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HEART AND
VASCULAR CENTER
University of Iowa Health Care

UI Heart and Vascular Center

Principles of ECMO Physiology and Methodolgy:

Respiratory Therapy's Role in ECLS Patient Management

Ryan Frede RRT-NPS

Objectives

- Identify key concepts of ECMO methodology and physiology.
- Describe mechanical equipment used to perform ECMO
- Demonstrate an understanding of patient populations appropriate for ECMO support
- Review gas exchange physiology
- Identify and apply underlying principles necessary for proper patient respiratory management
- Recall medical and mechanical emergency strategies

Extracorporeal Membrane Oxygenation

Article Discussion Read Edit View history Search

Extracorporeal

From Wikipedia, the free encyclopedia

This article includes a list of references, related reading or external links, but **its sources remain unclear because it lacks inline citations**. Please improve this article by introducing more precise citations where appropriate. *(May 2011)*

This article **needs additional citations for verification**. Please help improve this article by adding reliable references. Unsourced material may be challenged and removed. *(May 2011)*

An **extracorporeal** medical procedure is a medical procedure which is performed outside the body.

Look up *extracorporeal* in Wiktionary, the free dictionary.

Circulatory procedures [edit]

A procedure in which blood is taken from a patient's circulation to have a process applied to it before it is returned to the circulation. All of the apparatus carrying the blood outside the body is termed the **extracorporeal circuit**.

- Hemodialysis
- Hemofiltration
- Plasmapheresis
- Apheresis
- Extracorporeal membrane oxygenation (ECMO)
- Cardiopulmonary bypass during open heart surgery.

Other procedures [edit]

Extracorporeal shock wave lithotripsy (ESWL), which is unrelated to other extracorporeal therapies, in that the device used to break up the kidney stones is held completely outside the body, whilst the lithotripsy itself occurs inside the body.

Extracorporeal radiotherapy, where a large bone with a tumour is removed and given a dose far exceeding what would otherwise be safe to give to a patient.[citation needed]

External links [edit]

- Extracorporeal Circulation. MedicalGlossary.org

Courtesy Wikipedia

Extracorporeal Life Support

FY2018 ELSO/ECMO Data

	# Patient	Survived ECLS	Percent	Survive to DC or Tx	Percent
NICU					
Resp	3	3	100%	1	33%
Cardiac	0	--	--	--	--
ECPR	0	--	--	--	--
PICU					
Resp	5	4	80%	4	80%
Cardiac	2	1	50%	0	0%
ECPR	5	4	80%	2	40%
Adult					
Resp	21	16	76%	14	66%
Cardiac	19	15	79%	8	42%
ECPR	0	--	--	--	--

2018 ELSO/ECMO
July Data Comparison
(Accumulative Data)

	# of Patients	Survived ECLS	Percent	Survive to DC or Tx	Percent	Patients	Survived ECLS	Percent	Survive to DC or Tx	Percent
Neonatal			UIHC					International ELSO		
Resp	53	40	75%	22	41%	30,934	25,990	84%	22,599	73%
Cardiac	35	15	42%	4	11%	7,794	5,063	64%	3,231	42%
ECPR	7	4	57%	3	42%	1,718	1,140	66%	694	41%
Pediatric										
Resp	27	15	55%	11	40%	8,820	5,953	67%	5,079	58%
Cardiac	36	23	63%	15	41%	10,462	7,177	68%	5,375	52%
ECPR	14	9	64%	5	35%	3,946	2,262	57%	1,643	42%
Adult										
Resp	107	72	67%	67	62%	16,337	10,857	66%	9,264	59%
Cardiac	79	48	60%	29	36%	15,942	8,865	55%	6,379	42%
ECPR	5	3	60%	2	40%	4,952	1,896	38%	1,381	29%
Totals	363	229	63%	158	43%	100,905	69,203	68%	55,645	56%

First ECMO Survivor

Prolonged extracorporeal oxygenation for acute post-traumatic respiratory failure (shock-lung syndrome). Use of Bramson membrane lung. Hill JD, O'Brien TG, Murray JJ, Dontingny L, Bramson ML, Osborn JJ, Gerbode F. N Engld J Med. 1972 Mar 23:286(12):629-34. 1971

What does ECMO do?

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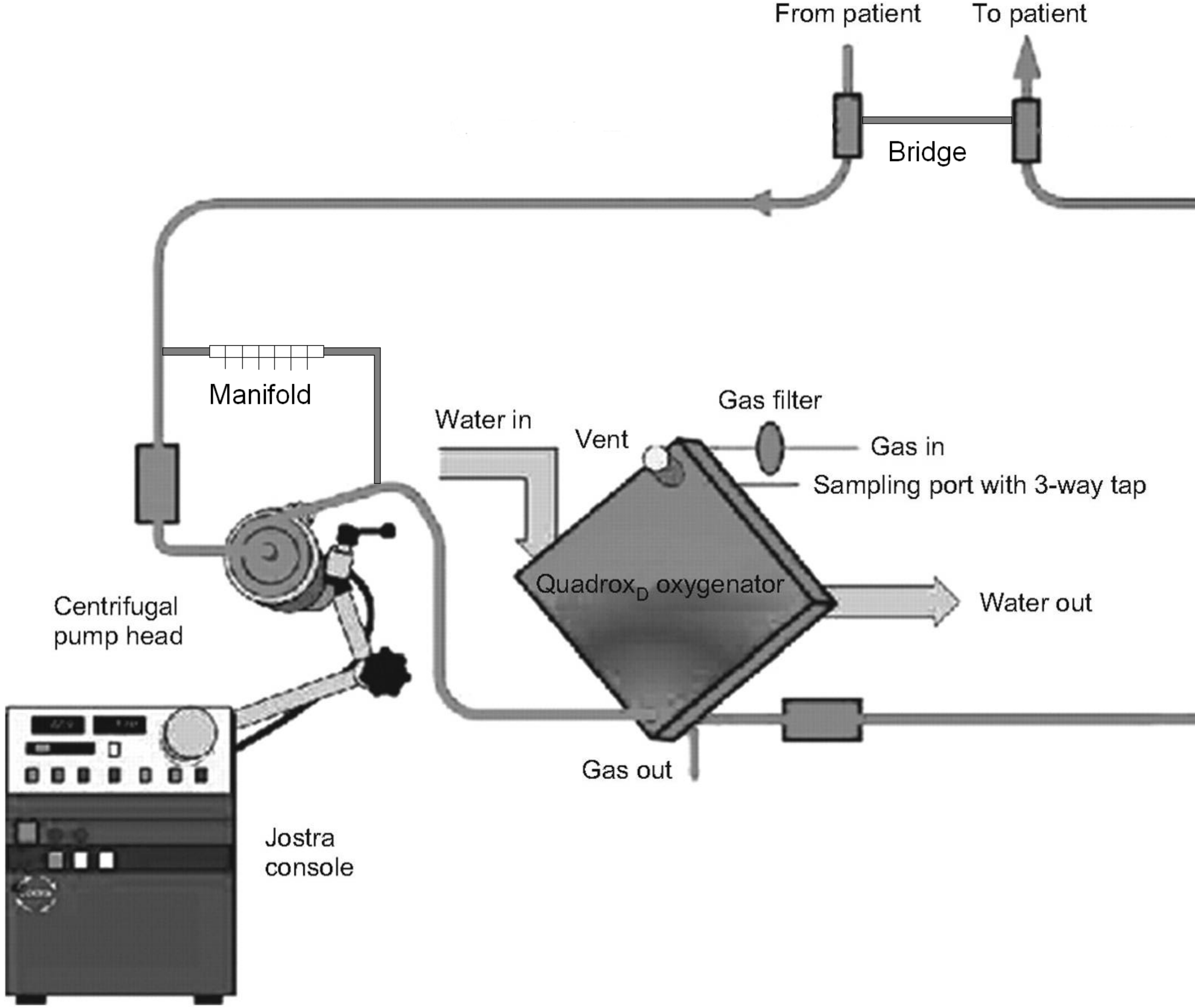
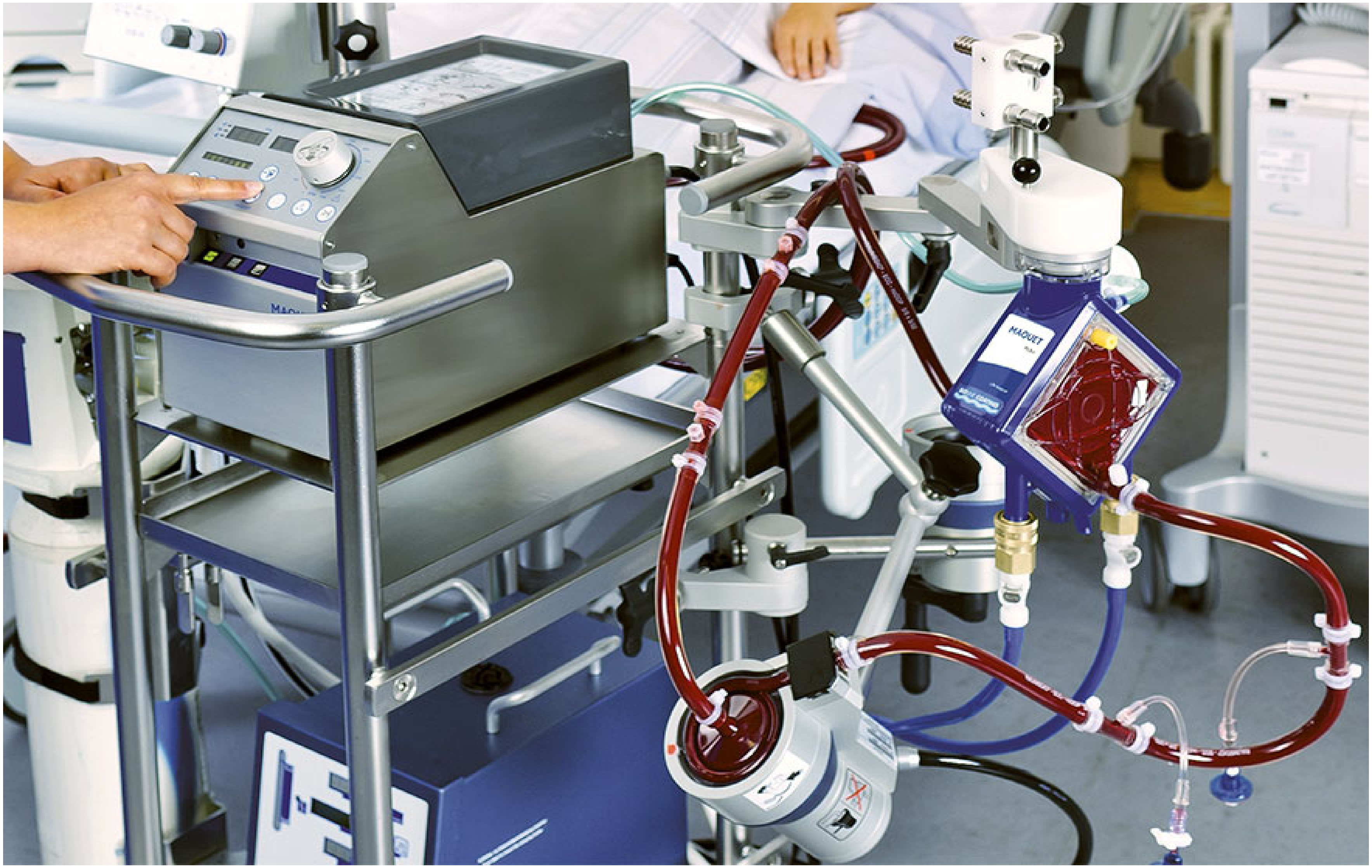
- The physiologic goal of ECMO is to improve tissue oxygen delivery, remove CO2, and allow normal aerobic metabolism to continue while lung/heart "rest" takes place.
- Provide cardio-pulmonary support during an acute, reversible, injury phase


