115年機械通氣重症繼續教育課程

ECMO in acute respiratory failure

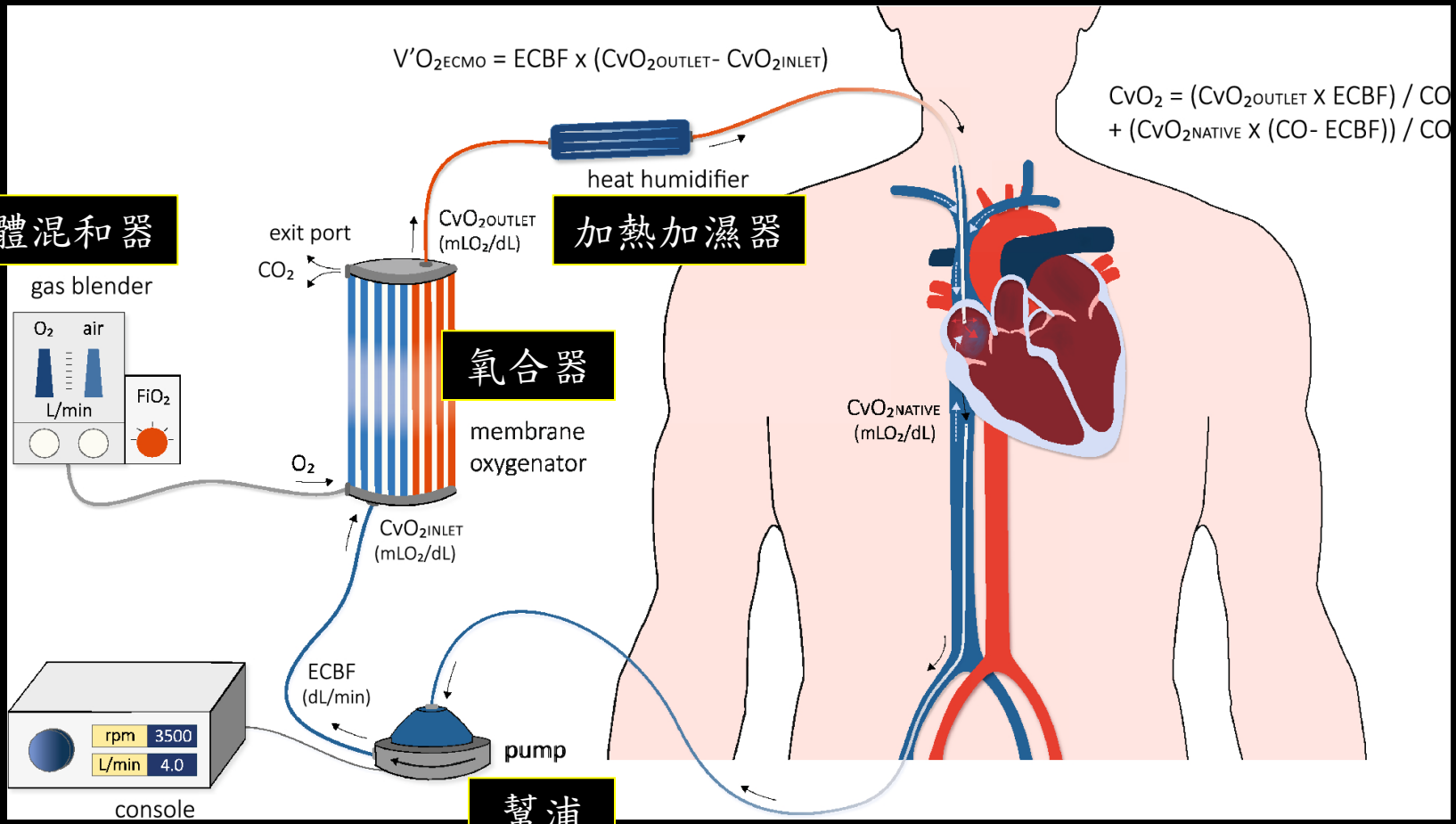
2026/08/16

林口長庚紀念醫院 呼吸胸腔科
張克威醫師

Outline

- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

ECMO

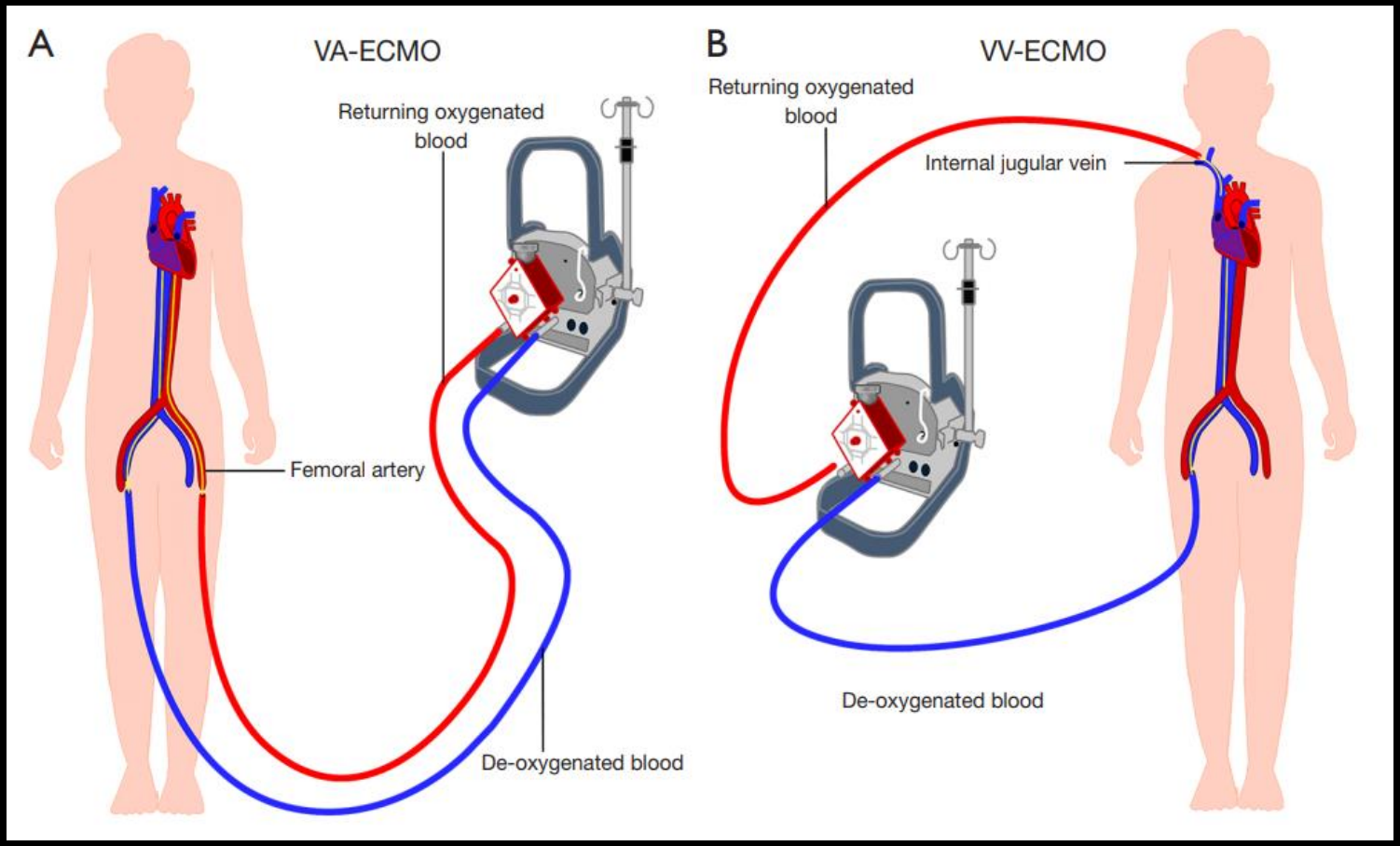


Evangelia Akoumianaki; Annals of Intensive Care 2021

ECMO mode

Veno-arterial ECMO
支持心臟；低血壓

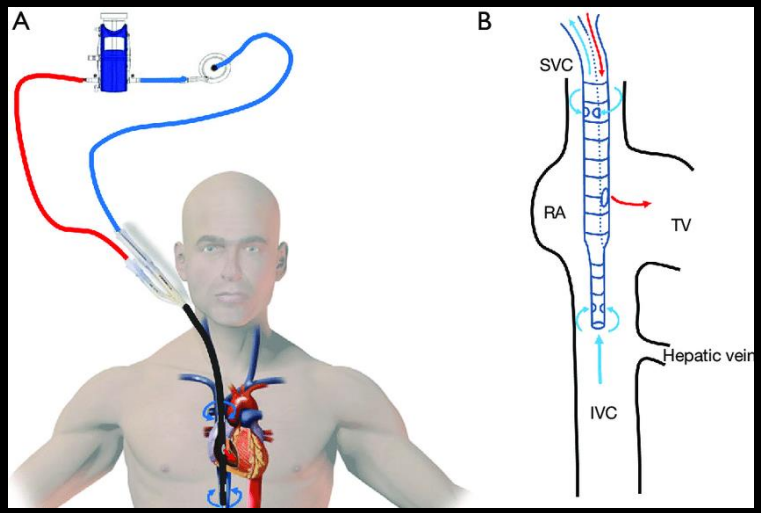
Veno-venous ECMO
支持肺臟；低血氧

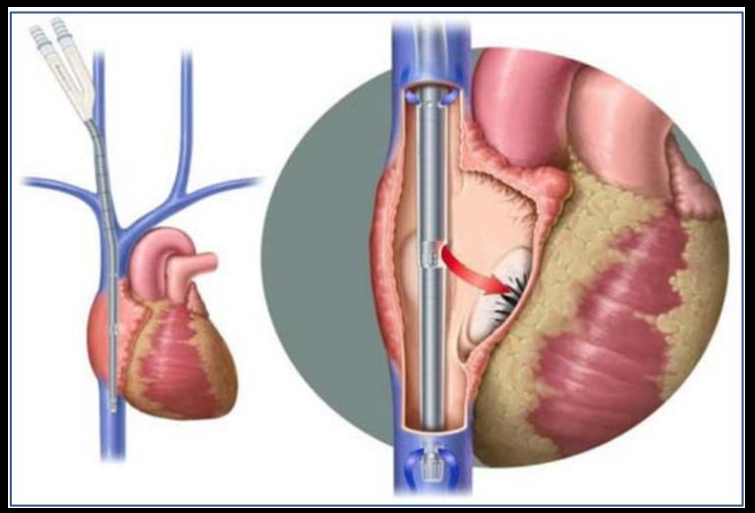


Anil K. Pillai; Cardiovascular Diagnosis and Therapy 2018

Double lumen bicaval cannula

- Minimal recirculation/shunt of oxygenated blood
- Avoids additional femoral cannulation
  - Allows the use of prone positioning
  - Early mobilization



