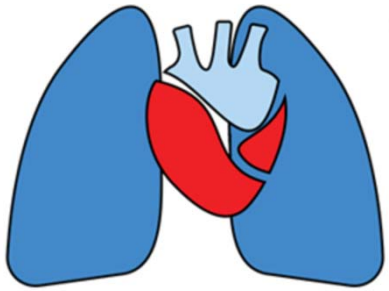

ECMO

ATS Fellows Track Symposium

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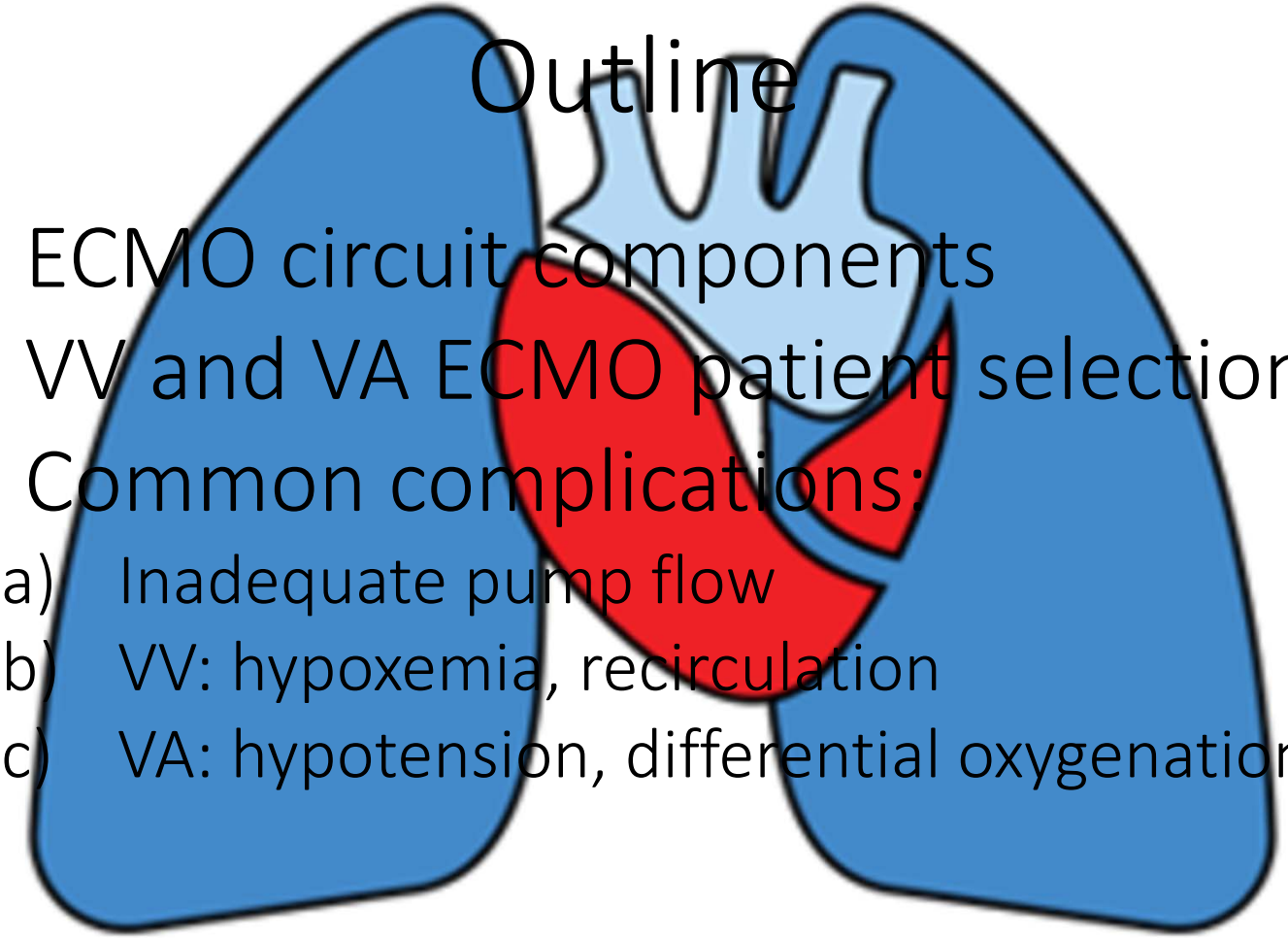
No Disclosures

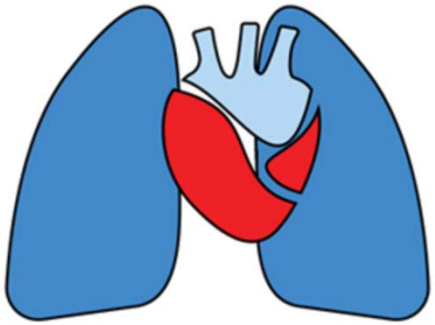
Outline

1. ECMO circuit components
2. VV and VA ECMO patient selection
3. Common complications:
    a) Inadequate pump flow
    b) VV: hypoxemia, recirculation
    c) VA: hypotension, differential oxygenation



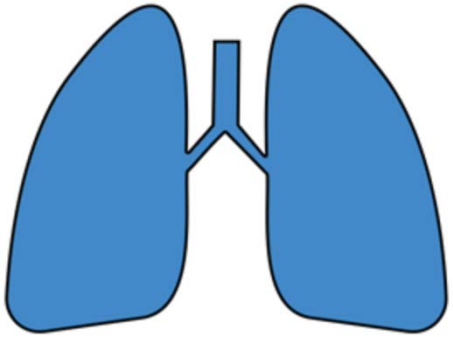
Circuit Components

Veno-arterial (VA)



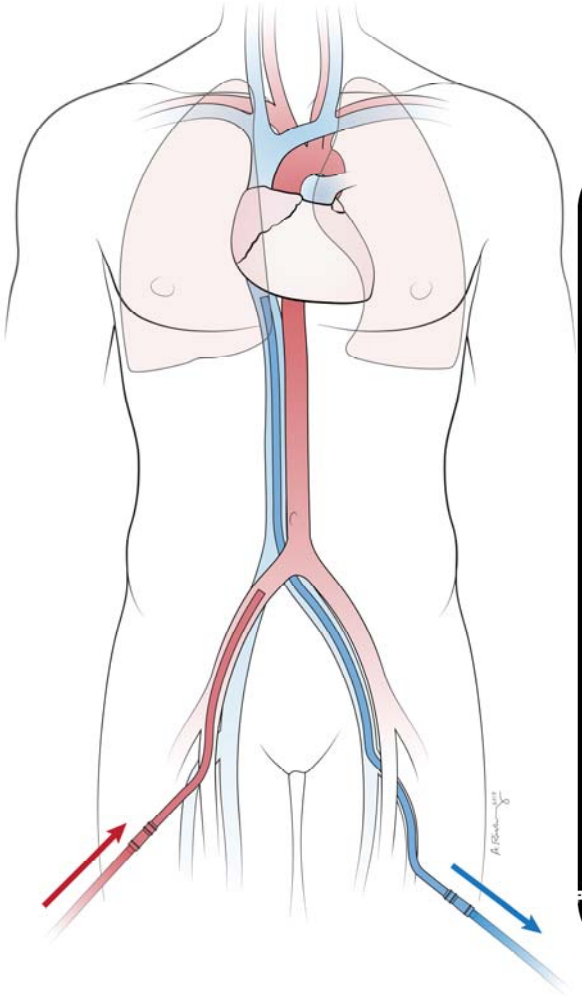
Venous → Pump → Gas Exchange → Arterial

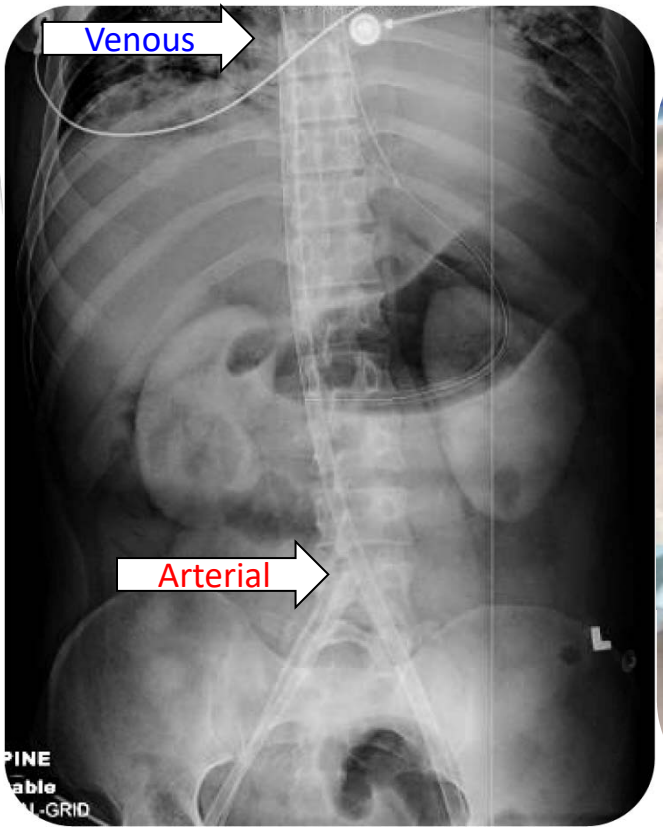
Veno-venous (VV)

