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What do I need to know about ECMO?

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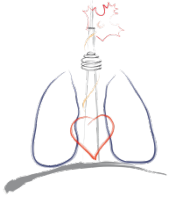
Disclosure

No conflicts of interest to disclose



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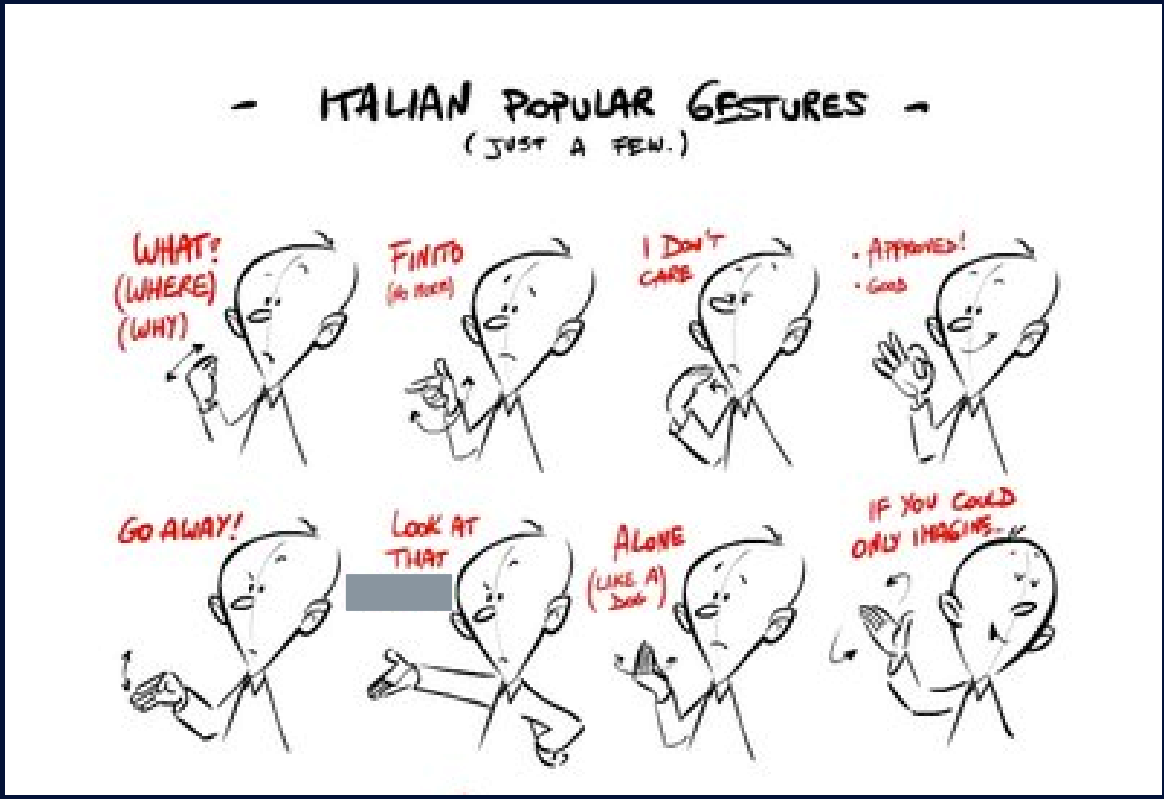

- ITALIAN POPULAR GESTURES -
(JUST A FEW.)
WHAT? (WHERE) (WHY)
FINITO
I DON'T CARE
GO AWAY!
LOOK AT THAT
ALONE
IF YOU COULD ONLY IMAGINE...

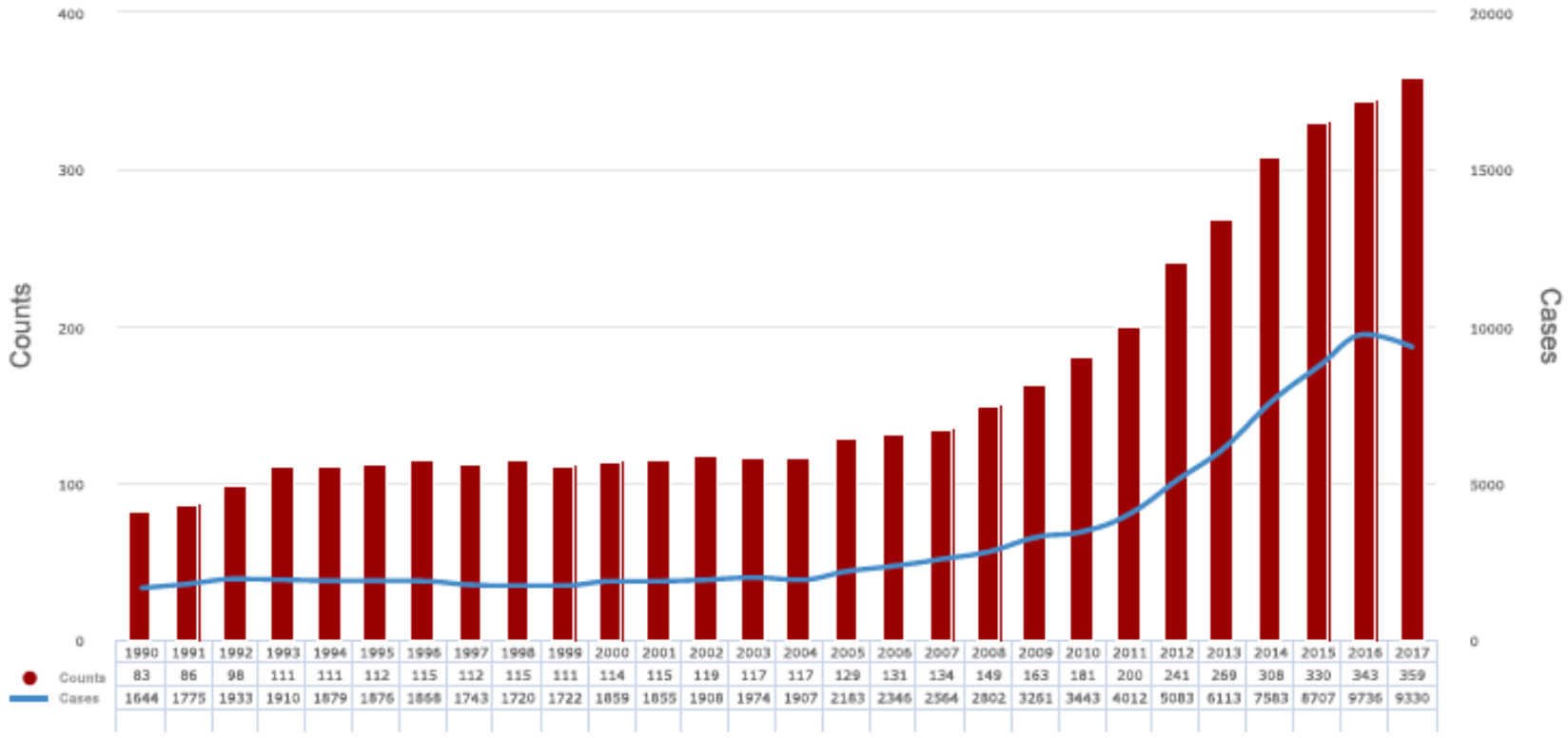
ECLS Registry Report

International Summary

January, 2018

Centers

Centers by year



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Counts	83	86	98	111	111	112	115	112	115	111	114	115	119	117	117	129	131	134	149	163	181	200	241	269	308	330	343	359
Cases	1644	1775	1933	1910	1879	1876	1868	1743	1720	1722	1859	1855	1908	1974	1907	2183	2345	2564	2802	3261	3443	4012	5083	6113	7583	8707	9736	9330

ECLS Registry Report

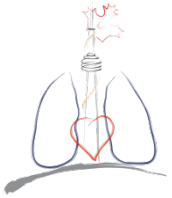
International Summary

January, 2018

Overall Outcomes

	Total Runs	Survived ECLS		Survived to DC or Transfer	
Neonatal					
Pulmonary	30,844	25,922	84%	22,599	73%
Cardiac	7,718	5,011	64%	3,231	41%
ECPR	1,694	1,125	66%	694	40%
Pediatric					
Pulmonary	8,739	5,890	67%	5,079	58%
Cardiac	10,332	7,088	68%	5,375	52%
ECPR	3,881	2,223	57%	1,643	42%
Adult					
Pulmonary	15,686	10,463	66%	9,264	59%
Cardiac	15,201	8,489	55%	6,379	41%
ECPR	4,745	1,830	38%	1,381	29%
Total	98,840	68,041	68%	55,645	56%

- What is ECMO?
- Why are we using it?
- How does it work?
- How do I assist patients who are on ECMO?




Take2Services

Mr. J.D.

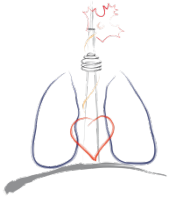
- 48 yr old ♂, previously healthy

- Admitted to E.R. at the local community hospital with respiratory failure → Endotracheal intubation and mechanical ventilation → ICU → ARDS related to Influenza A

Mr. J.D.

- Over the following 24 hours, worsening hypoxemia and hemodynamics (antivirals, sedation, NMBAs, high PEEP, FiO2 100%, norepinephrine, epinephrine, vasopressin)

- 2D echo shows biventricular failure - ? Viral myocarditis



Mr. J.D.

- The ICU team consults the ECMO centre, and consensus is that extracorporeal life support should be instituted

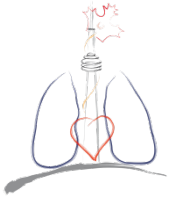
- A retrieval team is deployed, and reaches the referring ICU in 1h

Mr. J.D.

- The decision is made to proceed to V-A ECMO cannulation
- Due to unfavourable vascular anatomy on ultrasound, the plan is to proceed with surgical “cut-down” in the OR
- It’s 1am - The case is booked as an emergency, and you are the anesthesiologist on call…

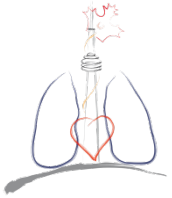
Outline

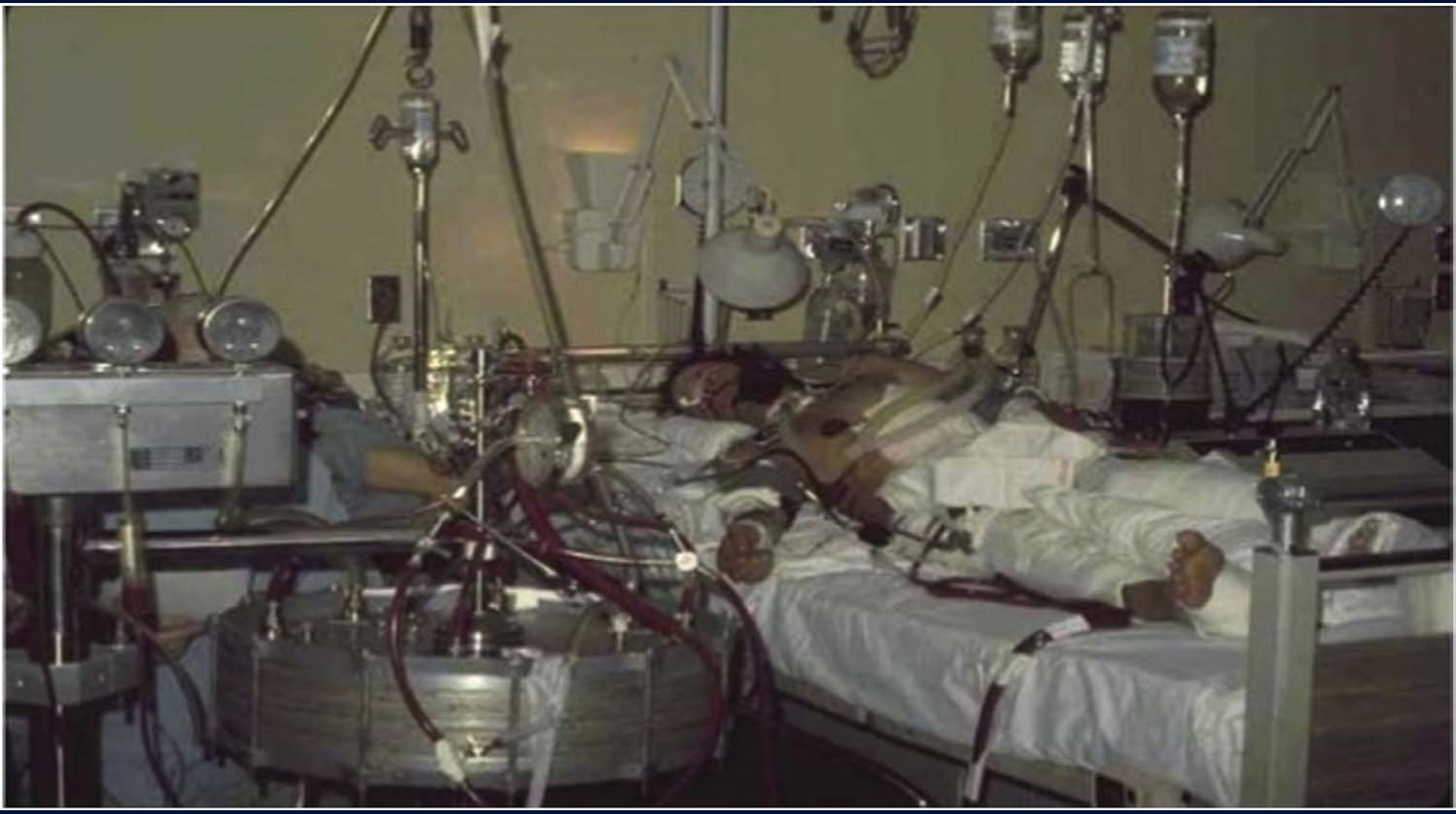
- Definition
- Indications
- Technical Aspects
- Clinical Management
- Conclusions