From patient
To patient
Bridge
Manifold
Water in
Vent
Gas filter
Gas in
Sampling port with 3-way tap
Quadrox$_D$ oxygenator
Water out
Centrifugal
pump head
Gas out
Jostra
console


MAQUET


MAQUET
VAD
MECC
PALP

Types of ECMO

- **Venoarterial (V-A)**
  - Blood is drained from a **vein** to the ECMO circuit and is returned to an **artery.**
  - **Used for cardiac and respiratory failure patients**
- **Venovenous (V-V)**
  - Blood is drained from a **vein** to the ECMO circuit and is returned to a **vein.**
  - **Used only for respiratory failure patients**

Comparing the Two

VA

- Adds afterload
- Decreased PL
- Risk of arterial inflow, emboli
- Carotid ligation
- Central cannulation
- Deoxygenated blood to the lungs
- Only way to provide cardiac support
- SpO2 near **100%**
- Ideal SVO2 65-75%

VV

- In and out right side
- Double lumen cannulas
- Normal LV pulsation
- High R side pO_2 for PHTN
- No effect PL/AL
- Microemboli/air to lungs
- Oxygenated blood to the lungs
- Respiratory support
- SpO2 in the **70%'s**

VV ECMO: Pros and Cons

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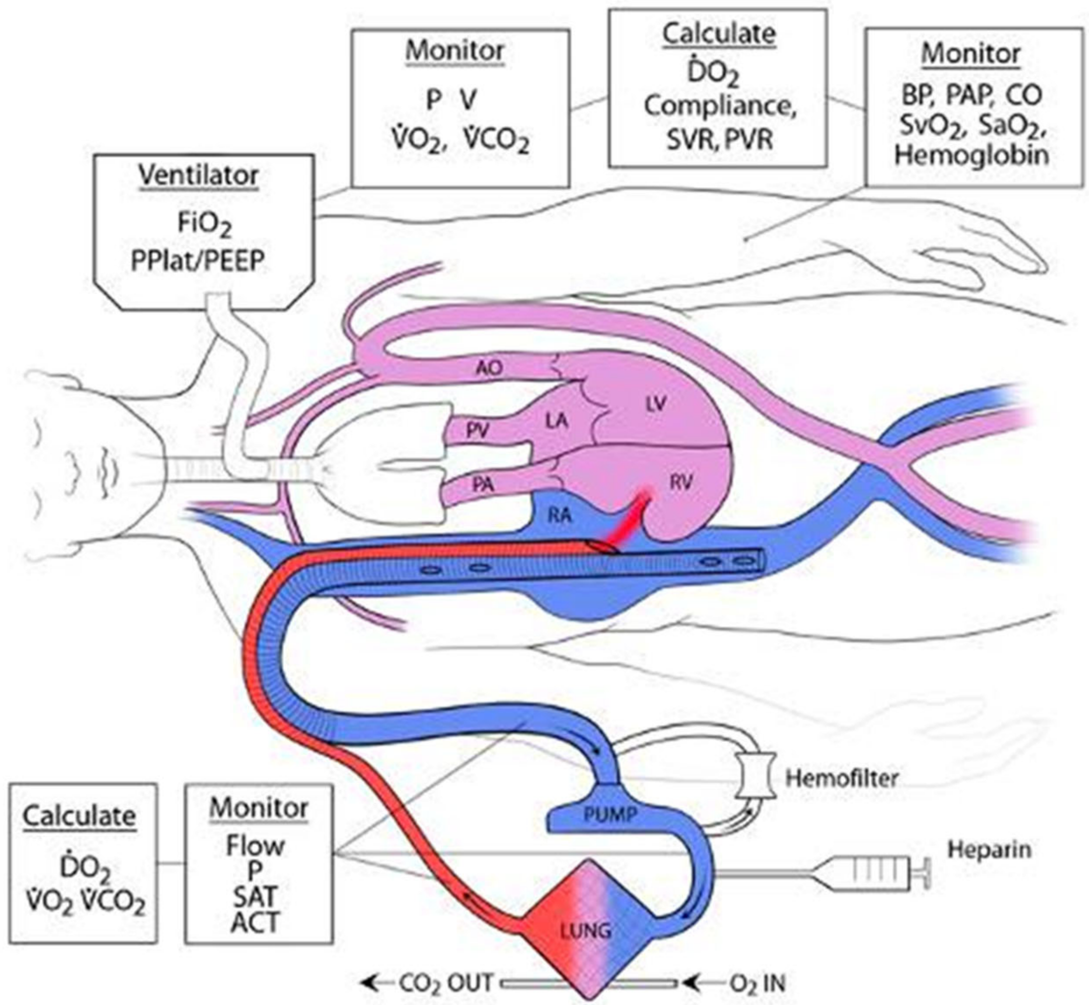
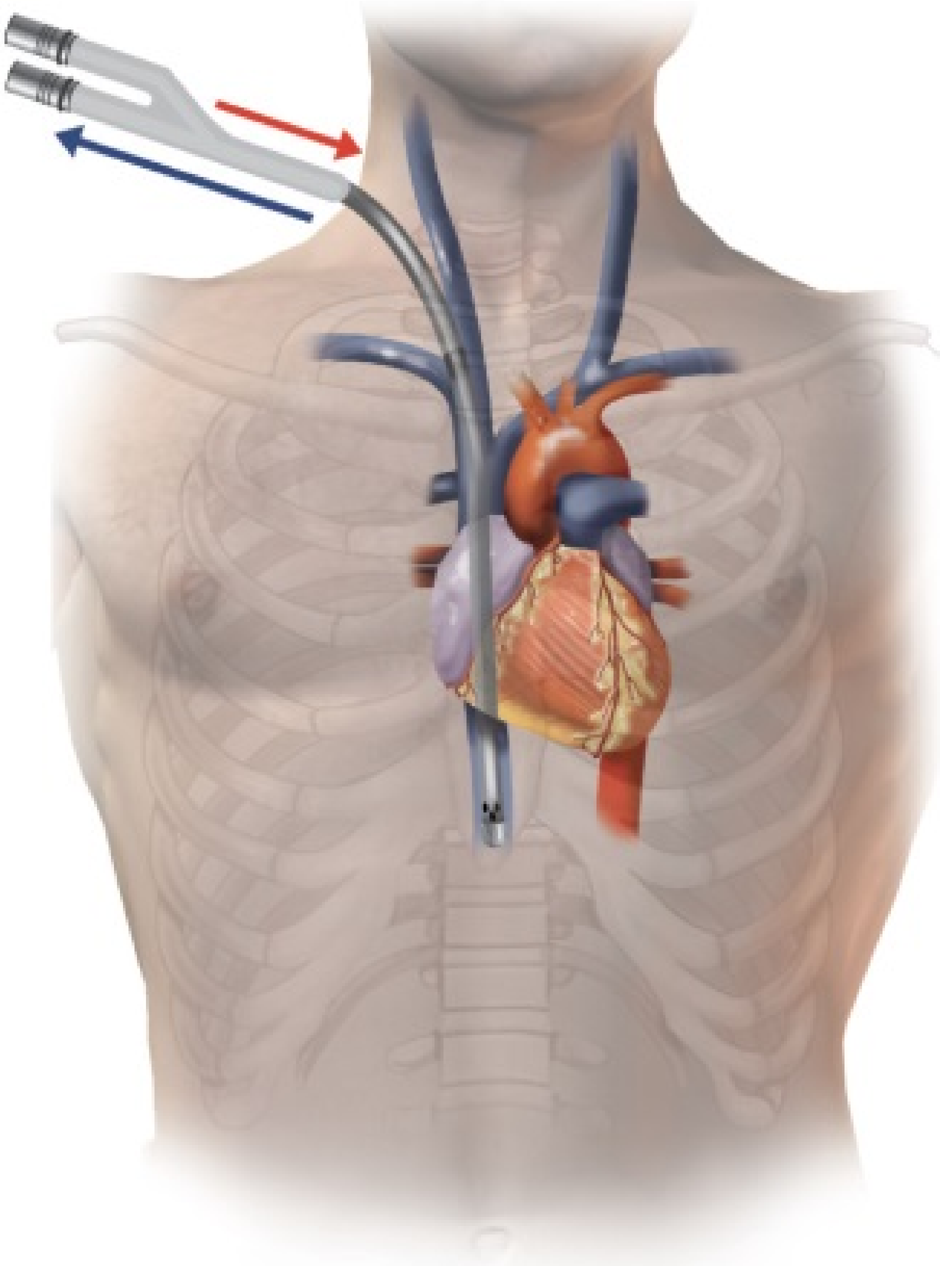
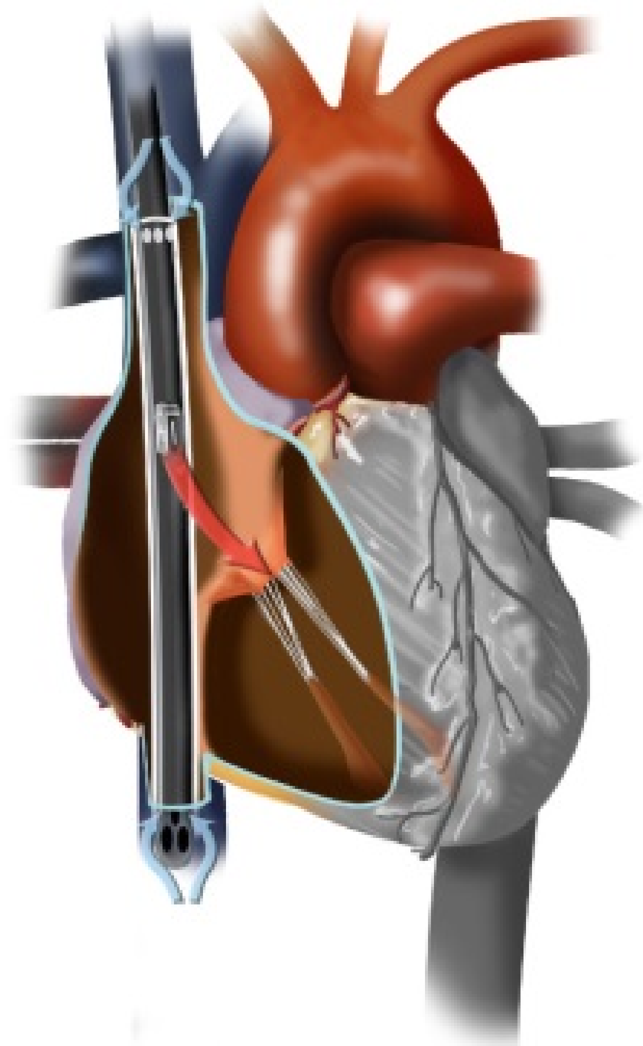
- VV ECMO is probably safer than VA ECMO.
- Single vessel cannulation
- Air and thrombo-emboli will go to the lungs to be absorbed
- Blood entering the cerebral arterial tree is less highly oxygenated and under less pressure. This difference may decrease the risk of neurological injury occurring with VA ECMO.
- The potential for ischemic injury to the lungs is decreased with VV ECMO.
- A disadvantage of VV ECMO is that it is not able to provide direct circulatory support.