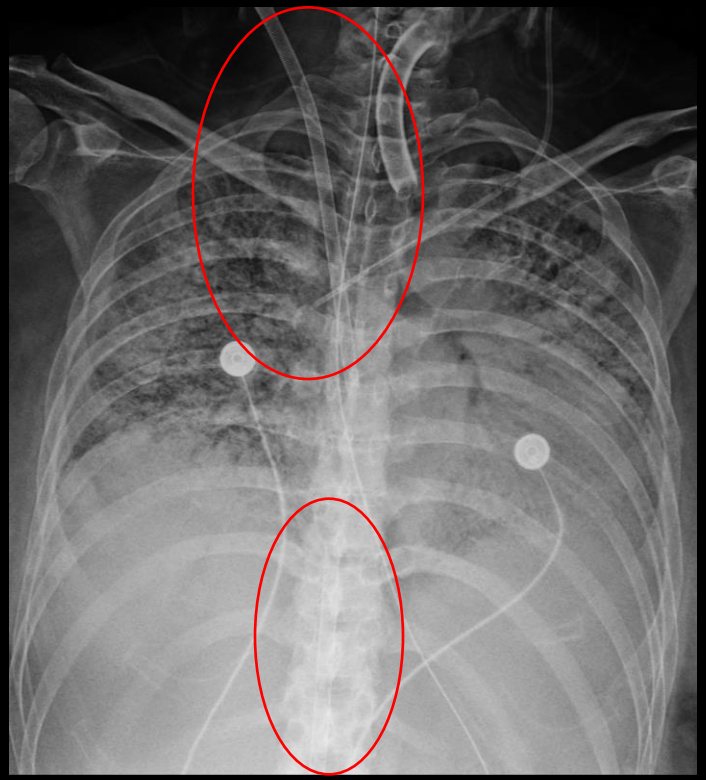


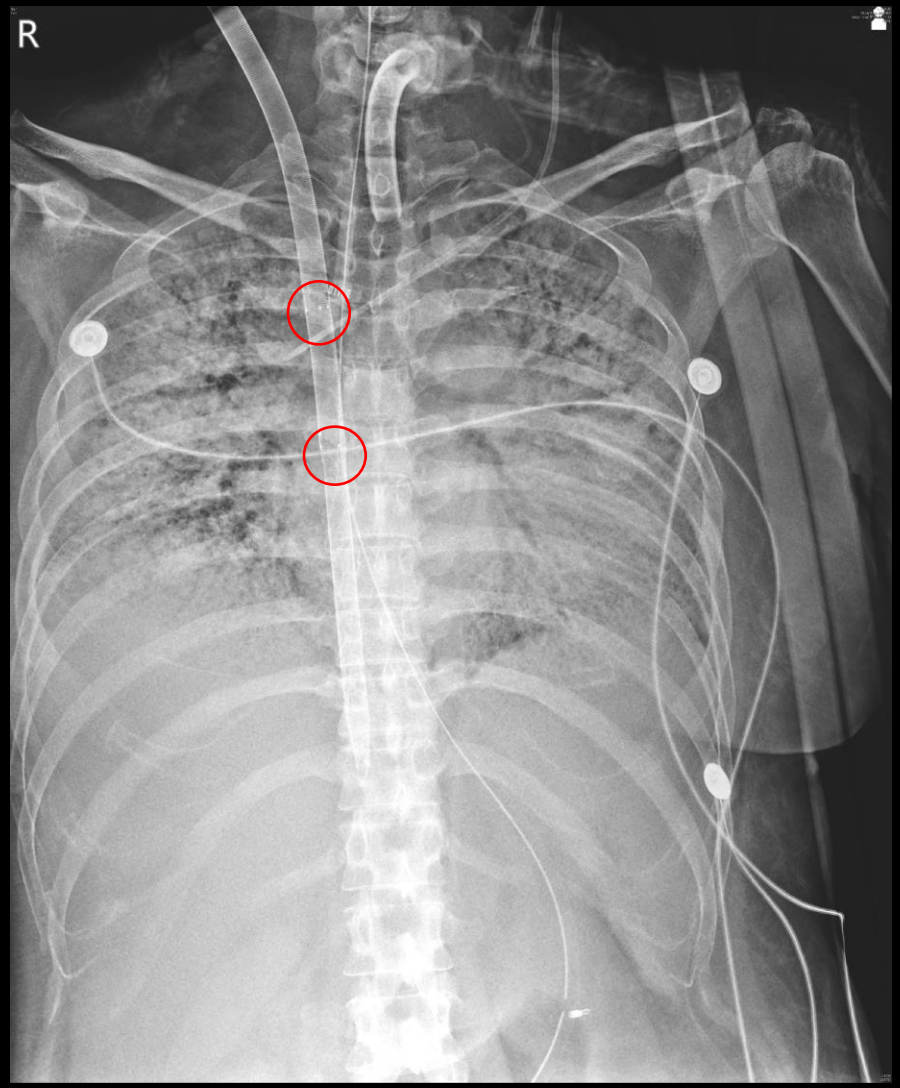
Avalon Elite bicaval dual lumen cannula

Carlo Banfi; Journal of Thoracic Disease 2016
Vanessa Marie Bazan; Indian Journal of Thoracic and Cardiovascular Surgery 2021

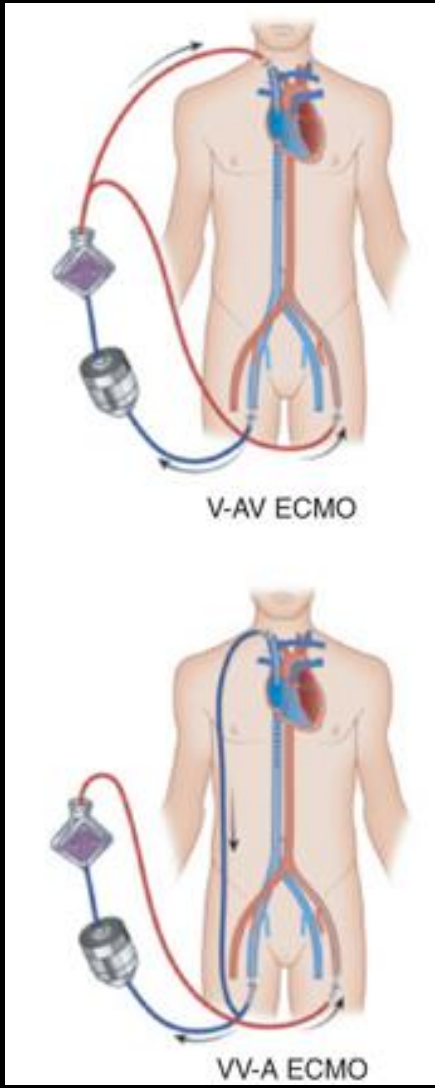
Double lumen bicaval cannula

43-year-old female
CTD-ILD
On waiting list of lung transplant





Hybrid ECMO



- Providing hemodynamic support
- Ensuring oxygenated blood
  - reaches the pulmonary circulation and left ventricle

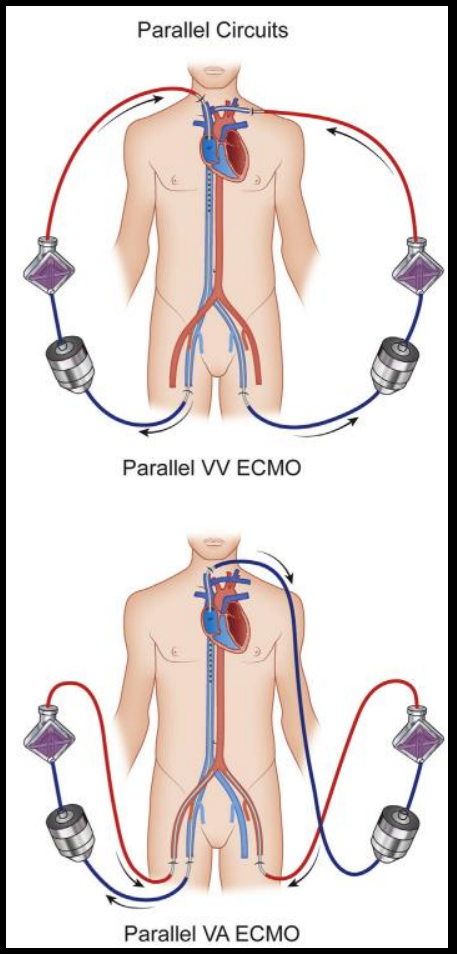
- Need for higher venous drainage
  - (double venous cannula)

Aakash Shah; JTCVS Techniques 2021

Parallel ECMO

- Flow limitations of a single ECMO circuit
  - Insufficient for adequate support

- Unusually high cardiac output state
- Obesity
- Septic shock with heart failure
- Refractory hypoxemia



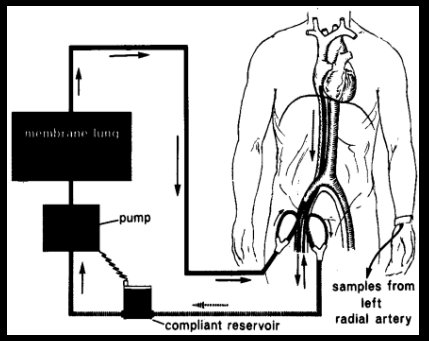
Aakash Shah; JTCVS Techniques 2021
Eun Seok Ka; J Chest Surg 2024

Outline

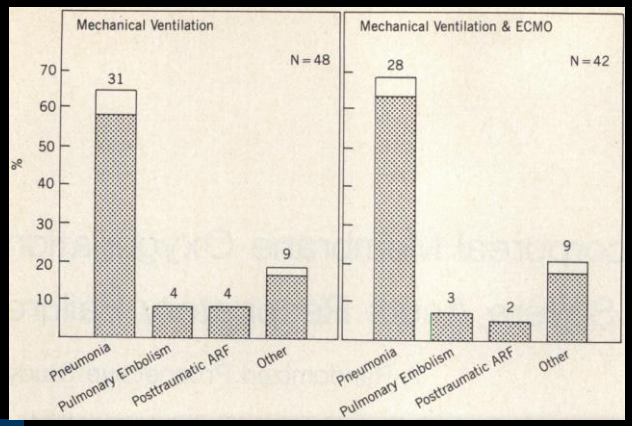
- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

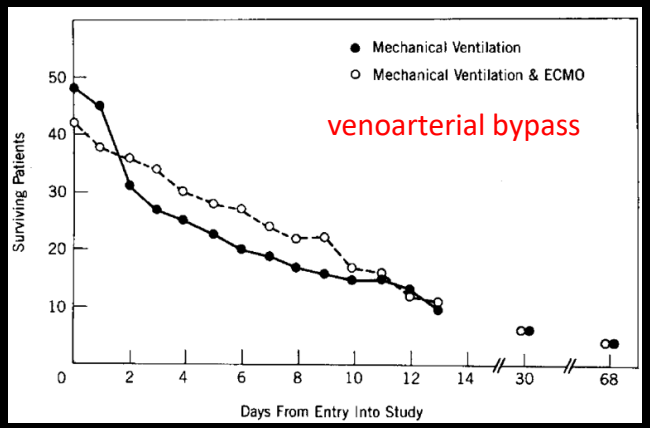
History

- First successfully deployed in ARDS (1971)
  - 24-year-old male; blunt trauma
  - venoarterial perfusion
  - Bramson-membrane heart-lung machine



- First randomized prospective study (1979)





J. Donald Hill; NEJM 1972
Warren M. Zapol; JAMA 1979

CESAR trial

Severe (Murray score >3.0 or pH <7.20) but potentially reversible respiratory failure

- referral to consideration for treatment by ECMO
- continued conventional management

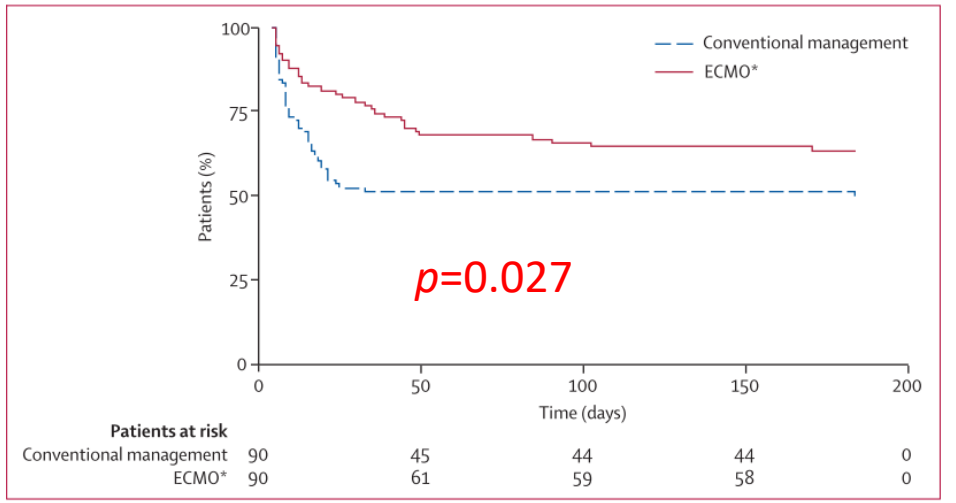


Figure 2: **Kaplan-Meier survival estimates**
ECMO=extracorporeal membrane oxygenation. *Patients were randomly allocated to consideration for treatment by ECMO, but did not necessarily receive this treatment.