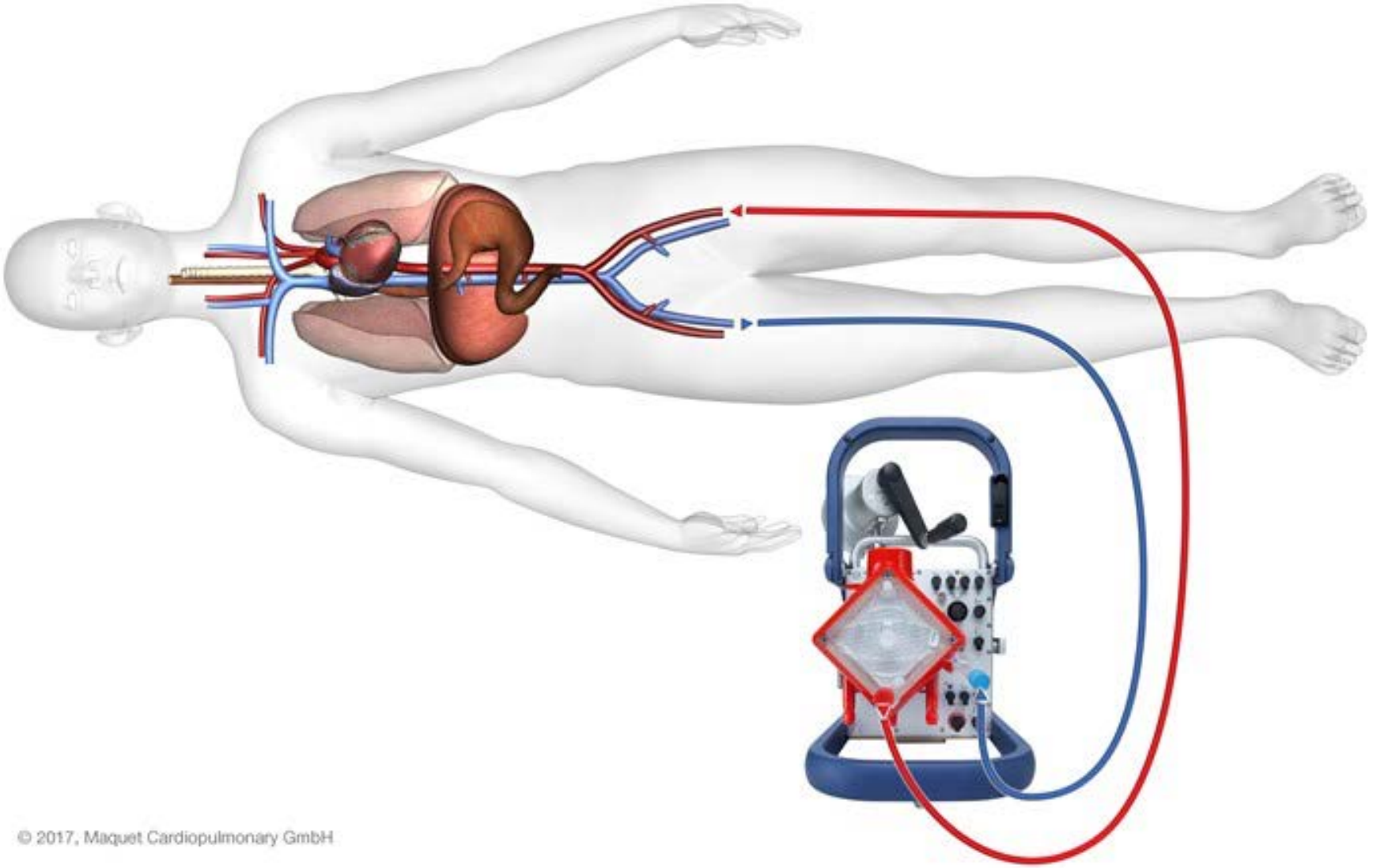
Definition

Extracorporeal membrane oxygenation (ECMO) is a temporary mechanical support system used to aid lung and/or heart function in patients with severe respiratory or cardiac failure





First successful extracorporeal life support patient, treated by J. Donald Hill - 1971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J Thorac Dis 2015;7(7):E166-E176

Table 1 ECMO Indications for cardiac support (VA ECMO only)

- Cardiogenic shock Severe cardiac failure due to almost any cause:
  - acute coronary syndrome
  - cardiac arrhythmic storm refractory to other measures
  - sepsis with profound cardiac depression
  - drug overdose/toxicity with profound cardiac depression
  - myocarditis
  - pulmonary embolism
  - isolated cardiac trauma
  - acute anaphylaxis
- Post cardiotomy: inability to wean from cardiopulmonary bypass after cardiac surgery
- Post heart transplant: primary graft failure after heart or heart-lung transplantation
- Chronic cardiomyopathy:
  - as a bridge to longer term VAD support
  - or as a bridge to decision
- Periprocedural support for high-risk percutaneous cardiac interventions
- Bridge to transplant

ECMO, Extra Corporeal Membrane Oxygenation; VA, venoarterial.

Table 2 ECMO indications for respiratory support

- Acute respiratory distress syndrome:
  - severe bacterial or viral pneumonia
  - aspiration syndromes
  - alveolar proteinosis
- Extracorporeal assistance to provide lung rest:
  - airway obstruction
  - pulmonary contusion
  - smoke inhalation
- Lung transplant:
  - primary graft failure after lung transplantation
  - bridge to lung transplant
  - intraoperative ECMO
- Lung hyperinflation:
  - status asthmaticus
- Pulmonary haemorrhage or massive haemoptysis
- Congenital diaphragmatic hernia, meconium aspiration

ECMO, Extra Corporeal Membrane Oxygenation.

J Thorac Dis 2015;7(7):E166-E176

Table 4 Differences between Venoarterial and Venovenous Extracorporeal Membrane Oxygenation

VA ECMO	VV ECMO
Provides cardiac support to assist systemic circulation	Does not provide cardiac support to assist systemic circulation
Requires arterial and venous cannulation	Requires only venous cannulation
Bypasses pulmonary circulation/decreases pulmonary artery pressures	Maintains pulmonary blood flow
Could be used in RV failure	Can't be used
Lower perfusion rates are needed	Higher perfusion rates are needed
Higher PaO_2 is achieved	Lower PaO_2 is achieved
ECMO circuit connected in parallel to the heart and lungs	ECMO circuit connected in series to the heart and lungs

ECMO, Extra Corporeal Membrane Oxygenation; VA, venoarterial; VV, venovenous.

Table 2
Contraindications to Extracorporeal Membrane Oxygenation Use

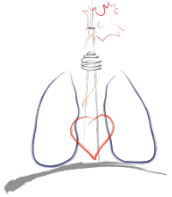
Absolute
Severe, irreversible non-cardiac organ damage limiting survival (eg, irreversible brain injury)
Irreversible pulmonary or cardiac failure if transplantation or long-term LVAD will not be considered
Severe aortic regurgitation
Aortic dissection
Relative
Severe coagulopathy or contraindication to anticoagulation
Limited vascular access
Severe peripheral arterial disease

Adapted from Abrams et al.[37]

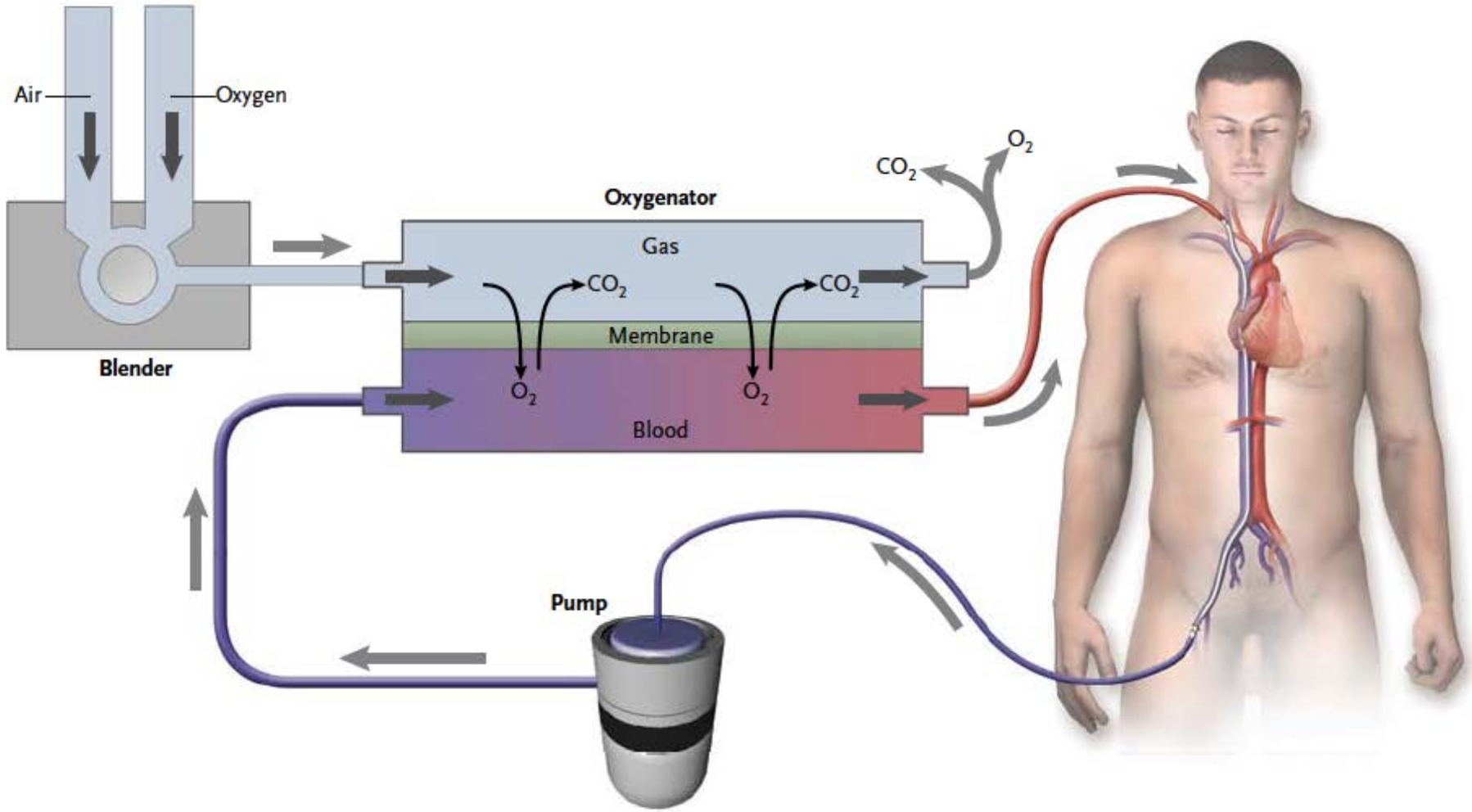
Technical Aspects

Basic ECMO circuit:

- Vascular cannulas
- Pump
- External membrane oxygenator
- Warmer



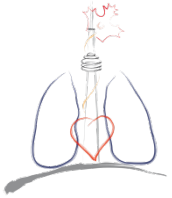
N Engl J Med 2011;365:1905-14.



