Basics in ECMO : what we should know

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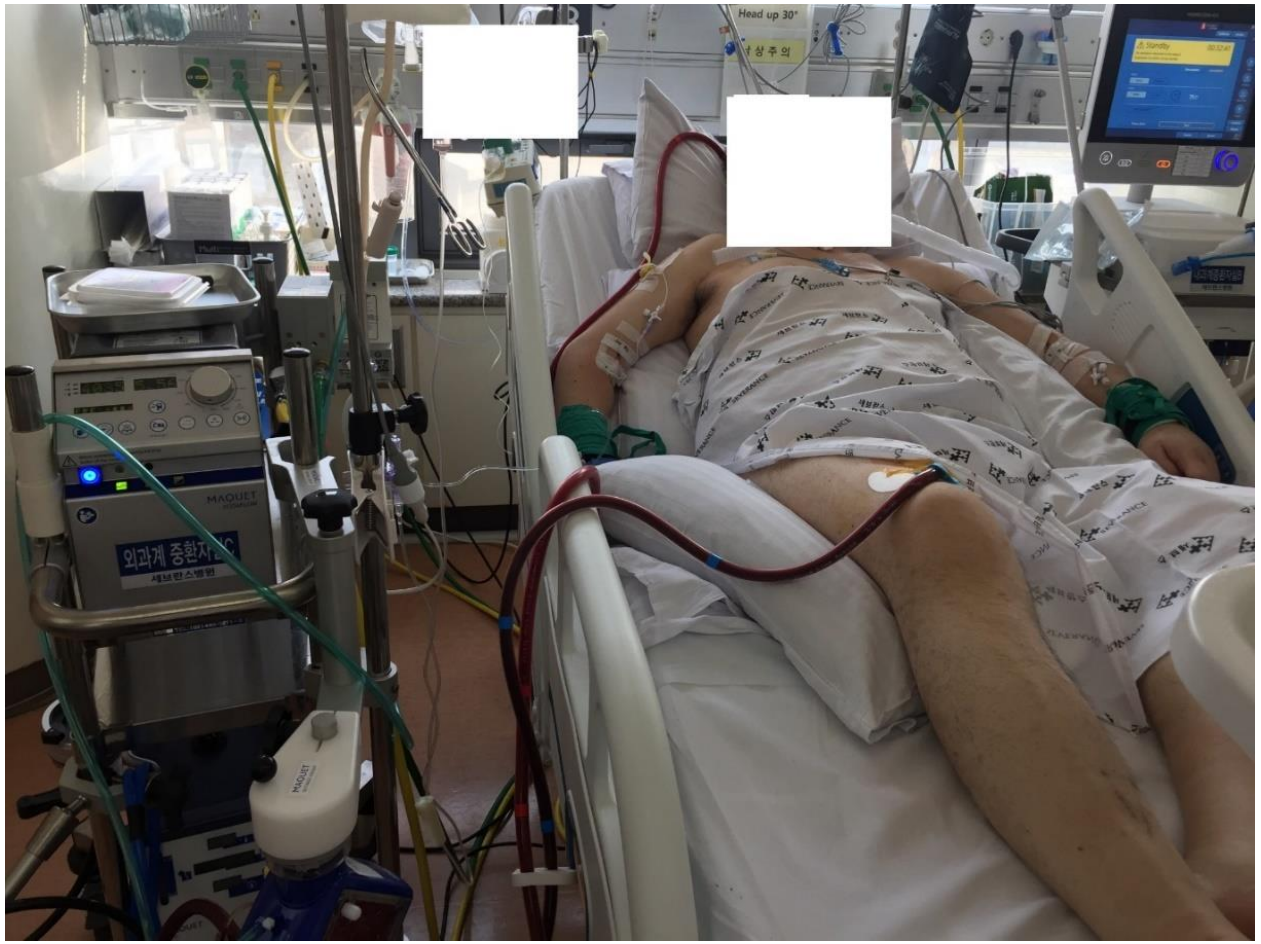
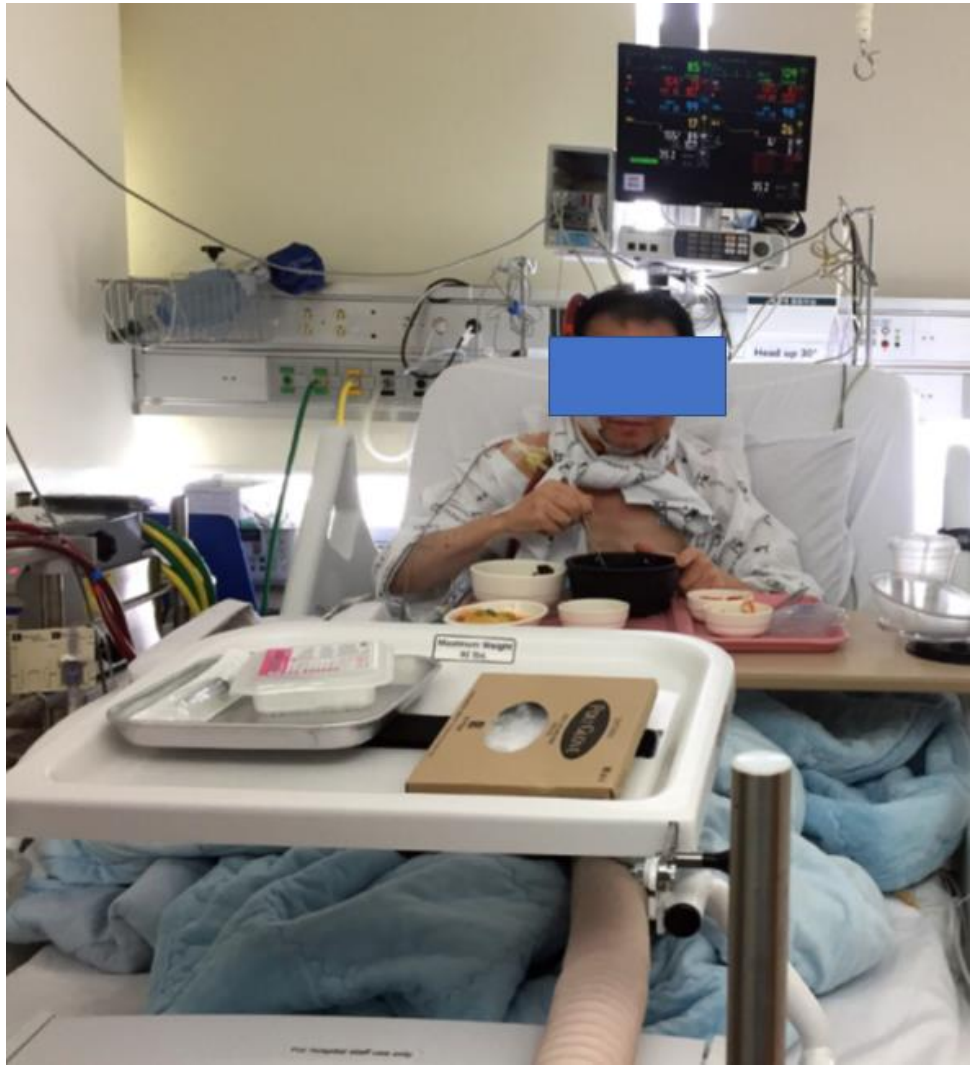
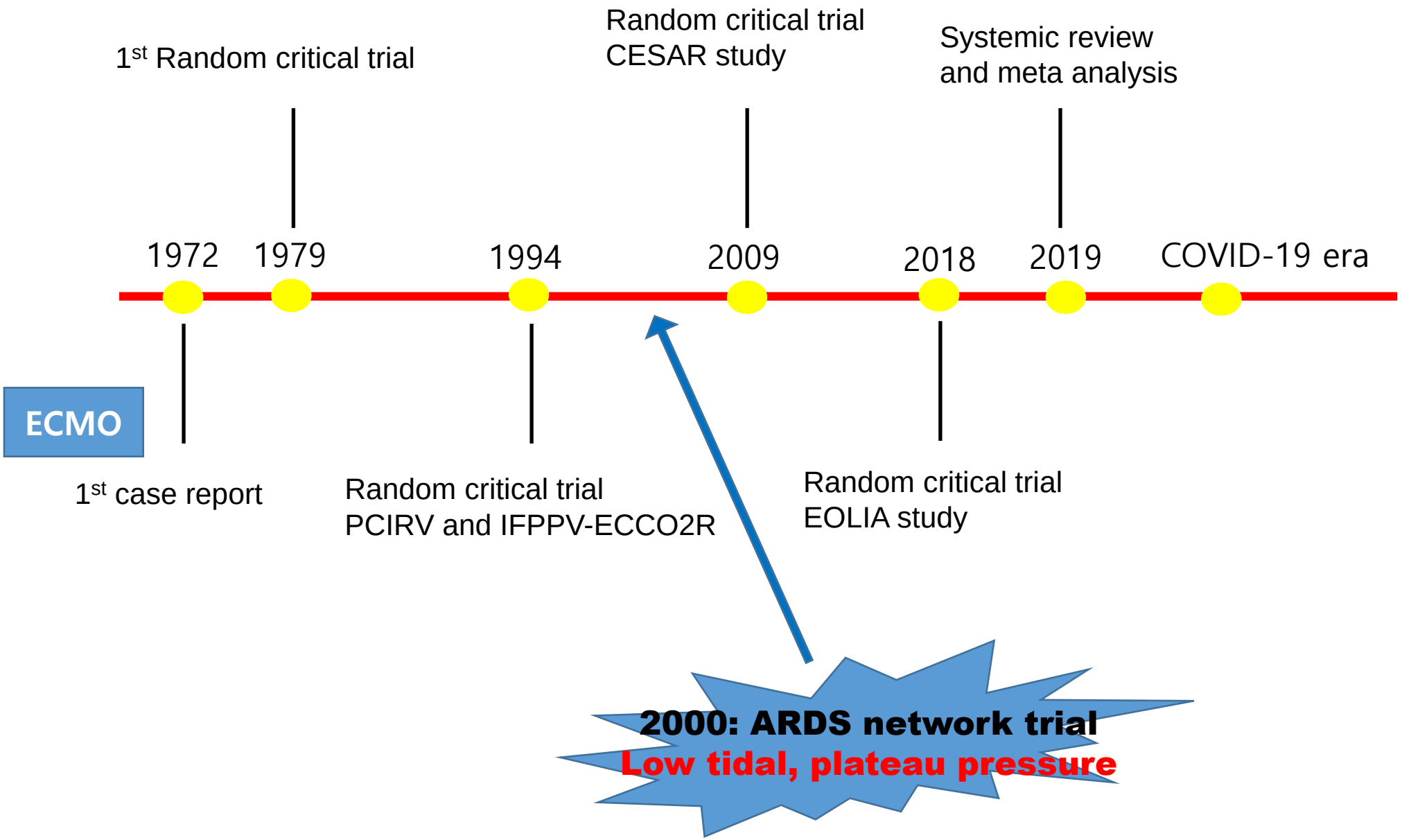
EXTRA CORPOREAL MEMBRANE OXYGENATION (ECMO)