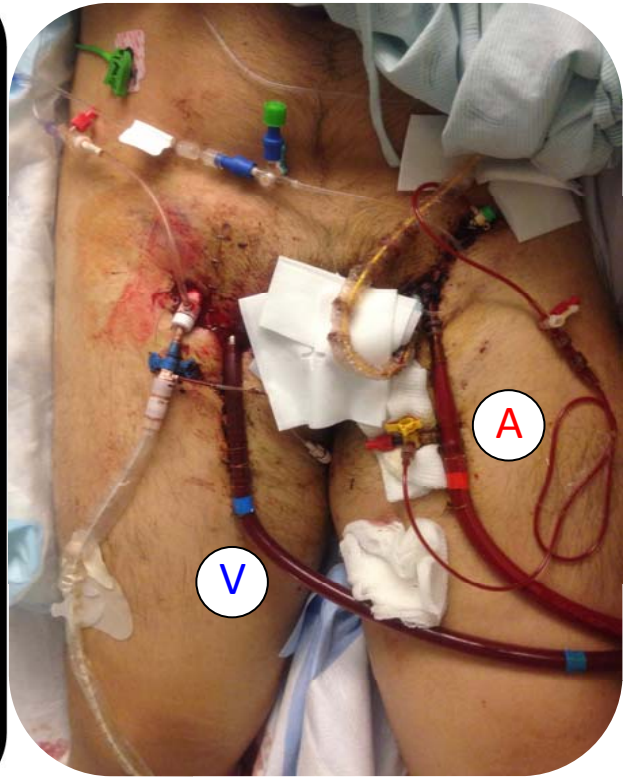


Venous → Pump → Gas Exchange → Venous

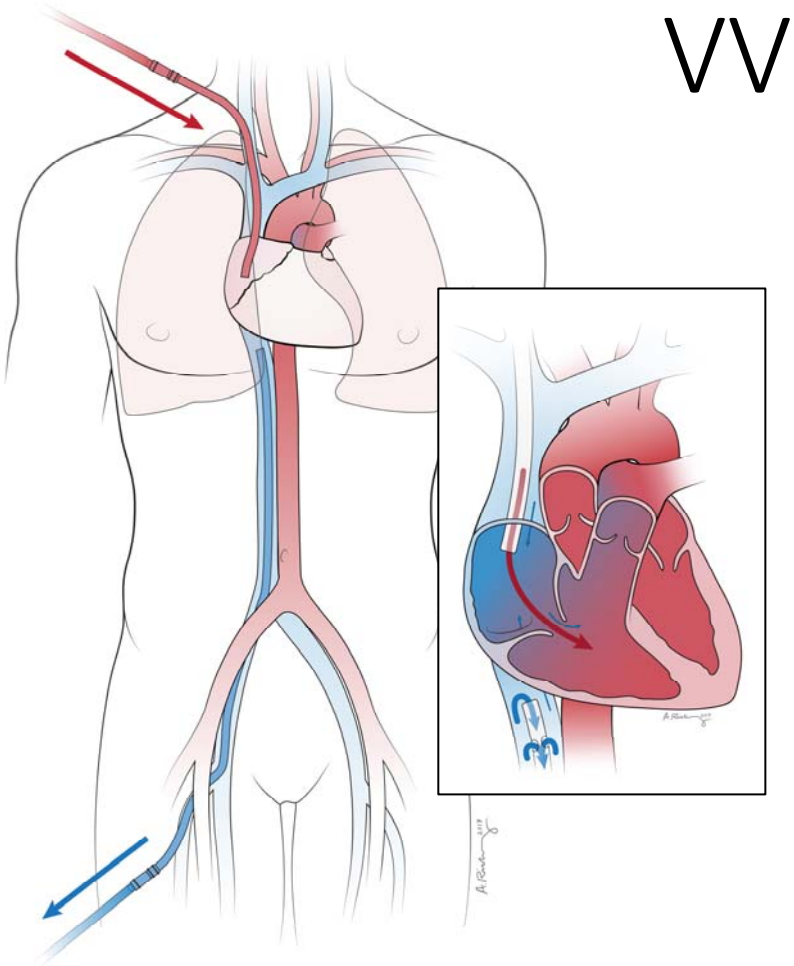
VA ECMO

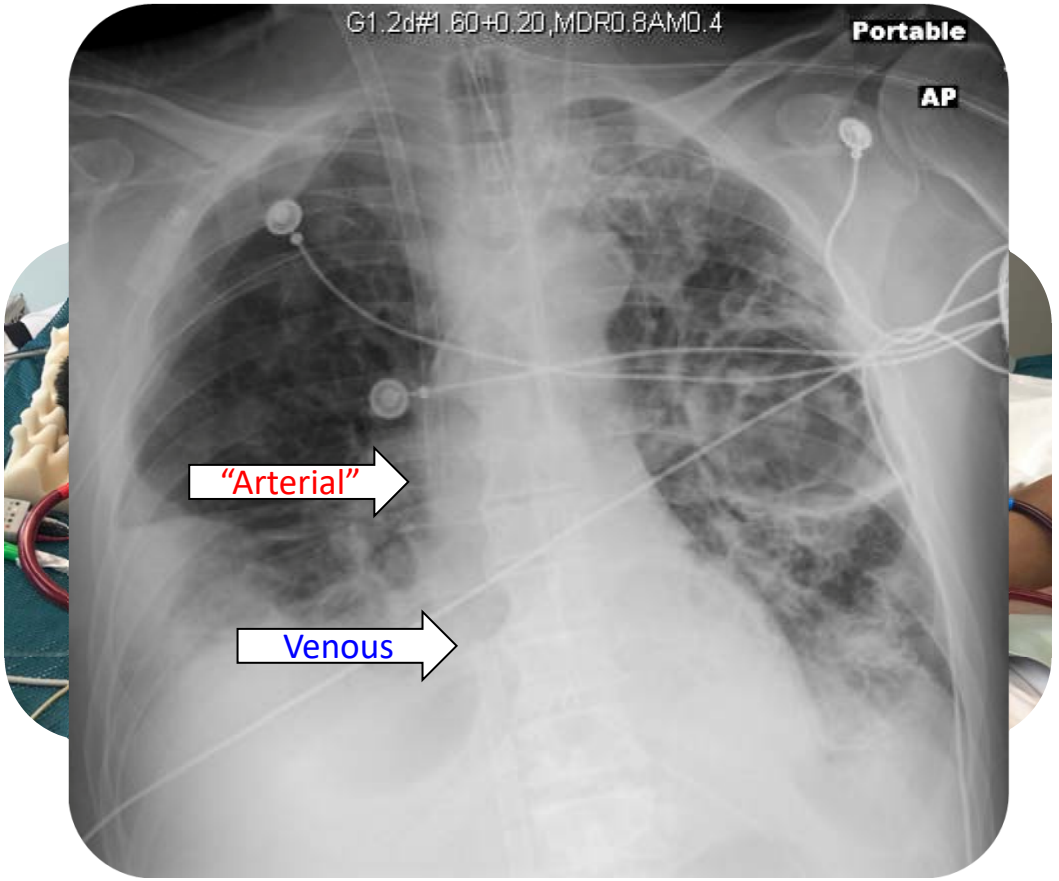




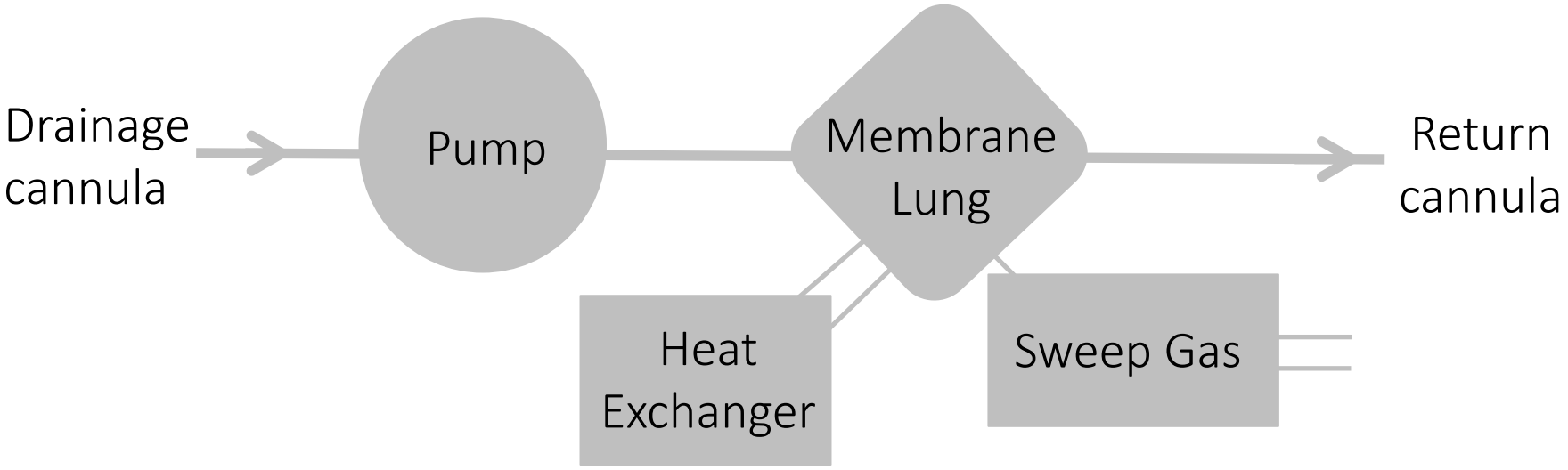


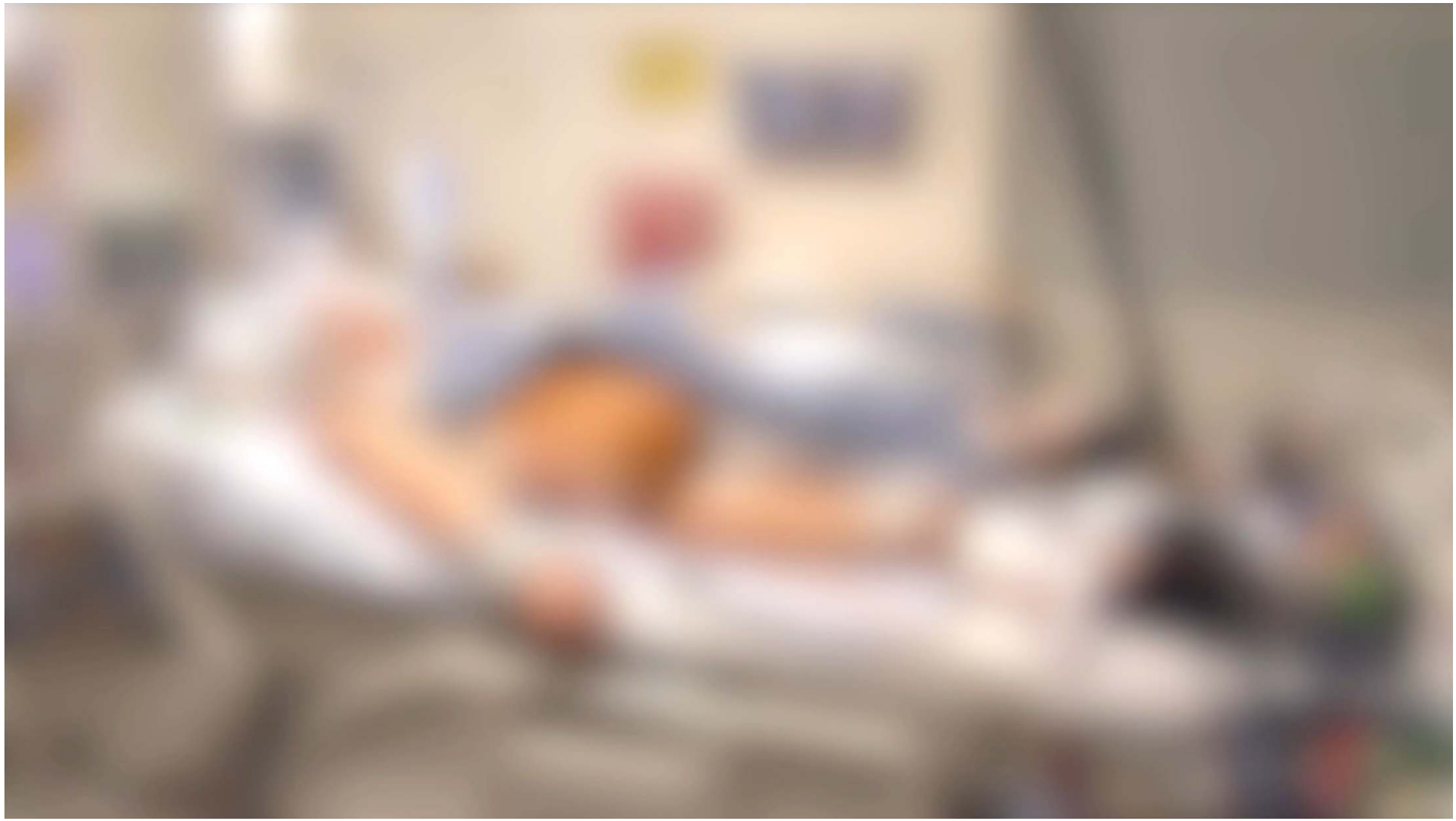
VV ECMO





The Circuit


Drainage cannula
Pump
Membrane Lung
Return cannula
Heat Exchanger
Sweep Gas



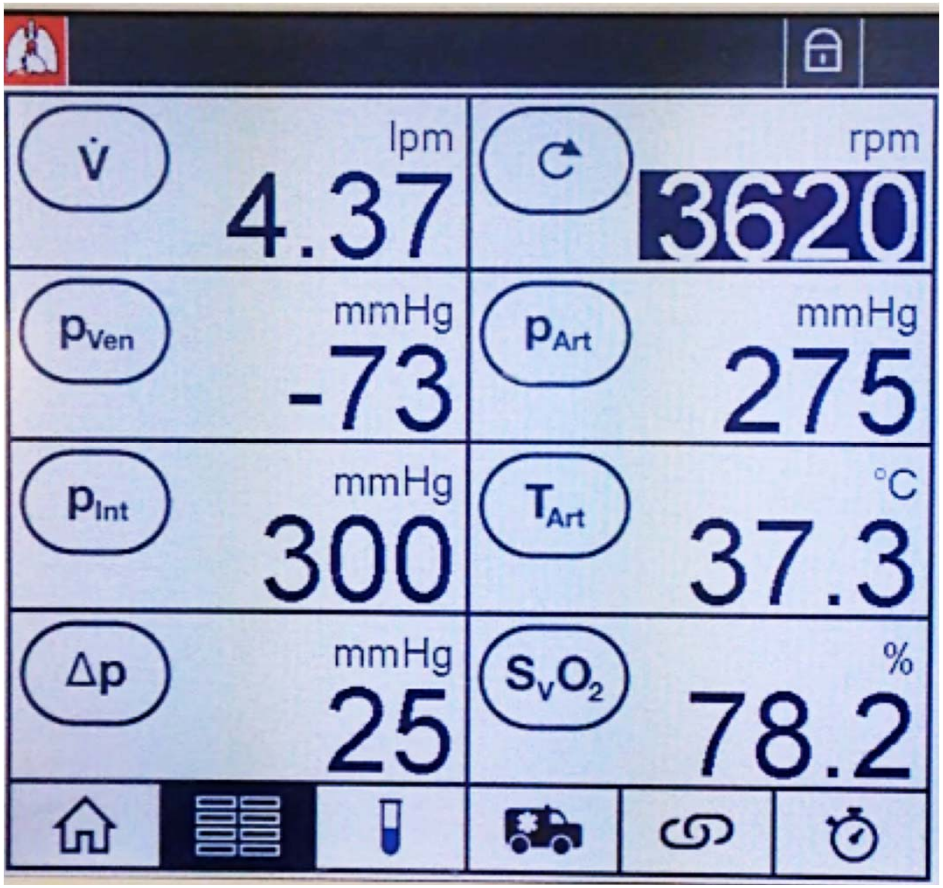
Pump Console Screen

ECMO Blood Flow ($\dot{V}$)

Venous Pressure (P_{ven})

Internal Pressure (P_{int})

$\Delta P = P_{int} - P_{art}$



Pump Speed

Arterial Pressure (P_{art})

Temperature (T_{art})

Pre-membrane saturation (S_VO_2)

Patient Selection

Meet Steve

35 M COVID19 ARDS day 4 IMV, prone, neuromuscular blockade, inhaled epoprostenol

VC
Vt 5cc/kg
RR 35
FiO2 100%
PEEP 18
Pplat 35

pH 7.22
$PaCO_2$ 60
PaO_2 47
SpO_2 83%

0.15 mcg/kg/min

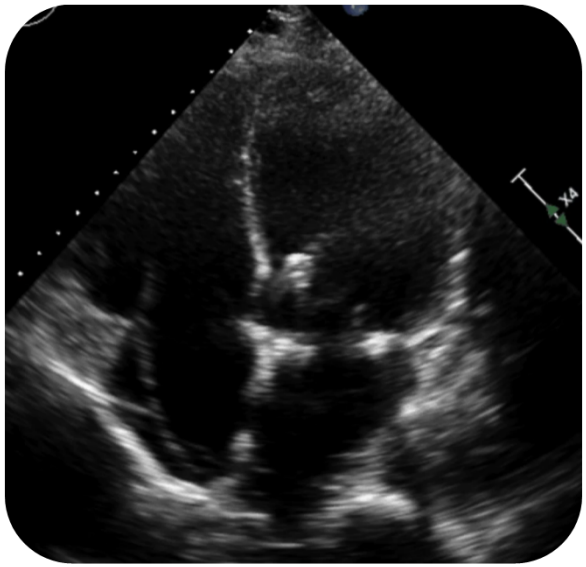
VV ECMO candidate?