Technical Aspects

Veno-venous (V-V) ECMO:

- 2 venous cannulas (or 1 double stage venous cannula)
- blood is typically drained from the body via an inflow (into the pump/oxygenator) cannula in the vena cava
- returned via an outflow cannula in close proximity to the right atrium



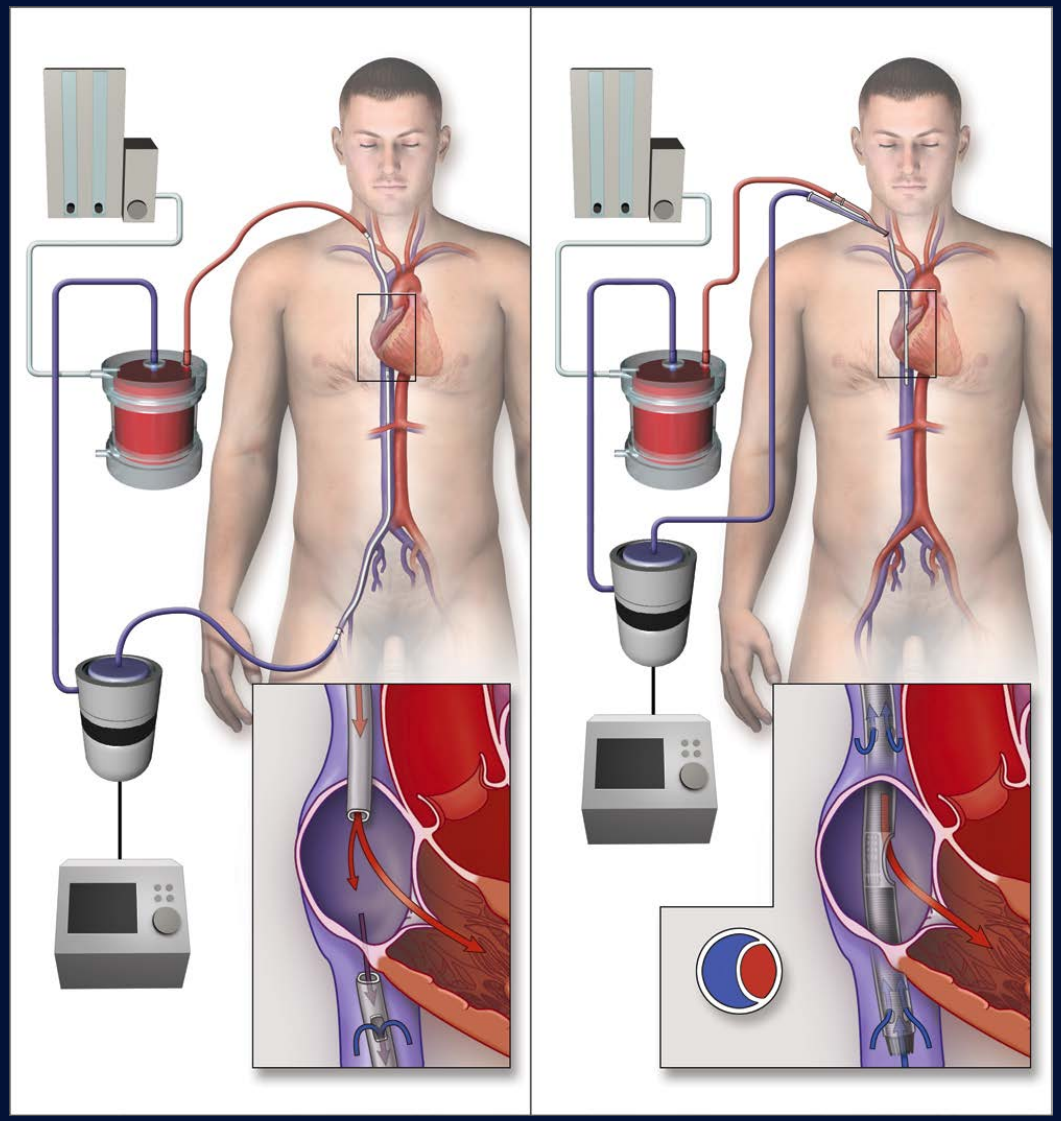
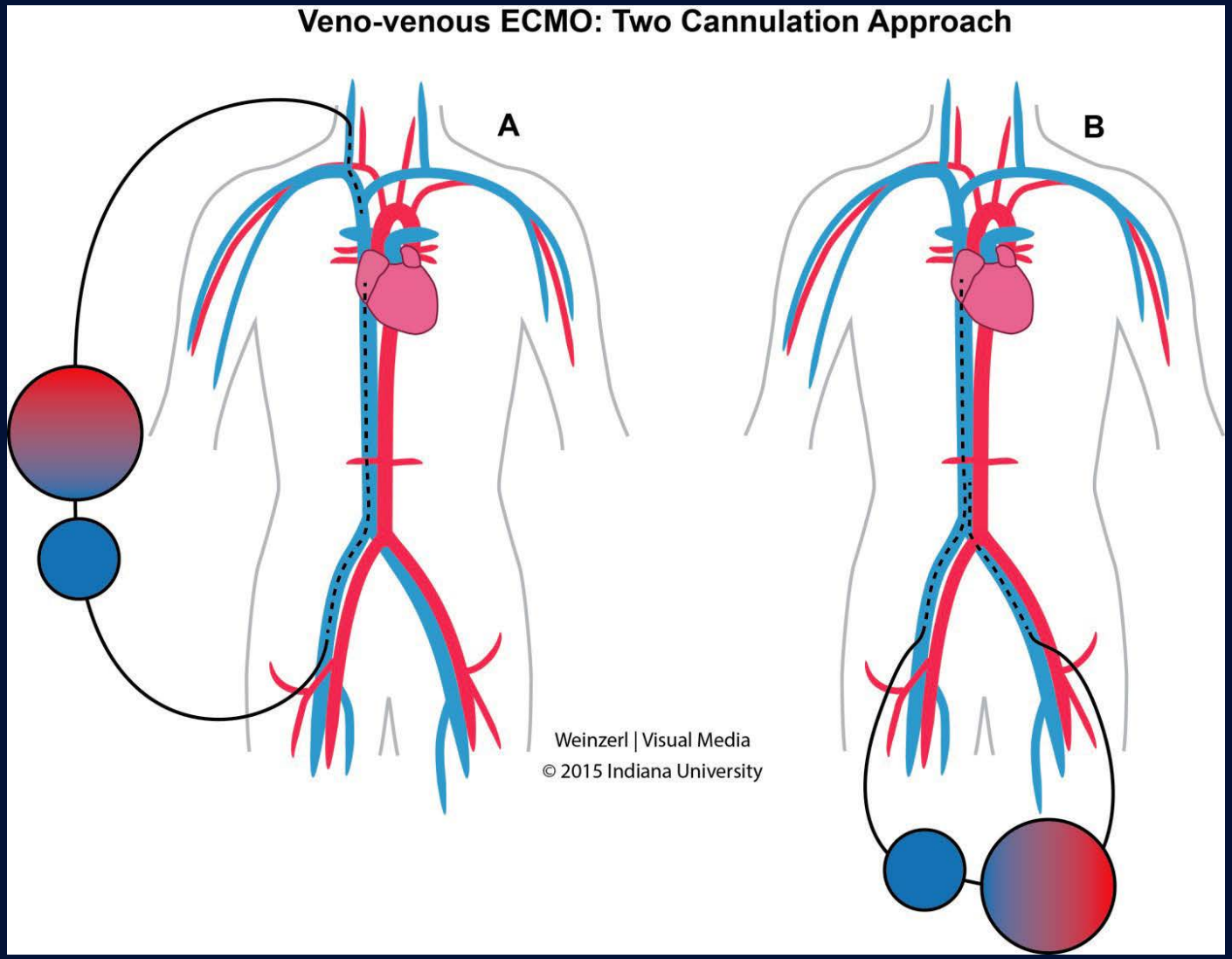


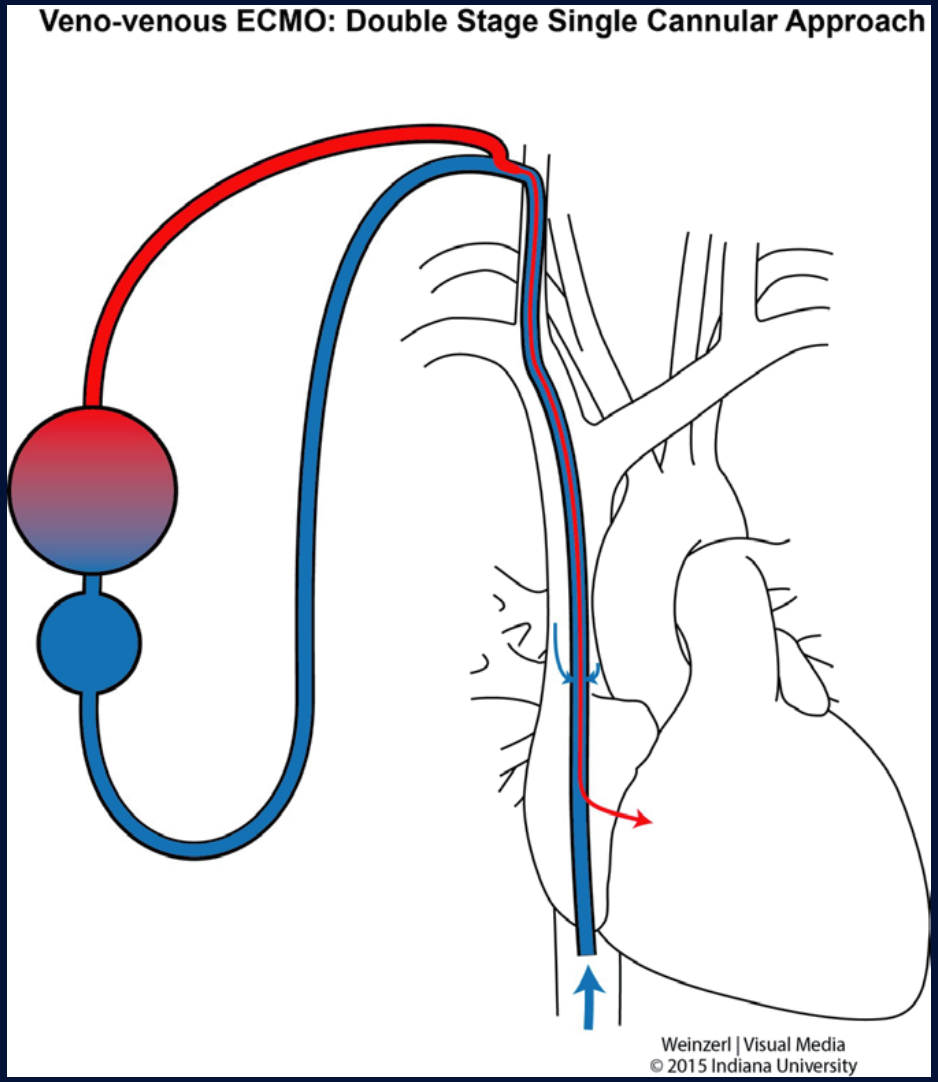
Table 2
Complications and Safety Considerations

Complication	Safety Tip
Injury of carotid or pleura	Ultrasound guidance of venous access
Perforation of RA, RV, IVC	Use multiplane TEE or fluoroscopy to exclude loop of wire in cardiac chamber before dilation and catheter advancement
Subacute tamponade and arrest	Surveillance echocardiography after initiation of ECMO
IVC difficult to cannulate, leading to prolonged attempts	• Decrease positive end-expiratory pressure or disconnect circuit • Fluid challenge • Leave cannula tip in RA and determine whether recirculation is prohibitive • Consider using only return lumen and place separate venous drainage cannula • Consider stiffer wire • Consider additional imaging modality