1st Random critical trial
Random critical trial
CESAR study
Systemic review
and meta analysis
1972
1979
1994
2009
2018
2019
COVID-19 era
ECMO
1st case report
Random critical trial
PCIRV and IFPPV-ECCO2R
Random critical trial
EOLIA study
2000: ARDS network trial
Low tidal, plateau pressure

Prolonged Extracorporeal Oxygenation for Acute Post-Traumatic Respiratory Failure (Shock-Lung Syndrome) — Use of the Bramson Membrane Lung

J. Donald Hill, M.D., Thomas G. O'Brien, M.D., James J. Murray, M.D., Leon Dontigny, M.D., M. L. Bramson, A.C.G.I., J. J. Osborn, M.D., and F. Gerbode, M.D.

March 23, 1972
N Engl J Med 1972; 286:629-634
DOI: 10.1056/NEJM197203232861204

Abstract

A 24-year-old man sustained subadventitial transection of the thoracic aorta and multiple orthopedic injuries resulting from blunt trauma. The aortic injury was repaired. Because respiratory failure occurred four days later and worsened despite maximal conventional supportive therapy, partial venoarterial perfusion with peripheral cannulation, with use of the Bramson-membrane heart-lung machine, was initiated and continued for 75 hours. At a by-pass flow of 3.0 to 3.6 liters per minute, oxygen tension increased from 38 to 75 mm of mercury, inspired oxygen concentration was reduced from 100 to 60 per cent, and peak airway pressure decreased from 60 to 35 cm of water. The shock-lung syndrome was reversed, and the patient recovered.

End-stage shock lung may be reversible if the patient receives adequate gas exchange through partial extracorporeal circulation with an appropriate membrane lung.

Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure

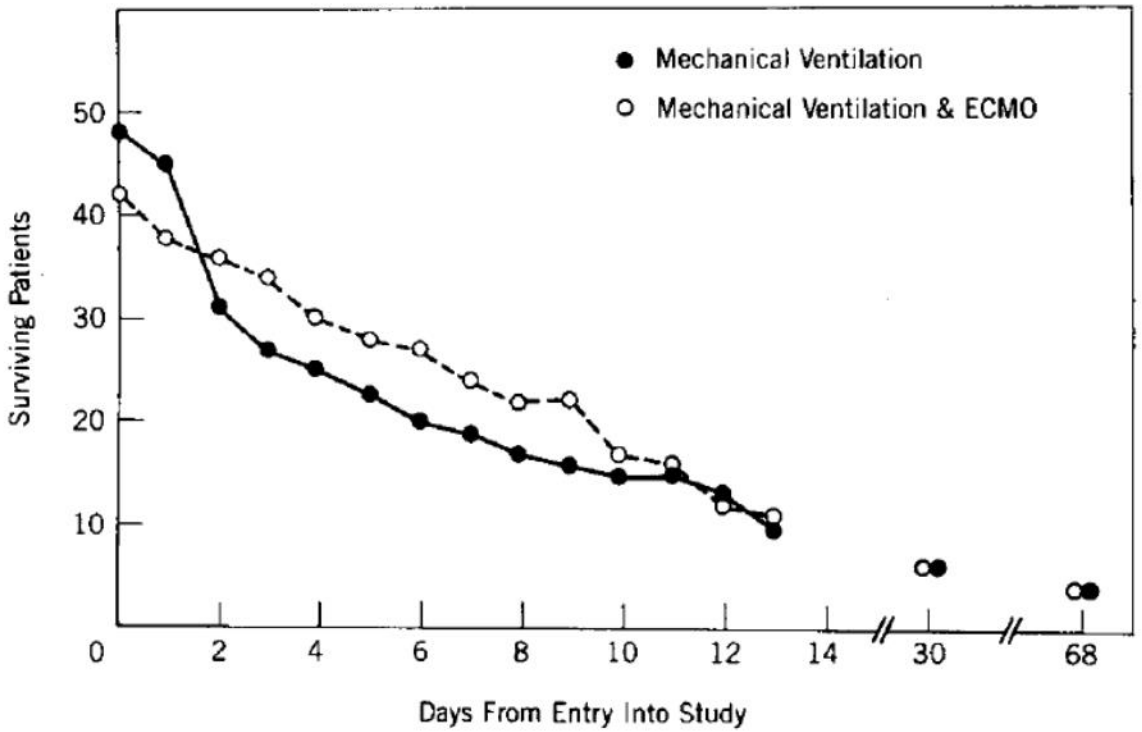
A Randomized Prospective Study

Warren M. Zapol, MD; Michael T. Snider, MD, PhD; J. Donald Hill, MD; et al

JAMA. 1979;242(20):2193-2196. doi:10.1001/jama.1979.03300200023016

Total N: 90 patients
Only MV: 48 patients
VA ECMO + MV: 42 patients

Patient Outcome			
Therapy*	Dead—Respiratory Improvement Never Occurred	Dead After Respiratory Improvement	Survived After Respiratory Improvement
ECMO and MV	34	4	4
MV (control)	41	3	4