Meet Sandy

55 F with palpitations for “a while”, hypotensive, rapid Afib, cool extremities

Intubated, DCCV, amiodarone, persistently hypotensive, end organ dysfunction

VC
Vt 8cc/kg
RR 30
FiO2 40%
PEEP 5
SpO_2 98%



RA 18
RV 36/17
PA 35/25(28)
Wedge 24
SvO_2 35%
CI 1.3(thermo)
BP 81/62

0.3 mcg/kg/min

10 mcg/kg/min

0.08 mcg/kg/min

VA ECMO candidate?

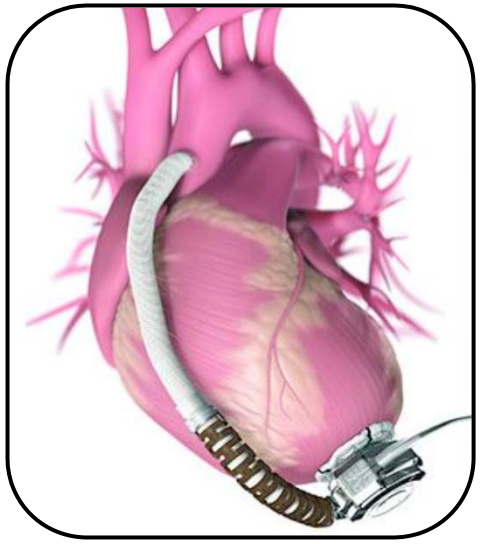
General Indications for ECMO

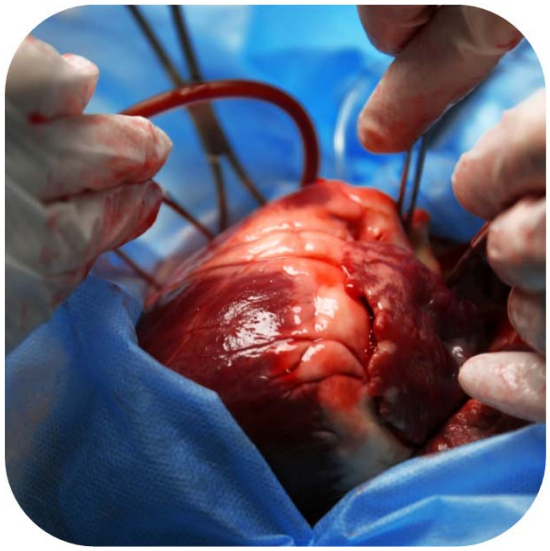
- Acute severe cardiopulmonary failure with high mortality risk refractory to conventional therapy
- Bridge to recovery, durable organ replacement… or decision

Use ECMO for a disease process with a solution

ECMO Discontinuation Strategies

Recovery





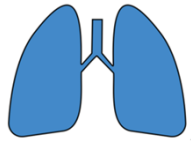
End Of Life Care

General Contraindications for ECMO

- Futility: too sick (irreversible multi-organ failure), on conventional therapy too long
- Preexisting life-limiting conditions: central nervous system pathology, end stage diseases (ESRD, cirrhosis, malignancy)
- Advanced age
- Limited vascular access

Disease-specific Indications

VA ECMO	VV ECMO
Refractory cardiogenic shock	Severe ARDS
Cardiac arrest (ECPR)	Refractory hypercarbia
Massive pulmonary embolus	Pulmonary injury
Environmental hypothermia	Bronchopleural fistula
Cardiotoxic ingestion	Bridge to lung transplant
Post-cardiac surgery	Post-thoracic surgery



Severity of Respiratory Failure

CESAR Inclusion Criteria[1]	
or	Murray score > 3
	pH < 7.2

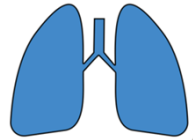
Modified Murray Lung Injury Score[2]
CXR quadrant consolidation
PaO_2/FiO_2
PEEP
Respiratory system compliance

EOLIA Inclusion Criteria[3]	
or	PaO_2/FiO_2 < 50 for > 3 hrs
	PaO_2/FiO_2 < 80 for > 6 hrs
	pH < 7.25 and $PaCO_2$ > 60 mm Hg for > 6 hrs

Despite maximal conventional therapy

[1]Peek et al. Lancet (2009) 374: 1351–63, [2]Murray et al. Am Rev Respir Dis (1988) 138:720-723, [3]Combes et al. N Engl J Med (2018) 378:1965-75

VV ECMO ARDS Outcomes



Study	Design	Table 1	Intervention (n)	Survival
CESAR Lancet 2009	RCT	P:F 75, PEEP 14 pH 7.1	ECMO referred (90) Usual care (90)	63% 47% (p = 0.03)
Noah H1N1 JAMA 2011	Prosp. cohort	P:F 55	ECMO referred (80) Matched control (195)	76% 50% (p < 0.01)
EOLIA NEJM 2018	RCT	P:F 72, PEEP 12 pH 7.24	ECMO (124) Usual care (125)	65% 54% (p = 0.09)

VA ECMO Outcomes

Study	Design	n	Data Source	Etiology of shock	Survival
Lorusso 2016	Cohort	57	13 centers Italy & UK	Myocarditis	71.9%
Aso 2016	Cohort	4,658	> 1k centers Japan	Ischemic 42.2%, ADHF 34.8%, valvular 13.7%, myocarditis 4%, cardiomyopathy 4.1%	26.4%
Truby 2015	Cohort	179	Single center New York City	Post-cardiotomy 39%, MI 26%, primary graft failure 10%, ADHF 13%	44.7%
Biancari 2018	Meta-analysis	2,986	31 studies International	Post-cardiotomy	36.1%
Meneveau 2018	Case series	52	9 centers France	Pulmonary embolism	39%

Acute decompensated heart failure (ADHF), myocardial infarction (MI)

ECLS Registry Report

International Summary

January, 2020

Extracorporeal Life Support Organization
2800 Plymouth Road
Building 300, Room 303
Ann Arbor, MI 48109

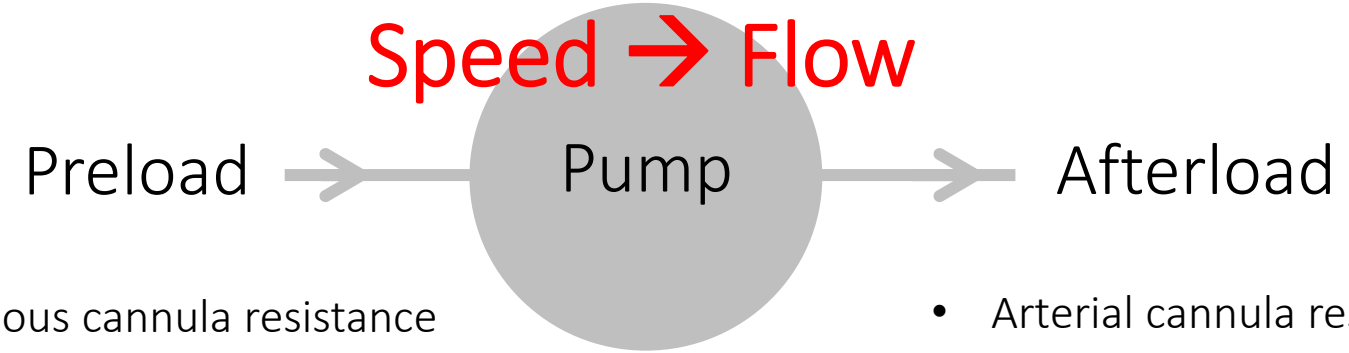
Overall Outcomes

	Total Runs	Survived ECLS		Survived to DC or Transfer	
Adult					
Pulmonary	24,395	16,971	69%	14,714	60%
Cardiac	25,488	15,184	59%	11,191	43%
ECPR	8,075	3,363	41%	2,387	29%

Extracorporeal cardiopulmonary resuscitation (ECPR)

Physiology

The Pump



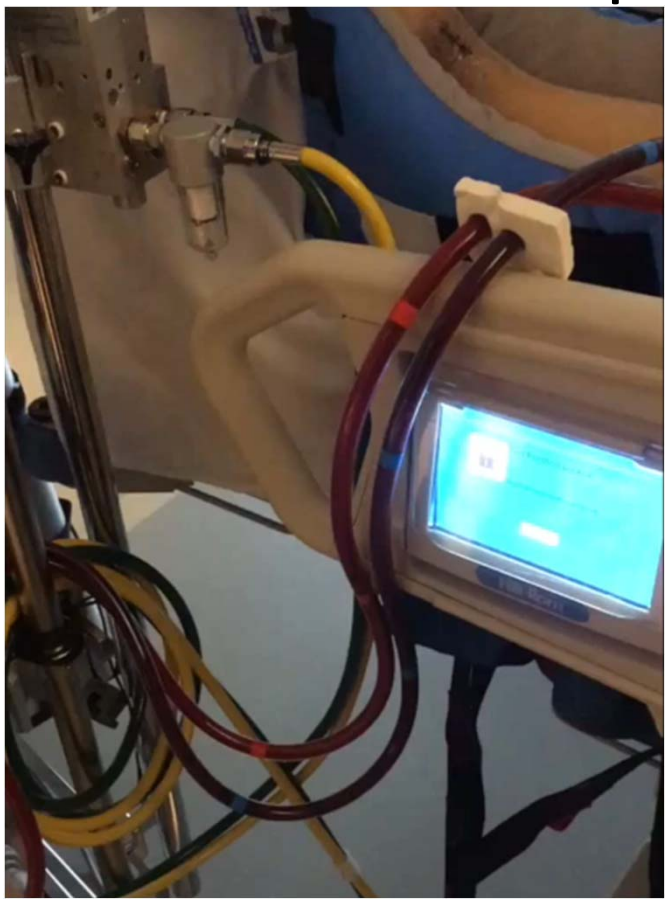
- Venous cannula resistance
- Blood volume
- Intra-thoracic pressure
- Intra-abdominal pressure