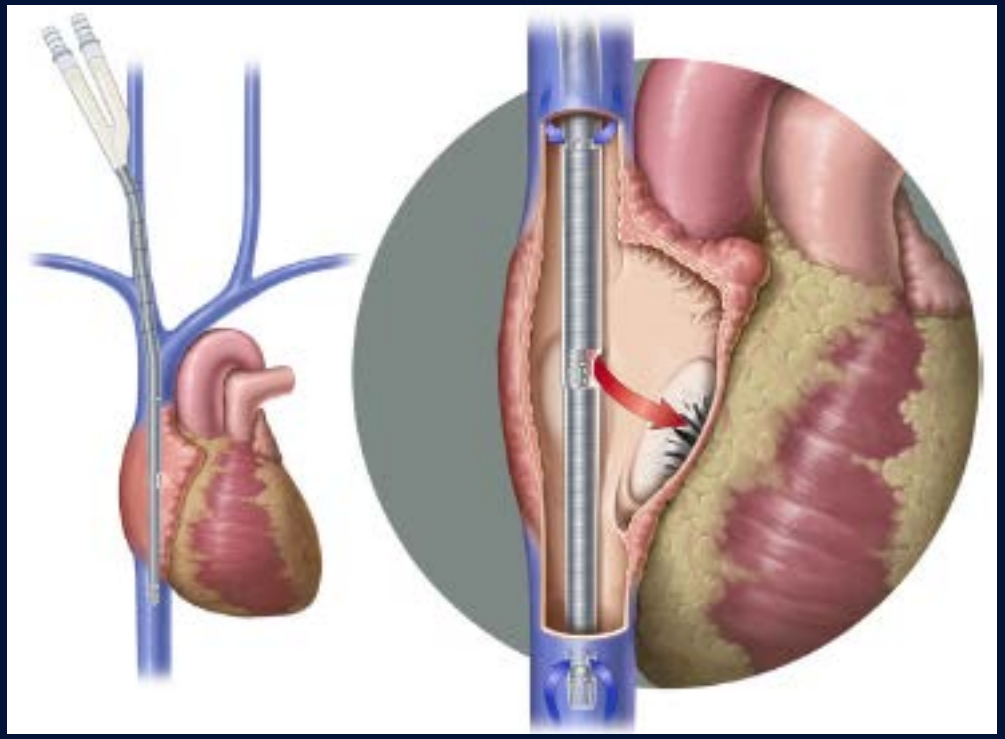
Abbreviations: ECMO, extracorporeal membrane oxygenation; IVC, inferior vena cava; RA, right atrium; RV, right ventricle; TEE, transesophageal echocardiography.

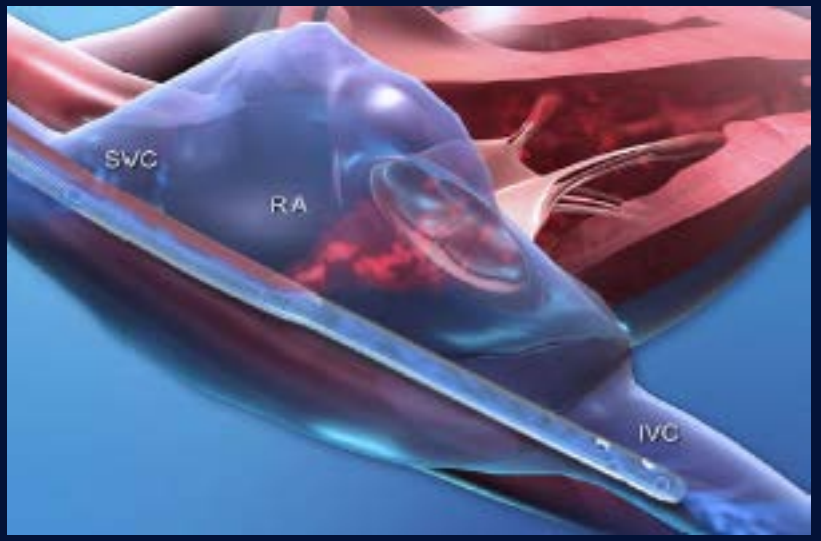


Makdisi and Wang. J Thorac Dis 2015;7(7):E166-E176



Makdisi and Wang. J Thorac Dis 2015;7(7):E166-E176




SVC
RA
IVC

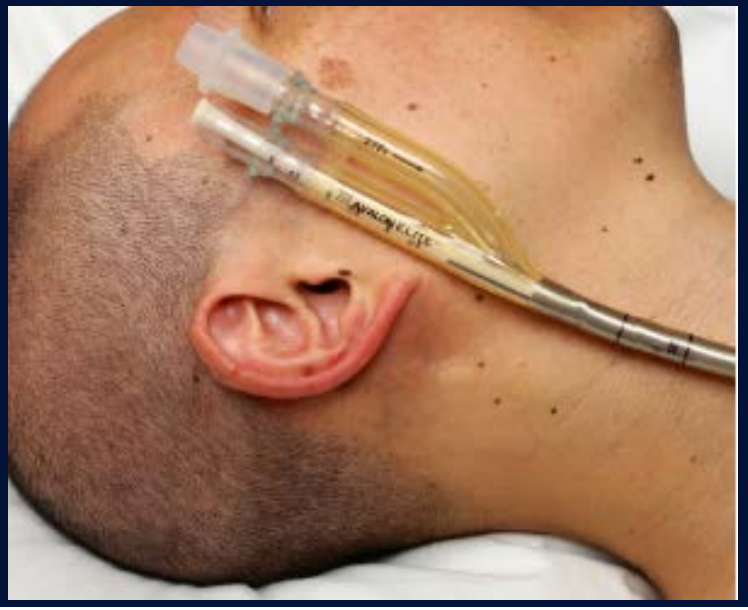


Table 4
Role of TEE for Management of Dual-Lumen Cannula

Phase of Cannulation	TEE Checklist
Precannulation	• Evaluate systolic function • If systolic failure evident, consider VA ECMO • Evaluate volume status • Exclude severe structural TR
Cannulation	• Confirm the course of the wire and cannula • Exclude looping in RA • Ensure tip of cannula is in IVC
Postcannulation	• Evaluate for pericardial effusion • Evaluate for signs of tamponade • Verify orientation of return jet across tricuspid valve, entering R

Abbreviations: ECMO, venovenous extracorporeal membrane oxygenation; IVC, inferior vena cava; RA, right atrium; TR, tricuspid regurgitation; VA, veno-arterial.

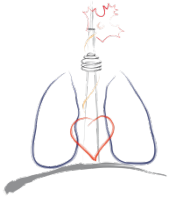
Table 2. Comparison of the Three Most Common VV ECMO Cannulation Strategies

Cannulation Strategy	Strengths	Weaknesses
Right internal jugular dual lumen cannula (currently only available as the Avalon Elite from Avalon Labs, USA)	- Ambulation feasible - Facilitates prone positioning[20] - May decrease transport risks[21] - Minimal recirculation unless tip migrates to hepatic vein or right atrium[21]	- Flow rates limited to 4.2 and 5.3 LPM in 27 and 31F models, respectively[21] - Risk of cardiac (RA or RV) or hepatic injury during placement[22] - Complex placement, which requires fluoroscopy or TEE[20,23]
Femoral–jugular* (femoral cannula will terminate in distal IVC at the level of the diaphragm, jugular cannula will terminate in RA, directed at the tricuspid valve)	- Allows for highest degree blood flow, especially in obese patients - A femoral drainage cannula (tip in the IVC) can be added to further increase flows	- Inflow and outflow cannulas having opposing lumens; recirculation is inversely related to the distance between the cannula tips
Femoral–femoral* (cannulas may be placed in a single or both femoral veins, with the tip of the drainage cannula terminating at the distal IVC at the level of the diaphragm and return cannula in the RA)[24]	- Least complex technically	- Prevents ambulation - Limits elevation of head of bed

Fierro MA et al. Anesthesiology 2018; 128:181-201

Veno-venous (V-V) ECMO:

- ***dependent on patients'*** intrinsic cardiac output (CO) and hemodynamics for support!!!
- its application is for isolated respiratory failure



Question 1

Veno-venous extracorporeal membrane oxygenation (ECMO) provides:

a) improved oxygenation

b) carbon dioxide removal

c) improved oxygenation and carbon dioxide removal

d) improved oxygenation, carbon dioxide removal and hemodynamic support

Question 2

Veno-venous ECMO can be provided via:

a) two venous cannulas

b) one dual lumen venous cannula

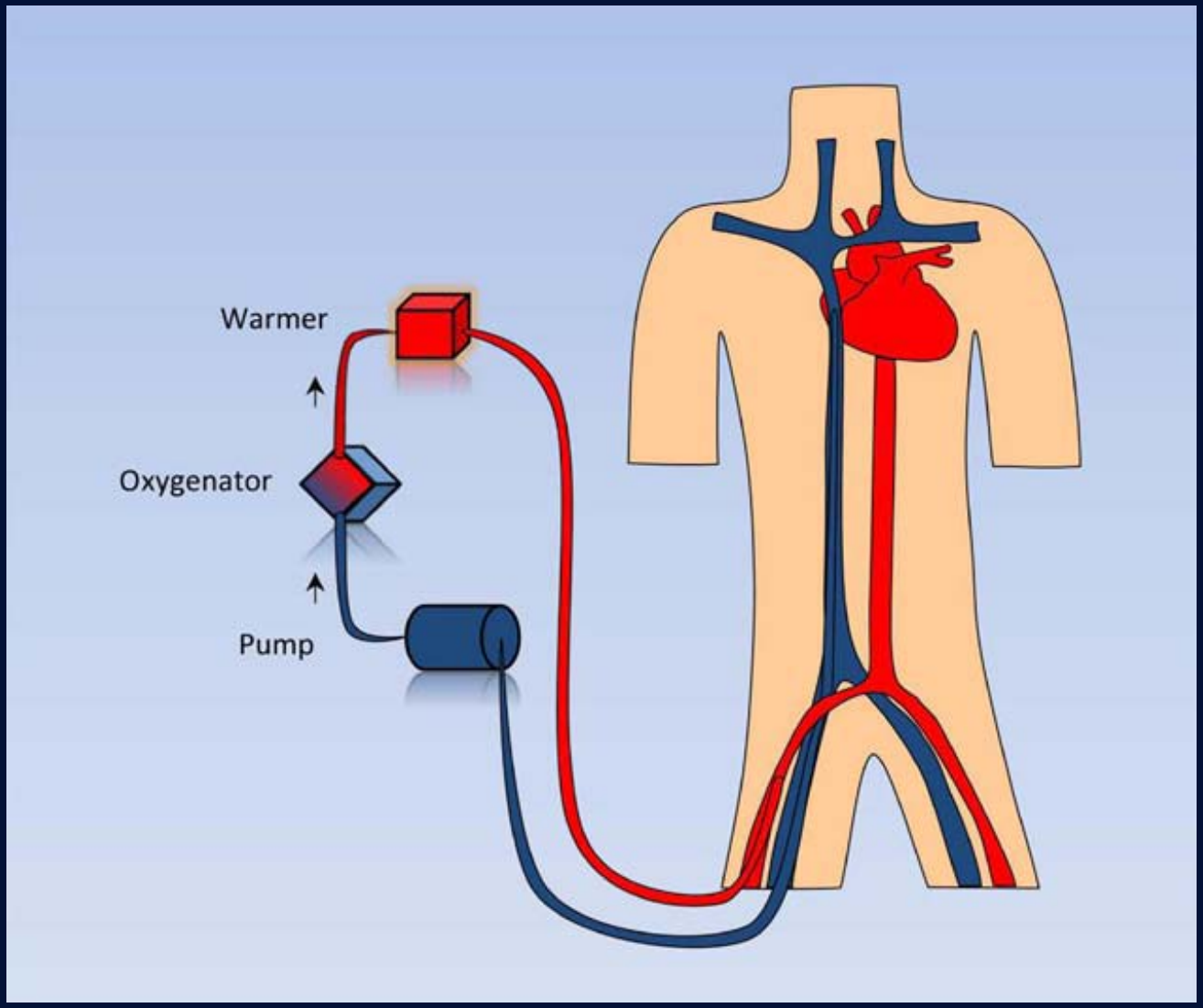
c) a or b

d) none of the above

Technical Aspects

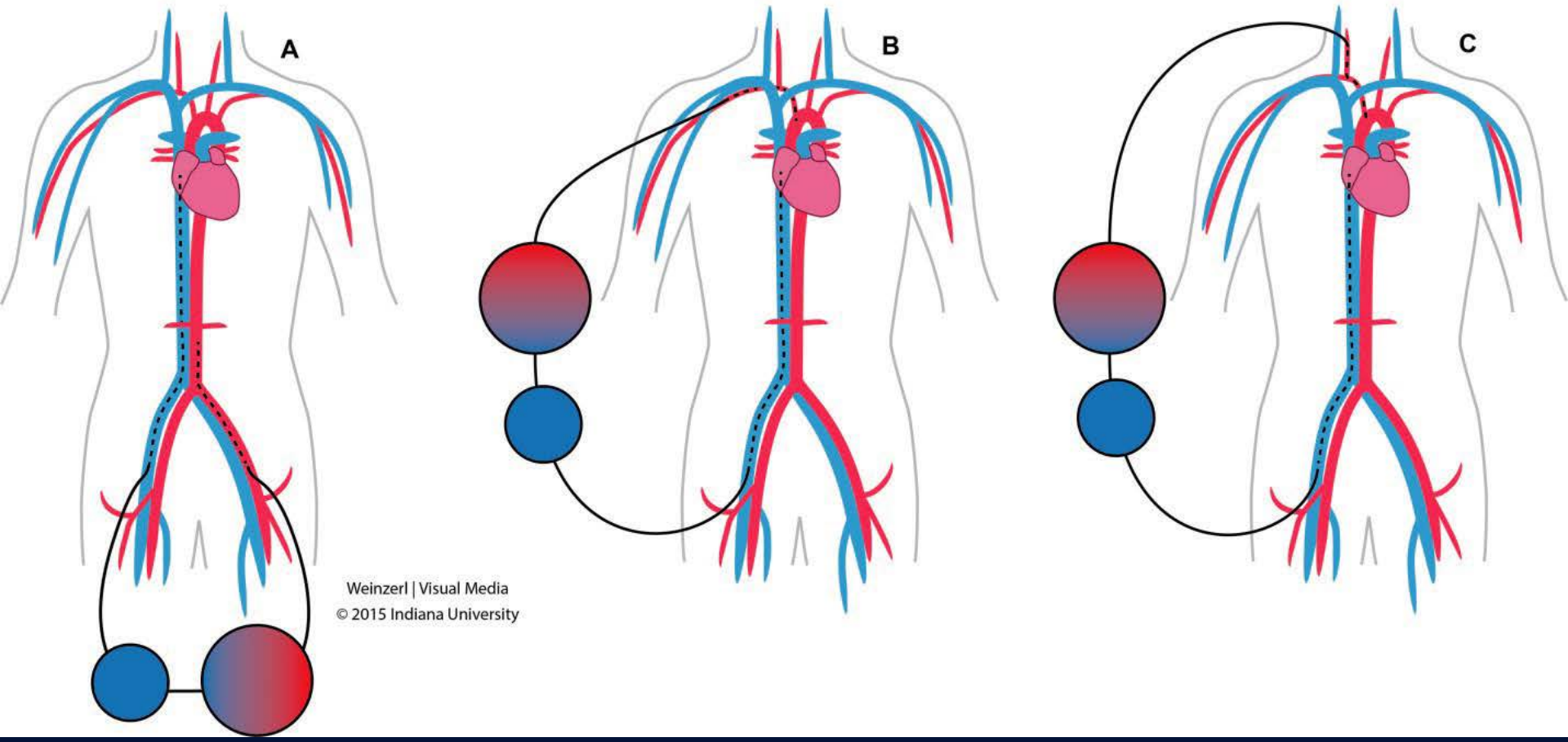
Veno-arterial (V-A) ECMO:

- blood is extracted from a venous inflow cannula in the vena cava
- returned to the arterial system via an outflow cannula, thus bypassing the heart and lungs

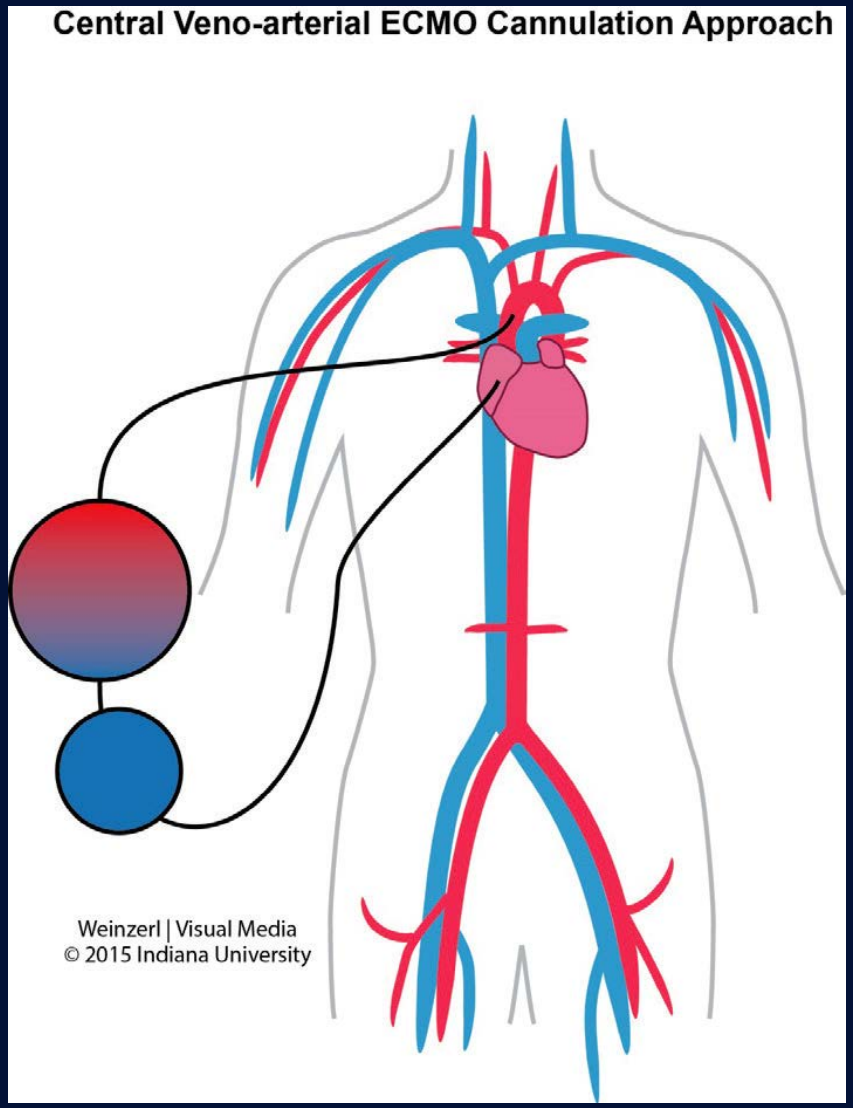


Lawler P et al. Circulation. 2015;131:676-680.

Peripheral Veno-arterial ECMO Cannulation Approach



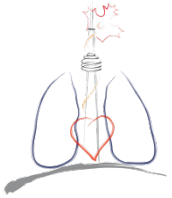
Makdisi and Wang. J Thorac Dis 2015;7(7):E166-E176



Makdisi and Wang. J Thorac Dis 2015;7(7):E166-E176

Veno-arterial (V-A) ECMO:

- is not dependent on native cardiac output
- therefore used in patients with cardiogenic shock
- cannulation can be *central* or *peripheral*



Clinical management

V-A ECMO – Peripheral Cannulation

- flow from the arterial cannula is required to perfuse extracorporeally oxygenated blood retrograde up the descending aorta and into the ascending aorta to assure delivery to the coronary arteries and cerebral great vessels

Clinical management

V-A ECMO – Peripheral Cannulation

- if the left ventricular CO is negligible, the required extracorporeal flow will be small

Clinical management

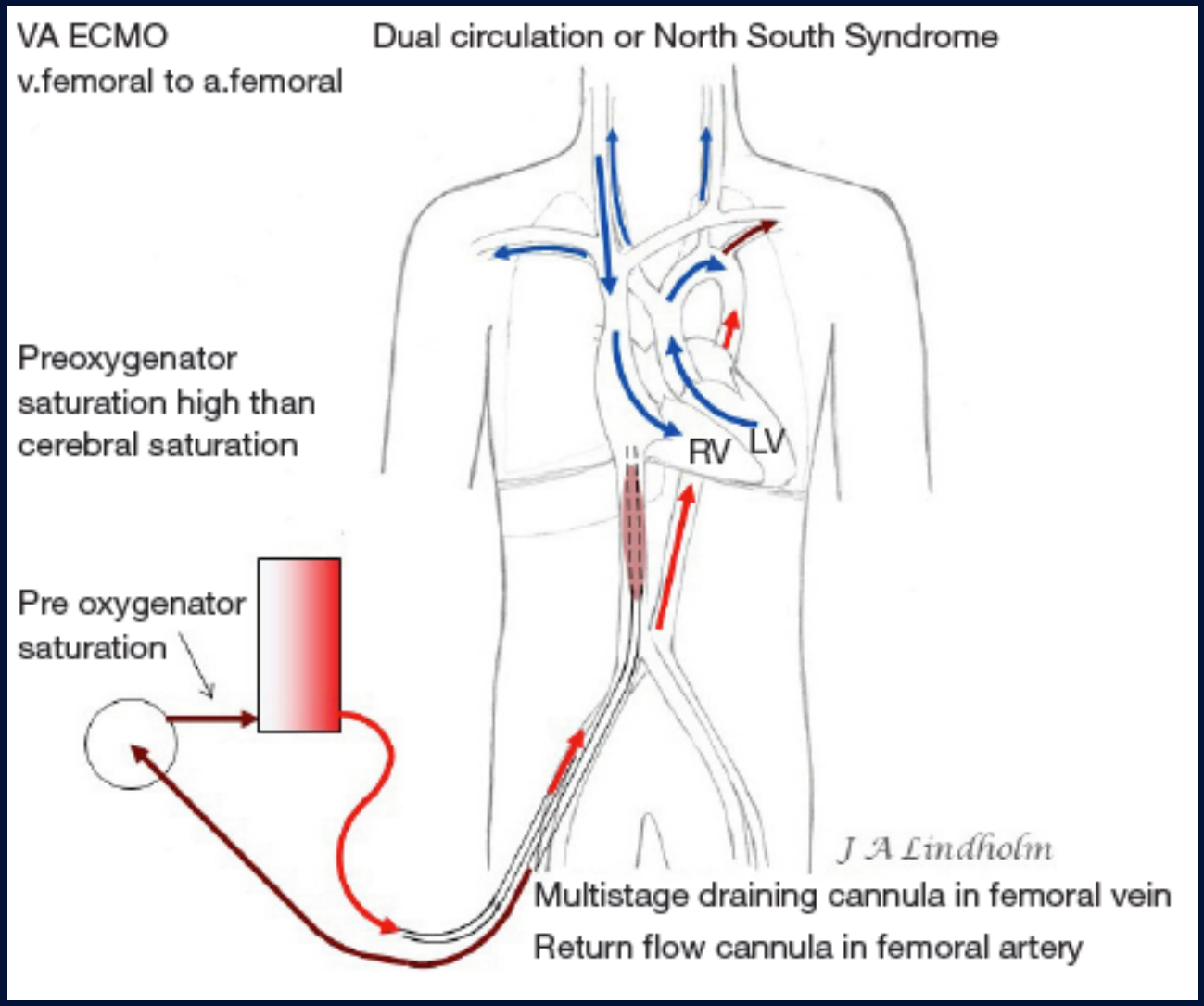
V-A ECMO – Peripheral Cannulation

- as native cardiac function recovers and native cardiac ejection increases, anterograde aortic flow will compete with retrograde flow from the femoral cannula
- a mixing zone of anterograde deoxygenated (in patients with respiratory failure) and retrograde oxygenated blood flow will occur

Clinical management

V-A ECMO – Peripheral Cannulation

- pulse oxygen saturation from the right upper extremity or arterial blood gases from the right radial artery will inform whether ECMO is providing adequate cerebral (although not necessarily cardiac) oxygenation



Lindholm JA. *J Thorac Dis* 2018;10(Suppl 5):S606-S612

Question 3

Veno-arterial ECMO provides:

a) respiratory support

b) hemodynamic support

c) a+b

d) none of the above

Clinical management

Once VA ECMO support is initiated, clinical targets for titration include:

- arterial oxyhemoglobin saturation of >90%
- venous oxyhemoglobin saturation of >70% to 80%
- adequate tissue perfusion (including monitoring of end-organ function and blood lactate levels)

Clinical management

As ECMO support is initiated:

- blood volume is drawn from the patient → may preventatively administer IV fluids
- unlike CPB, ECMO circuits do not include a reservoir nor cardiotomy suction → if bleeding occurs, need IV fluid/blood transfusions

Anticoagulation

Unfractionated heparin infusion – TARGET:

- activated clotting time (ACT) of 180 to 210 seconds

OR

- plasma partial thromboplastin time (PTT) of ≥1.5 times normal

Complications

- Bleeding
- Thrombosis

  - disseminated intravascular coagulation
  - shearing hemolysis
  - thrombocytopenia

→ coagulation factors and platelet count should be closely followed

Gaffney AM et al. BMJ. 2010;341:c5317

Complications

- Patients are at elevated risk of embolic, hypoxic, and hemorrhagic stroke
- Case series of VA ECMO have reported stroke rates of ≈8%

Combes A et al. Crit Care Med. 2008;36:1404–1411.