VV ECMO



Monitor
P V
$\dot{V}O_2$, $\dot{V}CO_2$
Calculate
$\dot{D}O_2$
Compliance,
SVR, PVR
Monitor
BP, PAP, CO
SvO_2, SaO_2,
Hemoglobin
Ventilator
FiO_2
PPlat/PEEP
AO
LV
LA
PV
PA
RV
RA
Hemofilter
PUMP
Heparin
Calculate
$\dot{D}O_2$
$\dot{V}O_2$ $\dot{V}CO_2$
Monitor
Flow
P
SAT
ACT
LUNG
CO_2 OUT
O_2 IN





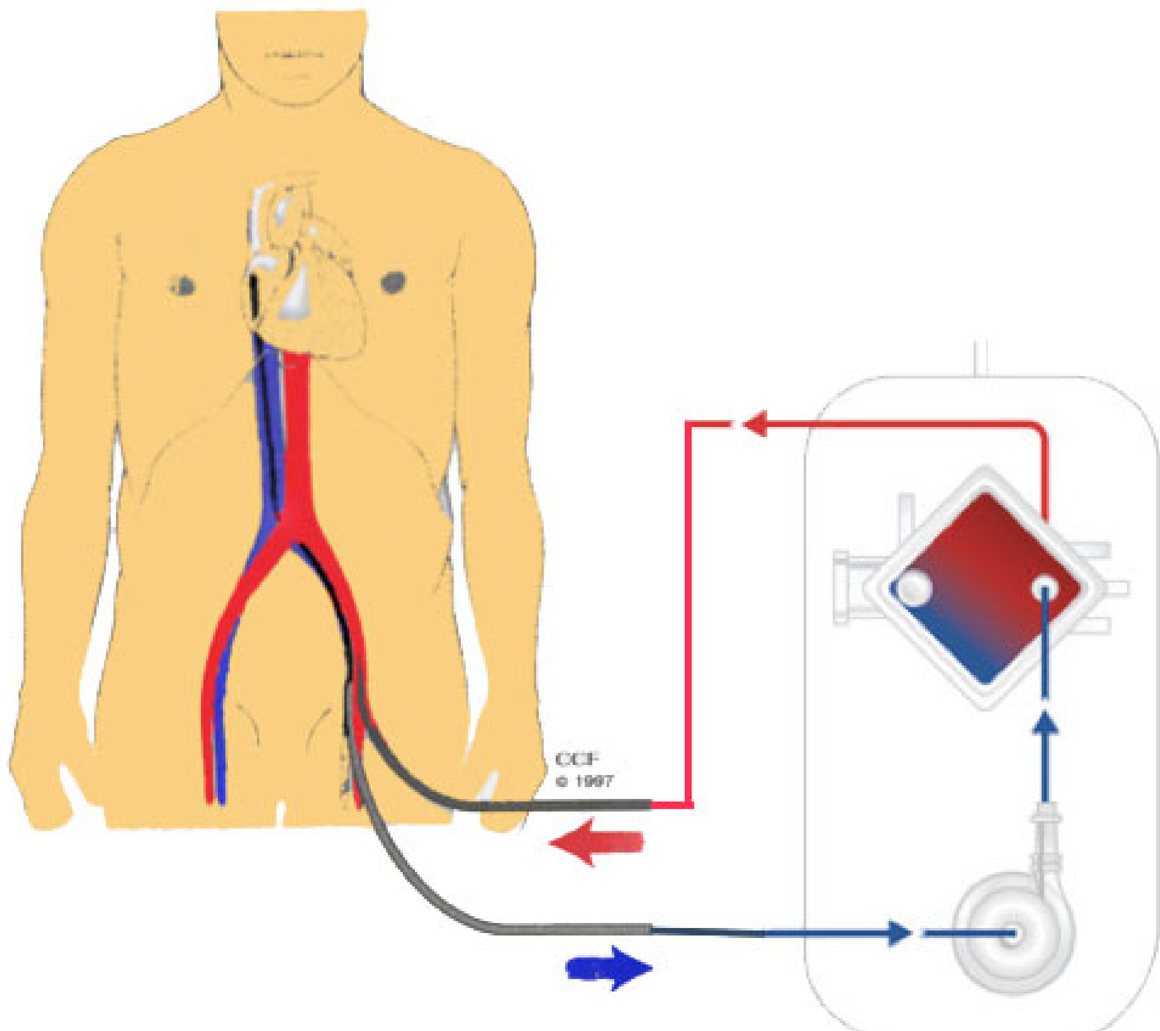
Recirculation

- The understanding of the concepts of recirculation is critical to successful application of VV ECMO
- Four factors that affect recirculation and oxygen delivery
  - **Pump flow**
  - **Catheter position**
  - **Cardiac output**
  - **Right Atrial Size/Intravascular Volume**

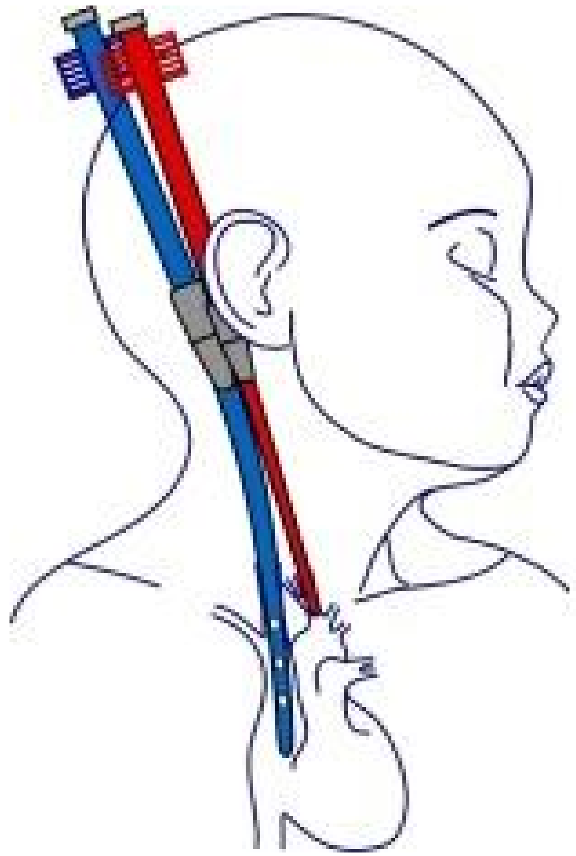
VA ECMO: Pros and Cons

- Non-pulsatile support
- Decrease arterial waveform with increased flow
  - Follow MAPS
- Watch for LV distention
  - Goal is to decompress the heart to allow healing
- Minimize afterload: Milrinone, Nipride, LV vent
- Indications of adequate support:
  - Urine output, SVO2, acid-base, lactate, serum creatine, LFTs