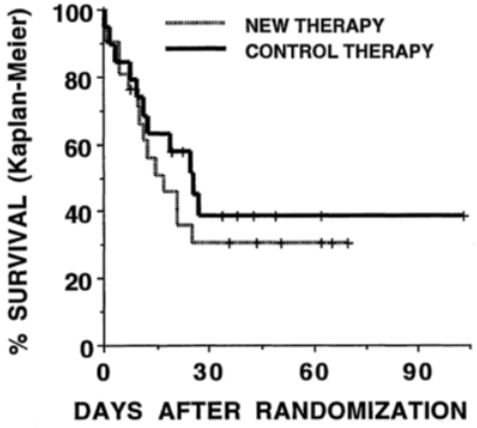


Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO2 removal for adult respiratory distress syndrome.

A H Morris , C J Wallace , R L Menlove , T P Clemmer , J F Orme Jr, L K Weaver , N C Dean , F Thomas , T D East , N L Pace , M R Suchyta ,

Am J Respir Crit Care Med. 1994 Feb;149(2 Pt 1):295-305.

Total N: 40 patients
Control therapy: 19 patients
New therapy(PCIRV and IFPPV-ECC02R) : 21 patients



CLINICAL TRIAL OUTCOME DATA, MEAN ± SEM OR RATIO*

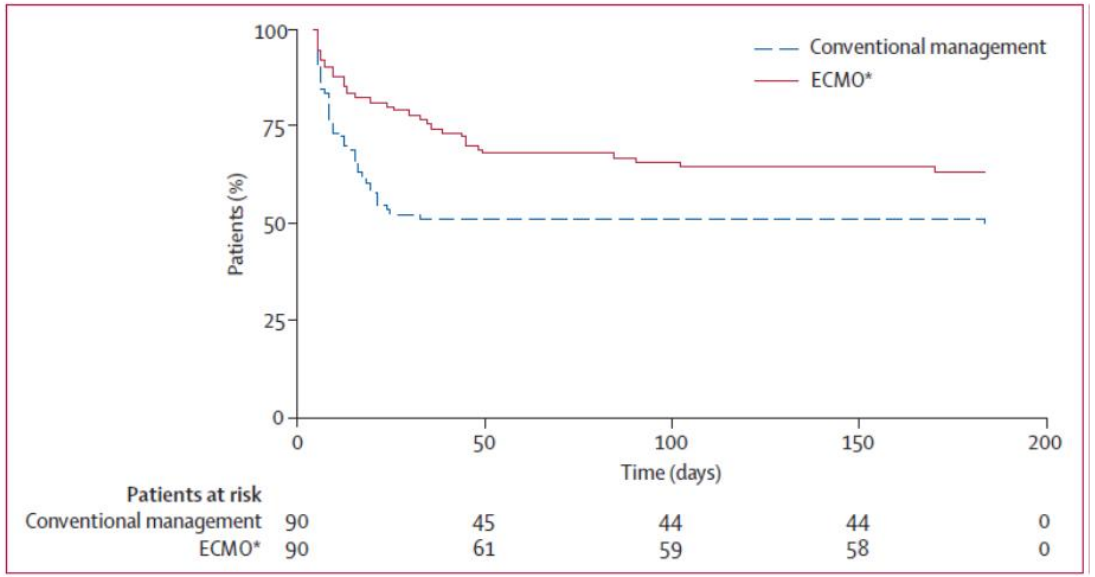
	Survived/ Died	Study Days	Hospital Days	ICU Days	CPPV Days	PCIRVb Days	$ECCO_2R$ Days	PCIRVa Days	CPAP Days
19 Control therapy group patients	8S/11D	27.1 ± 5.7	28.8 ± 5.7	24.2 ± 4.4	19.3 ± 3.7				2.0 ± 0.9
21 New therapy group patients	7S/14D	23.6 ± 4.8	26.9 ± 4.9	23.8 ± 4.0	4.46 ± 2.2	2.4 ± 0.6	8.7 ± 1.7	3.7 ± 1.6	0.9 ± 0.4
p Values for therapy group differences	0.56†	0.57	0.79	0.92	0.0001				0.50
All 40 randomized patients	15S/25D	25.3 ± 3.6	27.8 ± 3.7	24.0 ± 2.9	11.5 ± 2.4				1.5 ± 0.5

Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial

Giles J Peek, Miranda Mugford, Ravindranath Tiruvoipati, Andrew Wilson, Elizabeth Allen, Mariamma M Thalanany, Clare L Hibbert, Ann Truesdale, Felicity Clemens, Nicola Cooper, Richard K Firmin, Diana Elbourne, for the CESAR trial collaboration

Treatment by low-volume low-pressure ventilation strategy at any time	84 (93%)	63 (70%)	<0·0001

Conventional therapy: 90 patients
ECMO: 90 patients → 68 patients



No	57 (63%)	41 (47%)‡	NA
Yes	33 (37%)	46 (53%)‡	NA
No information about severe disability	0	3 (3%)§	NA
Died at ≤6 months or before discharge	NA	NA	0·73 (0·52–1·03, 0·07)
No	57 (63%)	45 (50%)	NA
Yes	33 (37%)	45 (45%)	NA
Severe disability			
No	57 (63%)	41 (46%)	NA
Yes	0	1 (1%)	NA
Cause of death			
Respiratory failure	8 (9%)	24 (27%)	NA
Multiorgan failure	14 (16%)	15 (17%)	NA
Neurological disorder	4 (4%)	2 (2%)	NA
Cardiovascular disorder	1 (1%)	3 (3%)	NA
Related to ECMO	1 (1%)	0	NA
Other	1 (1%)	0	NA
Unknown	4 (4%)	1 (1%)	NA
Time between randomisation and death (days)	15 (3–41)	5 (2–14)	NA

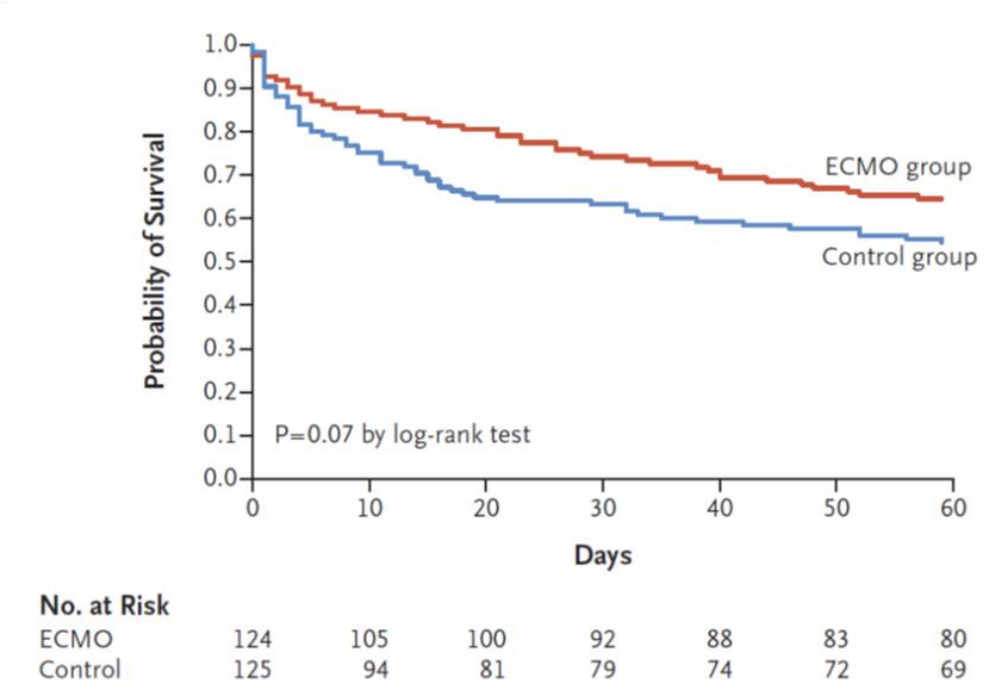
Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome

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*

N Engl J Med 2018; 378: pp. 1065-1075

Total N: 249 patients
Conventional therapy: 125 patients (35 patients crossover to ECMO)
ECMO: 124 patients

End Point	ECMO Group (N=124)	Control Group (N=125)	Relative Risk or Difference (95% CI)†	P Valu
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
Other end points				
Mortality at 90 days — no. (%)	46 (37)	59 (47)	−10 (−22 to 2)	
Median length of stay (interquartile range) — days				
In the ICU	23 (13–34)	18 (8–33)	5 (−1 to 10)	
In the hospital	36 (19–48)	18 (5–43)	18 (6 to 25)	
Median days free from mechanical ventilation (interquartile range)§	23 (0–40)	3 (0–36)	20 (−5 to 32)	
Median days free from vasopressor use (interquartile range)§	49 (0–56)	40 (0–53)	9 (0 to 51)	
Median days free from renal-replacement therapy (interquartile range)§	50 (0–60)	32 (0–57)	18 (0 to 51)	
Prone position — no. (%)¶	82 (66)	113 (90)	−24 (−34 to −14)	
Recruitment maneuvers — no. (%)¶	27 (22)	54 (43)	−21 (−32 to −10)	
Inhaled nitric oxide or prostacyclin — no. (%)¶	75 (60)	104 (83)	−23 (−33 to −12)	
Glucocorticoids — no. (%)¶	80 (65)	82 (66)	−1 (−13 to 11)	

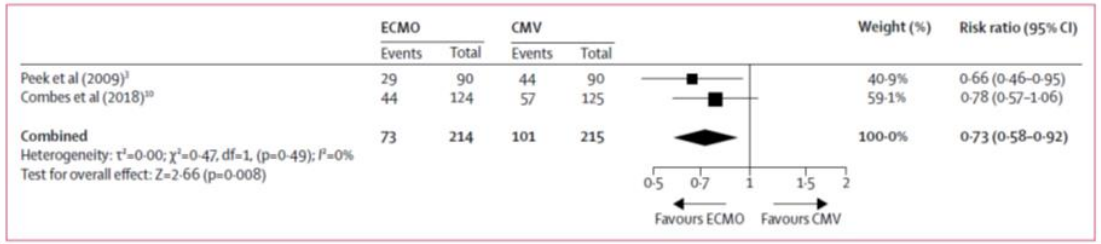


Venovenous extracorporeal membrane oxygenation for acute respiratory distress syndrome: a systematic review and meta-analysis

Laveena Munshi, Allan Walkey, Ewan Goligher, Tai Pham, Elizabeth M Uleryk, Eddy Fan

Lancet Respir Med 2019;7: 163–72

60 days mortality

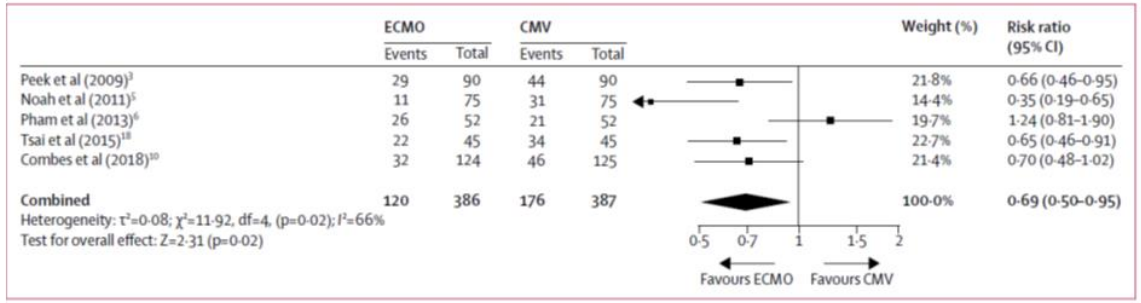


	ECMO Events	ECMO Total	CMV Events	CMV Total	Weight (%)	Risk ratio (95% CI)
Peek et al (2009)[3]	29	90	44	90	40·9%	0·66 (0·46–0·95)
Combes et al (2018)[10]	44	124	57	125	59·1%	0·78 (0·57–1·06)
Combined	73	214	101	215	100·0%	0·73 (0·58–0·92)

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)

0·5 0·7 1 1·5 2
Favours ECMO Favours CMV

30 days mortality in all study

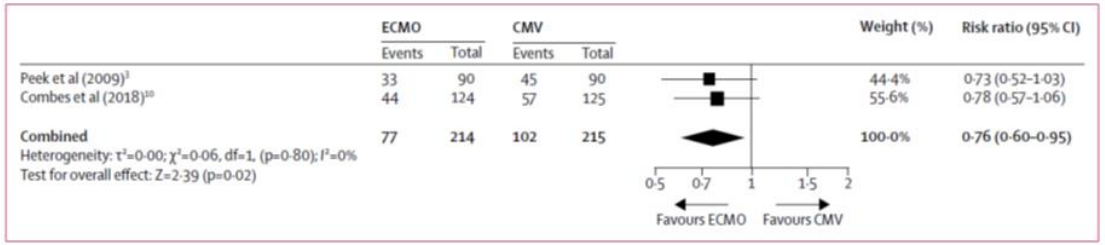


	ECMO Events	ECMO Total	CMV Events	CMV Total	Weight (%)	Risk ratio (95% CI)
Peek et al (2009)[3]	29	90	44	90	21·8%	0·66 (0·46–0·95)
Noah et al (2011)[5]	11	75	31	75	14·4%	0·35 (0·19–0·65)
Pham et al (2013)[6]	26	52	21	52	19·7%	1·24 (0·81–1·90)
Tsai et al (2015)[18]	22	45	34	45	22·7%	0·65 (0·46–0·91)
Combes 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)