68 (75%) patients actually received ECMO

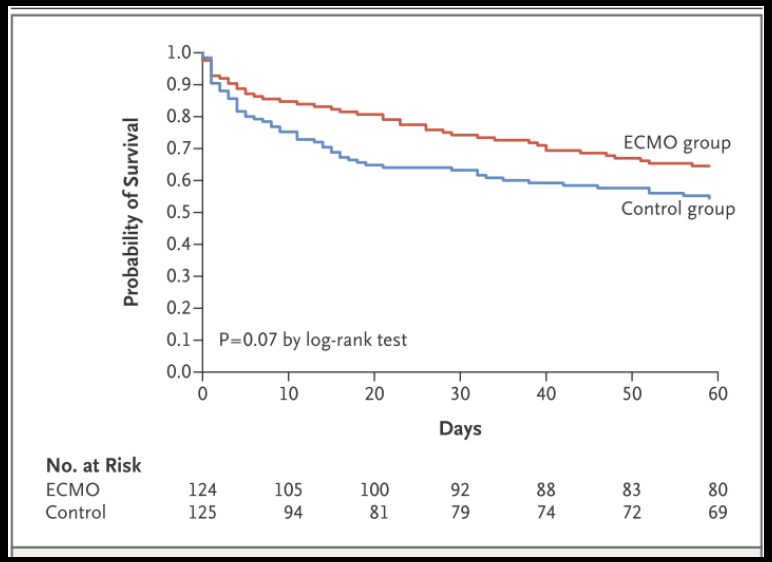
Control group: 70% received low TV

We recommend transferring of adult patients to a centre with an ECMO-based management protocol

Giles J Peek; Lancet 2009

EOLIA trial

P/F<50 mmHg for 3 hours
P/F<80 mmHg for 6 hours
pH<7.25 and $PaCO_2$>60 for 6 hours



Treatment failure:
- ECMO group: death
- Control group :
  - Crossover to ECMO: 35
  - Death

Table 2. End Points.*

End Point	ECMO Group (N=124)	Control Group (N=125)	Relative Risk or Difference (95% CI)†	P Value
Primary end point: mortality at 60 days — no. (%)	44 (35)	57 (46)	0.76 (0.55 to 1.04)	0.09
Key secondary end point: treatment failure at 60 days — no. (%)‡	44 (35)	72 (58)	0.62 (0.47 to 0.82)	<0.001

Mortality at 60 days
- 57% (20/35) among patients in the control group who crossed over to ECMO
- 41% (37/90) among the other patients in the control group

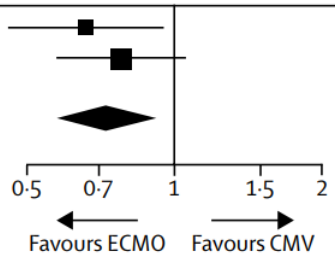
A. Combes; NEJM 2018

Meta-analysis

60-day mortality

	ECMO Events	ECMO Total	CMV Events	CMV Total	Weight (%)	Risk ratio (95% CI)
Peek et al (2009)[3]	29	90	44	90	40·9%	0·66 (0·46–0·95)
Combes et al (2018)[10]	44	124	57	125	59·1%	0·78 (0·57–1·06)
Combined	**73**	**214**	**101**	**215**	**100·0%**	**0·73 (0·58–0·92)**

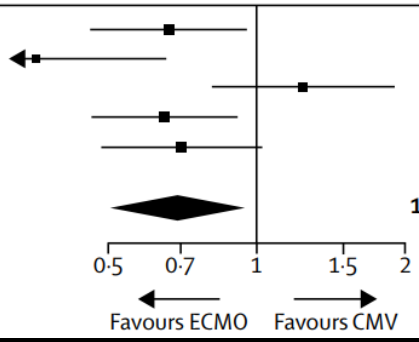
Heterogeneity: τ^2=0·00; χ^2=0·47, df=1, (p=0·49); I^2=0%
Test for overall effect: Z=2·66 (p=0·008)



30-day mortality

	ECMO Events	ECMO Total	CMV Events	CMV Total	Weight (%)	Risk ratio (95% CI)
Peek et al (2009)[3]	29	90	44	90	21·8%	0·66 (0·46–0·95)
Noah et al (2011)[5]	11	75	31	75	14·4%	0·35 (0·19–0·65)
Pham et al (2013)[6]	26	52	21	52	19·7%	1·24 (0·81–1·90)
Tsai et al (2015)[18]	22	45	34	45	22·7%	0·65 (0·46–0·91)
Combes et al (2018)[10]	32	124	46	125	21·4%	0·70 (0·48–1·02)
Combined	**120**	**386**	**176**	**387**	**100·0%**	**0·69 (0·50–0·95)**

Heterogeneity: τ^2=0·08; χ^2=11·92, df=4, (p=0·02); I^2=66%
Test for overall effect: Z=2·31 (p=0·02)



Jonathan A. Silversides; ICM 2017

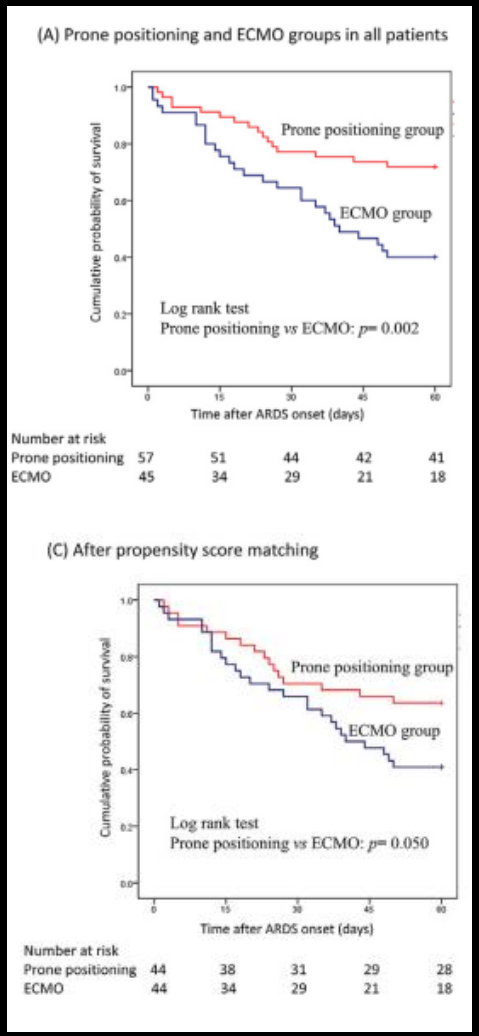
ECMO vs. prone positioning

Taiwan Severe Influenza Research Consortium

- Eight referral hospitals in Taiwan
- October 1, 2015, and March 31, 2016

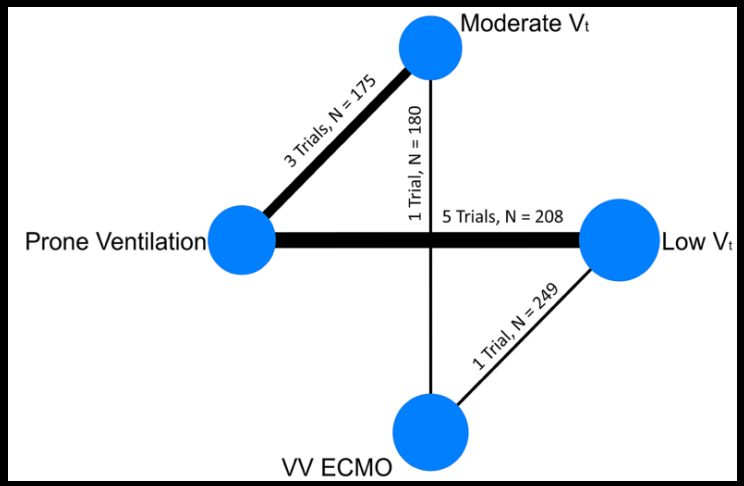
Characteristics	Before matching			After matching		
	Prone positioning group (n = 57)	ECMO group (n = 45)	p	Prone positioning group (n = 44)	ECMO group (n = 44)	p
PaO_2/FiO_2 (mm Hg)	98.0 ± 55.2	101.3 ± 70.7	0.698	96.3 ± 56.6	100.0 ± 71.0	0.854

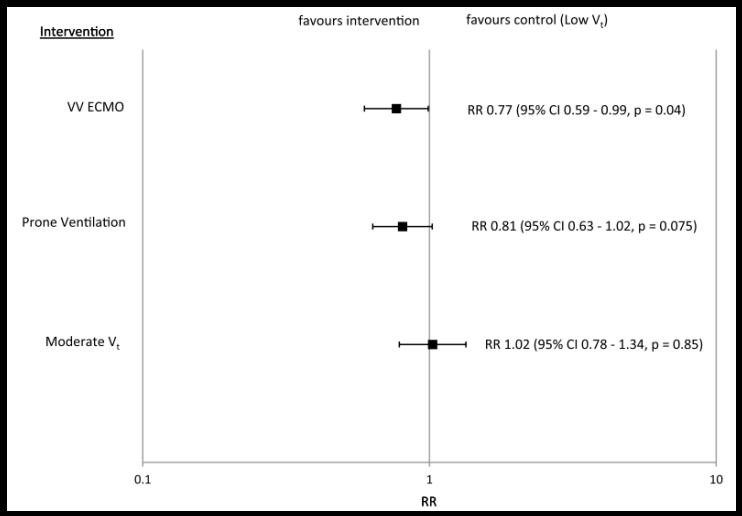
Outcomes	Before matching			After matching		
	Prone positioning group (n = 57)	ECMO group (n = 45)	p	Prone positioning group (n = 44)	ECMO group (n = 44)	p
Mortality — no. (%)						
At day 30	13 (23%)	16 (36%)	0.156	13 (30%)	15 (34%)	0.647
At day 60	16 (28%)	27 (60%)	0.001*	16 (36%)	26 (59%)	0.033*
Hospital	17 (30%)	28 (62%)	0.001*	17 (39%)	27 (61%)	0.033*



Ko-Wei Chang; Journal of the Formosan Medical Association 2021

Network meta-analysis





VV ECMO			
0.95 (0.72-1.26)	Prone Ventilaton		
0.77 (0.59-0.99)	0.81 (0.63-1.02)	Low V_t	
0.75 (0.57-0.98)	**0.78 (0.66-0.93)**	0.98 (0.75-1.27)	Moderate V_t
Grade Certainty:	High	Moderate	Low	Very Low

- Both VV-ECMO and prone ventilation improve mortality relative
- The impact of VV-ECMO versus prone ventilation remains uncertain

Sachin Sud; ICM 2024

Outline

- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

Indication

Guideline from the Extracorporeal Life Support Organization (ELSO)

Common indications for venovenous extracorporeal membrane oxygenation
One or more of the following:

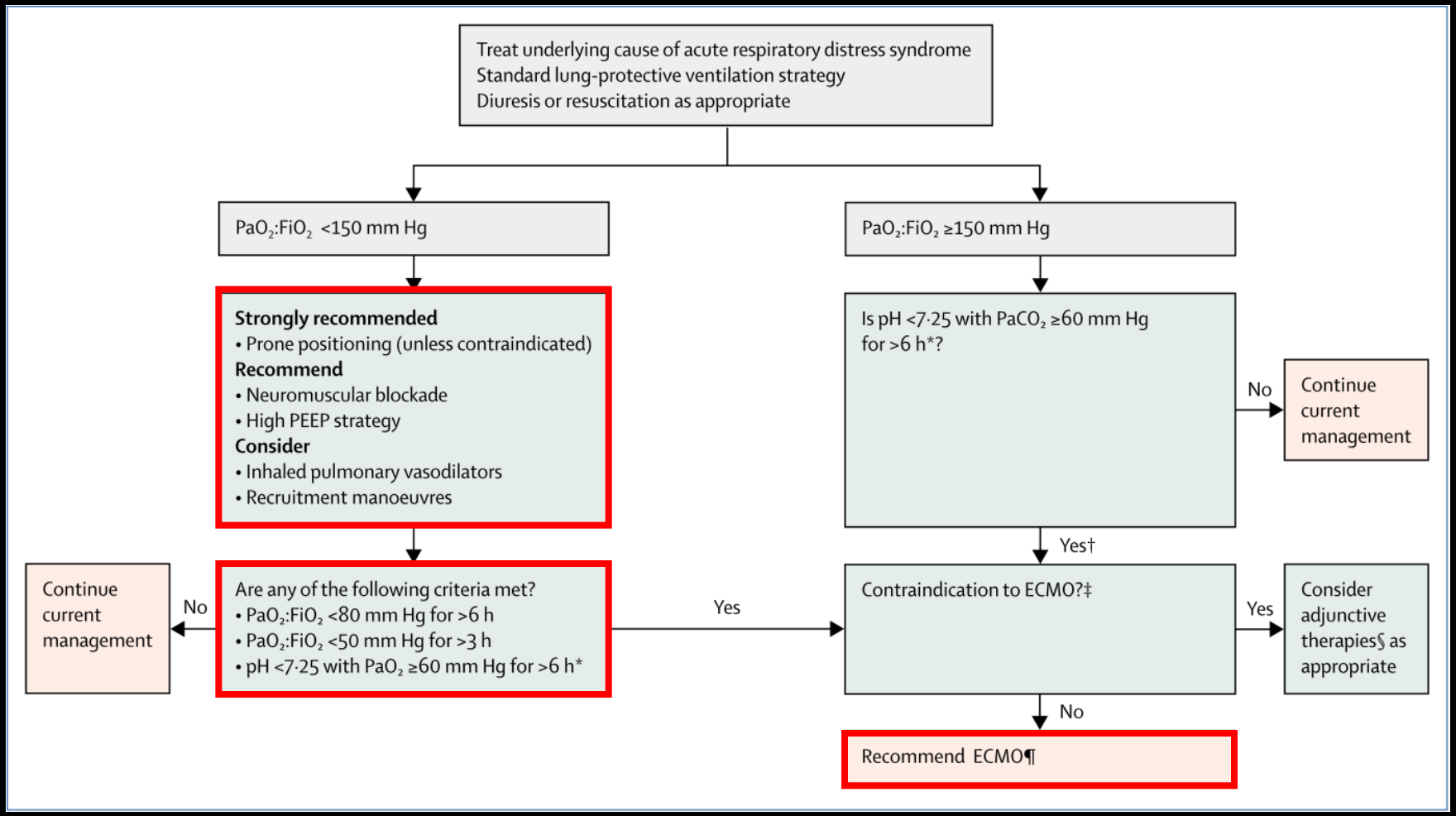
1) Hypoxemic respiratory failure ($PaO_2/FiO_2 < 80$ mm Hg)*, after optimal medical management, including, in the absence of contraindications, a trial of prone positioning.
2) Hypercapnic respiratory failure (pH < 7.25), despite optimal conventional mechanical ventilation (respiratory rate 35 bpm and plateau pressure [P_{plat}] ≤ 30 cm H_2O).
3) Ventilatory support as a bridge to lung transplantation or primary graft dysfunction following lung transplant.

Specific clinical conditions:

- Acute respiratory distress syndrome (*e.g.*, viral/bacterial pneumonia and aspiration)
- Acute eosinophilic pneumonia
- Diffuse alveolar hemorrhage or pulmonary hemorrhage
- Severe asthma
- Thoracic trauma (*e.g.*, traumatic lung injury and severe pulmonary contusion)
- Severe inhalational injury
- Large bronchopleural fistula
- Peri-lung transplant (*e.g.*, primary lung graft dysfunction and bridge to transplant)

JOSEPH E. TONNA; ASAIO Journal 2021

Indication



Darryl Abrams; Lancet Respir Med 2019

ECMO：資源分配問題

Influenza in 2016


02 Mar 2016

流感重症激增 大台北地區葉克膜一機難求

記者 許晴綺 報導 2016/03/02 18:02

▲(圖：資料畫面)

A型流感延燒，感冒民眾重爆急診，加護病房一位難求，確診病例屢屢創新高，台北市立仁愛醫院統計，截至2月已收治11例流感重症合併肺衰竭病患，甚至放置葉克膜維生，而其中有10例已證實為A型流感。


已無葉克膜救人 流感延燒 衛福部擺爛不調度

壯男早上騎車 下午加護病房 流感發病快又猛 已奪84命

出版時間：2016/03/04

【綜合報導】流感疫情大爆炸，急重症病患發病又快又猛，救命的葉克膜卻告急，台大、馬偕、中國醫藥大學附設醫院、彰化基督教醫院、高雄長庚等醫院的葉克膜體外循環器已全數滿機，陷入零空機困境，第一線醫師心急如焚，表示「已沒有武器（指葉克膜）可救人」，要求衛福部統籌調度。但衛福部無視人命


流感床位及葉克膜不足 政院協調調度

2016-03-04 20:56

〔記者李欣芳／台北報導〕對於傳出流感重症床位及葉克膜不足，行政院介入協調予以協助，閣揆張善政今天賈請副閣揆杜紫軍協調流感重症醫療資源調度事宜，杜隨即利用上午立法院質詢空檔，與衛福部長薛丙煌討論有關事宜，並請衛福部務必掌握最新資訊，主動洽各醫療院所瞭解需求積極協助，必要時召開會議。

衛福部表示，目前已全面掌握全國流感重度責任醫院急診即時訊息，包括等待加護病床人數、葉克膜、呼吸器空機數等。

衛福部指出，國內醫院的葉克膜含租用數量共計129台，全國36家重度級急救責任醫院計有32台葉克膜空機可用，至中午12時，已由醫院先自行調度8台。

對於先前媒體報導曾缺葉克膜的醫院，如台大、馬偕、中國、彰基及高雄長庚等，衛福部表示，經瞭解目前已無需求，對於醫院如有葉克膜需求支援部分，除透過醫院與醫院間自行調度外，衛福部及地方衛生局也將介入協助調度。目前26家流感應變醫院中，共計有18台葉克膜，必要時可協助調度。


流感重症非葉克膜不可？醫師公會：非萬靈丹

出版時間：2016/03/08 16:23

中華民國醫師公會全聯會理事長蘇清泉（右二）說明專家會議結論，解明權攝

流感疫情嚴峻，至今已奪走121命，日前衛福部因各醫院間的葉克膜（體外心肺維

Contraindication

The only absolute contraindication
- an irreversible underlying process
- when the patient is not a candidate for lung transplantation

Relative contraindications	Absolute contraindications
Invasive mechanical ventilation for more than 7–10 days	Moribund state with established multiple organ failure
Contraindication to anticoagulation	Prolonged cardiac arrest
Severe coagulopathy	Severe anoxic brain injury
Advanceed age	Massive intracranial hemorrhage
Salvage ECMO (referred to as "rescue" in EOLIA), i.e., employing ECMO when severe right heart failure, or other severe decompensation occurs	Severe chronic respiratory failure with no possibility of lung transplantation
	Metastatic malignancy or hematological disease with poor short-term prognosis
	Other advanced comorbidities with poor short-term prognosis

Daniel Brodie; JAMA 2019
Alain Combes; ICM 2020

Outline

- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

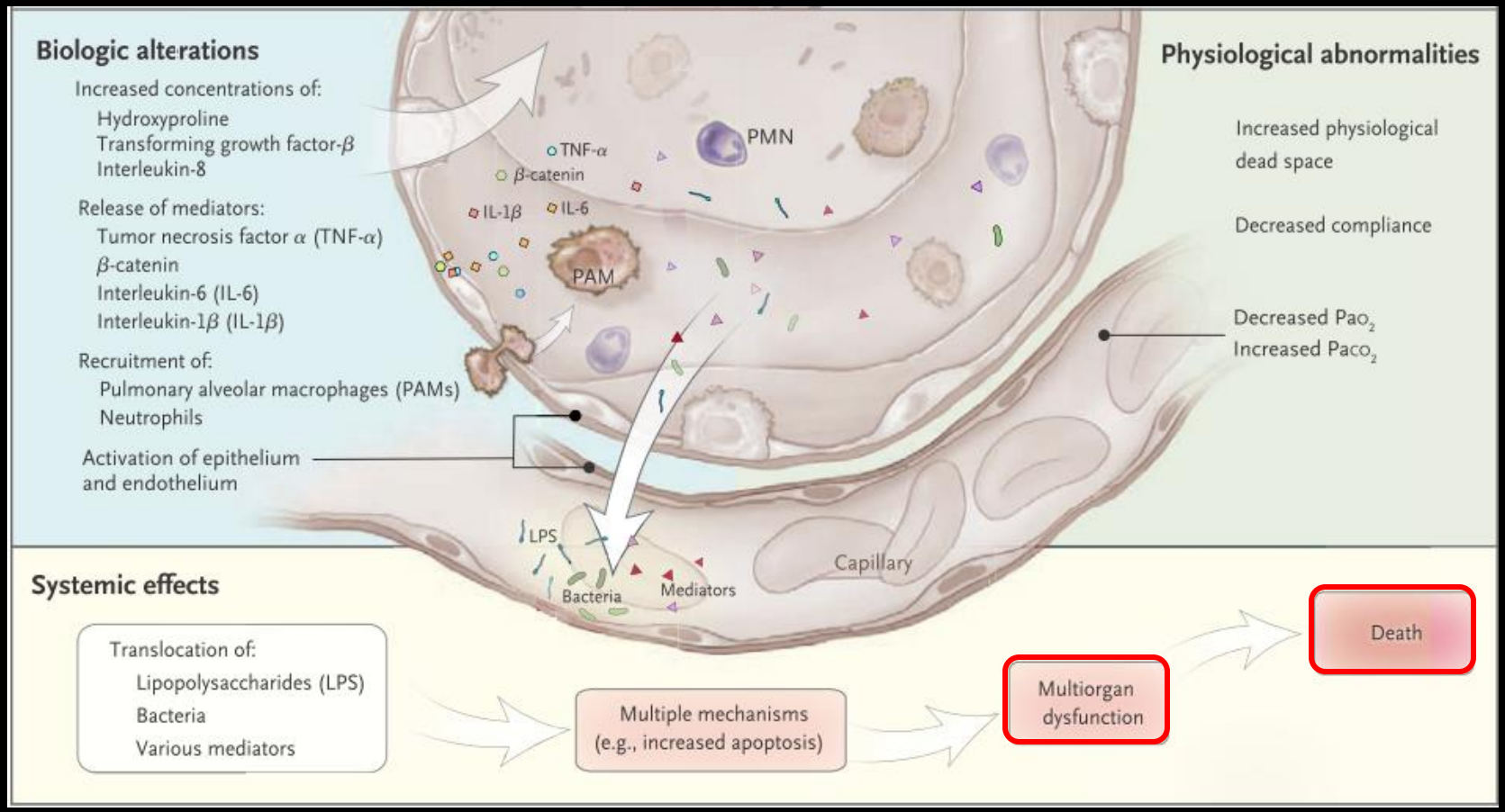
Goals of ECMO

- In the past
- Patients with severe hypoxemia
  - Dying from tissue hypoxia
  - ECMO: Maintain adequate oxygenation

- Achieve adequate PaO_2
  - Adjust circuit blood flow
  - 0.06 - 0.08 L/kg/min
- Achieve a desired $PaCO_2$
  - Adjust sweep gas flow
  - 2 - 8 L/min

Daniel Brodie; JAMA 2019
R. Noori; BJA Education 2026

Ventilator-induced lung injury (VILI)



Arthur S. Slutsky; NEJM 2013

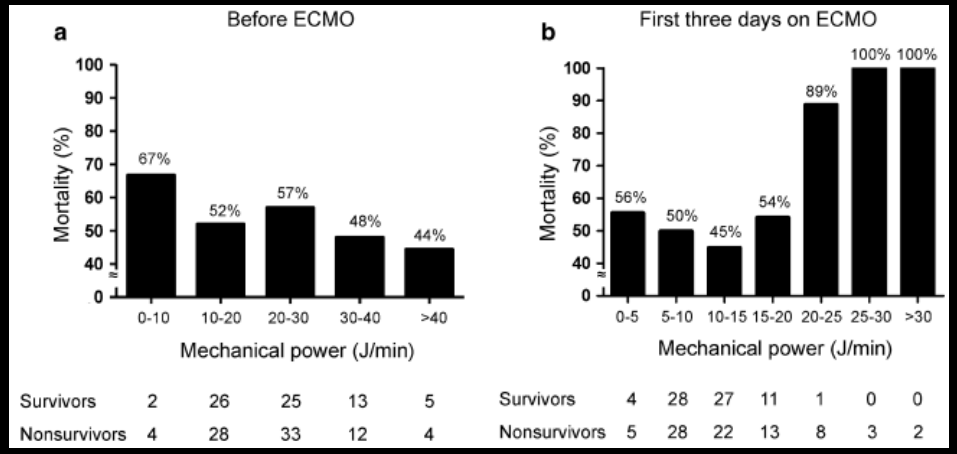
Ultra-lung-protective ventilation strategies