VA ECMO

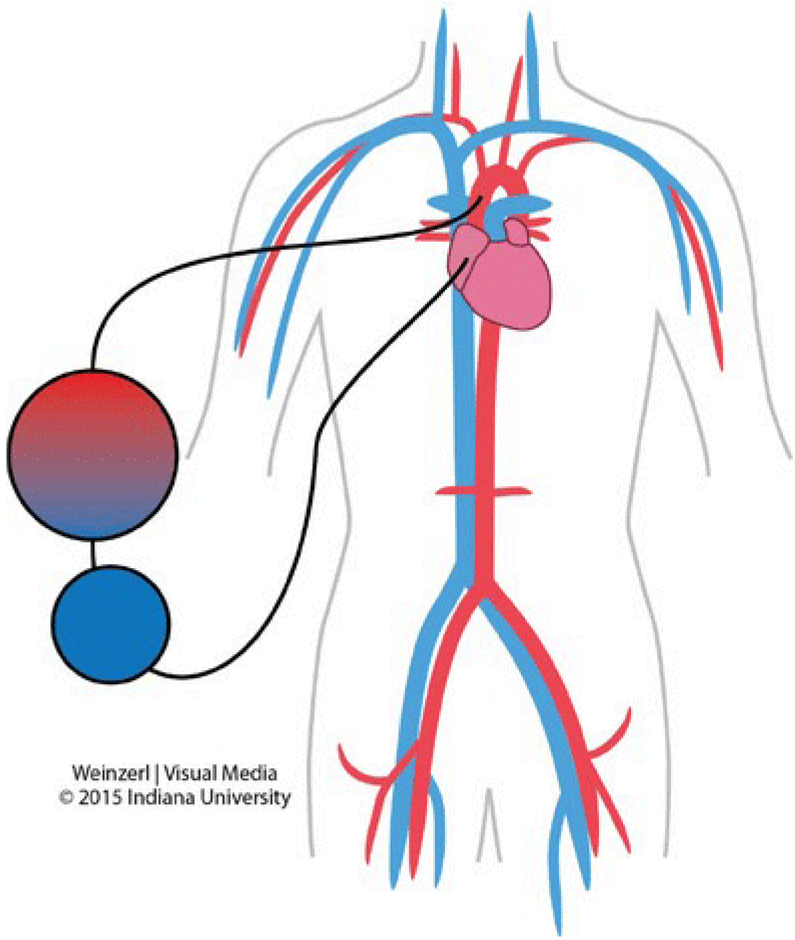


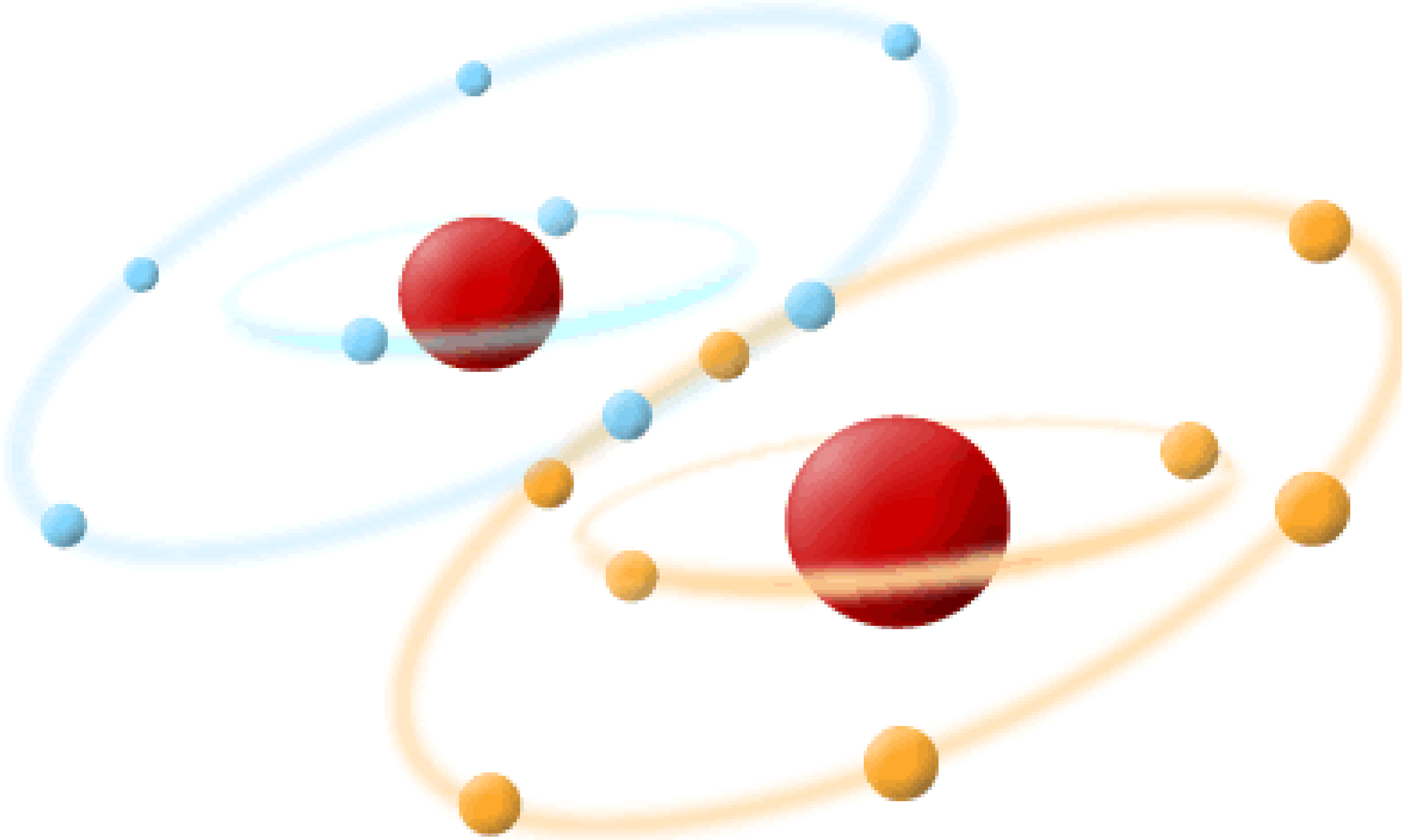
VA ECMO



VA ECMO

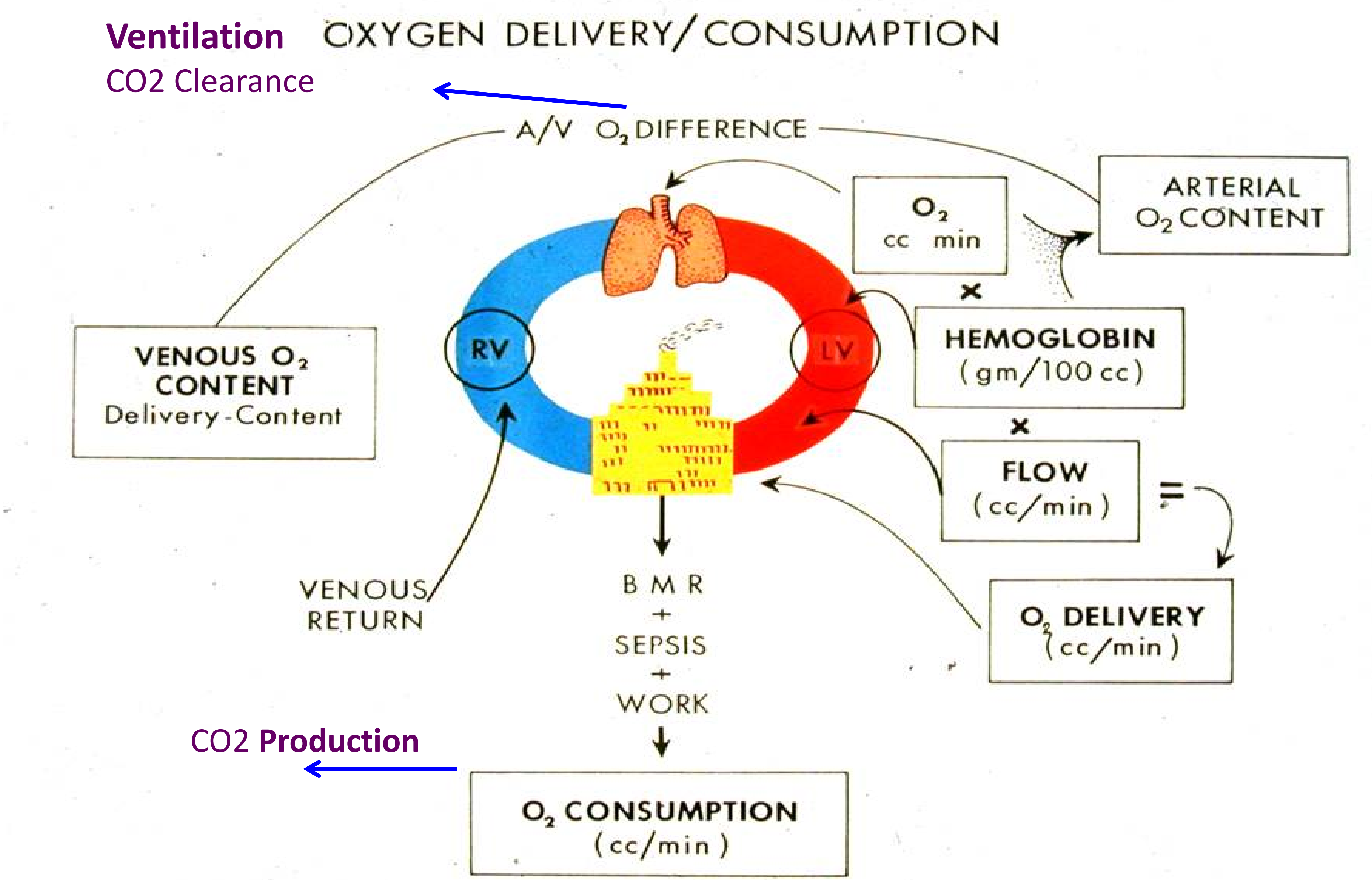
Central veno-arterial ECMO cannulation approach