0·5 0·7 1 1·5 2
Favours ECMO Favours CMV

60 month mortality

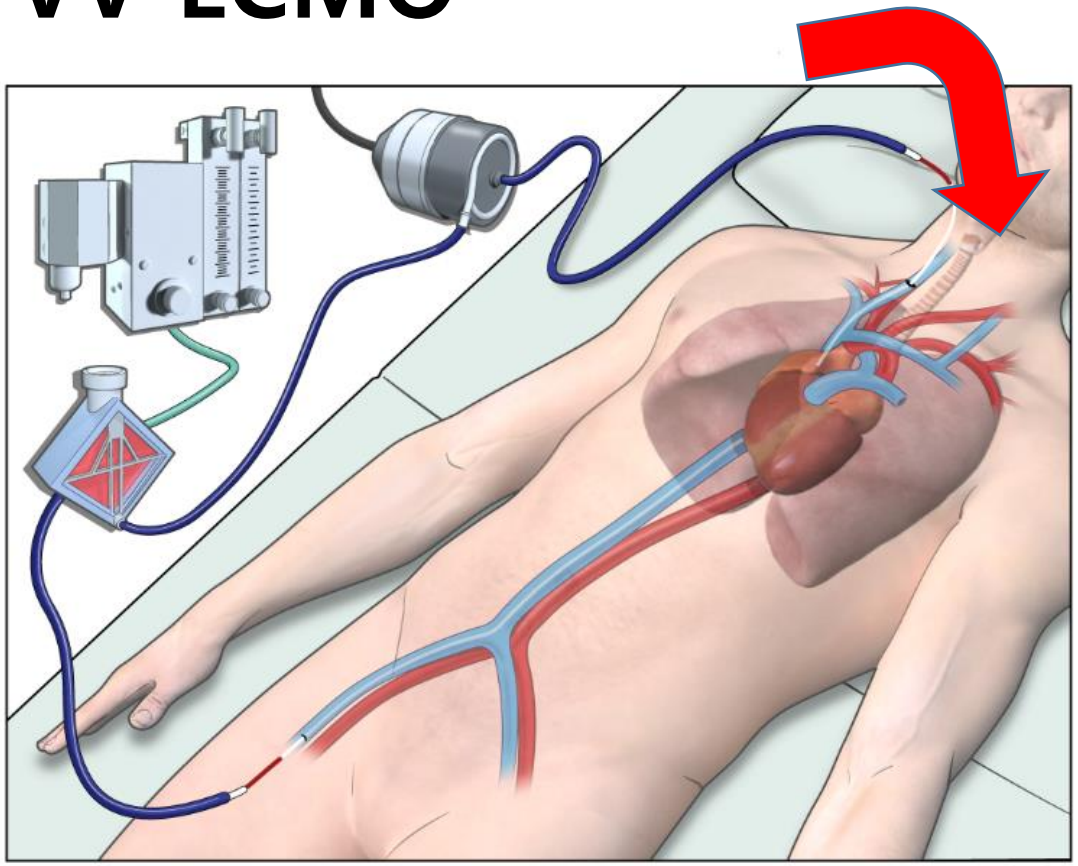


	ECMO Events	ECMO Total	CMV Events	CMV Total	Weight (%)	Risk ratio (95% CI)
Peek et al (2009)[3]	33	90	45	90	44·4%	0·73 (0·52–1·03)
Combes et al (2018)[10]	44	124	57	125	55·6%	0·78 (0·57–1·06)
Combined	77	214	102	215	100·0%	0·76 (0·60–0·95)

Heterogeneity: τ^2=0·00; χ^2=0·06, df=1, (p=0·80); I^2=0%
Test for overall effect: Z=2·39 (p=0·02)

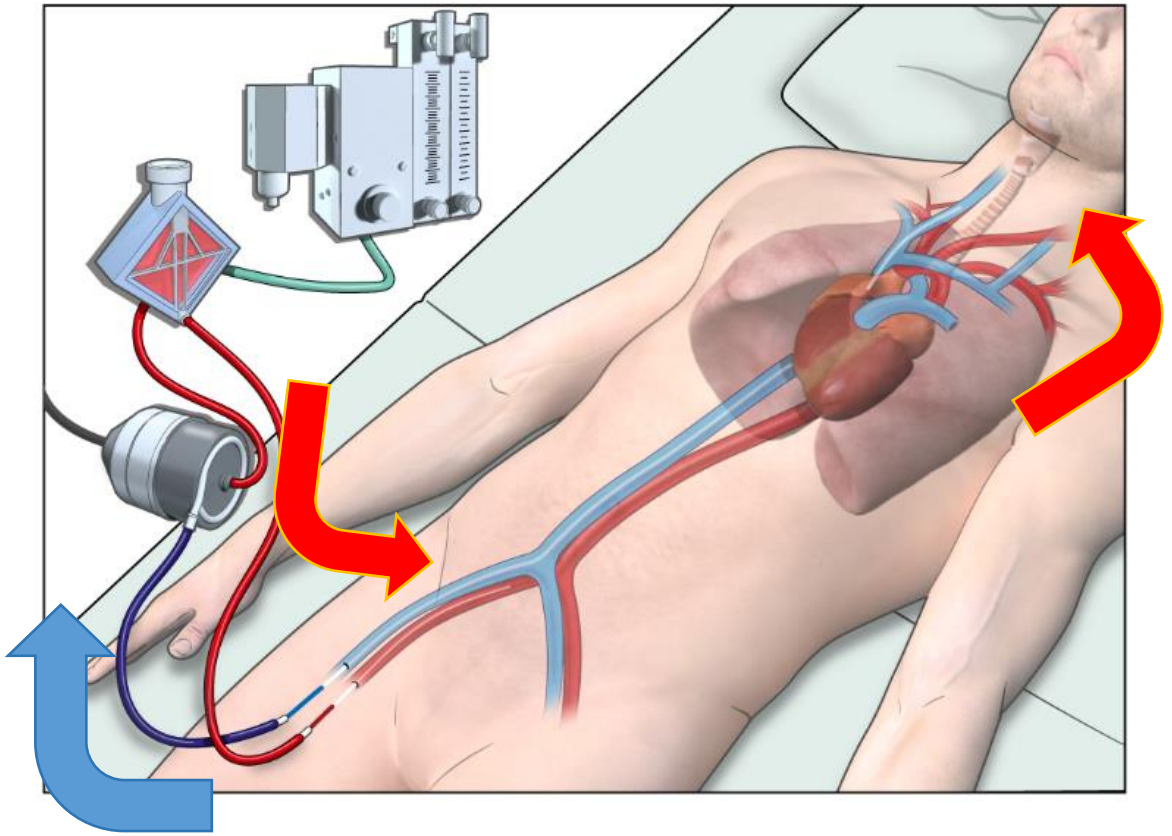
0·5 0·7 1 1·5 2
Favours ECMO Favours CMV

