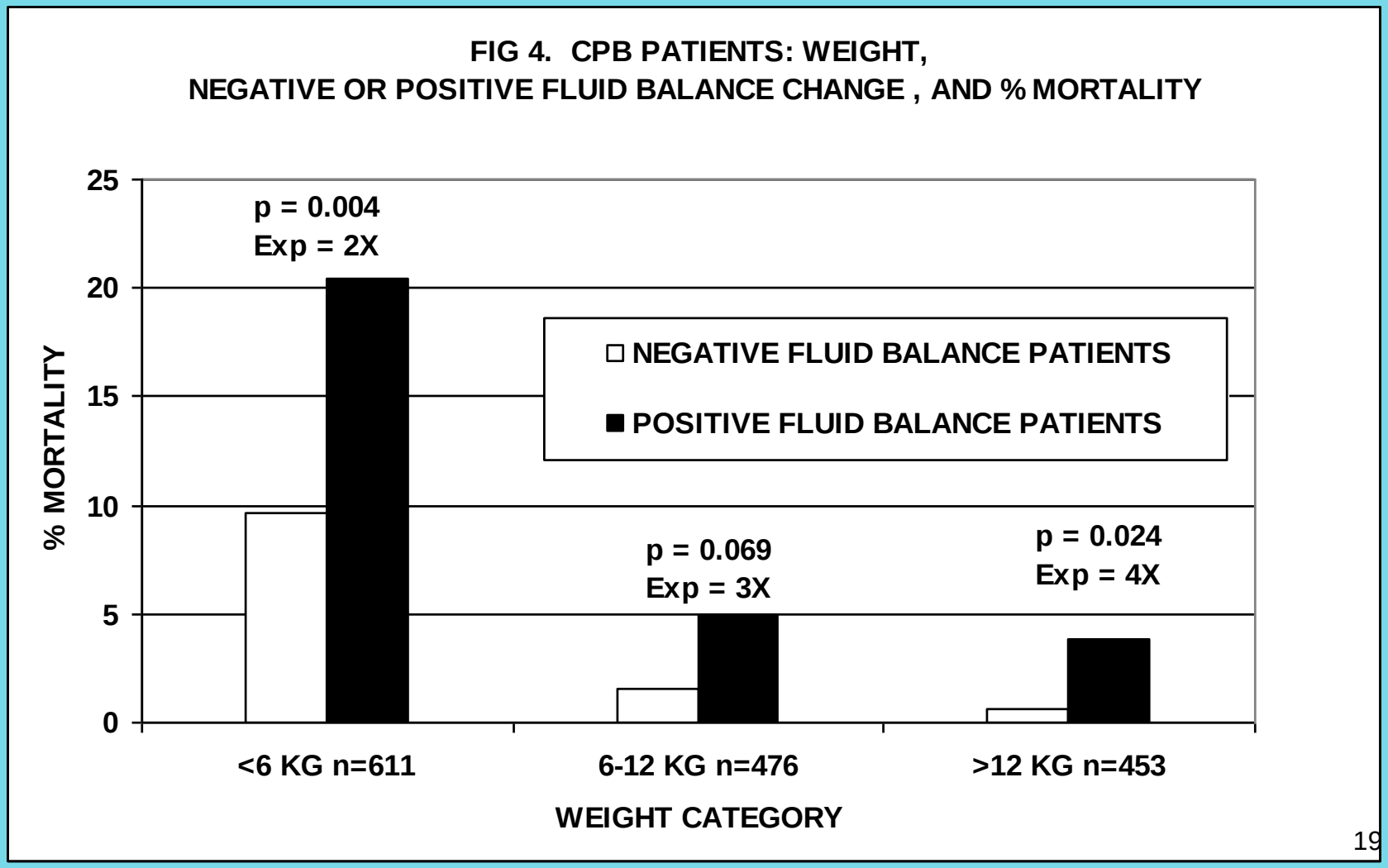

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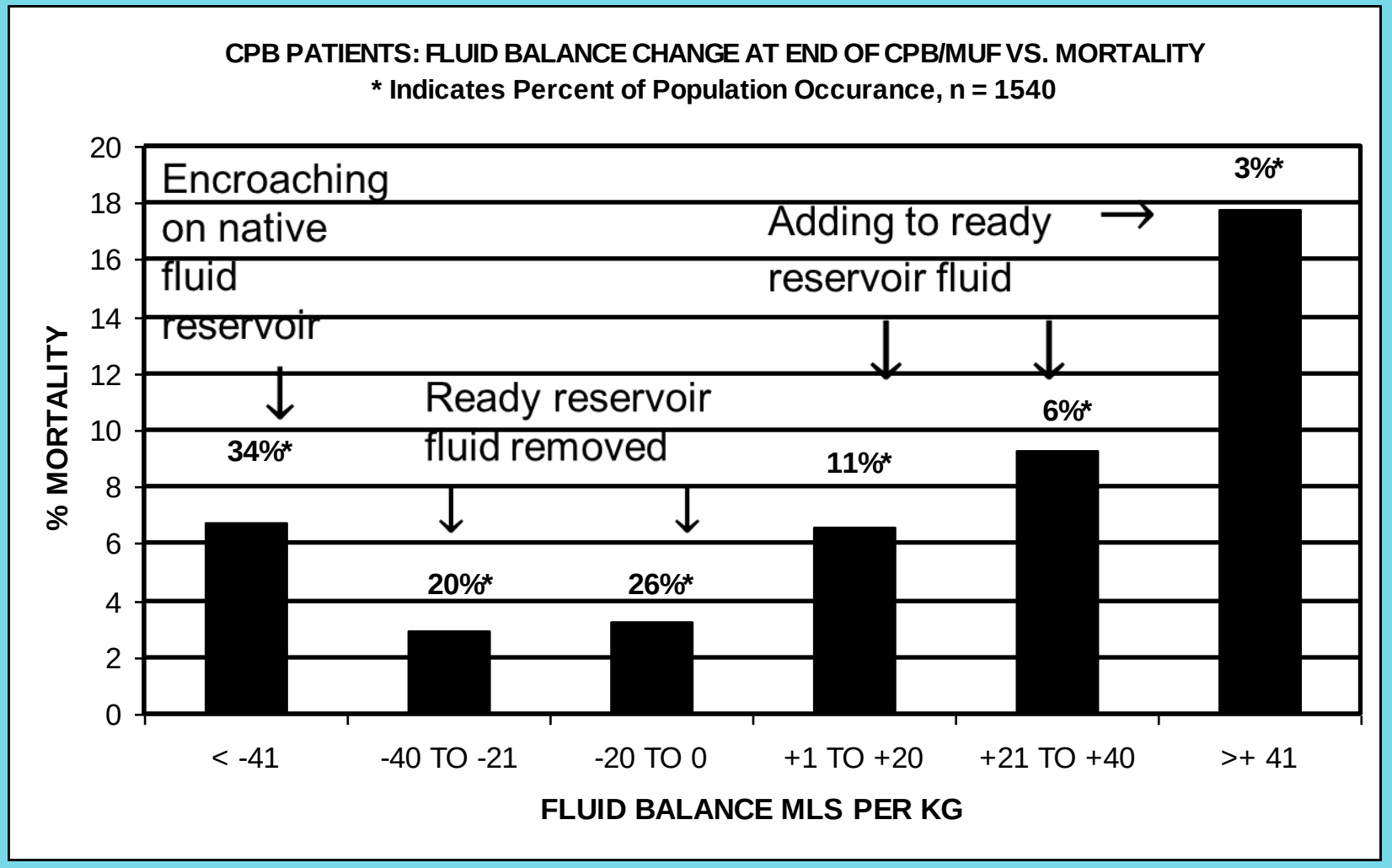


Targeting the Need for CUF

Do you need to ultrafiltrate?

Is The Patient Taking Diuretics (CHF)?

Do you want to avoid RAP (unstable BP) ?

DRY WT.	% CHF FLUID WT. GAIN	FLUID OVERLOAD	WET WT.	CPB TIME	CONTINUOUS UF FLUID REMOVAL RATE	TOTAL FLUID REMOVED	FLUID REMOVED	% NET FLUID BALANCE
70 KG	5%	3.5 L	73.5 KG	60 MIN	20 ML/MIN	1.2 L	- 17 ML/KG	-1.7%
70 KG	5%	3.5 L	73.5 KG	120 MIN	20 ML/MIN	2.4 L	- 34 ML/KG	- 3.4%
50 KG	5%	2.5 L	53.5 KG	60 MIN	20 ML/MIN	1.2 L	- 24 ML/KG	- 2.2%
50 KG	5%	2.5 L	53.5 KG	120 MIN	20 ML/MIN	2.4 L	- 48 ML/KG	- 4.4%