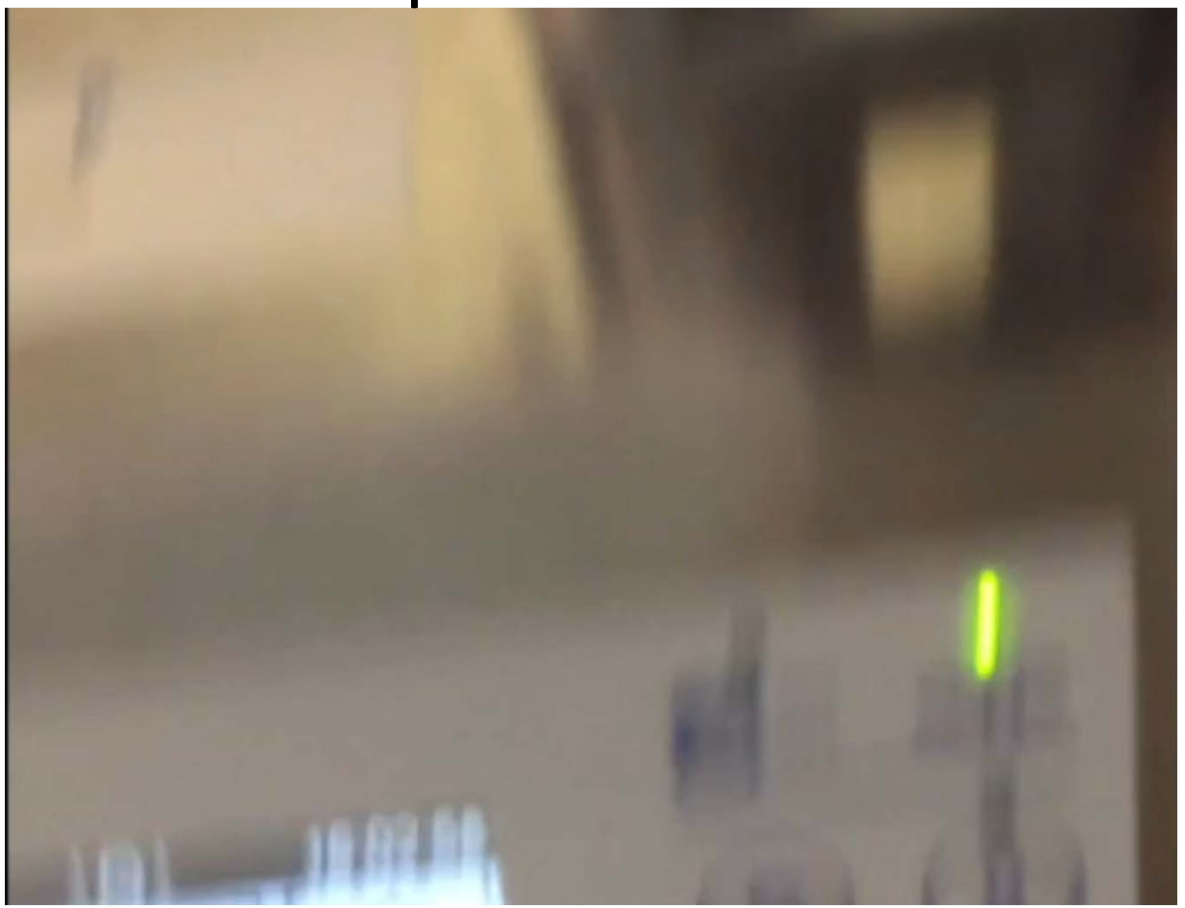
- Arterial cannula resistance
- Membrane lung resistance
- SVR & MAP (VA)

Preload sensitive and afterload limited

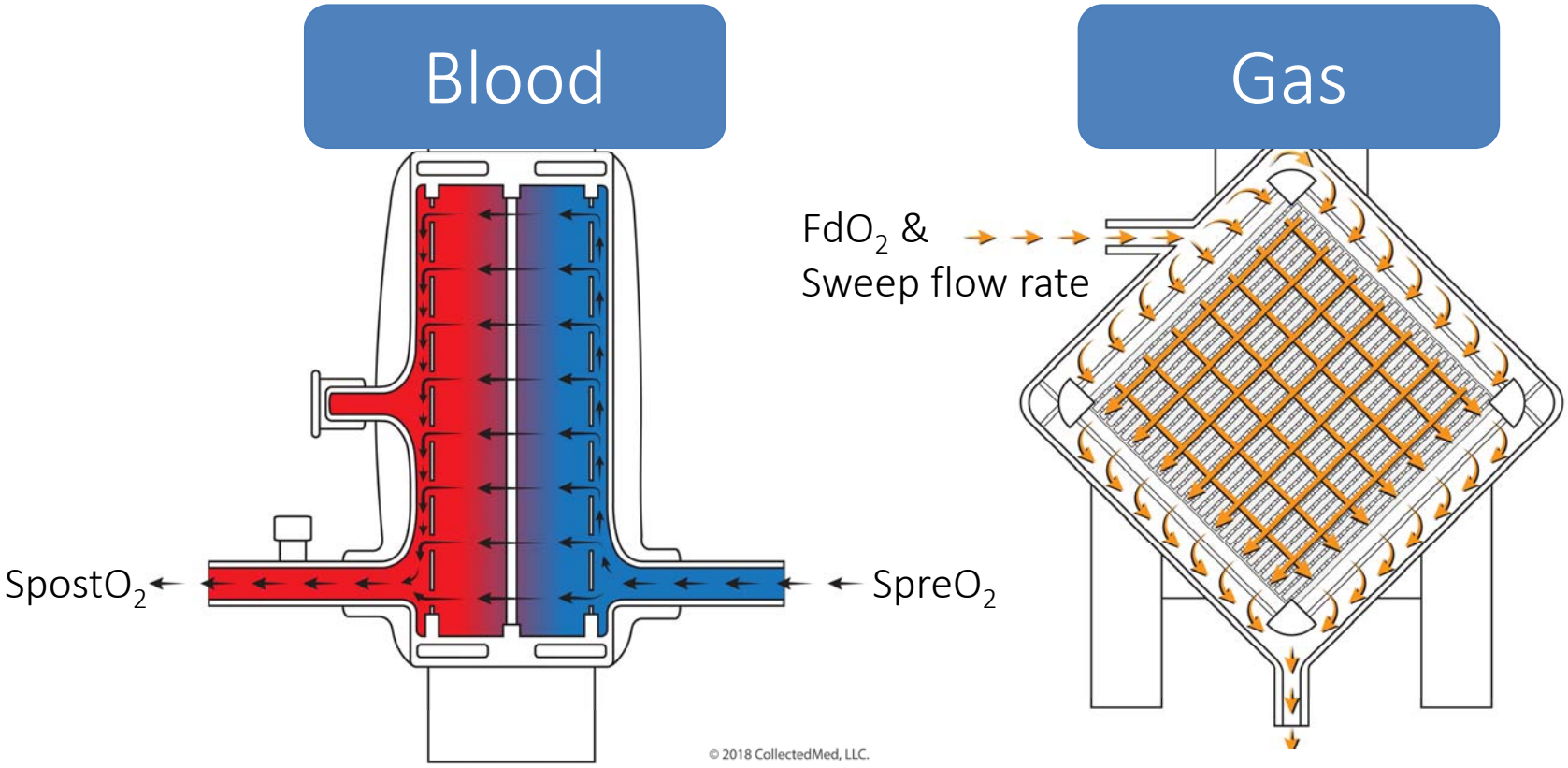
Systemic vascular resistance (SVR), mean arterial pressure (MAP)

Inadequate Pump Preload

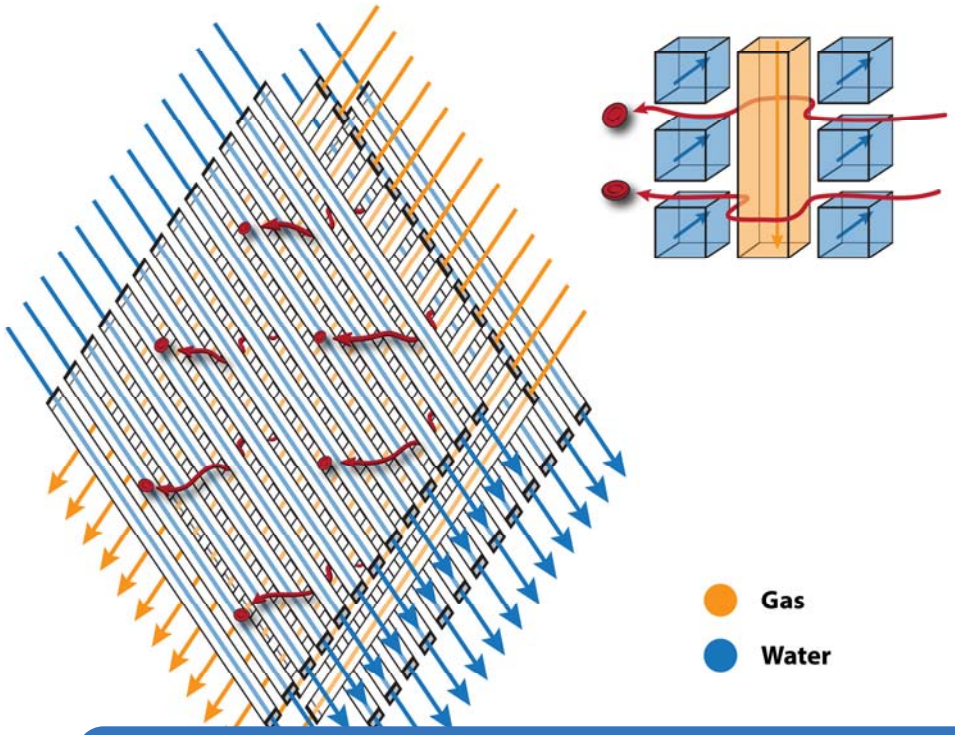


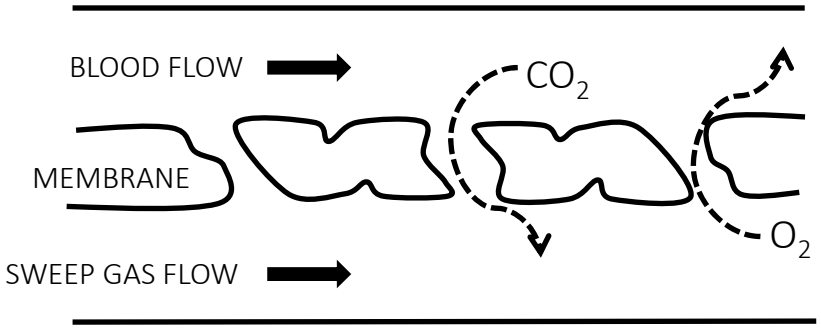


The Membrane Lung



The Membrane Lung





Increase sweep flow rate to remove more CO_2

VV ECMO

VV Day 1

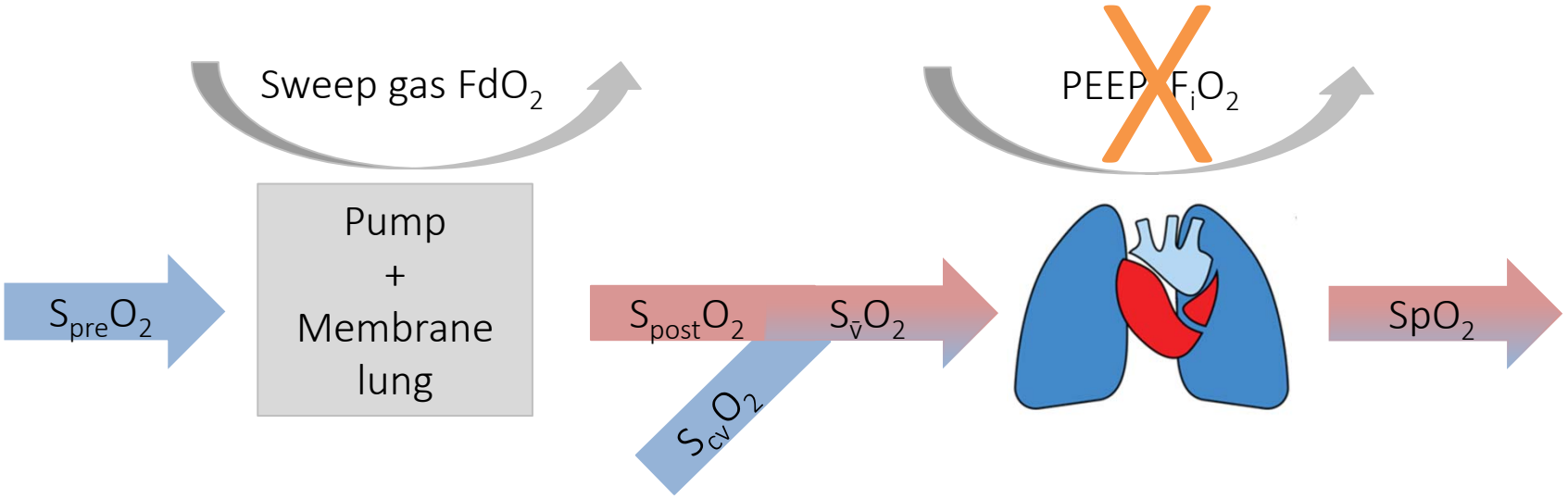
Steve is cannulated for VV ECMO

Sweep: 3 L/min, FdO_2: 100%

PC
Ppeak14
RR 10
FiO2 40%
PEEP 10
Vt 150cc

How can we improve SpO_2?