N Engl J Med 2018;378:1965-75.

Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome

A. Combes, D. Hajage, G. Capellier, A. Demoule, S. Lavoué, C. Guervilly, D. Da Silva, L. Zafrani, P. Tirot, B. Veber, E. Maury, B. Levy, Y. Cohen, C. Richard, P. Kalfon, L. Bouadma, H. Mehdaoui, G. Beduneau, G. Lebreton, L. Brochard, N.D. Ferguson, E. Fan, A.S. Slutsky, D. Brodie, and A. Mercat, for the EOLIA Trial Group, REVA, and ECMONet*

Among all the patients who were treated with ECMO

- the rate of bleeding was 53%
- the rate of hematoma at the cannula-insertion site was 6%
- the rate of infection at the cannula-insertion site was 14%
- the rate of intravascular hemolysis was 5%

Clinical management

Do not forget to protect the lungs:

- gas exchange is provided by ECMO
- keep low Vt (6ml/kg, or ?lower), PEEP, low FiO_2

→ PC 10 cmH_2O, PEEP 10 cmH_2O, FiO_2 0.21

Clinical management

How about pharmacokinetics?

J Thorac Dis 2018;10(Suppl 5):S629-S641

Table 1 Summary of pharmacokinetic changes and potential dosing adjustments for antimicrobials during ECMO

Drug (ref.)	N-octanol/water partition coefficient	Protein binding (%)	Anticipated/reported pharmacokinetic changes	Dosing recommendations & comments
Antibiotics				
Aminoglycosides (41-45)	<0.0	<30	Minimal circuit drug sequestration; enlarged Vd; decreased CL	Insufficient data to recommend optimal dosing[a]; TDM-guided dosing
Beta-lactams				
Ampicillin (24)	1.35	15–30	Minimal to moderate circuit drug sequestration; enlarged Vd	Consider alternative agents; less drug loss in blood-primed *vs.* crystalloid-primed circuit
Ceftriaxone (26,29)	−1.7	95	Significant circuit drug sequestration; enlarged Vd	Dosing similar to critically ill patients not on ECMO support; TDM-guided dosing
Meropenem (46,47)	−0.69	2	Minimal circuit drug sequestration; enlarged Vd; circuit drug loss due to stability issues associated with the carbapenems	Dosing similar to critically ill patients not on ECMO support; TDM-guided dosing; consider alternative dosing strategies (CI or EI dosing)
Piperacillin/tazobactam (46)	0.67	30	Minimal circuit drug loss; enlarged Vd	Dosing similar to critically ill patients not on ECMO support; TDM-guided dosing; consider alternative dosing strategies (CI or EI dosing)
Fluoroquinolones (26,29)	<2.3	20–40	Minimal circuit drug sequestration	Dosing to optimise AUC_{0-24}/MIC[b]
Vancomycin (48-51)	−3.1	50–60	Minimal circuit drug sequestration; enlarged Vd	Dosing similar to critically ill patients not on ECMO support; a loading dose 25–30 mg/kg followed by 30–40 mg/kg/day; TDM-guided dosing; consider CI dosing
Antifungals				
Caspofungin (24,52,53)	<0.17	97	Minimal to moderate circuit drug sequestration	Insufficient and conflicting data; dosing adjustments may be required
Voriconazole (24,52)	1	58	Significant drug sequestration	Higher initial loading dose with higher daily doses; TDM-guided dosing to monitor circuit saturation

[a], due to major refinements in ECMO technology, earlier pharmacokinetic data and dosing recommendations may potentially be irrelevant to current practice; [b], these may be achieved with a 400 mg 8-hourly or 600 mg 12-hourly for ciprofloxacin. ECMO, extracorporeal membrane oxygenation; MIC, minimum inhibitory concentration; TDM, therapeutic drug monitoring.

J Thorac Dis 2018;10(Suppl 5):S629-S641

Table 2 Summary of pharmacokinetic changes and potential dosing adjustments for sedatives and analgesics during ECMO

Sedatives and analgesics (ref.)	N-octanol/water partition coefficient	Protein binding (%)	Anticipated/reported pharmacokinetic changes	Dosing recommendations & comments
Benzodiazepines				
Midazolam (5,6,28)	3.9	97	Significant circuit drug sequestration	Higher initial loading dose with higher daily doses
Dexmedetomidine (17,20)	2.8	94–97	Significant circuit drug sequestration	Consider higher initial loading dose with higher daily doses[a]
Opioids				
Fentanyl (24,27,28,74-76)	4.1	80–85	Significant circuit drug sequestration	Consider alternative agents; to be considered only as a short-term analgesia
Morphine (24,27,28,32,33)	0.9	30–40	Minimal to moderate circuit drug sequestration	Higher initial loading dose with higher daily doses
Propofol (23,77)	3.8	95–99	Significant circuit drug sequestration	Insufficient data but likely to require higher doses over time

[a], should be considered due to favourable safety profile when compared to other traditional agents. ECMO, extracorporeal membrane oxygenation.

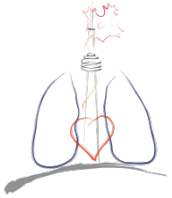
Mr. J.D.

- V-A ECMO was successfully instituted (RIJ venous cannula, Rfem arterial cannula)
- It's now 2:30am, and the team is ready to leave the operating room and transport the patient to the ECMO center
- …when you notice right leg discoloration…

Clinical management

V-A ECMO – Peripheral Cannulation

- Given the need for large femoral arterial cannulas (size 16 to 21 Fr), distal leg ischemia can develop
- This risk may be reduced by prophylactic insertion of a small (6 Fr) anterograde perfusion cannula into the superficial femoral artery, to perfuse the leg distal to the primary arterial cannula



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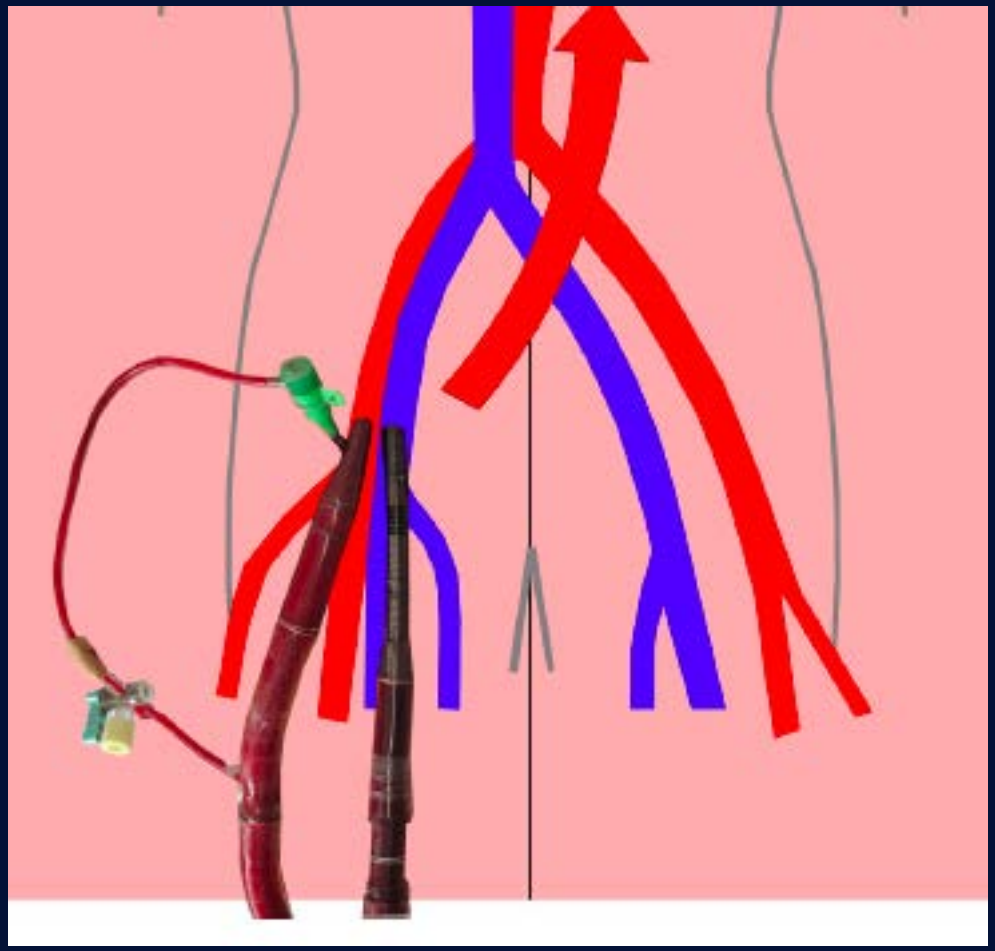

Mr. J.D.