VV ECMO



Respiratory
Vein → oxygenate → vein

VA ECMO

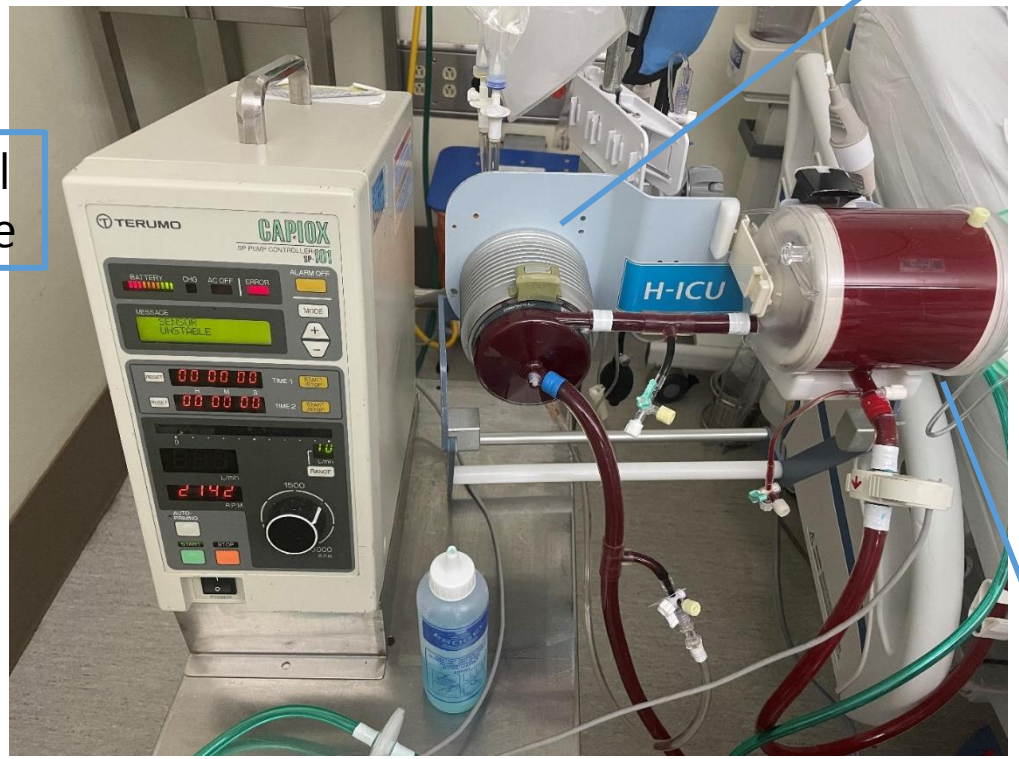


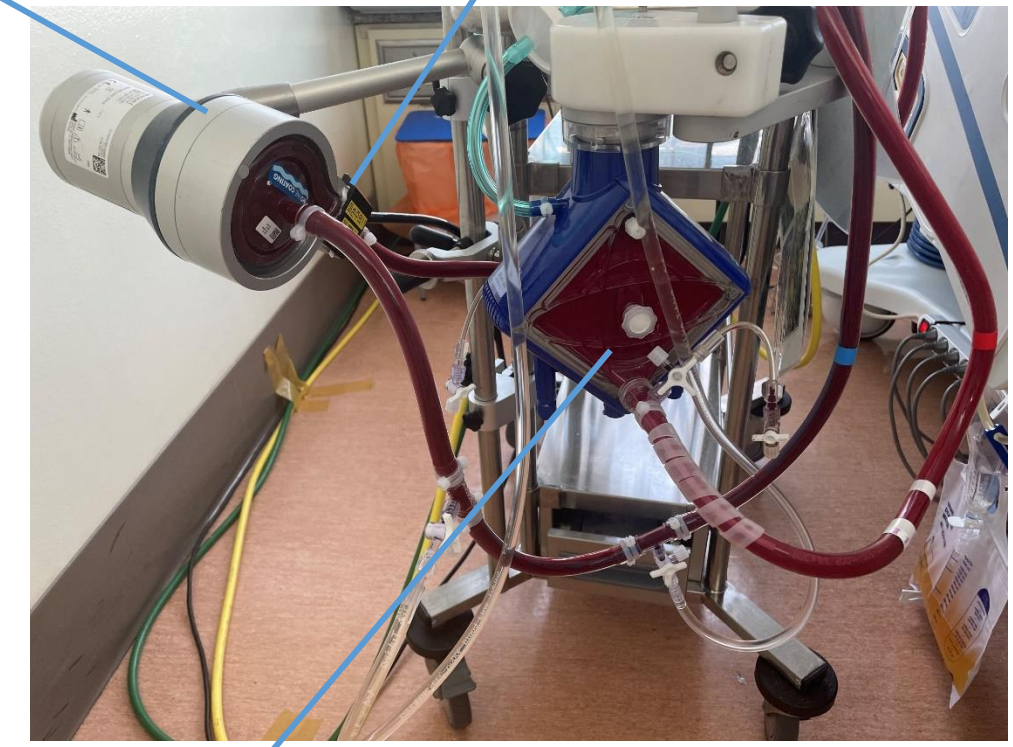
Cardiac
Vein → oxygenate → artery

Pump (centrifugal)

Flow sensor

Control console



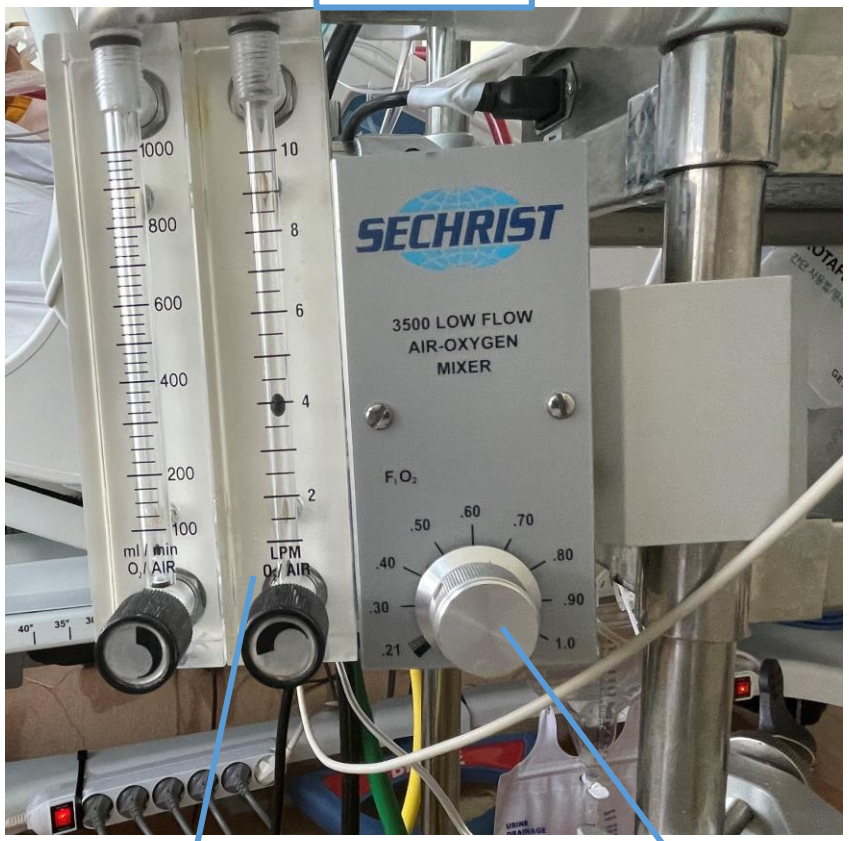


Oxygenator (membrane lung)

Pump 속도

실제 혈류 속도

Blender



Sweep gas 속도

ECMO FiO2

- 20세 군인,
- 3일전 부터 발열, 인후통, 기침, 복통, 설사
- 흉부 방사선 검사상 우상엽 폐 침윤
- 복부 전산화단층촬영에서 급성충수돌기염

→ 응급 충수돌기 제거 수술

→수술 후 빈 호흡 및 양측 폐 침윤 악화

→ 중환자실 입실, 기계환기 시행

→ FiO2 1.0 에도 불구하고 PaO2 53mmHg

→ Next one ?

Prone position, VV-ECMO ?

Indication and relative contraindication

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.

Relative contraindications for venovenous extracorporeal membrane oxygenation

- Central nervous system hemorrhage
- Significant central nervous system injury
- Irreversible and incapacitating central nervous system pathology
- Systemic bleeding
- Contraindications to anticoagulation
- Immunosuppression
- Older age (increasing risk of death with increasing age, but no threshold is established)
- Mechanical ventilation for more than 7 days with P_{plat} > 30 cm H_2O and FiO_2 > 90%

ASAIO J. 2021 Jun 1;67(6):601-610.

Specific clinical conditions:

- Acute respiratory distress syndrome (e.g., viral/bacterial pneumonia and aspiration)

1) Reversible condition
2) Bridge to device
3) Bridge to transplant

ion)

ansplant)

보건복지부 고시 (고시 제2020-194호)