Pressure control ventilation (PC)

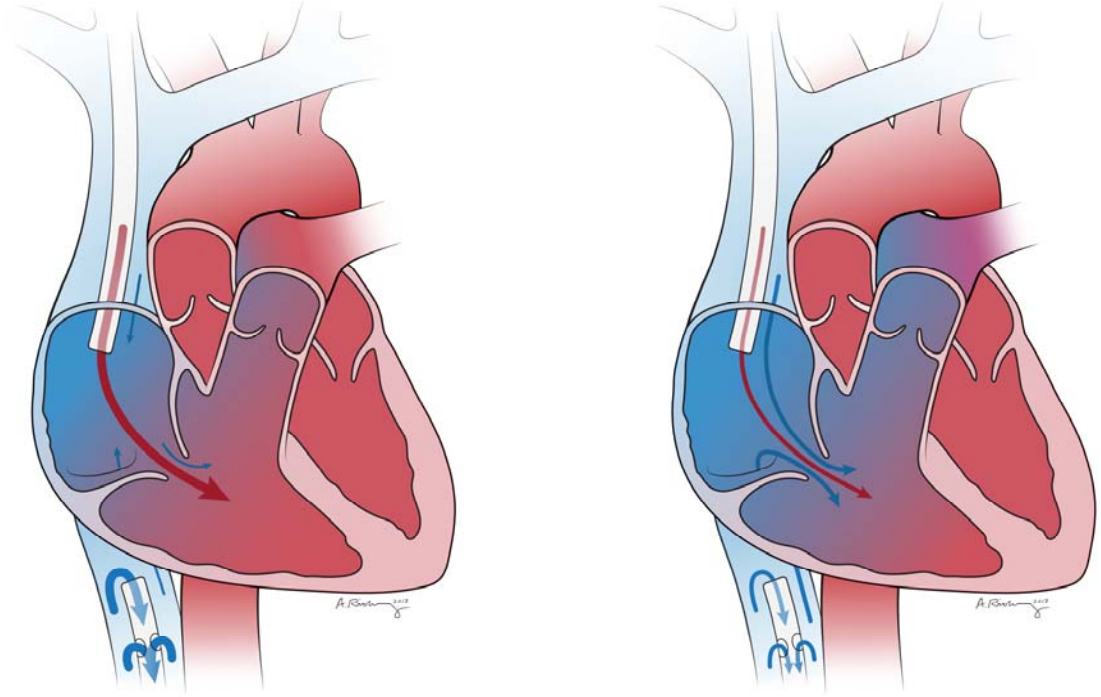


Two circulations in series

saturation pre-membrane ($S_{pre}O_2$)
saturation post-membrane ($S_{post}O_2$)
Fraction delivered oxygen percentage (FdO_2)

High ECMO: Q

Low ECMO: Q



ECMO blood flow –> Oxygenation

Schmidt et al. *Intensive Care Med*. 2013;39(5):838-846.

VV Day 1

Steve is cannulated for VV ECMO

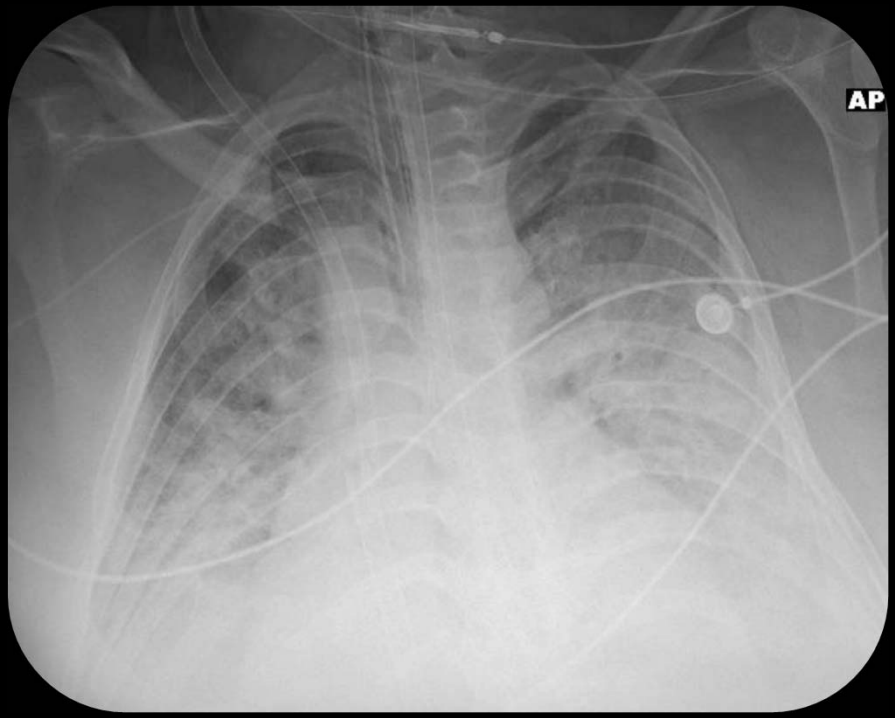
Sweep: 3 L/min, FdO_2: 100%

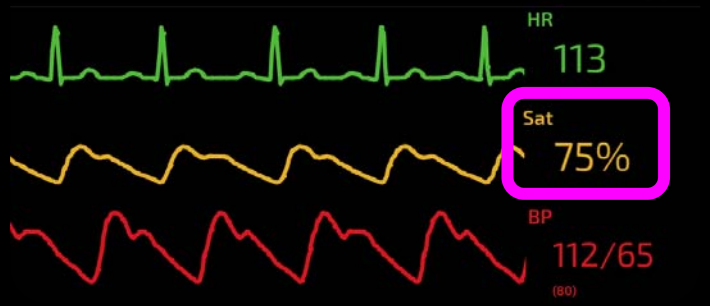
PC
Ppeak14
RR 10
FiO2 40%
PEEP 10
Vt 150cc

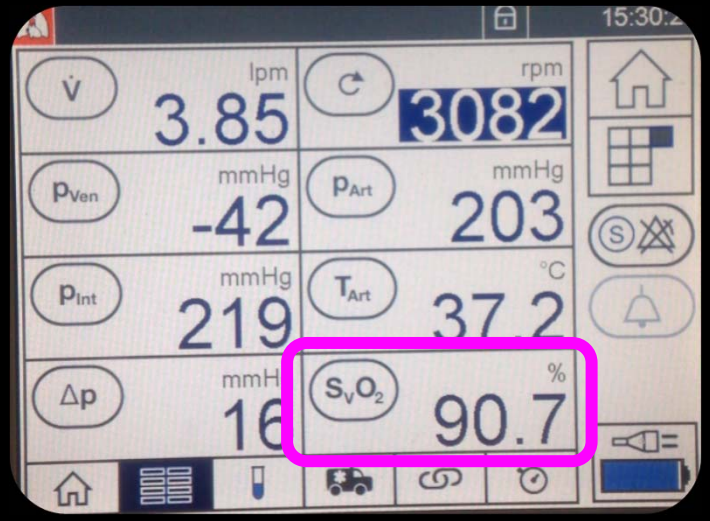
Increase ECMO blood flow!

Pressure control ventilation (PC)

VV Day 3

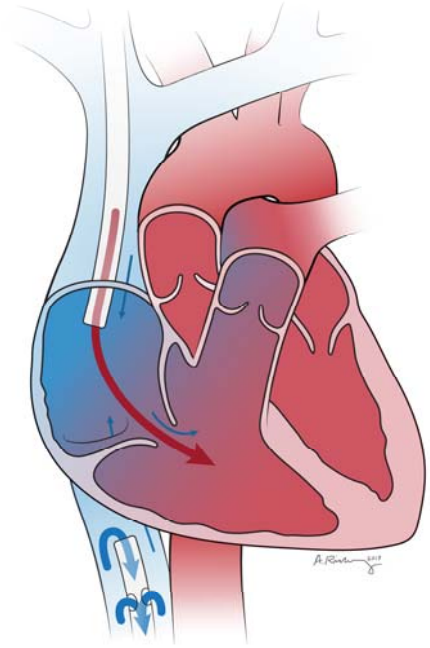

AP


HR
113
Sat
75%
BP
112/65
(80)

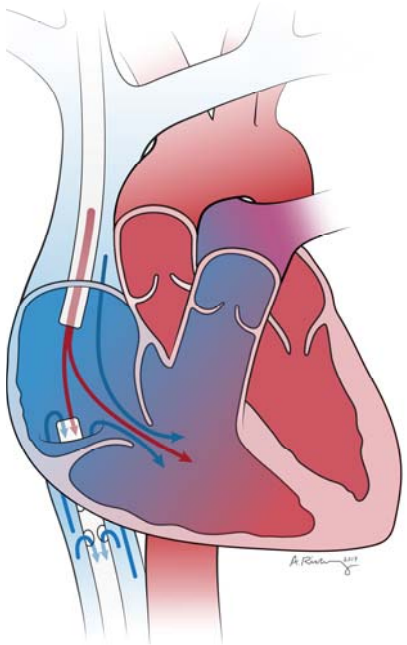

15:30:2
V̇
lpm
3.85
rpm
3082
pVen
mmHg
-42
pArt
mmHg
203
pInt
mmHg
219
TArt
°C
37.2
Δp
mmH
16
SvO2
%
90.7

Recirculation

Normal



Recirculation



Signs:

- Falling S_pO_2
- Rising $S_{pre}O_2$
- Both cannulas bright red

Treatment:

- Decrease speed
- Adjust cannula position

Abrams et al. ASAIO Journal 2015; 61:115–121

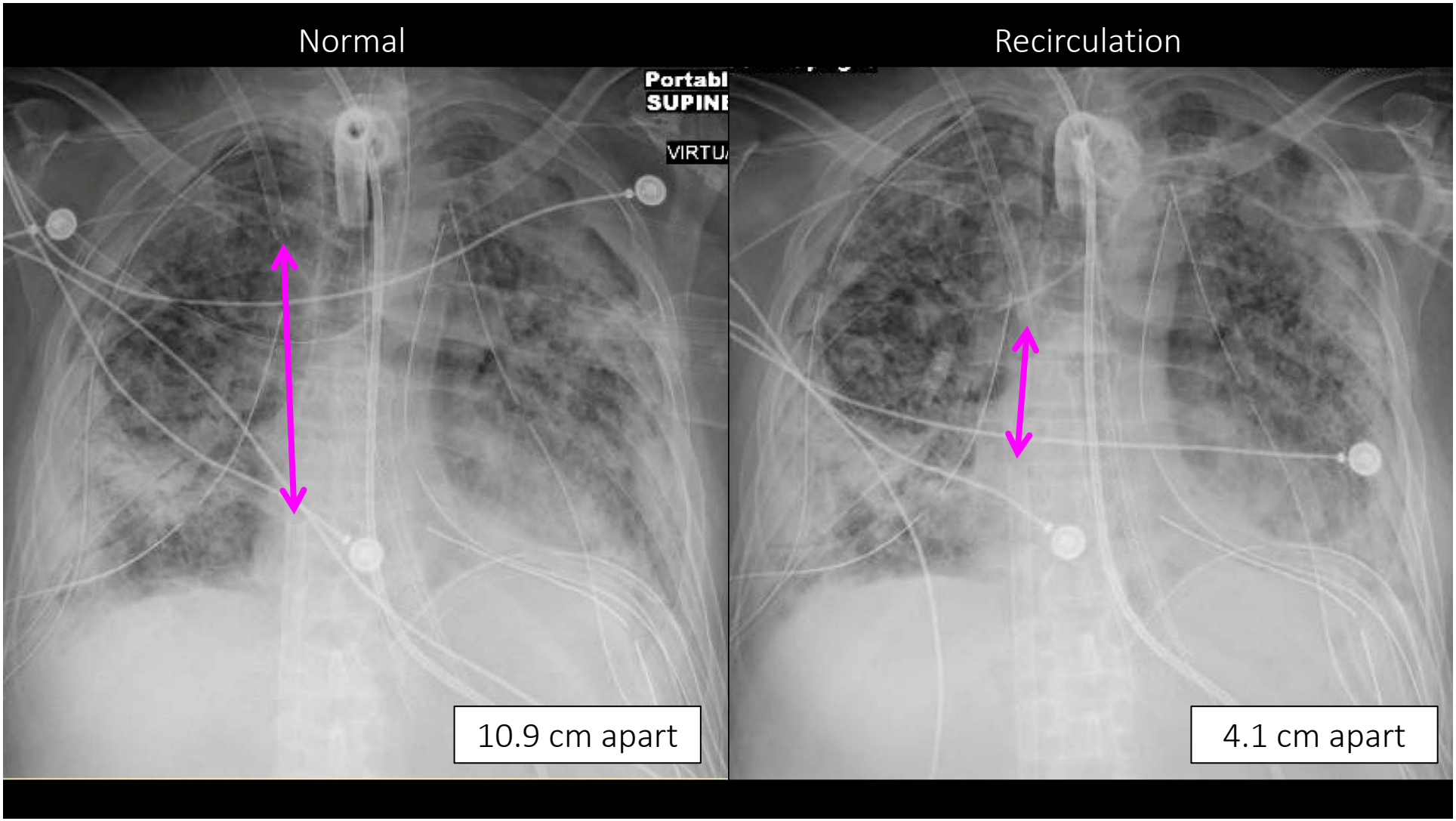
O_2 saturation of venous drainage cannula ($S_{VD}O_2$)

Check tubing color

Normal

Recirculation

Membrane lung failure


Normal
Recirculation
Portabl
SUPINE
VIRTU
10.9 cm apart
4.1 cm apart

VV ECMO Hypoxemia?