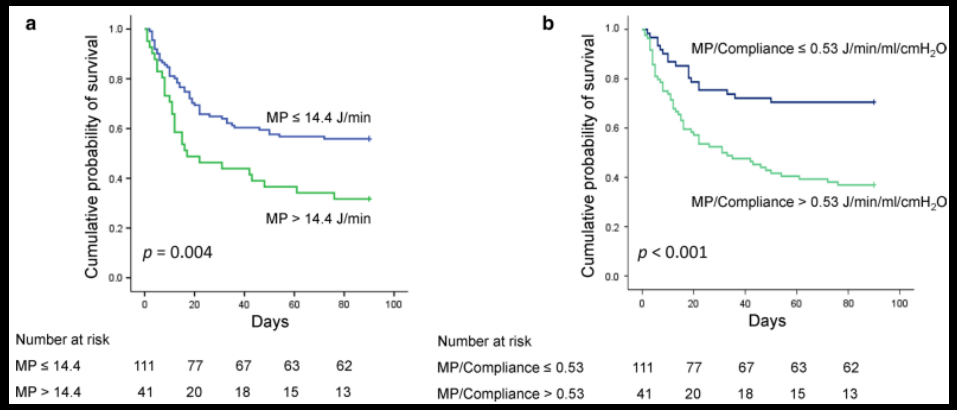
Mechanical Ventilator Settings	Target
Plateau pressure	≤24 cmH_2O and may be lower if feasible
PEEP	≥10 cmH_2O
Driving pressure	≤14 cmH_2O
Tidal volume	Typically ≤4 mL/kg PBW and adjusted for the goal of plateau pressure (≤24 cmH_2O)
Respiratory rate	≤10 breaths per minute
FiO_2	0.3–0.5

Li-Chung Chiu; J. Clin. Med. 2021

Mechanical power

- MP (J/min) = 0.098 × VT × RR × (Ppeak−1/2 × ΔP)
- May 2006 and October 2015
- 152 patients





Outline

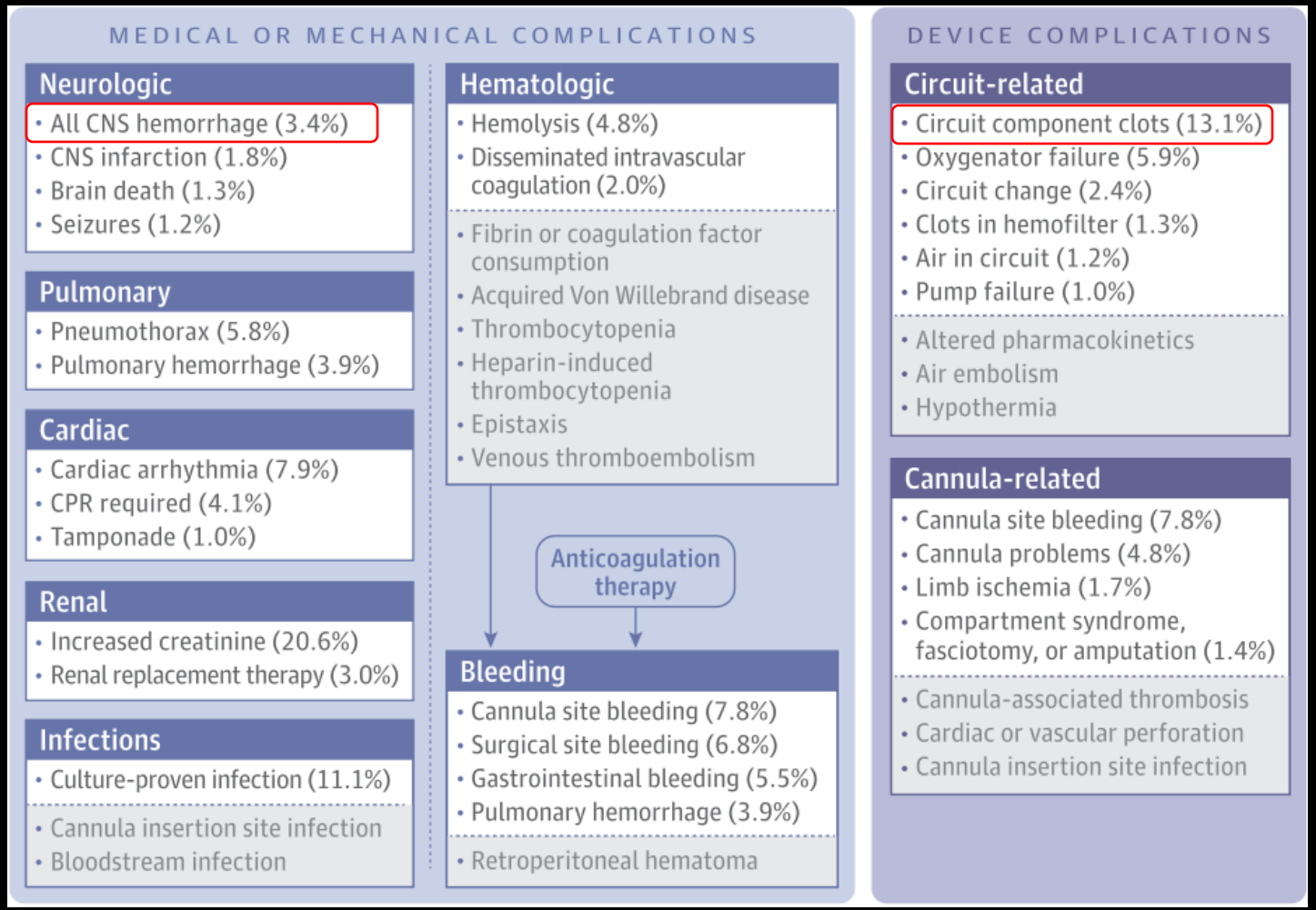
- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

Complication

- Directly
  - a result of the device
  - its insertion
- Indirectly
  - the use of anticoagulation
  - effects on distal organs

Daniel Brodie; JAMA 2019

Complication



Daniel Brodie; JAMA 2019

EOLIA trial

Table 3. Adverse Events as Defined by the Trial Protocol in the Intention-to-Treat Population.

Event	ECMO Group (N=124)	Control Group (N=125)	Absolute Risk Difference (95% CI)*
	number (percent)		*percentage points*
Pneumothorax	18 (15)	16 (13)	2 (–7 to 10)
Thrombocytopenia†			
Any	50 (40)	40 (32)	8 (–4 to 20)
Severe	33 (27)	20 (16)	11 (0 to 21)
Hypothermia‡	28 (23)	27 (22)	1 (–9 to 11)
Bleeding			
Leading to transfusion	57 (46)	35 (28)	18 (6 to 30)
Massive§	3 (2)	1 (1)	2 (–2 to 6)
Cardiac rhythm disturbances	38 (31)	46 (37)	–6 (–18 to 6)
Cardiac arrest	24 (19)	22 (18)	2 (–8 to 12)
Stroke¶	3 (2)	8 (6)	–4 (–10 to 1)
Ischemic stroke	0	6 (5)	–5 (–10 to –2)
Hemorrhagic stroke	3 (2)	5 (4)	–2 (–7 to 3)
Massive stroke	2 (2)	1 (1)	1 (–3 to 5)
Ventilator-associated pneumonia treated with antibiotic agents	48 (39)	46 (37)	2 (–10 to 14)
Gas emboli	0	0	0 (–3 to 3)

A. Combes; NEJM 2018

Anti-coagulant

J-CARVE is a multicenter retrospective registry
Between January 1, 2012, and December 31, 2022

Parameters	Anticoagulation Group ($n = 641$)	No-Anticoagulation Group ($n = 54$)	Unadjusted p	Adjusted p
28-d survival, *n* (%)	550 (85.8)	44 (81.5)	0.50	
60-d survival, *n* (%)	479 (74.7)	36 (66.7)	0.19	0.23
ECMO duration, d	11.0 (7.0–19.0)	9.0 (6.0–16.8)	0.05	0.09
Number of ECMO circuit exchanges, *n*	0.0 (0.0–1.0)	0.0 (0.0–1.0)	0.17	0.23
Bleeding complication, *n* (%)	201 (31.4)	22 (40.7)	0.21	0.23
Average activated partial thromboplastin time, s	51.3 (44.8–59.2)	39.3 (35.4–46.2)	<0.01	< 0.01
Transfusion volume				
Red cells concentrate, units	6.0 (0.0–14.0)	13.0 (6.0–26.5)	<0.01	< 0.01
Fresh frozen plasma, units	0.0 (0.0–8.0)	7.0 (0.0–43.5)	<0.01	< 0.01
Platelet concentrate, units	0.0 (0.0–20.0)	15.0 (0.0–65.0)	< 0.01	< 0.01

The higher transfusion volumes in the no-anticoagulation group

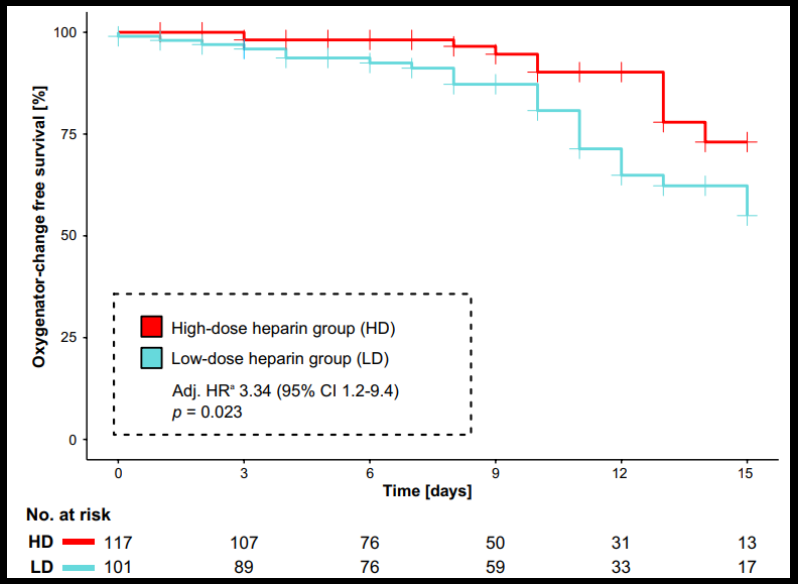
- the need to correct pre-existing bleeding
- consumptive coagulopathy at VV-ECMO initiation

Ginga Suzuki; CCM 2026

Anti-coagulant

Low-dose heparinization strategy: aPTT between 35 and 40 s (n = 101)
High-dose heparinization strategy: an ACT between 140 and 180 s (n = 117)

Oxygenator change



High vs. Low

- Severe bleeding events: 19.7% vs. 13.9% (P=0.256)
- Thromboembolic events: 6.8% vs. 19% (P=0.007)
- Mortality at 30 days: 33.3% vs. 30.7% (P=0.11)

Benjamin Seeliger; CC 2020

Plasma Leakage

Membrane loses water-repelling property
Lower blood surface tension
Wet the membrane

- Surfactants
- high lipid levels (hyperlipidemia)
- certain medications (like propofol)