- Profuse bleeding at the cannulation site

→ Hold anticoagulation, correct coagulopathy

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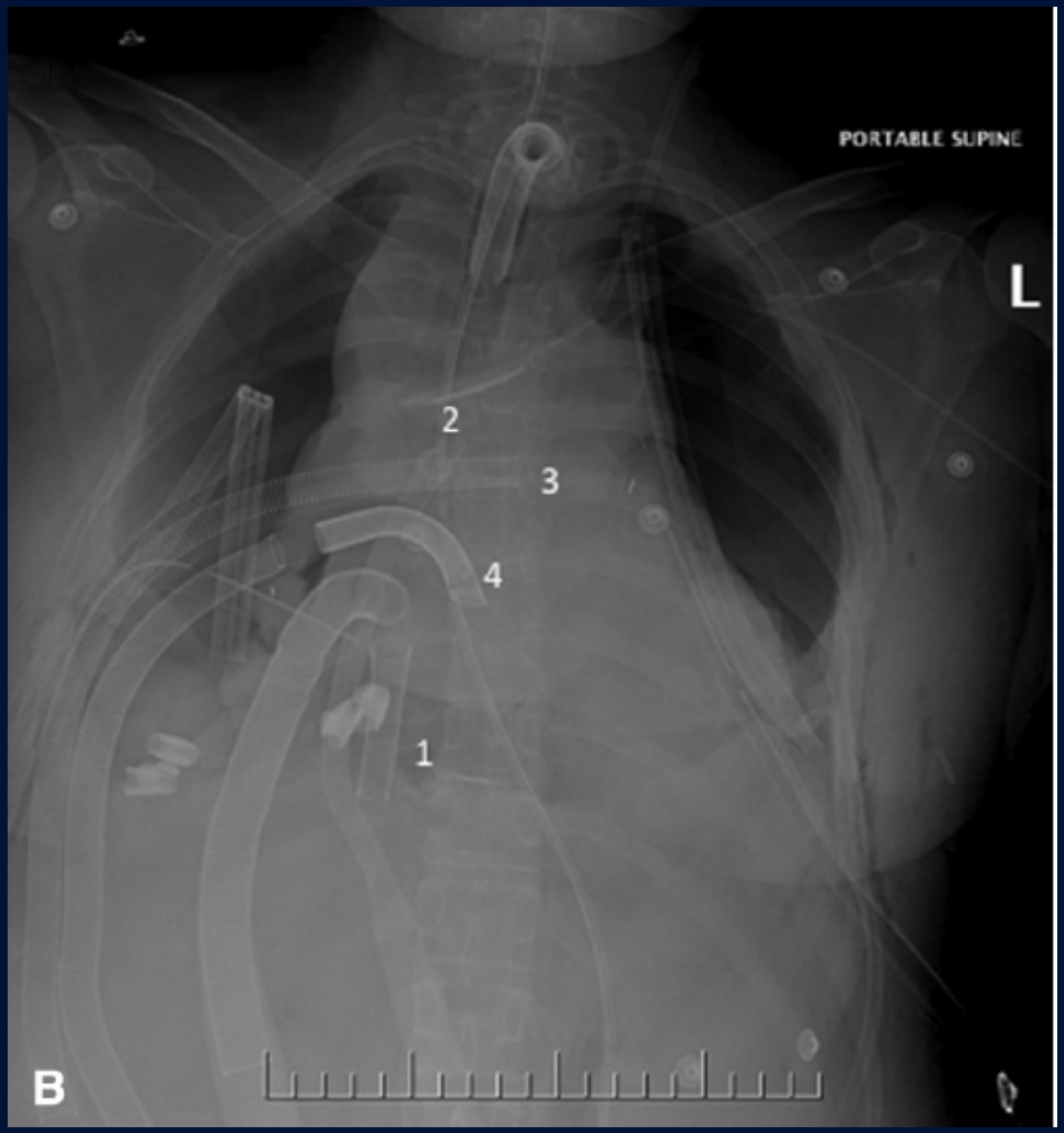
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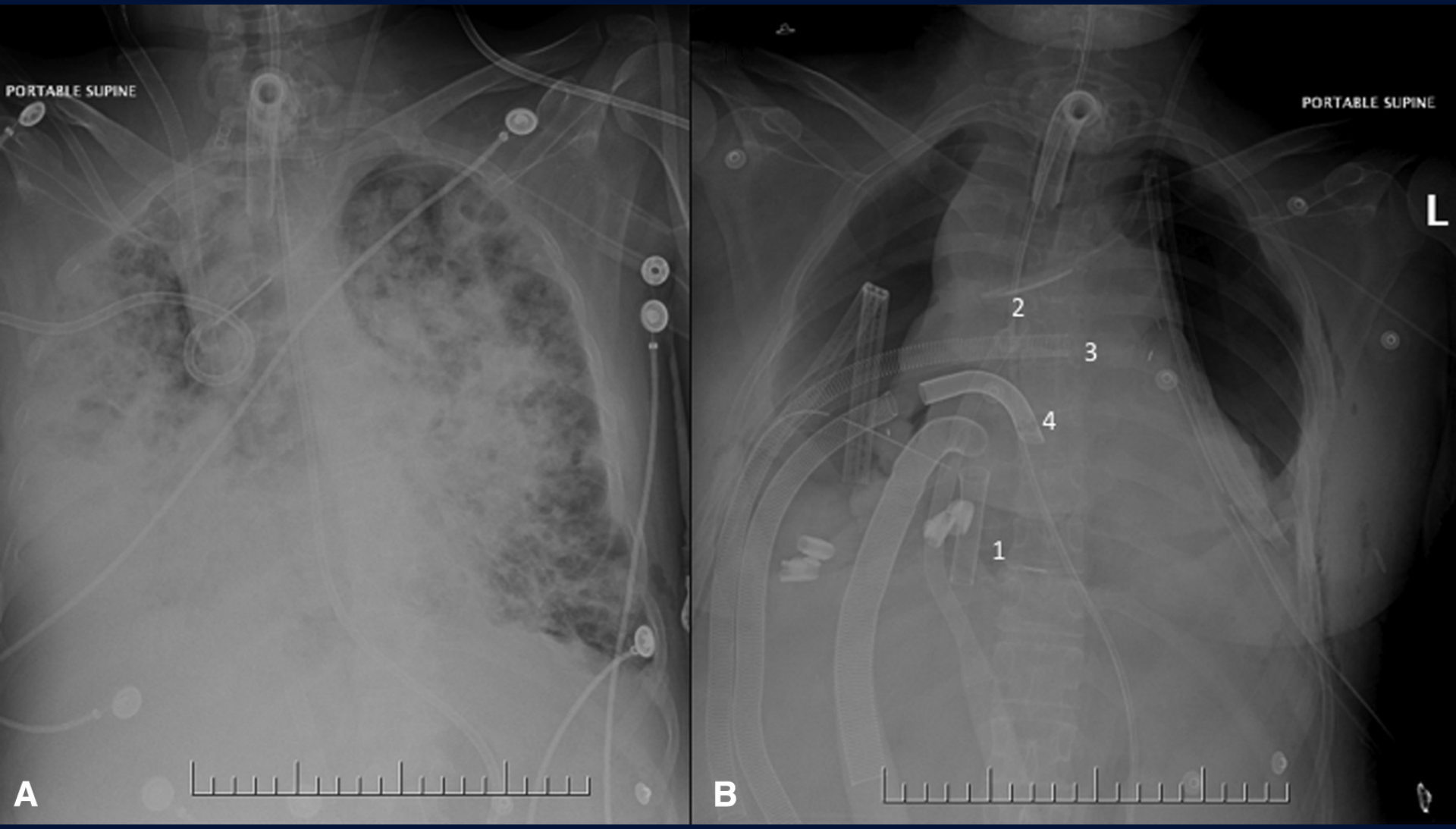
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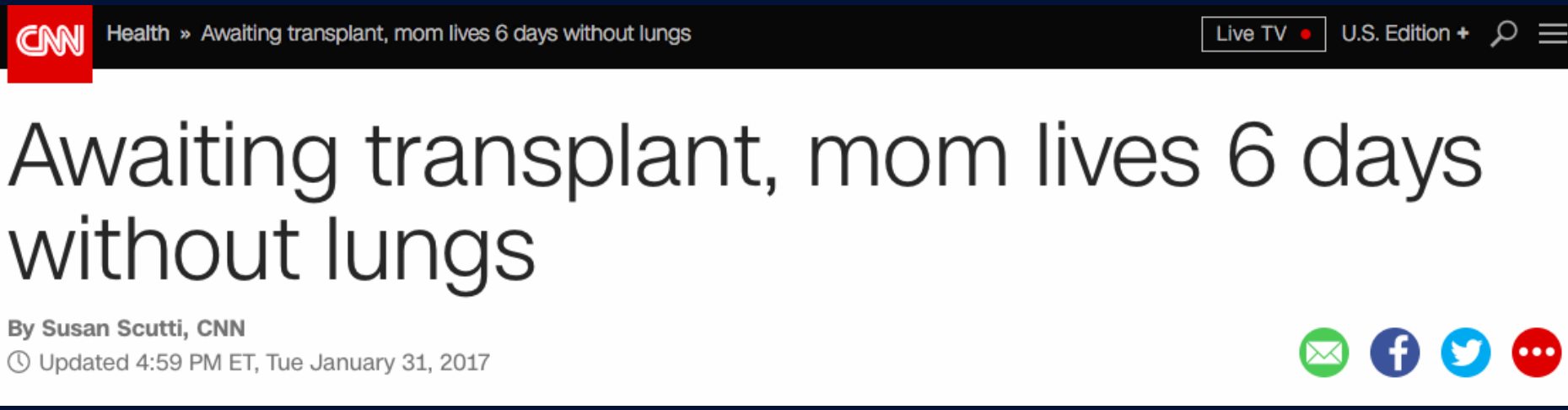
The Journal of Thoracic and Cardiovascular Surgery • Volume 153, Number 4

Bilateral pneumonectomy to treat uncontrolled sepsis in a patient awaiting lung transplantation

Marcelo Cypel, MD,[a,b] Thomas Waddell, MD,[a,b] Lianne G. Singer, MD,[a,c] Lorenzo del Sorbo, MD,[d] Eddy Fan, MD,[d] Matthew Binnie, MD,[a,c] Niall D. Ferguson, MD,[d] and Shaf Keshavjee, MD,[a,b] Toronto, Ontario, Canada



Awaiting transplant, mom lives 6 days without lungs

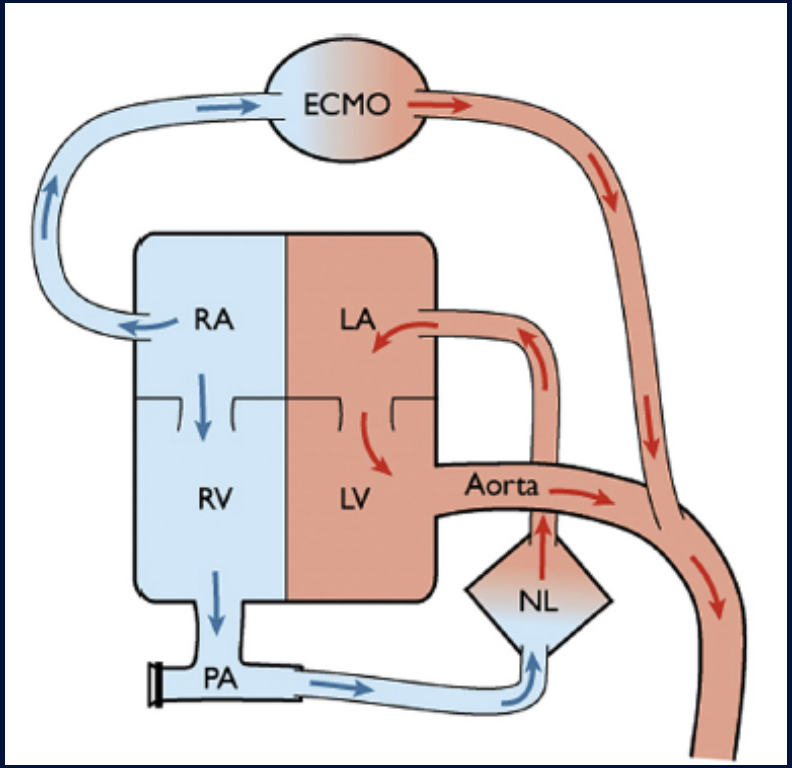
By Susan Scutti, CNN

Updated 4:59 PM ET, Tue January 31, 2017

UNIVERSITY OF TORONTO

Interdepartmental Division of Critical Care Medicine

Department of Anesthesia



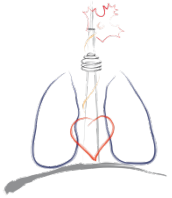
Central Message

A patient with cystic fibrosis developed pulmonary-induced septic shock. Bilateral pneumonectomy was performed to remove the septic source. Six days later, a successful lung transplantation was performed.