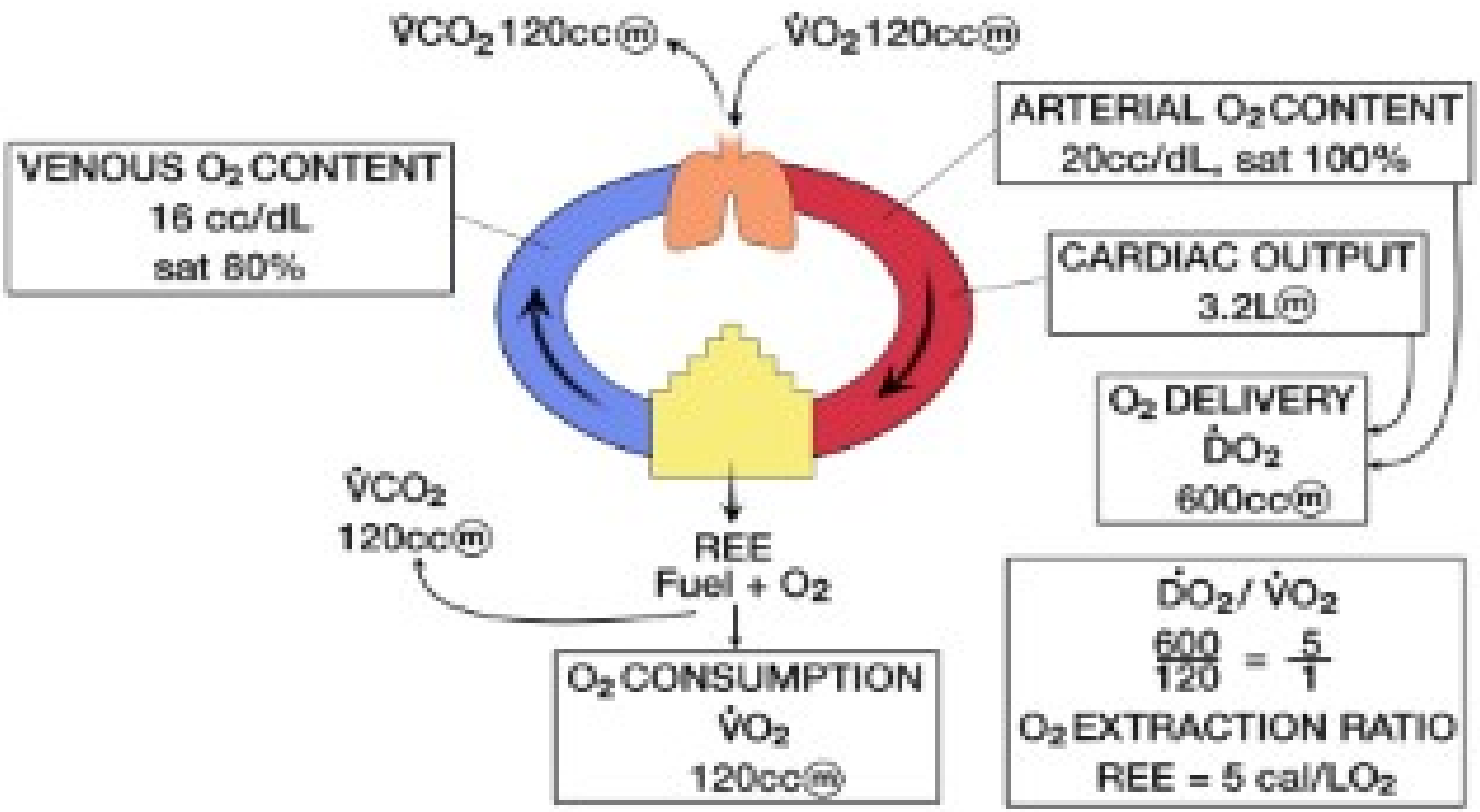


an oxygen molecule: O_2

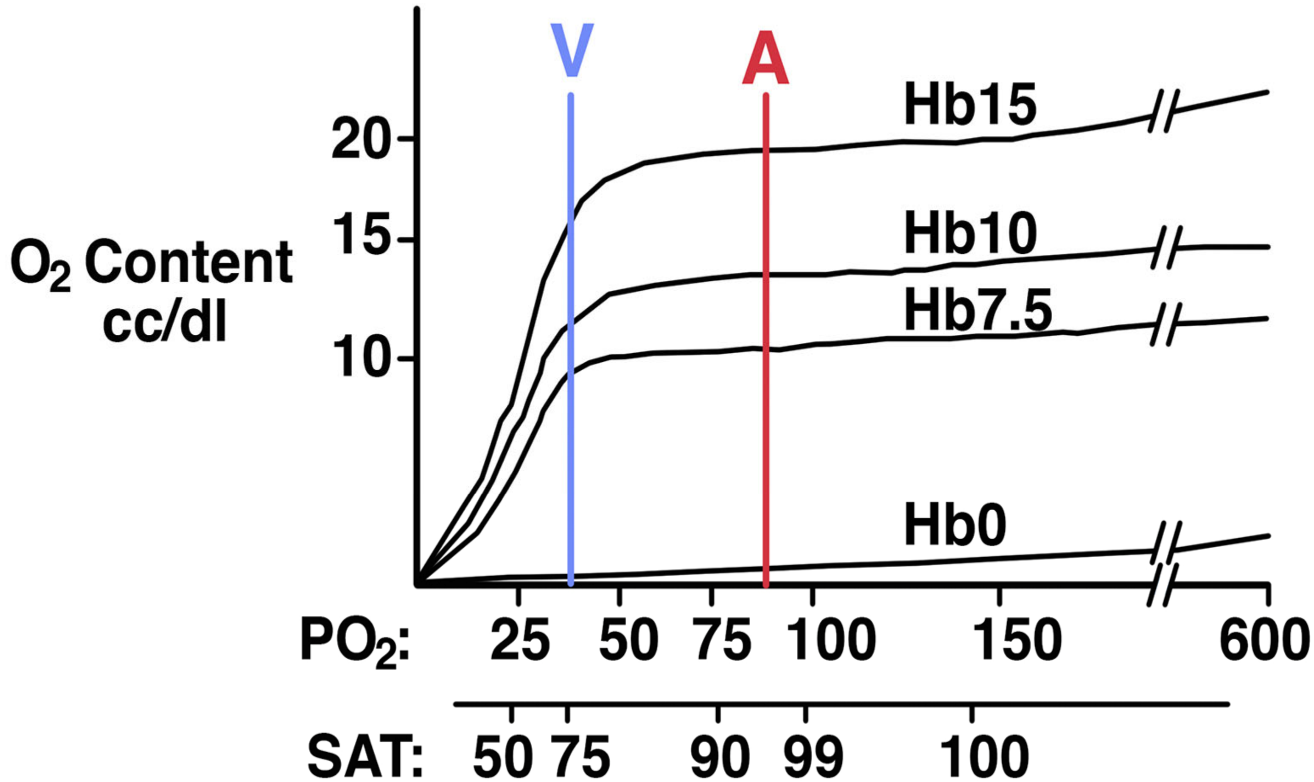
- Oxygen Content
- Oxygen Delivery
- Oxygen Consumption


Ventilation
CO2 Clearance
OXYGEN DELIVERY/CONSUMPTION
A/V O_2 DIFFERENCE
ARTERIAL O_2 CONTENT
O_2 cc min
×
HEMOGLOBIN (gm/100 cc)
×
FLOW (cc/min)
=
O_2 DELIVERY (cc/min)
RV
LV
VENOUS O_2 CONTENT
Delivery-Content
VENOUS RETURN
B M R
+
SEPSIS
+
WORK
CO2 Production
O_2 CONSUMPTION (cc/min)