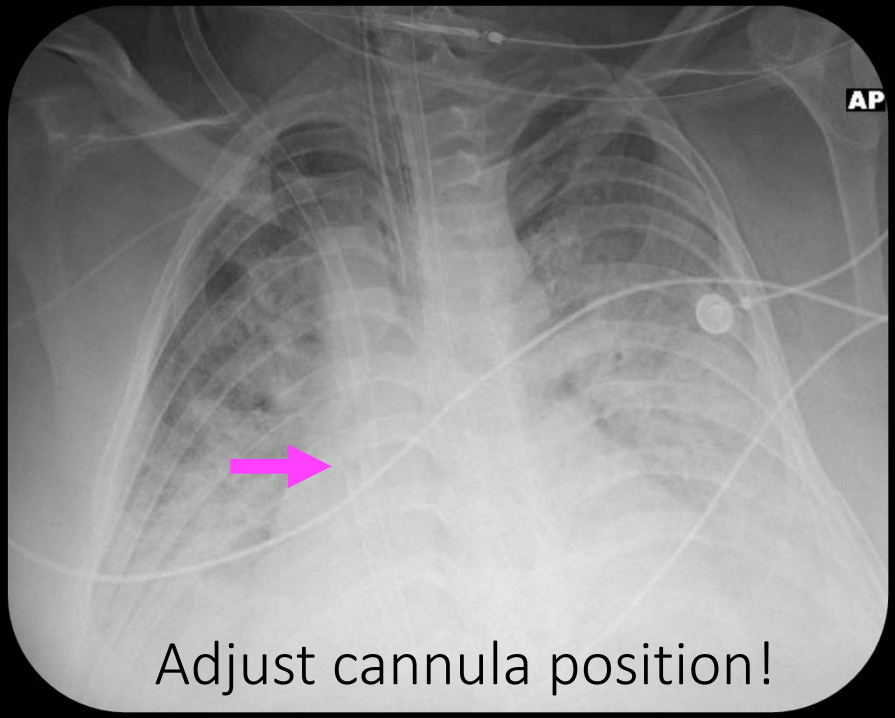
ECMO blood flow

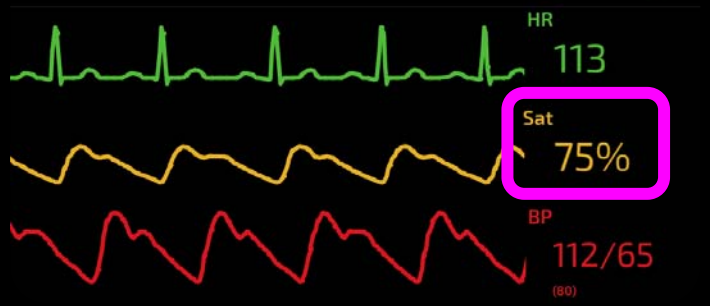
Tubing color change

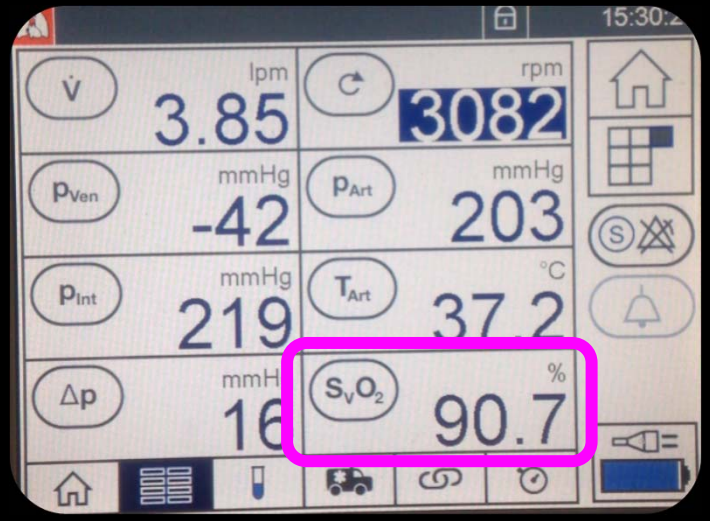
$SpreO_2$

saturation pre-membrane ($S_{pre}O_2$)

VV Day 3


AP
Adjust cannula position!


HR
113
Sat
75%
BP
112/65
(80)

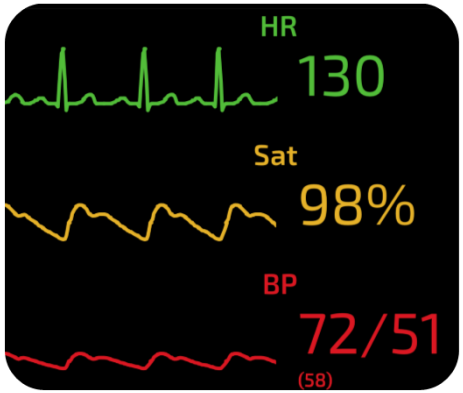

15:30:2
V̇
lpm
3.85
rpm
3082
pVen
mmHg
-42
pArt
mmHg
203
pInt
mmHg
219
TArt
°C
37.2
Δp
mmH
16
SvO2
%
90.7

VA ECMO

VA Day 1

Sandy is cannulated for VA ECMO

Sweep: 2 L/min, FdO_2: 100%



0.3 mcg/kg/min

10 mcg/kg/min

0.08 mcg/kg/min

How should we improve blood pressure?

Fraction delivered oxygen percentage (FdO_2)

VA ECMO Hemodynamics

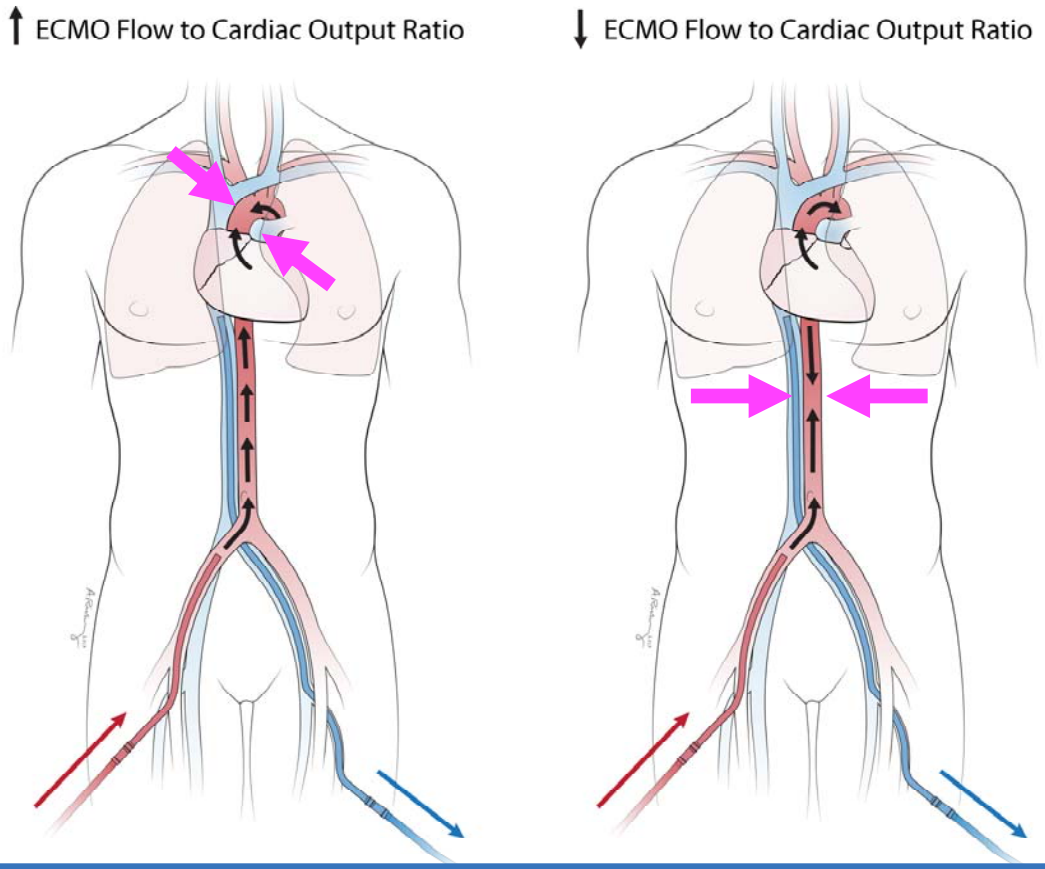
vs.

MAP = (Q x SVR) + RAP

+

vs.

MAP: mean arterial pressure
Q: flow
SVR: systemic vascular resistance
RAP: right atrial pressure



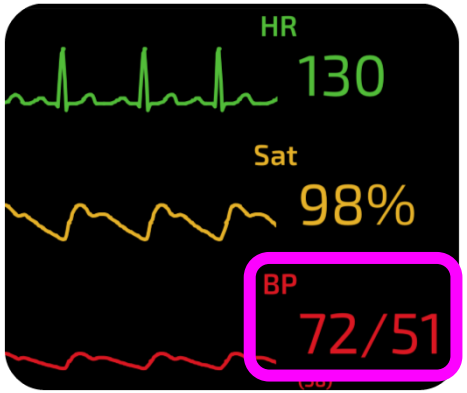
Total systemic blood flow= ECMO Flow + CO

Stevens et al. *J Biomech*. 2017;55:64-70

VA Day 1

Sandy is cannulated for VA ECMO

Sweep: 2 L/min, FdO_2: 100%



0.3 mcg/kg/min

10 mcg/kg/min

0.08 mcg/kg/min

Increase ECMO blood flow!

Fraction delivered oxygen percentage (FdO_2)