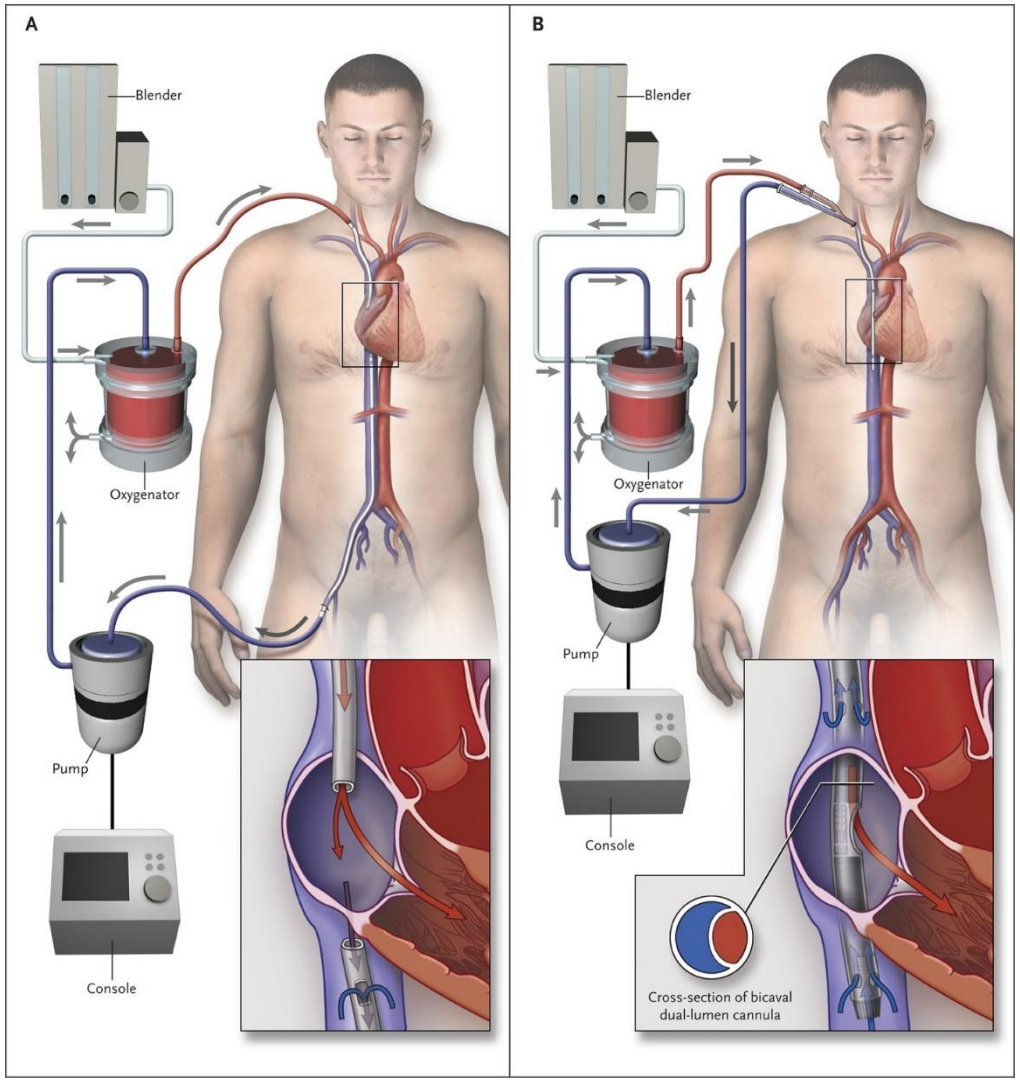
적응증

1) 기존의 치료법에 의해 교정되지 않으나 회복 가능성이 있는 중증 급성 심부전
   가)급성심근경색증, 급성심근염, 주산기심근증(Peripartum Cardiomyopathy), 대상부전의 만성심부전(Decompensated chronic heart failure), 수술 후 심기능부전, 불응성 심실성빈맥(Refractory ventricular tarchycardia) 등
   나)충전(volume replacement)·약물치료(drug intervention)·대동맥내풍선 등 기존의 심부전치료에 반응하지 않는 급성 쇼크
2) 목격된 심정지(witnessed arrest)이거나 심정지 시점이 비교적 정확히 유추 가능한 경우로 심폐소생술이 시행되어 회생가능성이 있는 경우 또는 가역적 심정지(accidental hypothermia, drug intoxication)
3) 기존의 기계적 인공호흡기 치료로는 생명유지가 불가능하지만 ECMO 시술로 회복 가능성이 있는 중증 급성 호흡부전
   가) 급성호흡곤란증후군, 중증폐렴, 폐이식 후 원발성 이식실패
   나) 일시적인 air way유지를 위해 실시하는 경우(기도 이물질, 기도 시술(수술) 등)
   다) 심한폐공기누출증후군(Severe air leak syndromes)
   라) 폐이식 전 기관내삽관이 필요한 급성호흡곤란증후군
   마) 급박한 심장 또는 폐의 허탈(최선의 치료에 반응하지 않는 폐색전증, 기도폐쇄)
4) 심장 또는 폐 이식대상환자의 교량치료 (Bridge to transplantation)로써 이식등록과정이 사전·사후에 확인된 경우

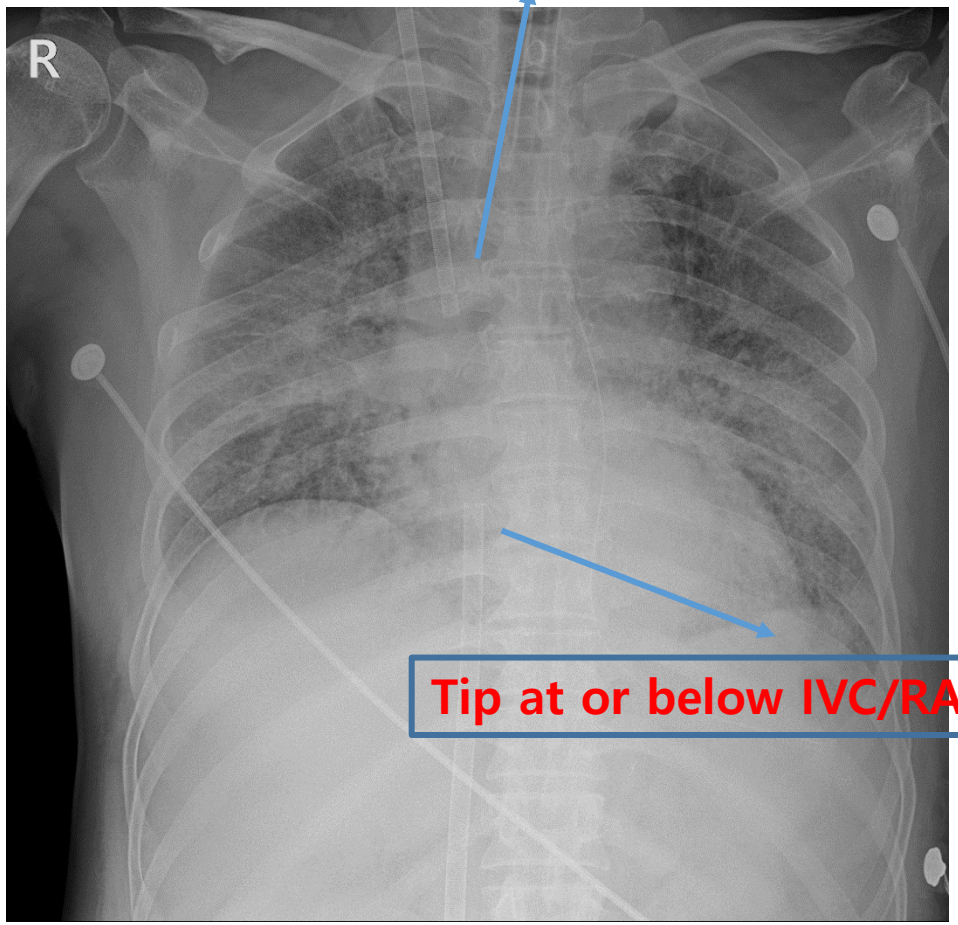
금기증

1) 회복이 불가능한 심장질환으로, 이식 또는 심실보조장치를 시행 할 수 없는 경우
2) 충분한 조직관류(adequate tissue perfusion)없이 60분을 초과하여 심폐소생술을 시행하는 경우
3) 심폐소생술을 거부한 경우
4) 의학적으로 심폐소생술이 필요한 심정지가 목격되지 아니하여, 심정지 시간과 심폐소생술이 적시에 시행되었음을 확인할 수 없는 경우
5)호흡부전환자에서 FiO2>90% 이거나 Pplat> 30cmH2O의 높은 설정의 인공호흡기를 7일 이상 유지하는 경우
6) 지혈이 불가능한 출혈부위가 있어서 항응고요법의 절대적 금기증에 해당하는 경우
7) 최근(recent) 뇌출혈이 있거나 출혈이 증가하는 경우
8) 이미 진행된 다발성장기부전 등으로 회복가능성이 없는 경우
9) 진행성 혈액암, 골수이식 실패, 무과립구증, 절대호중구수(ANC)<400/mm3 등 심한 면역기능저하상태인 경우
10) 회복 불가능한 뇌손상, 비가역적 중추신경계 장애가 있는 경우
11) 말기암, 회복가능성이 없는 폐, 간, 신장 등의 만성중증장기부전
12) 동 시술이 의의가 없는 고령 환자의 경우