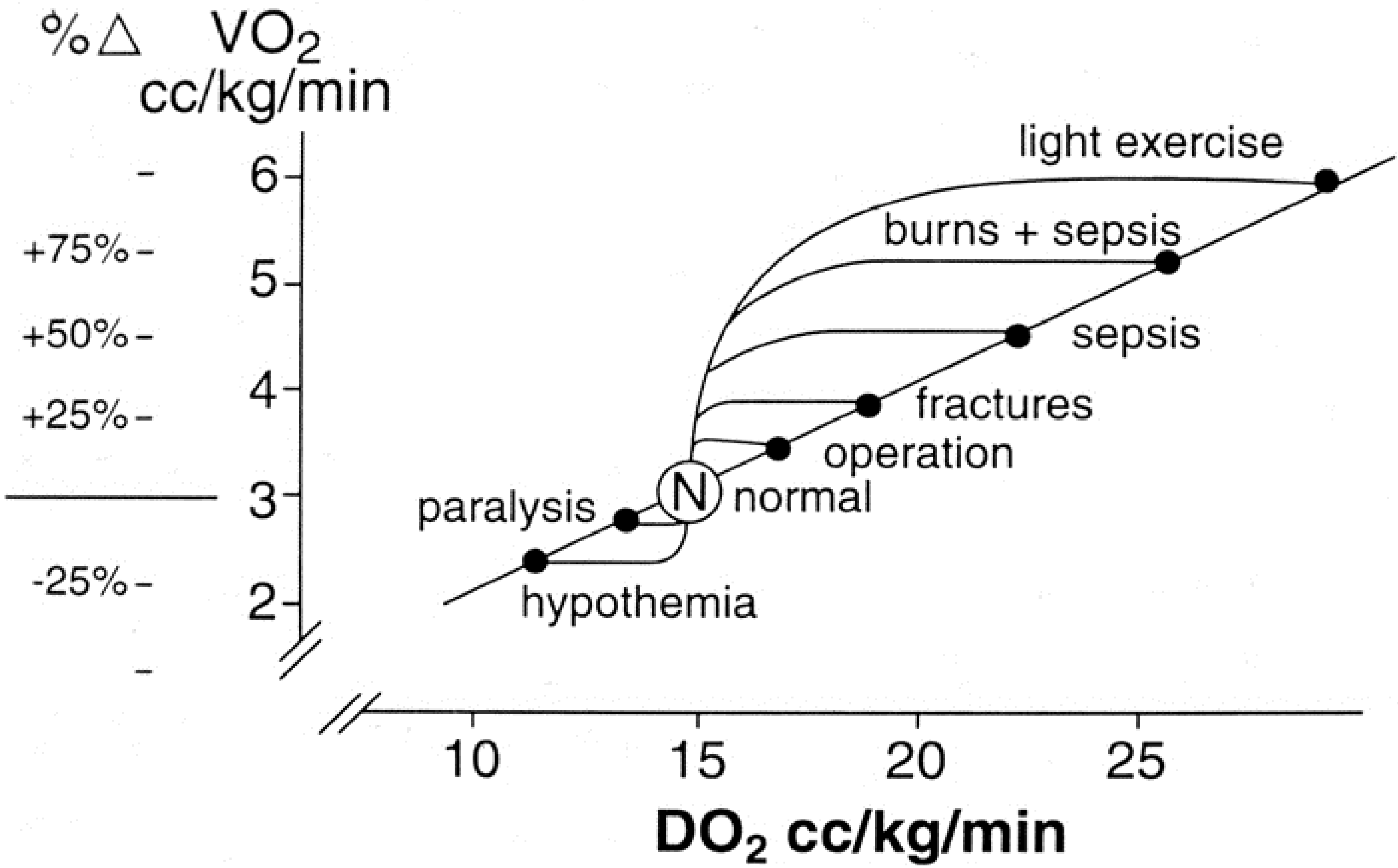
O_2 KINETICS

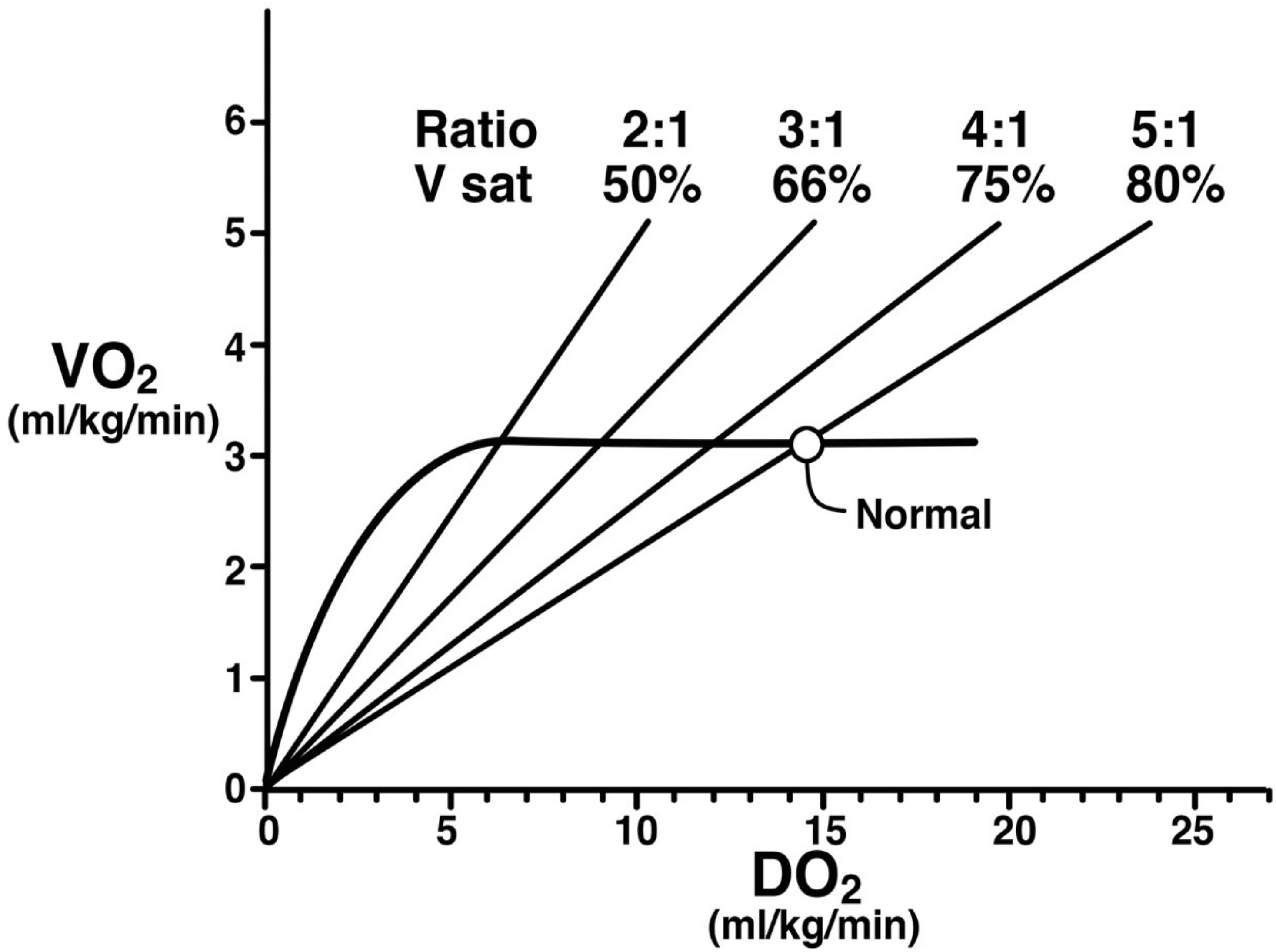

V̇CO2 120cc/m
V̇O2 120cc/m
ARTERIAL O2 CONTENT
20cc/dL, sat 100%
VENOUS O2 CONTENT
16 cc/dL
sat 80%
CARDIAC OUTPUT
3.2L/m
O2 DELIVERY
ḊO2
600cc/m
V̇CO2
120cc/m
REE
Fuel + O2
O2 CONSUMPTION
V̇O2
120cc/m
ḊO2 / V̇O2
600/120 = 5/1
O2 EXTRACTION RATIO
REE = 5 cal/LO2

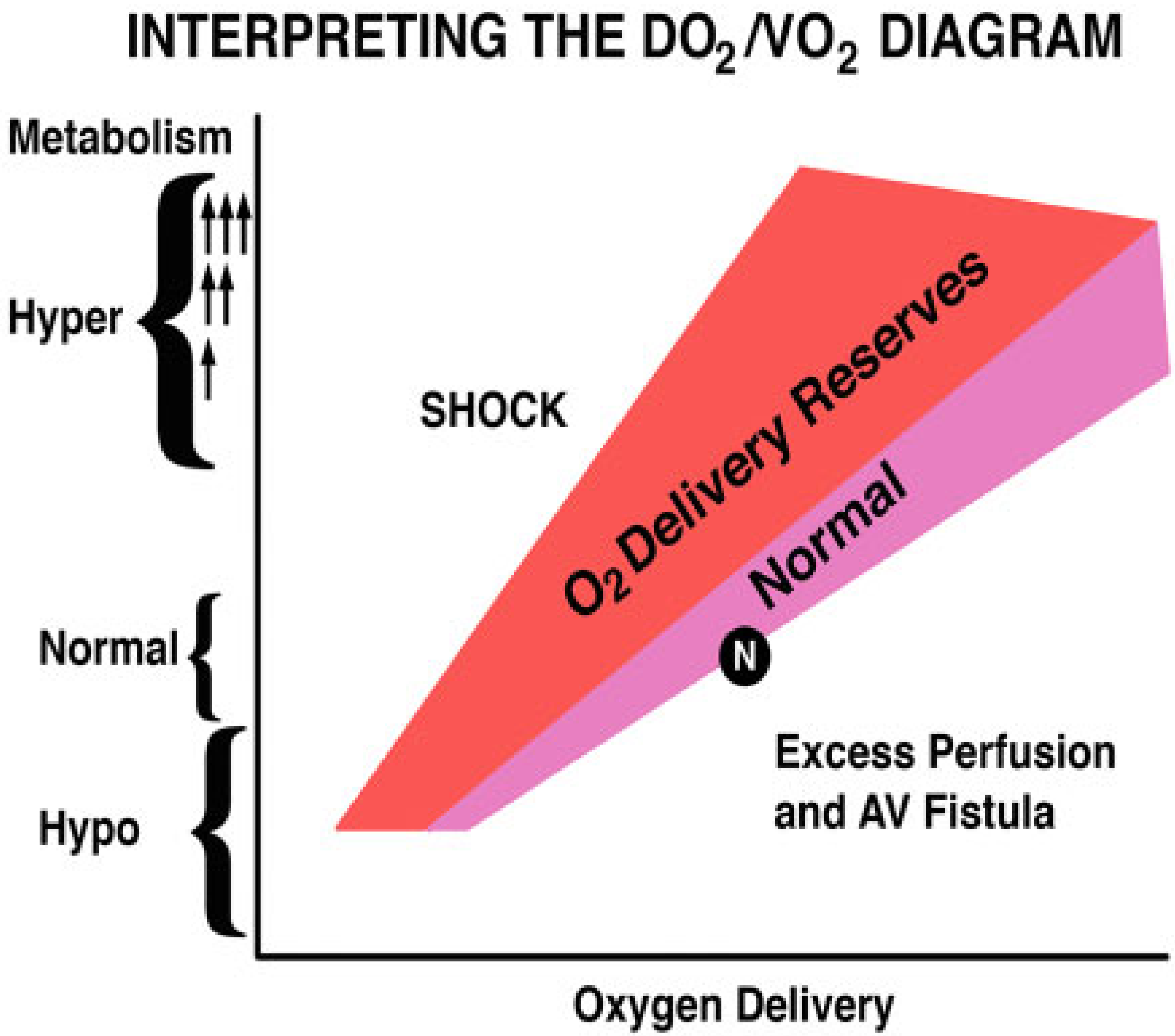
O_2 Content vs. PO_2 and SAT



O2 Content = Hb x % sat x 1.36 (plus dissolved O2)