Montoya JP; ASAIO Journal 1992

Antibiotics usage

Northwestern Medicine Antimicrobial ECMO Dosing Guidance

Antimicrobials High Impact – Likely Requires Dose Adjustment			
Amphotericin	Itraconazole	Posaconazole	
Isavuconazole	Micafungin	Voriconazole	
Antimicrobials Potential Impact – Potentially Requires Dose Adjustment			
Ampicillin	Ceftaroline	Linezolid	Penicillin G
Aztreonam	Ceftriaxone	Meropenem	Piperacillin-Tazobactam
Cefazolin	Ertapenem	Nafcillin	Vancomycin
Cefepime	Fluconazole	Oxacillin	
Antimicrobials Minimal Impact – Standard Dosing is Most Likely Appropriate			
Amikacin	Ceftolozane-tazobactam	Gentamicin	Tobramycin
Azithromycin	Ciprofloxacin	Levofloxacin	Trimethoprim-Sulfamethoxazole
Cefiderocol	Daptomycin	Metronidazole	
Ceftazidime	Doxycycline	Oseltamivir	
Ceftazidime-avibactam	Ganciclovir	Tigecycline	

https://adsp.nm.org/uploads/1/4/3/0/143064172/nm_antimicrobial_ecmo_dosing.pdf

Sedatives and Analgesics

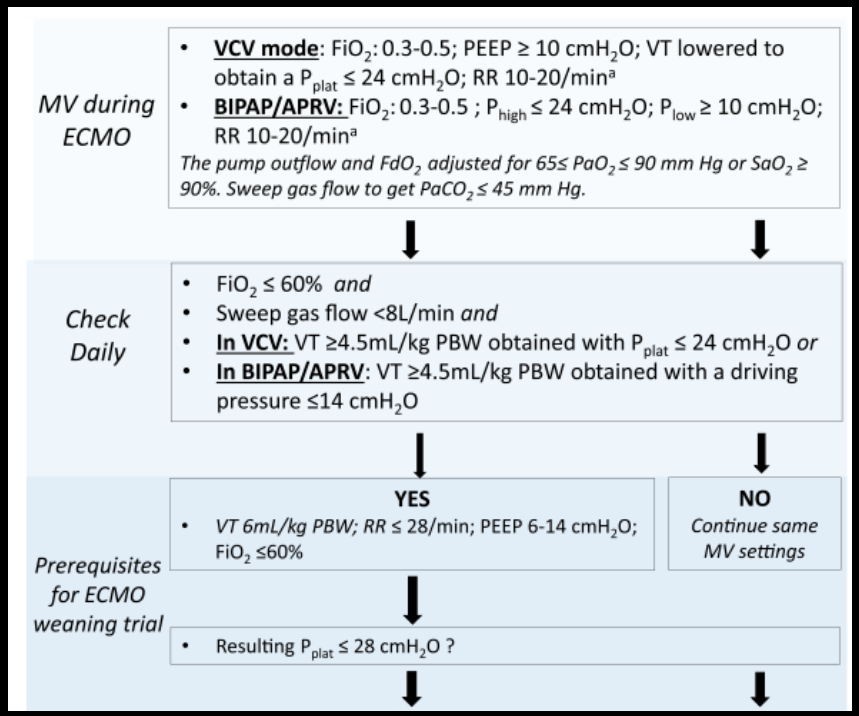
Sedatives and analgesics (ref.)	N-octanol/water partition coefficient	Protein binding (%)	Anticipated/reported pharmacokinetic changes	Dosing recommendations & comments
Benzodiazepines				
Midazolam (5,6,28)	3.9	97	Significant circuit drug sequestration	Higher initial loading dose with higher daily doses
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

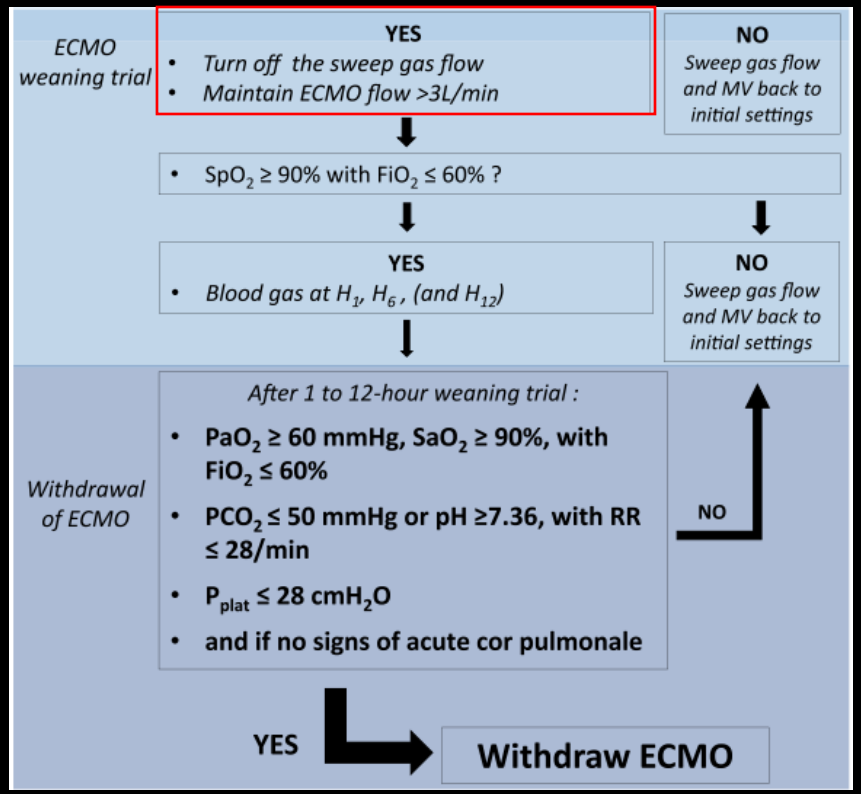
Vesa Cheng; J Thorac Dis 2018

Outline

- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

Weaning





Alain Combes; ICM 2020

Weaning

68-year-old female
COVID-19-induced ARDS

	Day 12	Day 14	Day 19	Day 20	Day 21	Day 25	Day 26	Day 27	Day 29	Day 33	Day 35	Day 39	Day 41	Day 50
Ventilator setting														
Mode	PCV	PCV	PCV	PCV	PCV	PCV	PCV	PCV	PCV	PCV	PS	PS	PS	NC
Positive end expiratory pressure (cm H_2O)	12	12	14	14	14	14	14	10	10	10	10	8	8	
Peak airway pressure (cm H_2O)	32	30	35	30	30	30	28	34	28	28	22	16	16	
Fraction of inspired oxygen (%)	100	80	90	70	40	40	50	55	45	40	35	35	35	32
Respiratory rate (/min)	24	24	28	12	10	10	18	28	22	16	22	27	25	
Tidal volume (ml/kg PBW)	9.2	7.7	5.0	4.0	4.2	6.7	4.5	7.2	7.0	7.0	8.7	9.4	6.4	
ECMO setting														
Blood flow (L/min)				3.5	3.5	3.5	3.5	3.5						
Air flow (L/min)				4	4	4	4	0						
Fraction of inspired oxygen (%)				100	100	90	30	0						
Laboratory Data														
Absolute lymphocyte count (/μL)	1467	520	275	490	1255	1699	2189	2684	860	1047	1260	1228	1806	2220
C-reactive protein (mg/L)	227.6	282.2	118.0				191.6	201.3	136.7	81.4	72.8	45.6	83.8	11.6
Interleukin-6 (pg/ml)					56.5		116.0			21.6			59.0	15.0

Ko-Wei Chang; IDcases 2021

Outline

- Introduction
- History and clinical trial
- Indications and contraindications
- Goals of ECMO
- Complication
- Weaning
- Hypoxemia during ECMO and strategies to improve

Hypoxemia during ECMO

- Mixture of blood from ECMO and venous blood
- Recirculation
- Intrapulmonary Shunt
- Flow exceeding oxygenator performances
  - Rarity with the current technology

Andrea Montisci; ASAIO Journal 2015

Mixture of blood

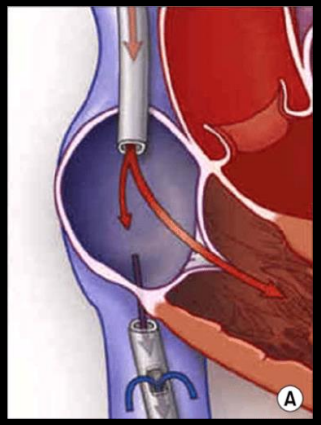
- ELSO guidelines
- Setting a blood flow of 60–80 ml/kg
  - Guarantees an oxygen delivery of 3 ml/kg/min
- Pump flow: deoxygenated arterial blood = 3:1

- Septic patient
  - Cardiac output (CO) is usually elevated
- VV ECMO flow/patient's CO ≥ 60%
  - associated with SaO_2 > 90% and arterial PaO_2 > 60mmHg

Andrea Montisci; ASAIO Journal 2015
Schmidt M; ICM 2013

Recirculation

- The fraction of oxygenated blood
  - Aspirated back into the venous line of the ECMO circuit



- Pump speed
- Blood flow rates
- Intrathoracic, intracardiac, intra-abdominal pressure
- Cannula type, size, and position
- Direction of extracorporeal blood flow

Andrea Montisci; ASAIO Journal 2015
Abrams D; ASAIO Journal 2014
Go Woon Kim; Tuberc Respir Dis 2012

Recirculation

- R = (SO_2 preoxy−SvO_2)/(SO_2 postoxy−SvO_2)
  - SO_2 preoxy: blood in the venous cannula
  - SO_2 postoxy: blood in the arterial cannula
  - SvO_2: mixed venous saturation

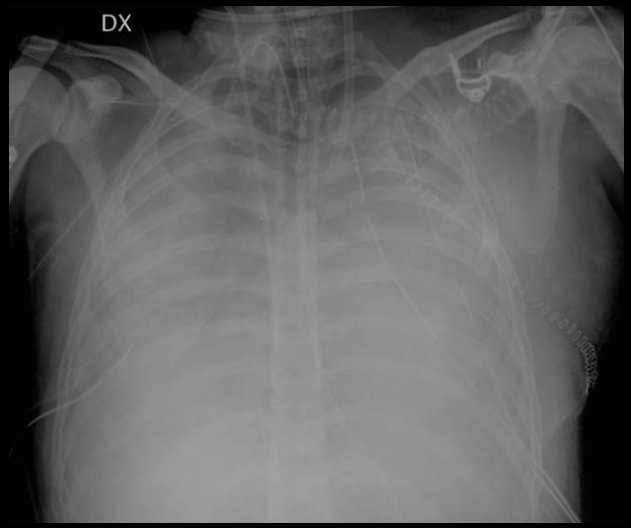
- Exclude meaningful recirculation
  - PaO_2 of drained blood is in the normal range (42 mmHg)
  - PaO_2 of drained blood < 10% of the infusion cannula
  - blood oxygen saturation in the drainage cannula < 75%

Andrea Montisci; ASAIO Journal 2015
Extracorporeal Life Support Organization (ELSO) General Guidelines

Intrapulmonary shunt

- Alveolus is perfused but not ventilated
- $Qs/Qt = 100 \times (CcO_2 – CaO_2)/(CcO_2 – CvO_2)$
  - c: pulmonary end-capillary blood
  - a: arterial blood; v: mixed venous blood

- Vascular pressures
- Vasoactive substances
- The degree of lung inflation
- Cardiac output



Andrea Montisci; ASAIO Journal 2015

Strategies: Improve Oxygenation

- Increase the blood's oxygen content
  - Increase ECMO flow
  - Increase blood oxygen-carrying capacity
- Strategies to reduce recirculation
- Strategies to reduce oxygen consumption
  - Sedation and neuromuscular blockade
  - Therapeutic hypothermia
- Manipulation of CO and intrapulmonary shunt
  - β-blockers infusion
  - Prone positioning
- Switch to venoarterial or a hybrid configuration

Andrea Montisci; ASAIO Journal 2015

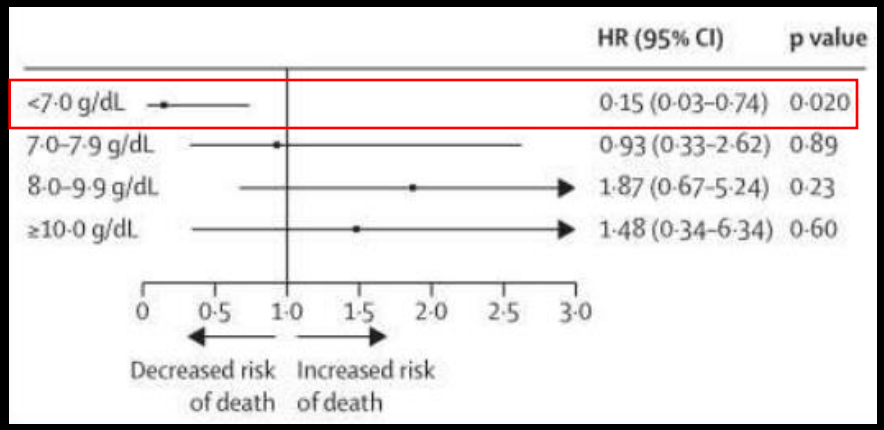
Increase ECMO flow

- Determined by
  - Vascular access
  - Drainage tubing resistance
  - Pump properties
- Risk
  - augmented recirculation fraction
  - hemolysis