SUMMARY

Take Home Messages

- ECMO use is expanding – even if you are not in an ECMO centre, you may be exposed to it
- It may provide isolated respiratory (V-V ECMO) or cardio-respiratory (V-A ECMO) support
- Lower anticoagulation targets than CPB – and no anticoagulation is acceptable for short periods of time
- Be aware of volume status/bleeding



Questions

Thank You

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Question 1

Veno-venous extracorporeal membrane oxygenation (ECMO) provides:

a) improved oxygenation

b) carbon dioxide removal

c) improved oxygenation and carbon dioxide removal

d) improved oxygenation, carbon dioxide removal and hemodynamic support

Question 2

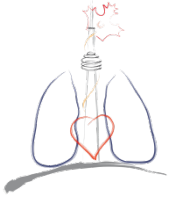
Veno-venous ECMO can be provided via:

a) two venous cannulas

b) one dual lumen venous cannula

c) a or b

d) none of the above



Question 3

Veno-arterial ECMO provides:

a) respiratory support

b) hemodynamic support

c) a+b

d) none of the above

Oxygenation Response to Positive End-Expiratory Pressure Predicts Mortality in Acute Respiratory Distress Syndrome

A Secondary Analysis of the LOVS and ExPress Trials

Ewan C. Goligher[1,2,3,4], Brian P. Kavanagh[1,5,6], Gordon D. Rubenfeld[1,2,7], Neill K. J. Adhikari[1,2,7], Ruxandra Pinto[7], Eddy Fan[1,2,4], Laurent J. Brochard[1,2,8], John T. Granton[1,2,4], Alain Mercat[9], Jean-Christophe Marie Richard[10], Jean-Marie Chretien[11], Graham L. Jones[12], Deborah J. Cook[12,13], Thomas E. Stewart[1,2,4], Arthur S. Slutsky[1,2,4], Maureen O. Meade[12,13], and Niall D. Ferguson[1,2,3,4]

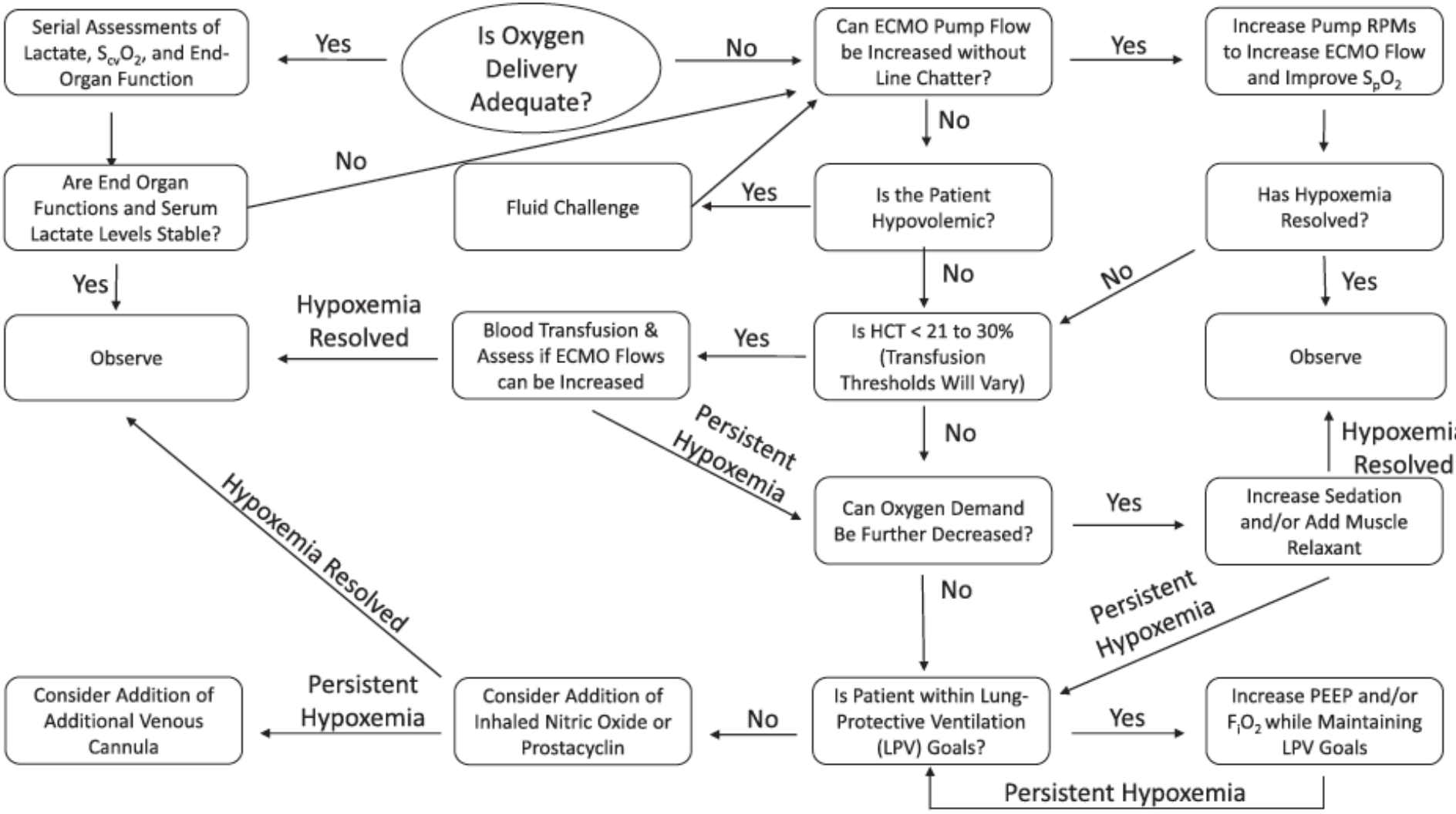


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Table 6. Management and Troubleshooting of Hypoxemia, Hypercapnia, and ECMO Parameters

	ECMO Interventions	Patient Interventions
Hypoxemia	- Increase ECMO flow/RPMs	- Volume challenge if flows have acutely decreased - Increase F_{IO_2} during the perioperative period - Increase PEEP - Decrease patient demand (sedation, muscle relaxation, cooling)
Hypercarbia	- Increase sweep gas flow rate	- Decrease patient demand (sedation, muscle relaxation, cooling)
Decreased ECMO circuit blood flow (with signs of hypoxemia, hypercarbia, or new clinical instability)	- Increase pump RPMs - No intervention is necessary if patient condition is unchanged	- Assess for changes to patient position - Volume challenge - Consider line position change during transport
ECMO tubing vibration or partial collapse ("line chatter")	- Decrease pump RPMs	- Volume challenge - Reverse changes to patient position
Increasingly negative inflow pressure	- Decrease RPMs (if flows adequate for oxygenation)	- Volume challenge if progressive change from baseline - Reverse changes to patient position
High outflow line pressure	- Decrease RPMs (if flows adequate for oxygenation)	
Increased transmembrane pressure	- Assess for membrane clot; if severe consider replacement before OR - If acute, membrane change may be needed	- Consider using higher perioperative anticoagulation goals and restarting heparin earlier
High pre–ECMO Spo_2 (not available on all consoles)	- Consider a sign of possible recirculation: (1) Compare to systemic Spo_2 (should be lower), (2) assess for changes to cannula position, and (3) surgeon evaluation if likely requires cannula manipulation	- Can reflect improved cardiac output, improved lung function/oxygenation, or transfusion of blood
Low pre–ECMO Spo_2 (not available on all consoles)	- Consider this a sign of low $Scvo_2$ - Increase ECMO flows	- Increase cardiac output - Transfuse blood - Decrease patient oxygen demand

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Table 5. Summary of Anesthetic Implications for VV ECMO Patients Undergoing Surgery

Preoperative evaluation	- Assess and document ECMO settings and blood flow - Asses for coagulopathy, consider risks of platelet dysfunction and DIC - Type and cross for red blood cells, consider preparation of FFP - Assess ECMO–specific complications (arrhythmias, anemia, bleeding, pneumothorax, thrombosis) - Pause anticoagulation, if feasible and indicated
Transport to the OR	- Utilize standard ICU monitors - Utilize transport ventilator or portable ICU ventilator with alarms - Include a practitioner dedicated to ECMO and capable of troubleshooting
Induction and maintenance of anesthesia	- Patients may require little or no additional anesthetic depending on baseline degree of sedation - TIVA is preferred - Titrate anesthetics to clinical effect/depth monitor
Monitoring	- Arterial line can be at any site with VV ECMO - Anesthetic depth monitoring is useful - Echocardiography is a reliable measure of cardiac output; all other techniques have limitations - $ETco_2$ remains reliable, but value also reflects decarboxylation done by ECMO
Volume assessment and management	- Negative fluid balance is general goal in VV ECMO patients - Decreases in ECMO flows, venous pressure, and development of “chatter” can reflect low preload - Consider volume challenge if ECMO flows are decreasing during period of acute blood loss (especially if associated with decreased Spo_2)
RBC transfusion: indications/triggers	- Blood can be used to increase DO_2, regardless of hemoglobin level - Guidelines are widely variable; transfusion to Hb > 7 g/dl acceptable in selected patients
Management of anticoagulation for ECMO	- Acceptable to hold anticoagulation in perioperative period for most VV ECMO patients (unless they have had thromboembolic events) - Generally, aPTT goals are 40–60 s and ACT goals are 180–220 s in VV ECMO patients
Assessment and treatment of coagulopathy	- Utilize traditional coagulation labs and or thromboelastometry to direct management of surgical bleeding; aPTT elevations may be artificial due to critical illness - Platelet dysfunction and acquired von Willenbrand’s disease common with prolonged ECMO durations - Prothrombin complex concentrate may be considered for patients with bleeding and prolonged INR or clotting time who cannot tolerate volume - Consider cryoprecipitate for hypofibrinogenemia

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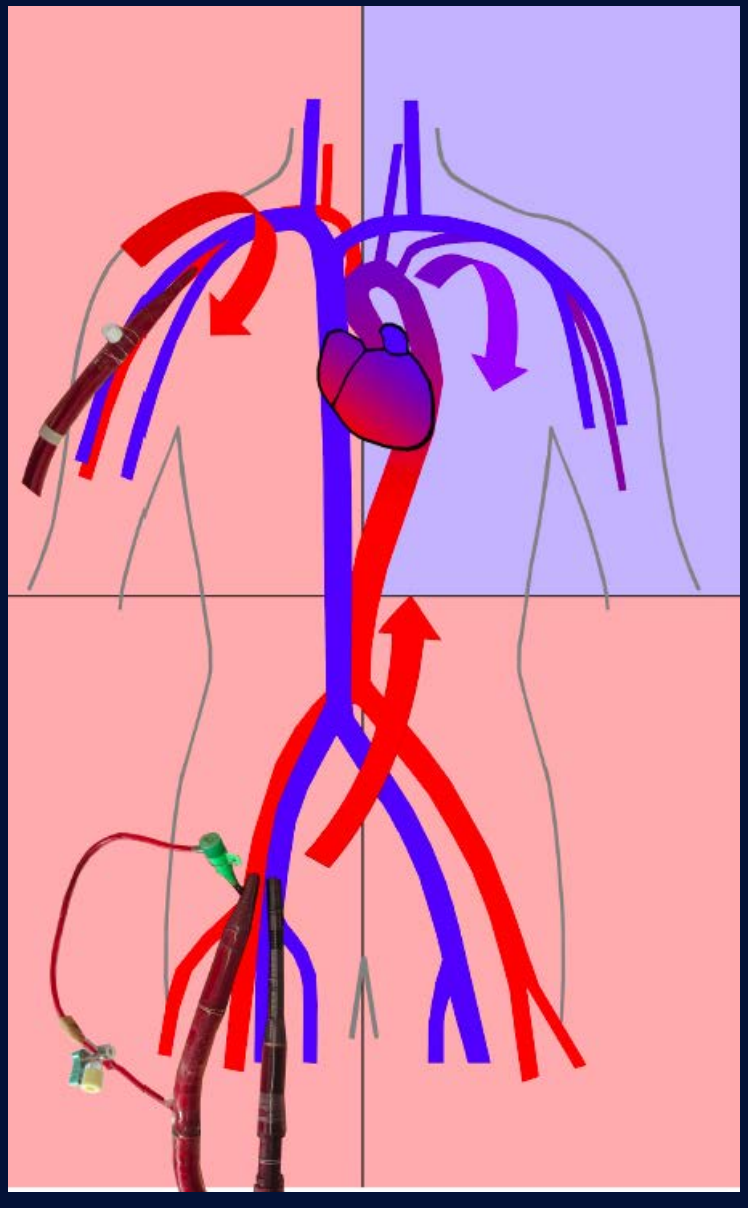

Table 4. Management Strategies for Hypercarbia

Intervention	Increases CO_2 Elimination	Decreases CO_2 Production	Decreases $Paco_2$
Increasing fresh gas flow (sweep flow rate)	Yes	No	Yes
Increasing ECMO blood flow	No	No	No
Muscle relaxation, sedation, cooling, controlled ventilation	No	Yes	Yes
Increasing alveolar ventilation (increased mechanical ventilator minute ventilation)	Yes	No	Yes
Increasing ventilator PEEP	No	No	No

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continuous renal replacement therapy

(CRRT) may be added to the circuit.

Makdisi and Wang. J Thorac Dis 2015;7(7):E166-E176