%Δ
VO_2
cc/kg/min
+75%
+50%
+25%
-25%
6
5
4
3
2
light exercise
burns + sepsis
sepsis
fractures
operation
N
normal
paralysis
hypothemia
10
15
20
25
DO_2 cc/kg/min


Ratio
V sat
2:1
50%
3:1
66%
4:1
75%
5:1
80%
VO_2
(ml/kg/min)
6
5
4
3
2
1
0
Normal
0
5
10
15
20
25
DO_2
(ml/kg/min)


INTERPRETING THE DO2/VO2 DIAGRAM
Metabolism
Hyper
Normal
Hypo
SHOCK
O2 Delivery Reserves
Normal
N
Excess Perfusion
and AV Fistula
Oxygen Delivery

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DO_2/VO_2 Ratio

			SVO2
Normal	=	5:1	80%
Critical low point	=	2:1	50%
Ischema, shock, Supply dependency	=	< 2:1	

Ischemia time/dose can be quantitated

Gas Exchange on ECLS

Oxygen Delivery

- Native Lungs
  - Hemoglobin, Saturation, Cardiac Output
- Membrane Lung
  - Rated Flow
  - Circuit Design based on Total Support

CO_2 Removal

- Native Lungs
  - Volume, Respiratory Rate
- Membrane Lung
  - Membrane Surface Area
  - Sweep Gas
  - Unrelated to Blood Flow

Flow

Rules to LIVE by:

- $PaCO_2$ is related to the rate of sweep gas flow
  - Increasing sweep gas will decrease PCO_2
  - Decreasing sweep gas will increase PCO_2
- PaO_2 is related to your pump flow
  - Increasing pump flow should increase PO_2
  - VV ECMO: Oxygen Content
  - VA ECMO: Oxygen Delivery

Indications for ECMO

- Offered to patients who have reversible respiratory and/or cardiac failure that is unmanageable using maximum medical and pharmacological strategies
- Bridge to recovery, transplant, device, or decision.

Indications for ECMO

- 1. In hypoxic respiratory failure due to any cause (primary or secondary) ECMO should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of 80% or greater.
  - $PaO_2/FiO_2 < 80$; OI >30; Murray Score >3; $FiO_2 > 0.9$; PEEP ≥ 15
  - If you're considering proning/paralyzing a patient, you should be considering ECMO.

Indications for ECMO

- 2. CO_2 retention due to asthma or permissive hypercapnia with a $PaCO_2 > 80$ or inability to achieve safe inflation pressures ($P_{plat} \leq 30$ cm H_2O) is an indication for ECMO.

- 3. Severe air leak syndrome

Indications for ECMO

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- Serious systemic hypotension
- Acute hypoxemia (cardiac related)
- Cardiogenic shock with
  - Hypotension requiring inotropes
  - Low cardiac output despite adequate intravascular volume
  - Intraaortic balloon counterpulsation, if appropriate.
  - Myocardial stun
- Bridge to transplant via other assistive device.

Pediatric Indications

- Cardiac surgical population
  - Pre-op stabilization
  - Failure to wean from bypass
  - Low cardiac output syndrome
- Non-surgical
  - ECPR
  - Myocarditis, cardiomyopathy, arrhythmias, pulmonary HTN
  - Respiratory illnesses
  - Pulmonary hemorrhage

Neonatal Indications

- PPHN
- Meconium Aspiration
- Severe air leak syndrome
- CDH

Contraindications

- Incurable malignancy
- Advanced MSOF
- Extreme prematurity
- Severe CNS injury
- *Special consideration for non-transplantable cases

Pulmonary management on ECMO

Repeat after me…..

LUNG

REST

- Minimize FiO_2, PIP (distending pressure), and plateau pressure.
- Attempt to decrease WOB (P 0.1)
- Utilize any mode (PC, VC, PS, PRVC, BiVent, HFOV)
- Diuresis/CRRT
- Pulmonary toilet (suctioning, bronchoscopy)
- Extubation
- Early tracheostomy
- DO NOT attempt lung recrtuitment during the first 48 hours

Determining Adequacy of Support

- Blood gas and SpO2
- SVO2
- Lactate
- VA: BP (MAP)
- Assess your patient

Pre-, Post-, and Patient gas….WHAT?

- We compare all three gases.
  - Pre-ox gas CO_2 to patient CO_2
    - Trending CDI
  - Pre-ox gas to post-ox gas
    - CO_2 and PaO_2
    - Still have clearance?
    - 10 torr difference for CO_2
    - Post-ox PaO_2 >90

Practice makes Perfect!

- Your patient is a 70kg Influenza on VV ECMO on rest vent setting + the following ECMO settings:
- Pump flow of 4.2L
- Sweep gas 8L
- Pump FiO_2 100%
- Acceptable ranges of blood gases are Patient PO_2 40-80, PCO_2 30– 50, and Post Membrane PO_2 90 – 400

	Patient	Pre	Post
pH	7.32	7.31	7.40
PCO2	59	58	41
PO2	45	40	537
BE	+5	+5	+5
Sat	84%	78%	100%

VA Physiology

- Factors to consider:
  - Native cardiac output
  - Cannula position

femoral cannulation

central cannulation

When can we come off ECMO? (VV Support)

- Have the lungs improved?
  - Chest x-ray?
- Can the patient tolerate stimulation/activity?
  - Svo2?
  - Saturations?
- Pump flow and sweep
  - As patients lungs start to do more work the patient will require less pump flow and sweep.
- Trial offs are easy…shut off sweep/clamp gas line.
  - May need to increase ventilator settings a little during trial.


SportsArt

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When can we come off ECMO? (VA support)

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- Has the cardiac function returned/improved?
- Wean pump flow to minimum that circuit requires
  - ¼" circuit typically 200cc/min
  - 3/8" circuit typically 500cc/min

- Hoffman clamp applied to bridge
  - Once minimal flow established to circuit

    begin slowly opening the Hoffman clamp
- Hoffman clamp vs. clamp off trial
- Per policy we don't wean sweep or FIO2
  - Single ventricles Hoffman wean to clamp off