Andrea Montisci; ASAIO Journal 2015

Increase oxygen-carrying capacity

- $DO_2 = 1.34 \times CO \times Hb \times SaO_2$
- ELSO guideline before 2021
  - Maintain hemoglobin level of 12–14 g/dl
  - Maintain normal hematocrit
- PROTECMO study
  - Prospective, cohort study; 41 ECMO centers in Europe



Andrea Montisci; ASAIO Journal 2015
Gennaro Martucci; Lancet Respir Med 2023

Neuromuscular blockade

Retrospective cohort analysis
Cleveland Clinic
January 2022 to December 2023
329 patients

Characteristic	Results
Required NMB during ECMO*	134 (48)
Number of doses per patient†	0 (0–2)
Indication for NMB*‡	
Bedside procedure	209 (66)
Hypoxemia	29 (9)
ECMO low flow	13 (4)
Hemodynamic instability/arrhythmia	11 (3)
Other	20 (6)
Unknown	31 (10)
Bolus administered*‡	306 (96)
Bolus dose (mg)†§	50 (50–50)
Continuous infusion administered*‡	39 (12)
Continuous infusion agent*	
Cisatracurium	27 (69)
Atracurium	12 (31)

Hypoxemia (N = 29)

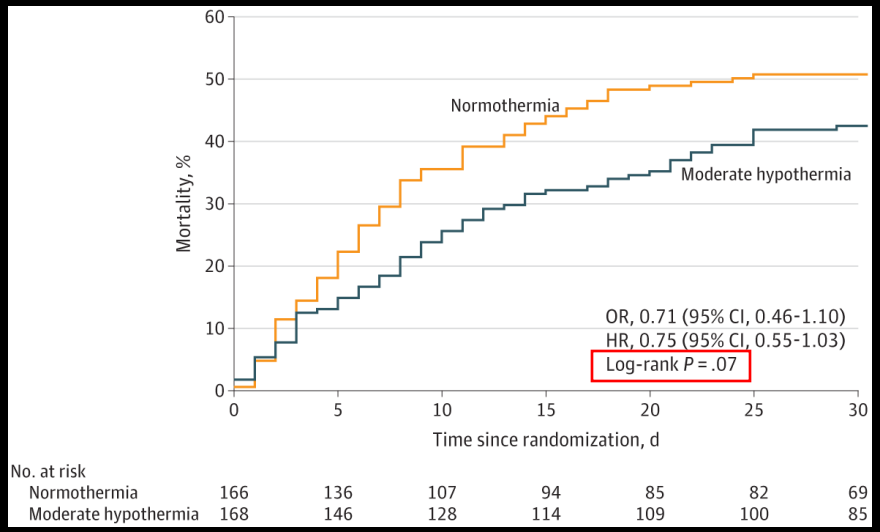
Characteristic	Result*	p Value†
PaO_2 at NMB administration	64 (58–70)	
1 hour post-NMB	105 (78–140)	<0.001
24 hour post-NMB	95 (83–122)‡	<0.001
ECMO flow at NMB administration (L/min)	2.9 (1.8–3.5)	
1 hour post-NMB	4 (3.7–4.4)	0.016
24 hour post-NMB	4.5 (3.5–5.1)§	0.11

Benjamin Hohlfelder; ASAIO Journal 2026

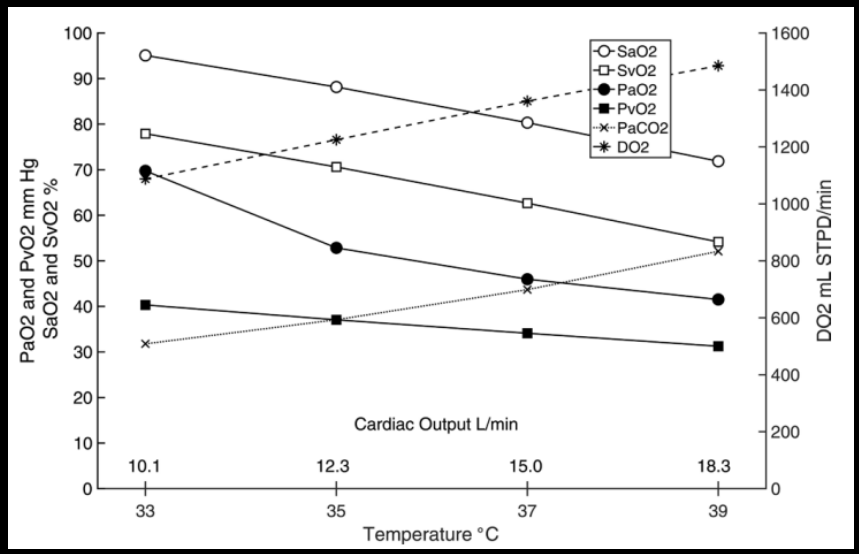
Therapeutic hypothermia

HYPO-ECMO Trial
Randomized clinical trial
334 patients; VA ECMO
Early moderate hypothermia for 24 hours

- 33-34 ˚C



In Silico study
VV ECMO

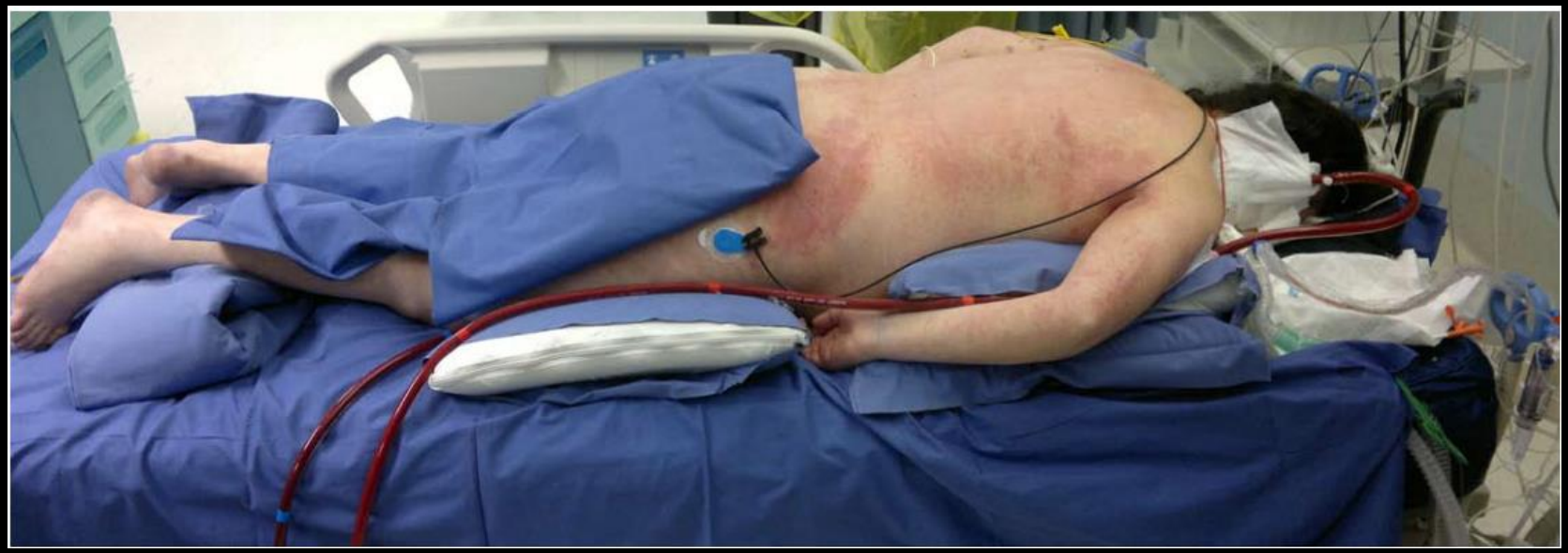


Cooling to 33ºC

- Improve oxygenation in refractory hypoxemia

Bruno Levy; JAMA 2022
Christopher J. Joyc; ASAIO journal 2023

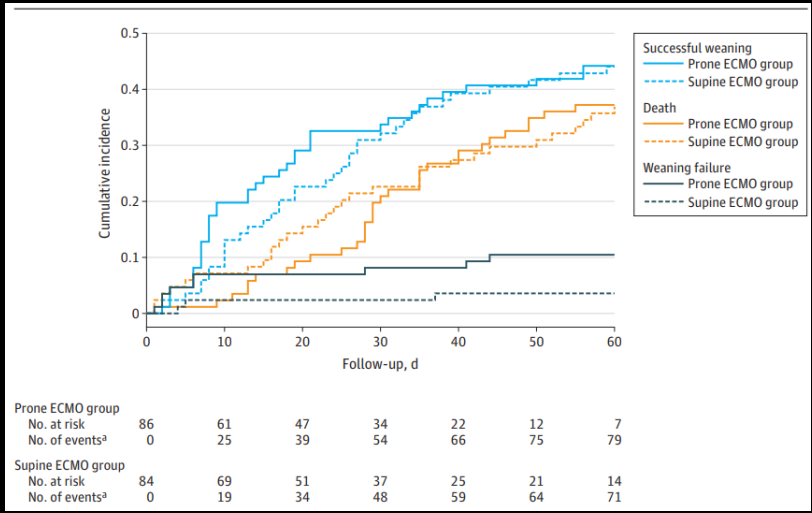
Prone positioning (1)



Andrea Montisci; ASAIO Journal 2015

Prone positioning (2)

PRONECMO Randomized Clinical Trial
14 sites in France
At least 4 prone position sessions of 16 hours were performed during the first 4 days



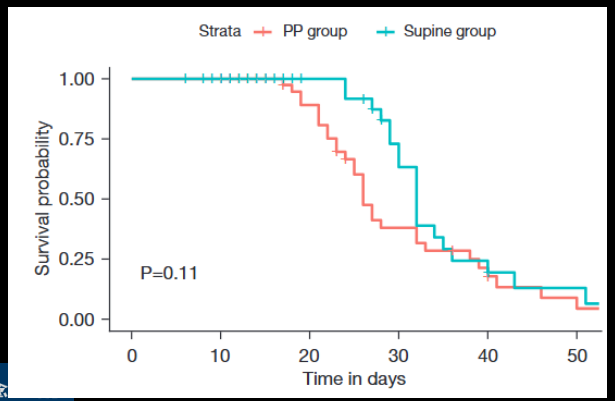
Outcomes/events	Prone ECMO (n = 86)	Supine ECMO (n = 84)	Mean, median, or risk difference, (95% CI)	Relative difference (95% CI)	*P* value
Primary outcome					
Successful ECMO weaning by day 60, No. (%)	38 (44.2)	37 (44.0)	0.1 (−14.9 to 15.2)	sHR, 1.11 (0.71-1.75)	.64
Competing events					
Death before ECMO weaning, No. (%)	32 (37.2)	31 (36.9)	0.3 (−14.5 to 14.1)	sHR, 3.76 (0.71-21.1)	.12
ECMO weaning failure, No. (%)[b]	9 (10.5)	3 (3.6)	6.9 (−1.9 to 15.7)	sHR, 0.94 (0.58-1.53)	.80

Matthieu Schmidt; JAMA 2023

Prone positioning (3)

Prospective multicenter randomized controlled study
June 2021 to July 2023
Three tertiary hospitals in China

Variables	PP group (n=49)	Control group (n=48)	P value
Duration of ECMO support (days)	10 [8–11]	10 [8–14]	0.038
Duration of MV (days)	14 [12–16]	14 [12–16]	0.502
Duration of ICU stay (days)	19 [15–23]	18 [13–24]	0.588
Duration of hospital stay (days)	26 [17–32]	22 [13–32]	0.302
Successful ECMO weaning	38 (77.5)	24 (50.0)	0.005
Survival			
30-day	33 (67.3)	22 (45.8)	0.033
In-hospital	30 (61.2)	19 (39.6)	0.033