Infant MUF vs. Adult MUF

- Blood passing through the hemoconcentrator develops a high oncotic pressure as excess fluid is removed from it.
- Infant MUF ratio = 1/5 MUF blood to venous return
  - 100 cc/min MUF flow : 500 cc/min CO
    - Higher oncotic blood going to the right heart and lungs
    - Pulmonary water (edema) removed from the lungs
    - Improved pulmonary and hemodynamic function
  - Typically 5-10% hematocrit increase
  - Clotting factors increased w/o increasing blood volume

Adult MUF

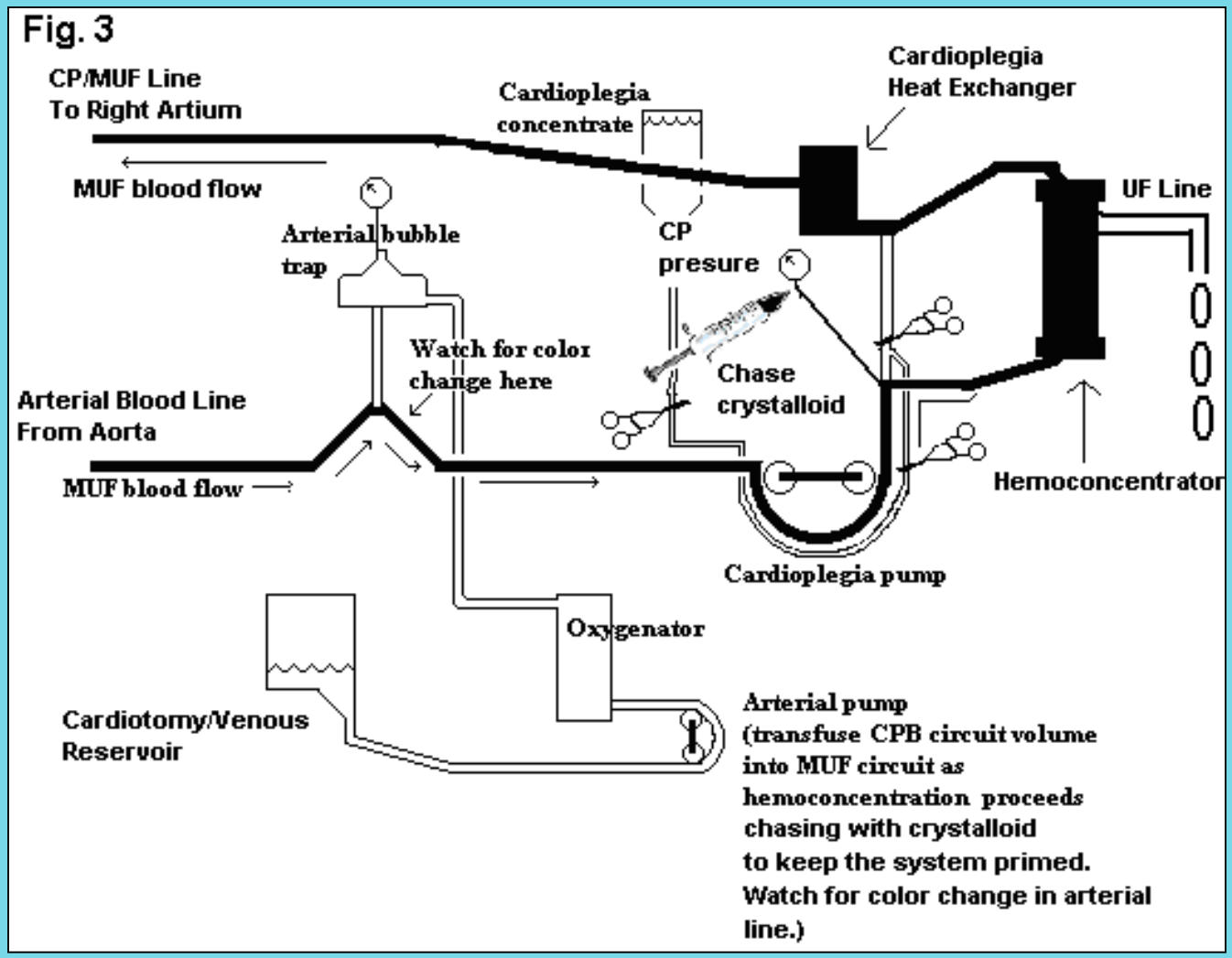
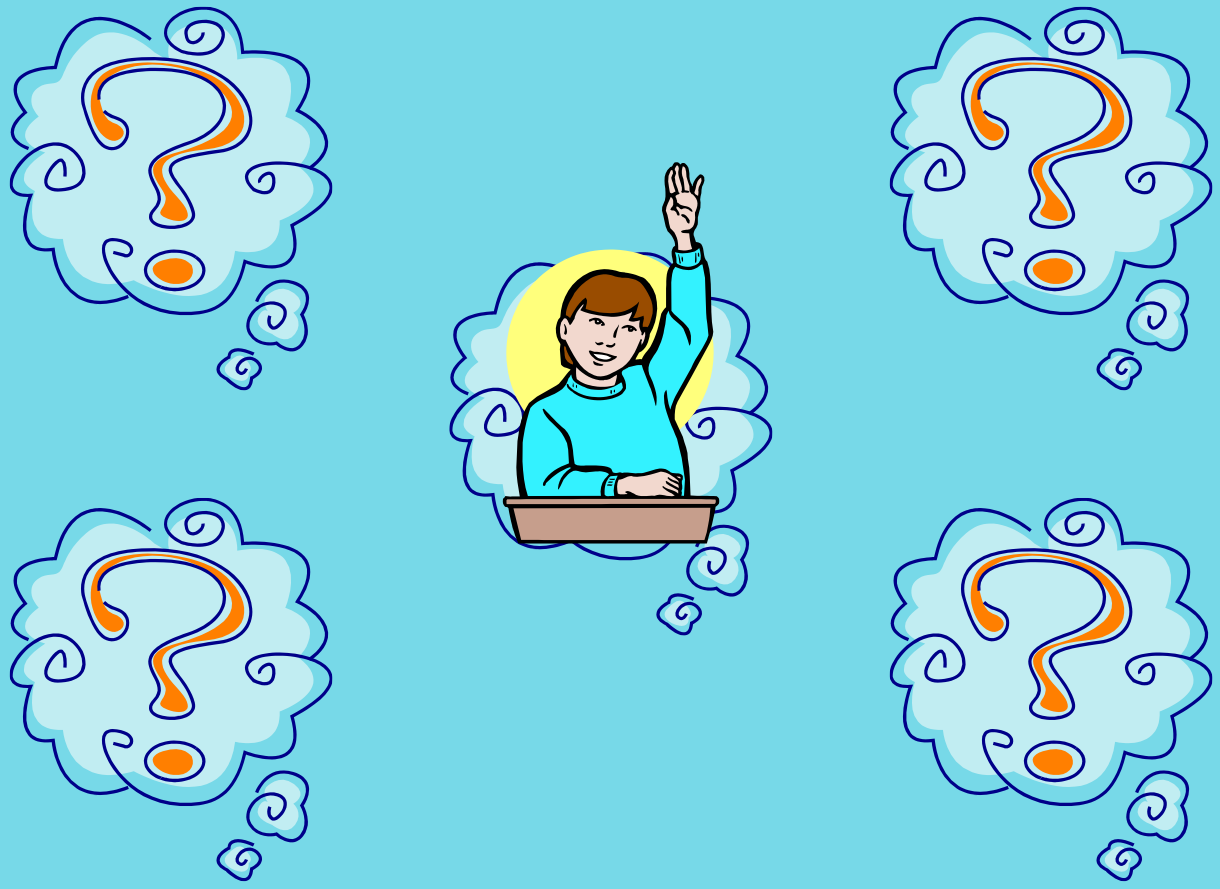
- Blood passing through the hemoconcentrator develops a high oncotic pressure as excess fluid is removed from it.
- 1/20: MUF blood flow / venous return to the lungs
  - 200 cc/min MUF flow : 4000 cc/min CO
    - High oncotic MUF blood diluted by the high volume of right heart blood
    - Relatively low oncotic blood goes to the lungs
    - No significant oncotic drag to remove water from lung tissue
    - Pulmonary benefits negligible
  - Typically 1- 4% hematocrit increase
  - Clotting factors minimally concentrated
    - +/- reduced bleeding

Adult MUF: Pulmonary effects can be improved

- After CPB, patient osmolarity = 300 mosmoles
- Residual circuit volume = 1 L @ 300 mosmoles
- Add 50 mEq/L NaHCO3 or 2 gm/L mannitol to circuit
  - Increases residual circuit fluid osmolarity to 400 mosmols/L
- 200 mls/min MUF blood (400 mosmols/L) + 4000 mls/min patient blood (300 mosmols/L) passing through the right heart to the lungs
- Pulmonary artery blood osmolarity increases from 300 to 305
- Osmotic drag removes 67 mls/min fluid from lung tissue
- Removes 335 mls from lungs in 5 minutes of MUF

- Also, can add 50% albumin (50-100 mls) to circuit volume.

Circuit Configuration: Cardioplegia, CUF and MUF



Questions