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Coagulation Management

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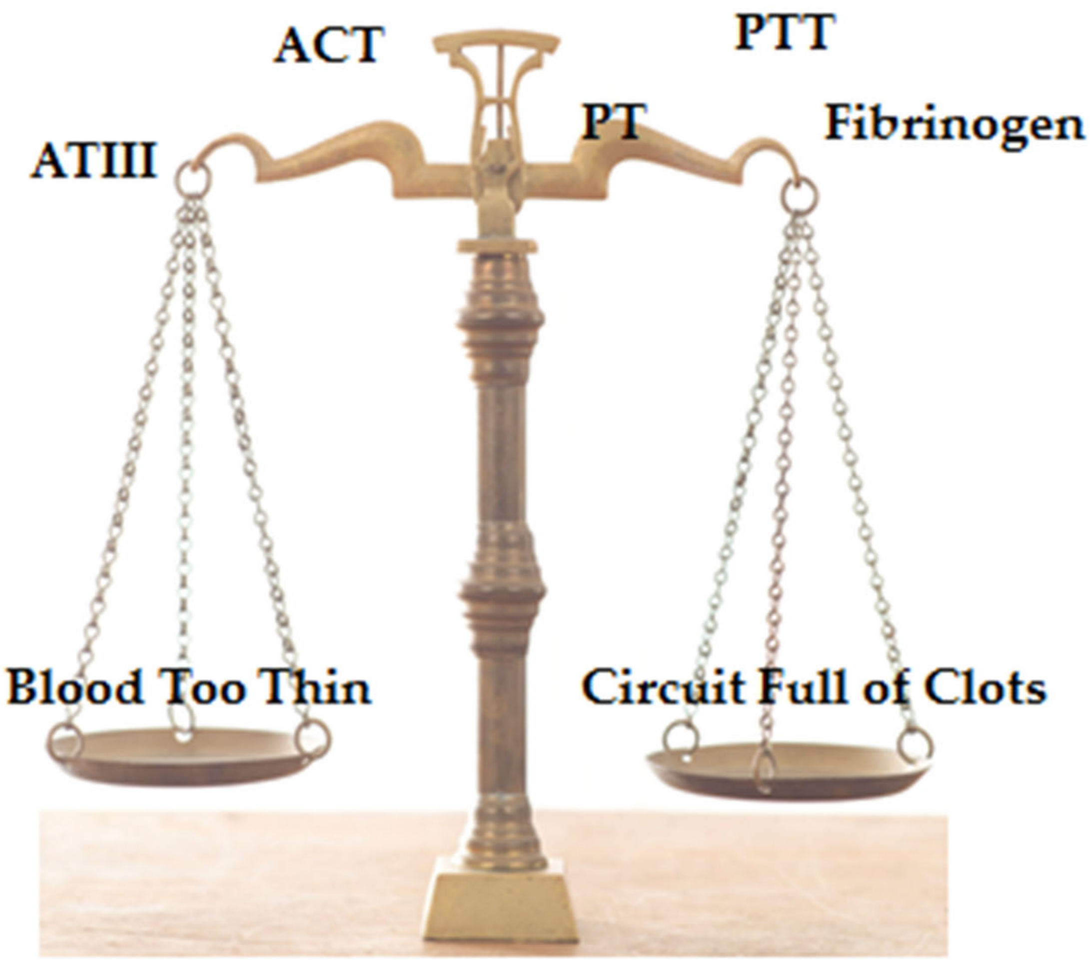
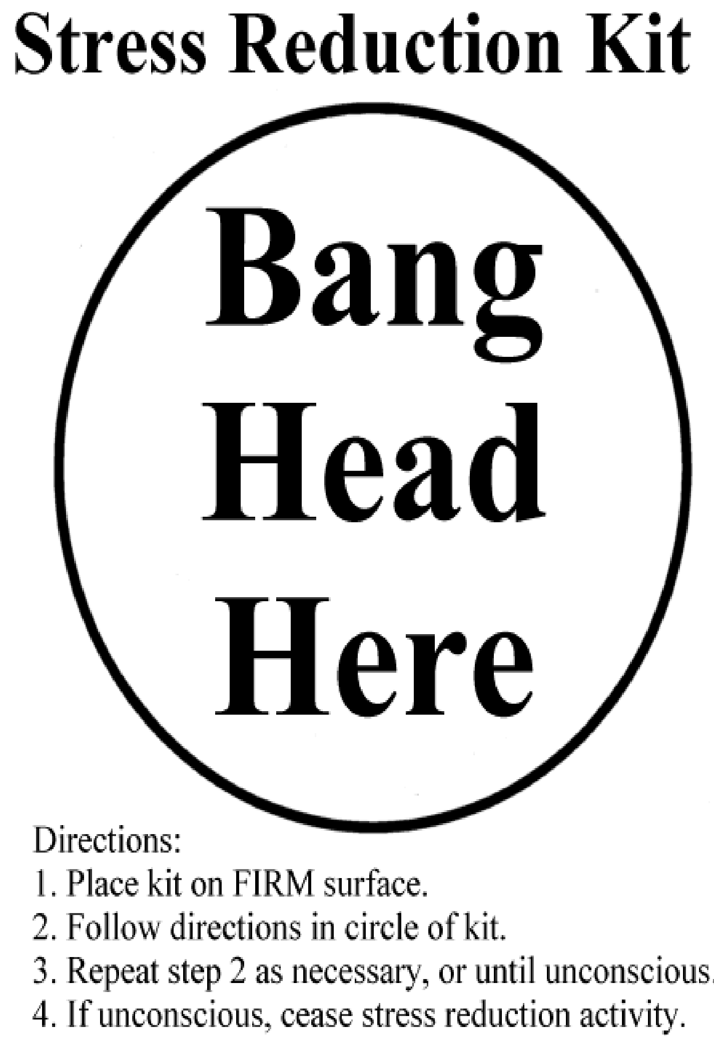


Procoagulant vs. Anticoagulant

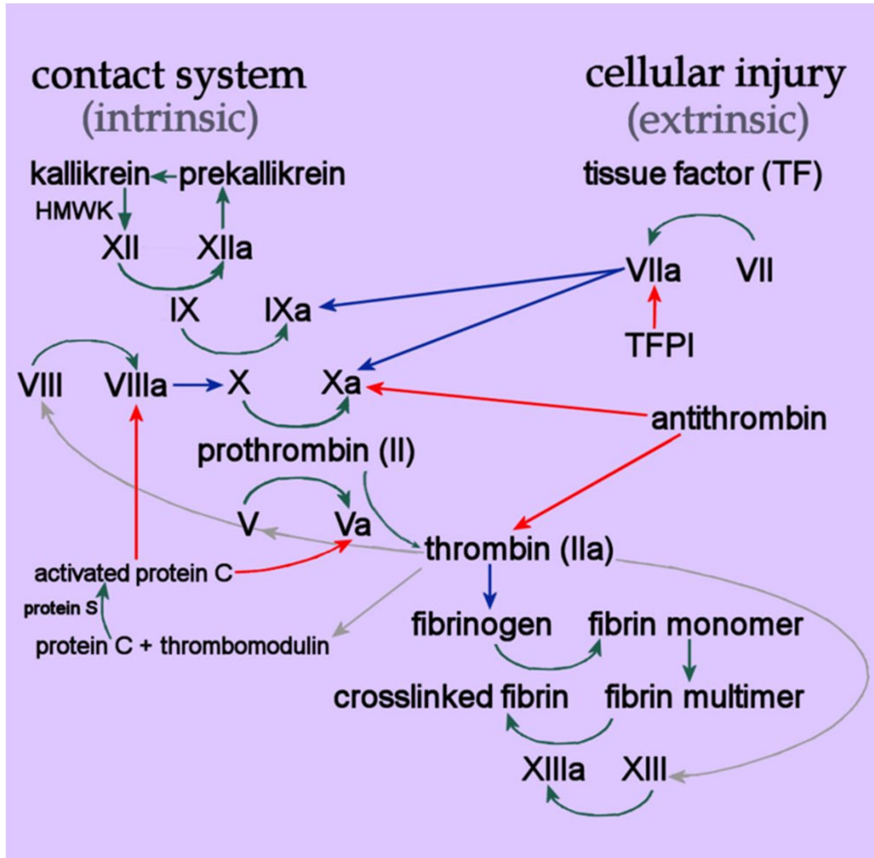
- Continuous contact between circulating blood and the foreign surface of the circuit initiates coagulation. (***Procoagulant Activity***)
- In an attempt to minimize this activity and prevent thrombosis in the ECLS circuit and exogenous anticoagulant (heparin) is necessary. (***Anticoagulant Activity***)



Testing

- Activated Clotting Time (ACT)
- Antithrombin III (ATIII)
- Heparin Assay (Anti-Xa)
- Prothrombin Time (PT)
- Partial Thromboplastin Time (PTT)
- Fibrinogen
- Thromboelastograph (TEG)

Clotting Cascade



Heparin

- Action:
  - Accelerating the action of antithrombin
  - Inhibit thrombin and factor Xa
- Average Heparin infusion rate 10-30 u/kg/hr
- Heparin is <u>dependent</u> on circulating antithrombin for most of its anticoagulant activity.

Bleeding

- Most common complication
- Anticoagulation, platelet dysfunction
- Prevention
  - No subcutaneous therapies
  - Try not to remove or add lines once on ECMO
  - Suctioning, ng tubes, foleys...
- Communication is key!

This patient is being continuously anticoagulated with

Heparin *for the purpose of ECMO*

- **NO** subcutaneous injections
- **NO** finger/heel sticks for point of care testing
- **DO NOT REMOVE** intravascular devices or any modes of therapy that may cause bleeding
- **Swabs ONLY** for oral care. Use toothettes and gentle suctioning. Assess for risk of bleeding with oral pharyngeal suctioning. (*N-11.046*)
- **HOLD** PO anticoagulants
- **If you have any questions, please speak with your bedside** ***ECMO Specialist***

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Emergency Management

sucking air, squirting blood, pump failure, accidental decannulation

Protect the Cannulas and the ECMO Circuit

- Discourage approach to the cannula side of the patient
- If someone must approach from the cannula side of the patient…STAND GUARD!!!
- Watch cannulas closely when doing physical cares of all kinds
- Get help…you should guard the cannulas and delegate the cares to others if the ES is unable to guard them
- Obtain approval from the ES before moving the patient
- Always have plenty of help and a doctor's "OK"/order for patient activity/cares

How do we stay prepared to care for these complex patients.....

- Ask yourself these questions every time you take care of an ECMO patient.
  1. How do I protect the patient in the event of an emergency?
  2. Will this patient code during an ECMO emergency?
  3. How can I assist the ECMO specialist until more help arrives?

How do I Protect the Patient?

- In the event of a circuit disruption (***blood escaping from the system, air entrained in the circuit, a mechanical failure or an accidental decannulation***) how do I protect the patient?

AVB to remove a patient from ECMO

- ***Arterial line***
- ***Venous line***
- ***Bridge***

Will this Patient Code?

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- Pressors should be readily available
- Have volume readily available: Albumin, NS, blood.
- Compressions or no compressions??
- Shock or no shock??
- Emergency Vent Settings

- Emergency Vent Settings
  - Discussed with Staff/Fellow physicians when patient is initiated onto ECMO
  - Should attempt to be adequate to support patient in the event of ECMO emergency
  - Should be put into orders as a note under the current vent orders
  - Should be written and taped onto ventilator

Conclusion

- ECMO is an effective support therapy for patients in severe respiratory or cardiac failure.
- VA and VV ECMO have distinct risks and benefits.
- The physiology of gas exchange is the key to ECMO.
  - Oxygent content
  - Oxygen delivery
  - Oxygen consumption

Conclusion

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- Pump flow affects oxygenation. Sweep flow affects CO_2 clearance.
- Indications/contraindications of ECMO – It’s a bridge, not a treatment.
- RT’s play a key role in initiation, daily and emergency management, and discontinuation of ECMO support.
- Don’t be afraid to be a patient advocate…ask questions, be involved, communicate.

Thank you!

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