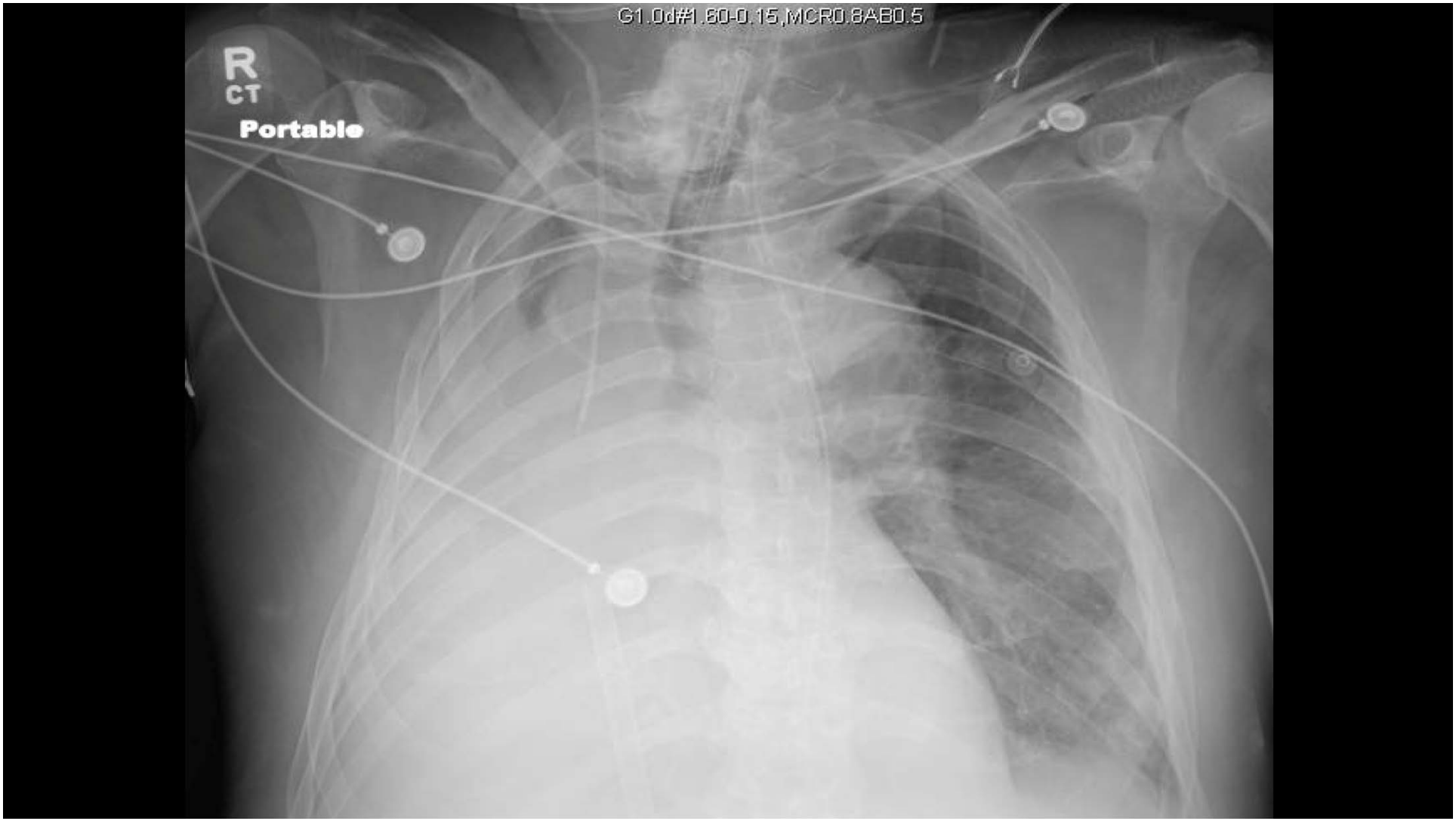
VA Day 4

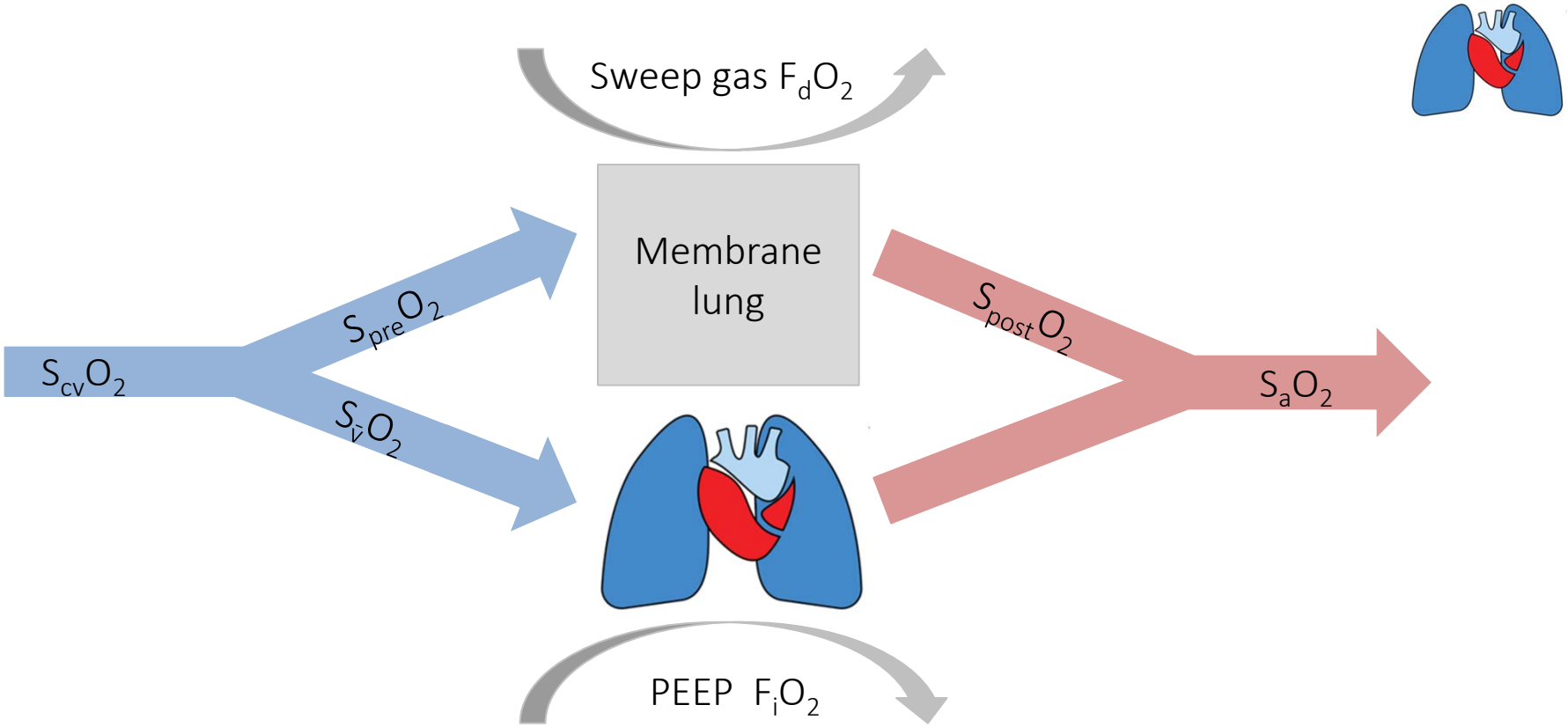
- LVEF now 20% (was 10%)
- Ventilator starts alarming with increased peak pressure on volume control

0.04 mcg/kg/min

3 mcg/kg/min

How do you troubleshoot this?

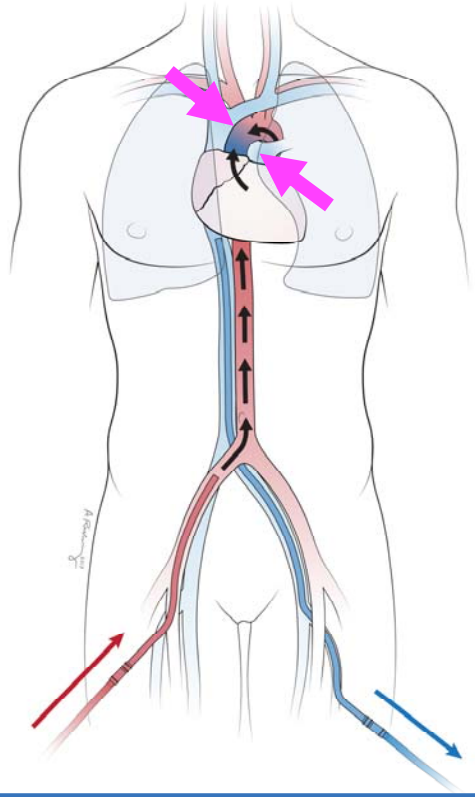

G1.0d#1.80-0.15,MCR0.8AB0.5
R
CT
Portable

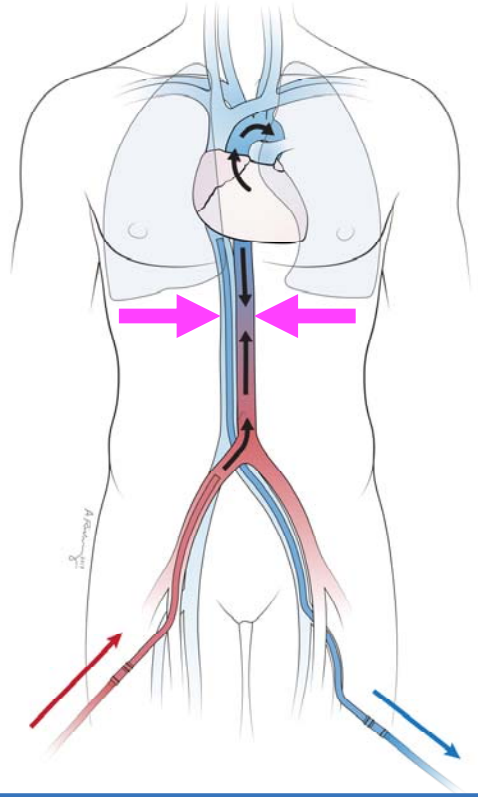


Two circulations in parallel

Fraction delivered oxygen percentage (FdO_2), saturation pre-membrane ($S_{pre}O_2$), saturation post-membrane ($S_{post}O_2$)

Upper body hypoxemia

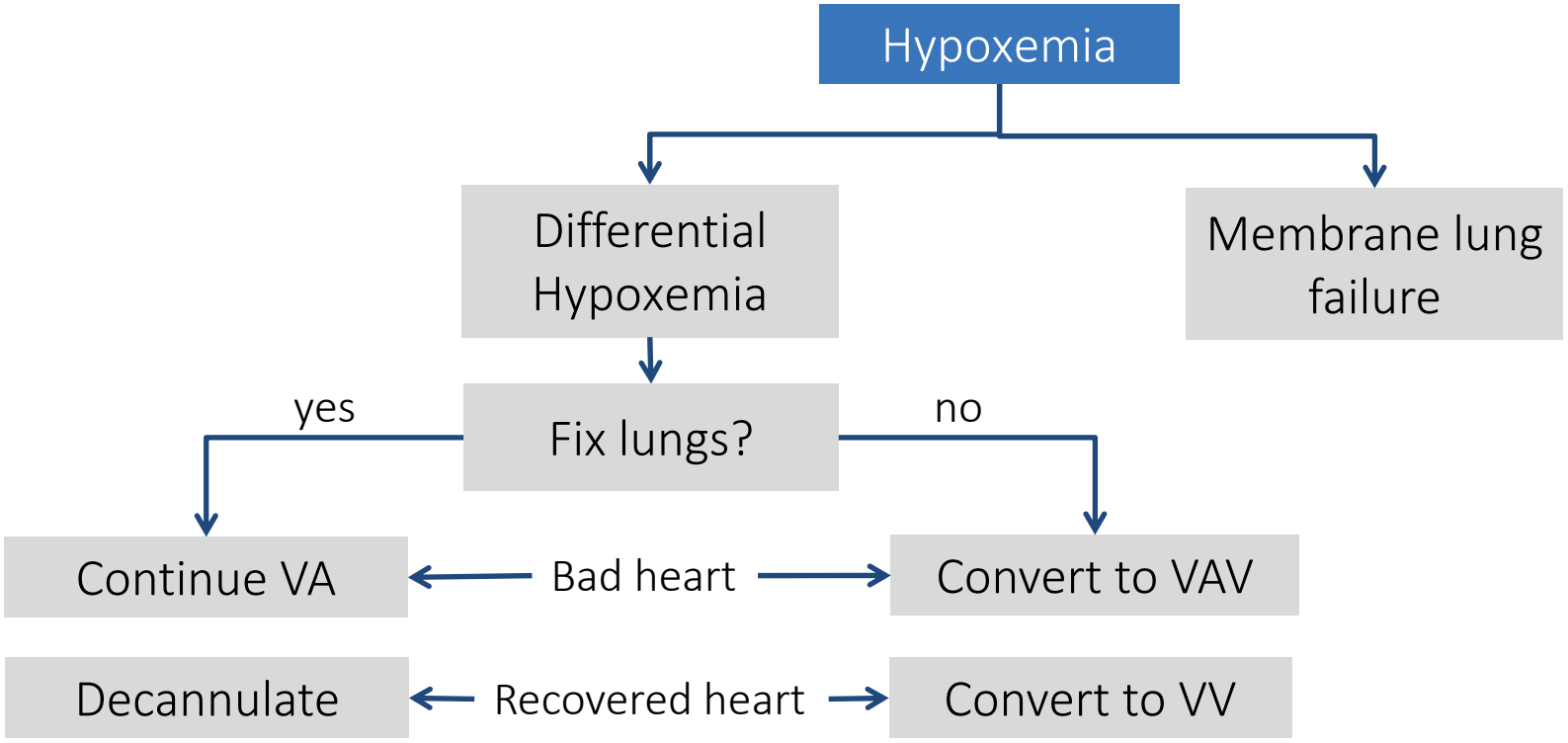




Keep pulse oximeter on right upper extremity!

Regional gas exchange → differential oxygenation

Hypoxemia on VA ECMO



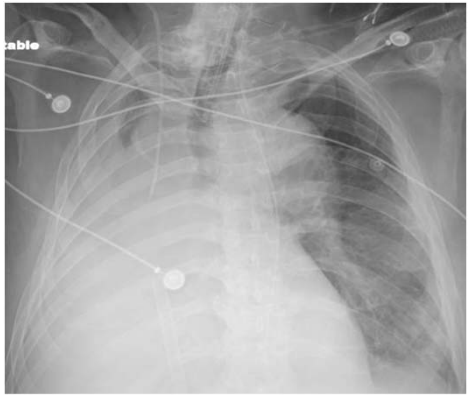
Venoarteriovenous (VAV)

VA Day 4

- LVEF now 20% (was 10%)
- Ventilator starts alarming with increased peak pressure on volume control

0.04 mcg/kg/min

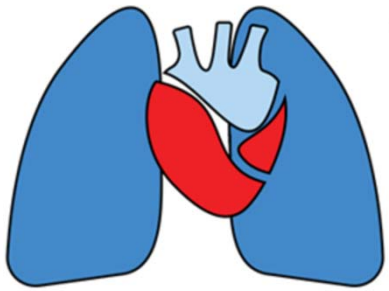
3 mcg/kg/min



Fix lungs!

Summary

- Drainage→ pump → membrane lung (sweep) → return
- Cannulate only with discontinuation strategy
- Centrifugal pump pre-load dependent & afterload sensitive
- Increase sweep gas rate to decrease $PaCO_2$
- VV oxygenation improved with increased blood flow
- VV recirculation when $PpreO_2$ high and SpO_2 low
- VA ECMO flow + native cardiac output are additive
- Regionalized gas exchange in peripheral VA ECMO



Questions?