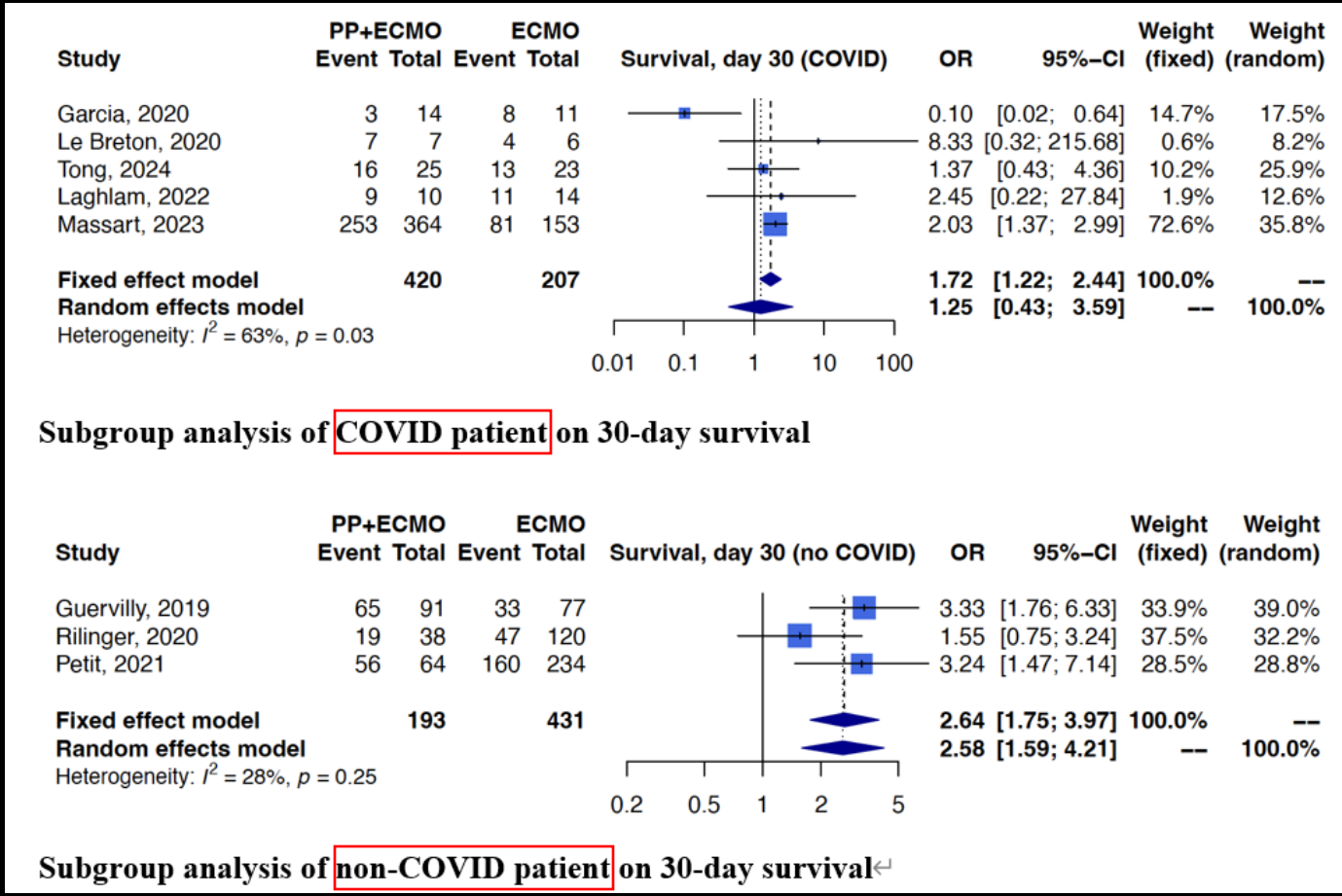


PRONECMO Trial
- >95% underwent PP before ECMO initiation
- included predominantly COVID-19 patients (> 90%)

Ton et al.
- <15% received PP before ECMO
- COVID-19: approximately half of patients

Hongjie Ton; J Thorac Dis 2024

Prone positioning (4)



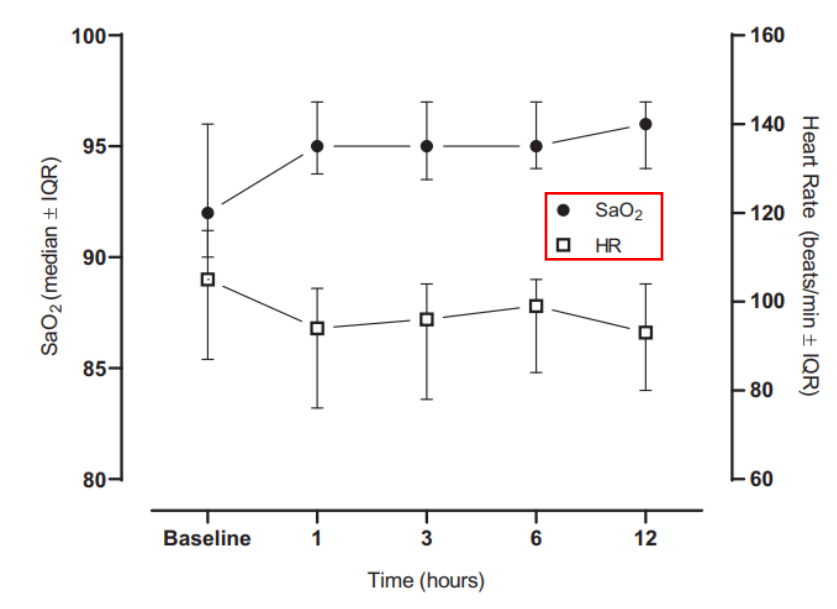
The 30-day survival benefit was more pronounced in non-COVID than in COVID patients

Po-Huang Chen; Journal of Clinical Anesthesia 2025

Beta-blocker (1)

Retrospective analysis
Two ECMO centers (Netherlands and Belgium)
January 2012 and December 2017
N = 33

	n (%)
Metoprolol oral,	11 (33)
Metoprolol iv,	16 (45)
Esmolol iv,	5 (15)
Labetalol iv,	1 (3)



	n = 33
Any potential safety endpoint (composite of below)	**15**
Number of patients affected by any safety endpoint	13
during treatment with oral beta-blocker	6
during treatment with intravenous beta-blocker	7
Heart rate 50/min with need for intervention, n	**2**
Withholding one dose, beta-blocker continued thereafter, n	1
Withholding one dose, dose adjusted, n	1
Need for resuscitation, n	**0**
Need for an increase in norepinephrine, n	**9**
Beta-blocker continued	8
Beta-blocker stopped	1
New rise in lactate levels	**2**
Transient serious ECMO flow problems[a]	1
Episode of severe coughing, dyspnea, agitation	1
Any reason to stop beta-blocker, other than end of indication	**2**
New septic shock[a]	1
Risk for interaction	1

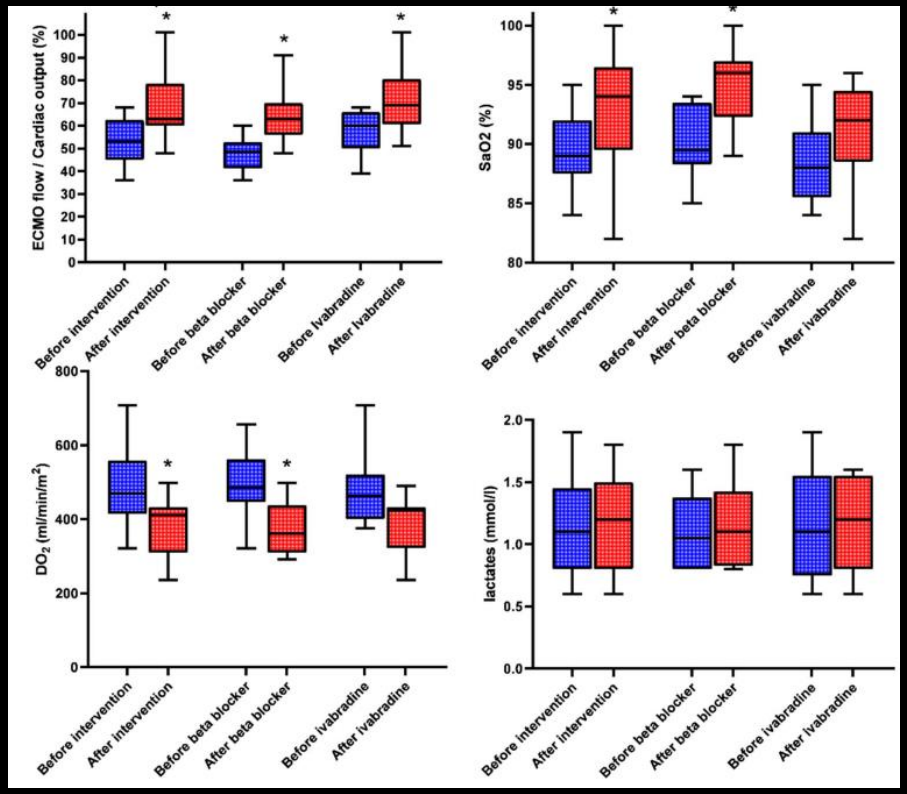
Jeroen J.H. Bunge; Journal of Critical Care 2019

Beta-blocker (2)

Retrospective analysis
France
March 2020 and May 2022

9 with ivabradine
8 with beta-blockers (landiolol or esmolol)

ECMO flow/CO



SaO_2

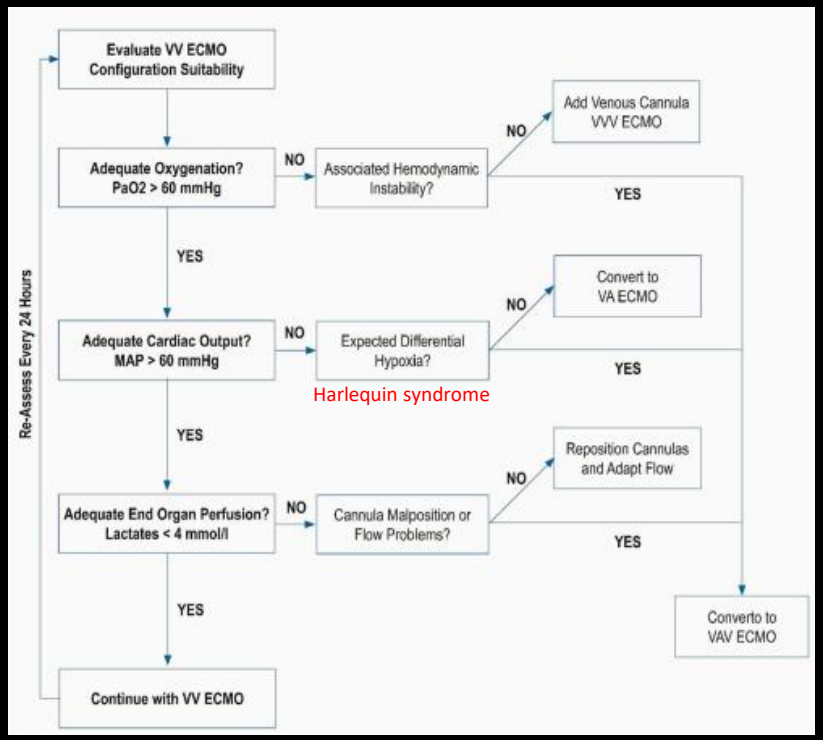
DO2

Lactate

Paul Masi; Cardiovascular Drugs and Therapy 2025

Switching to VA ECMO

- Refractory hypoxemia
  - When all the strategies listed above have failed
  - But the cardiac function is normal
- Cardiac dysfunction supervenes in terms of
  - septic myocardial dysfunction
  - right ventricular dysfunction (acute cor pulmonale)



Andrea Montisci; ASAIO Journal 2015
Maria Elena De Piero, CCM 2026

Take home message

- Indication
  - P/F<50 mmHg for 3 hours
  - P/F<80 mmHg for 6 hours
  - pH<7.25 and PaCO2>60 for 6 hours
- Ultra-lung-protective ventilation
  - TV ≦ 4 mL/kg PBW
  - RR ≦ 10 /minutes
- Strategies to improve oxygenation
  - NMB (only retrospective study)
  - Prone positioning (for non-COVID-19)
  - Beta-blocker (only retrospective study)
  - Switch to VA or VAV

Thanks for Your Attention

林口長庚醫院 呼吸胸腔科
張克威 醫師
B9302072@cgmh.org.tw