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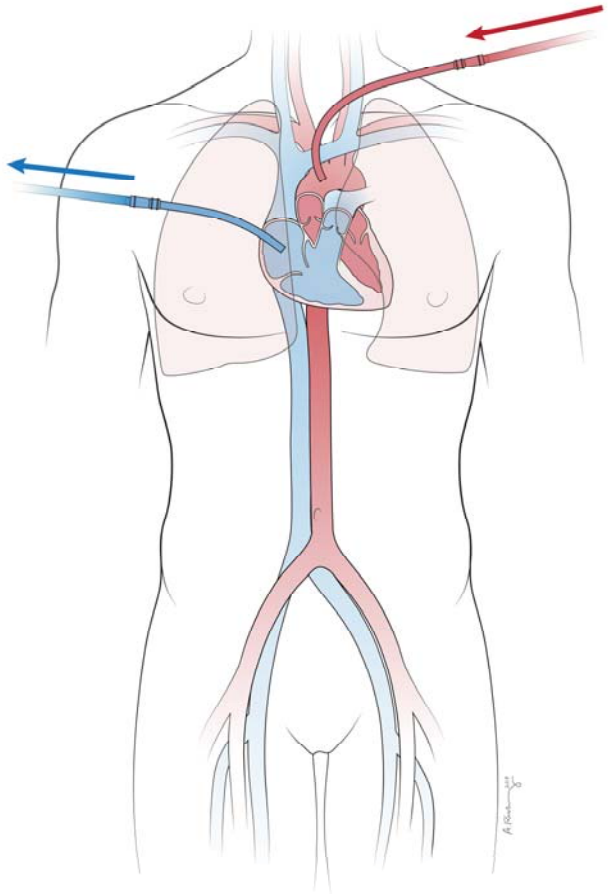
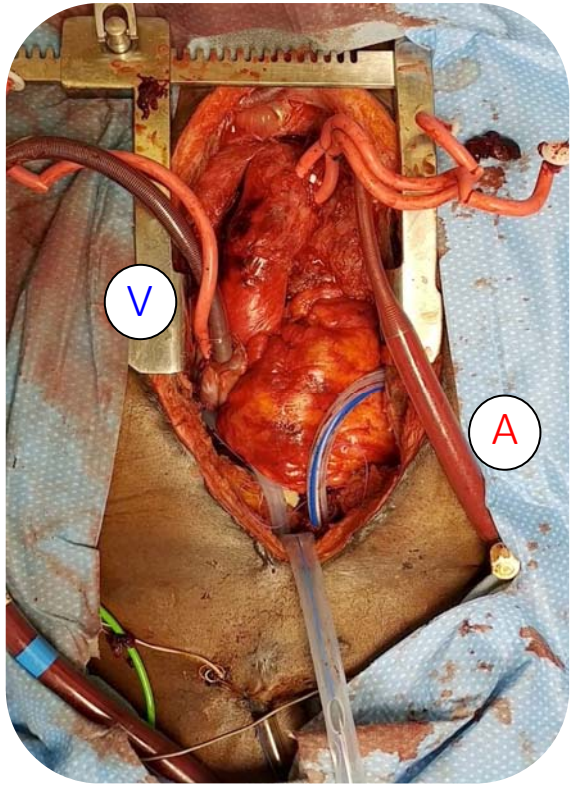
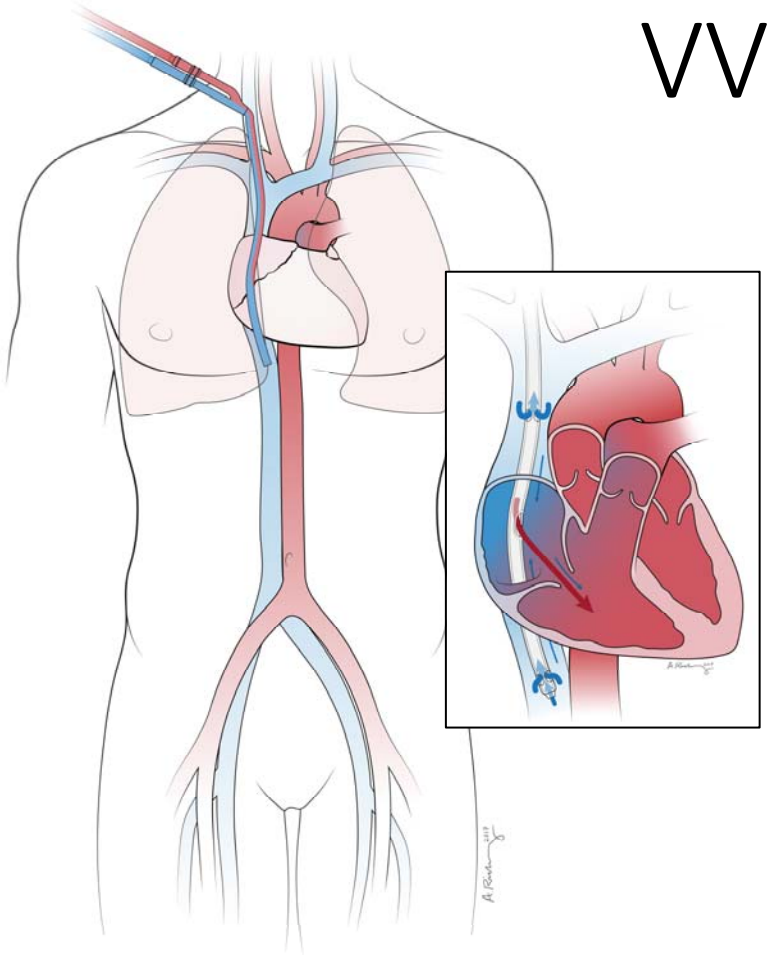
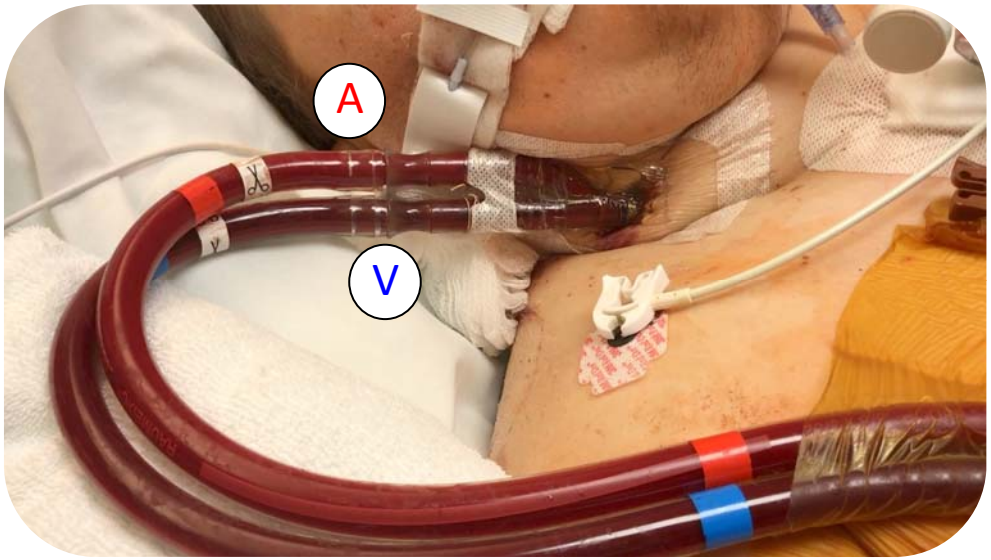


VA ECMO



VV ECMO





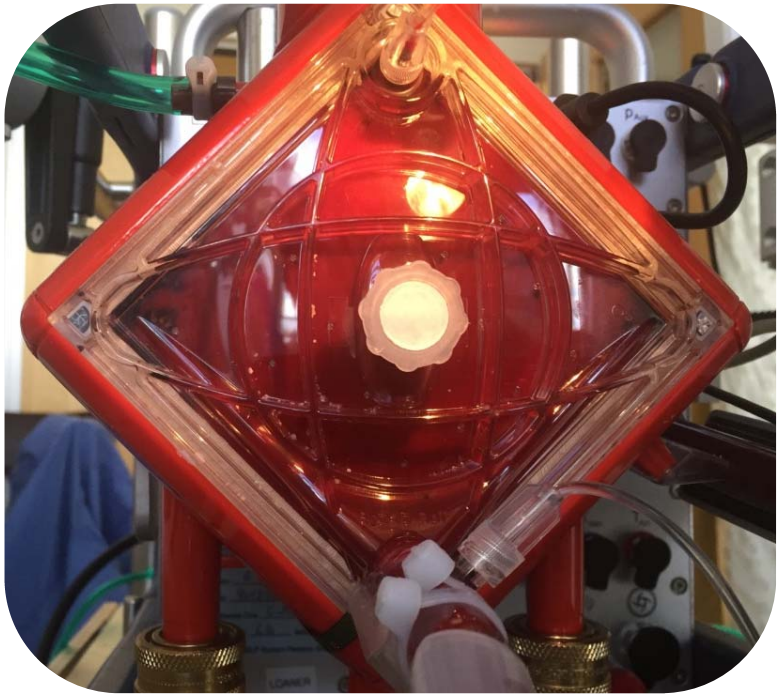
Membrane Lung Failure

Intrinsic

Microtubule dysfunction
High delta P, clot
Poor CO_2 or O_2 transfer on pre/post gas

Sweep gas interruption

Acute
Normal delta P
Clear window



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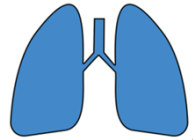
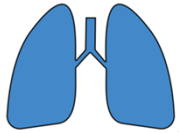
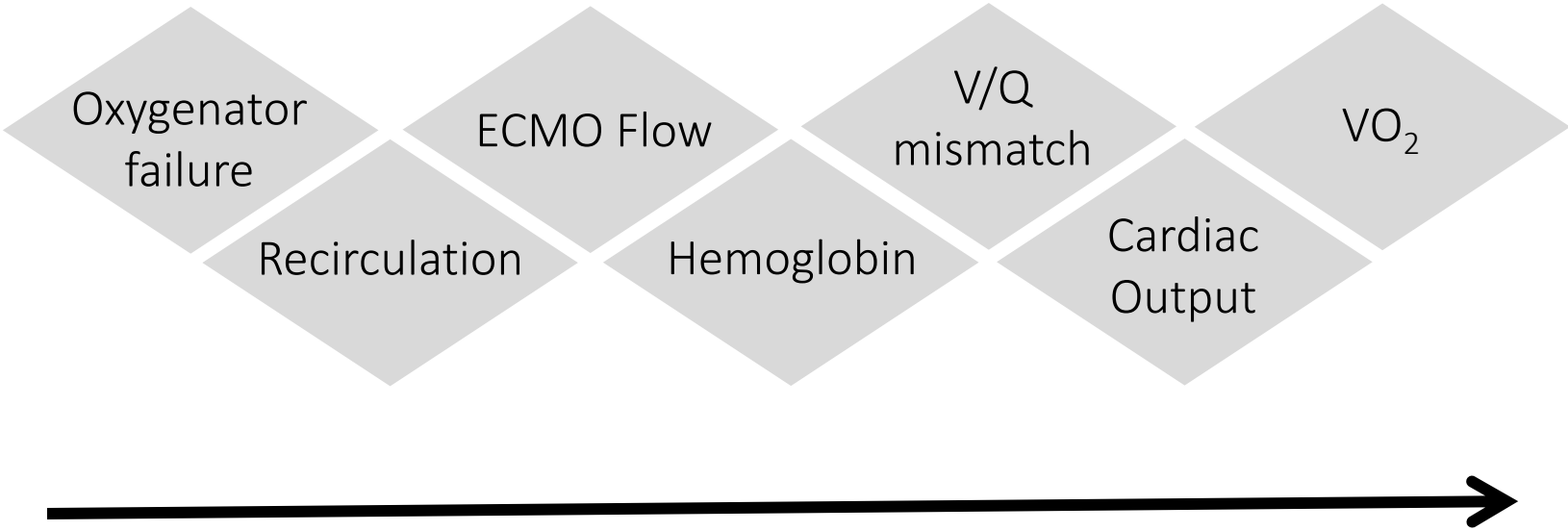


VV ECMO ARDS Outcomes

Study	Design	Table 1	Intervention (n)	Survival
CESAR Lancet 2009	RCT	P:F 75, PEEP 14 pH 7.1	ECMO referred (90) Usual care (90)	63% 47% (p = 0.03)
ANZ H1N1 JAMA 2009	Obs.	P:F 56, PEEP 18 pH 7.2	ECMO (68)	79%
Noah H1N1 JAMA 2011	Prosp. cohort	P:F 55	ECMO referred (80) Matched control (195)	76% 50% (p < 0.01)
Pham H1N1 AJRCCM 2013	Prosp. cohort	P:F 63, PEEP 13 pH 7.26	ECMO referred (123) Matched control (52)	65% for both (p = 0.32)
EOLIA NEJM 2018	RCT	P:F 72, PEEP 12 pH 7.24	ECMO (124) Usual care (125)	65% 54% (p = 0.09)

Oxygenation





Montisci et al. *ASAIO J*. 2015;61(3):227-236.