Cannulation



tip at or above SVC/RA junction

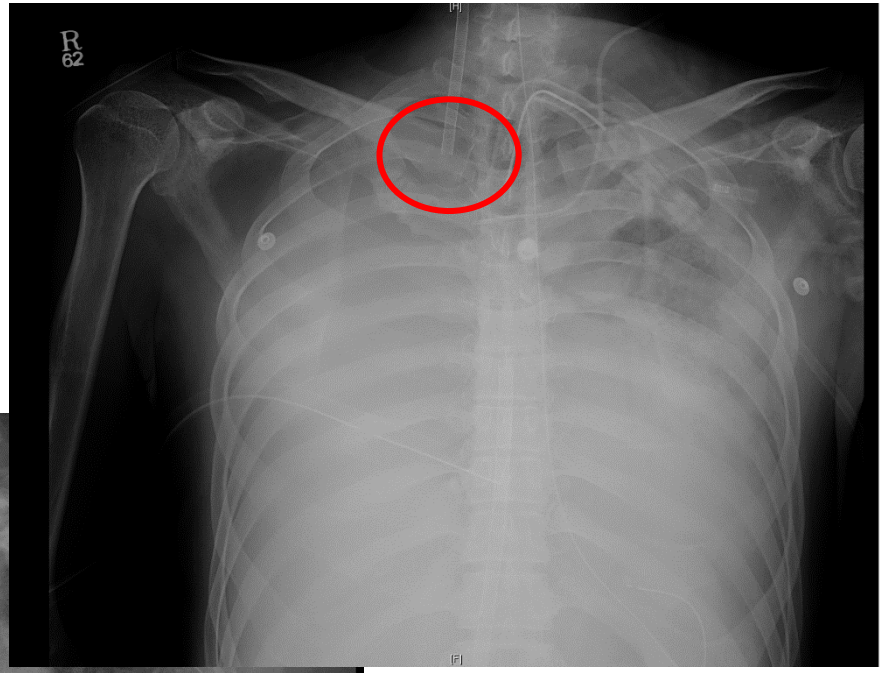


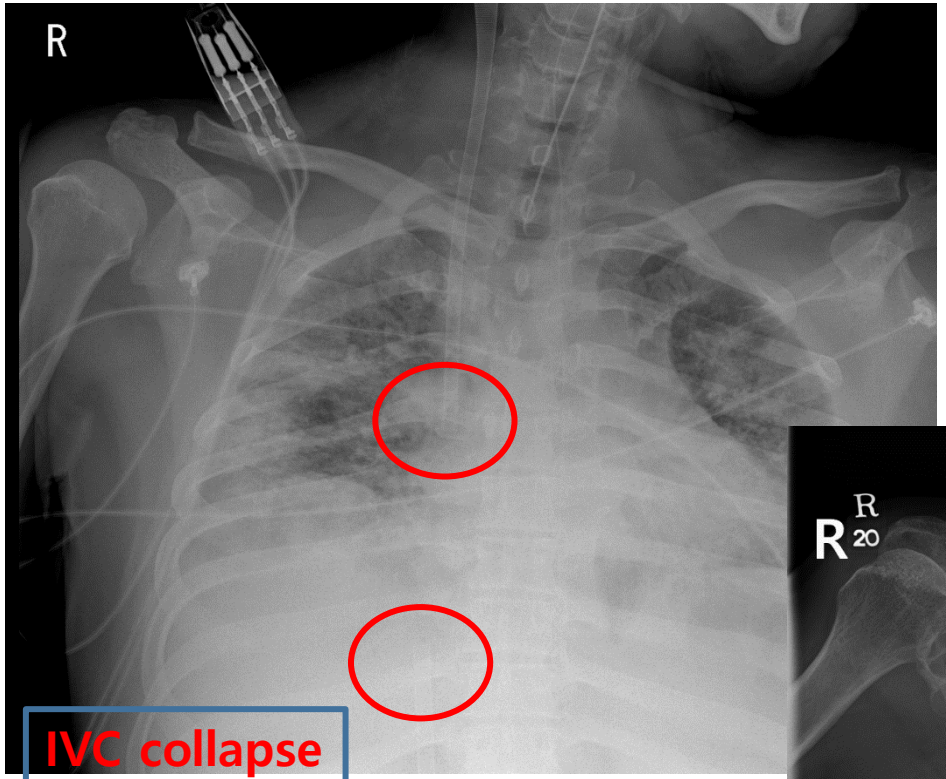
Tip at or below IVC/RA junction

Bolus dose of unfractionated heparin 50 units/kg

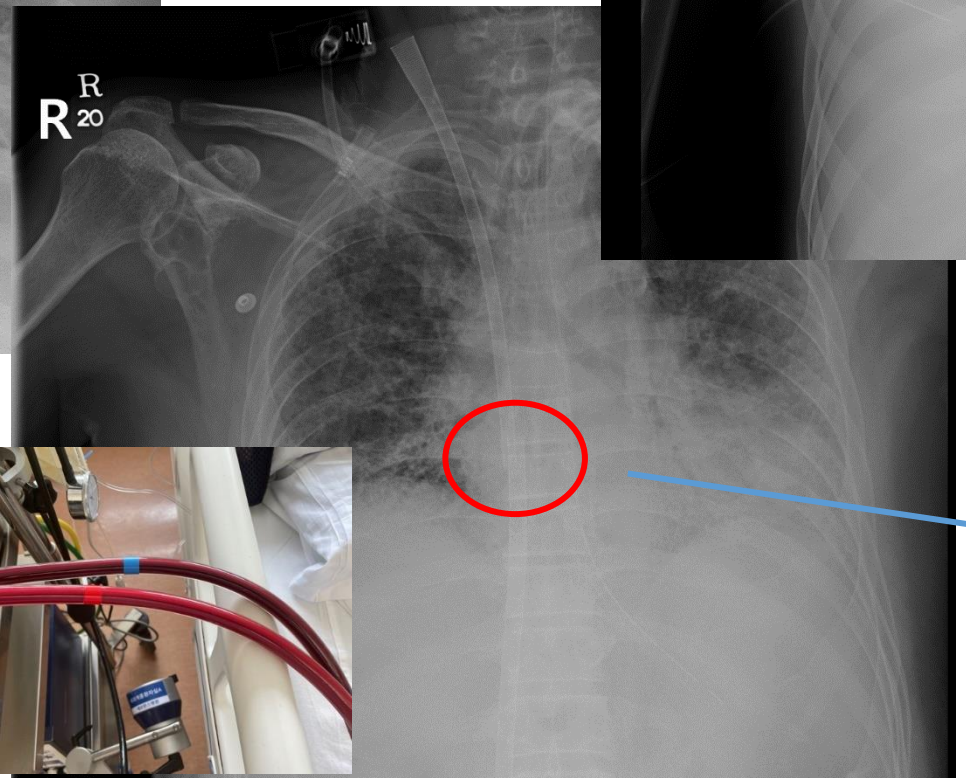
N Engl J Med 2011; 365:1905-1914

decannulation

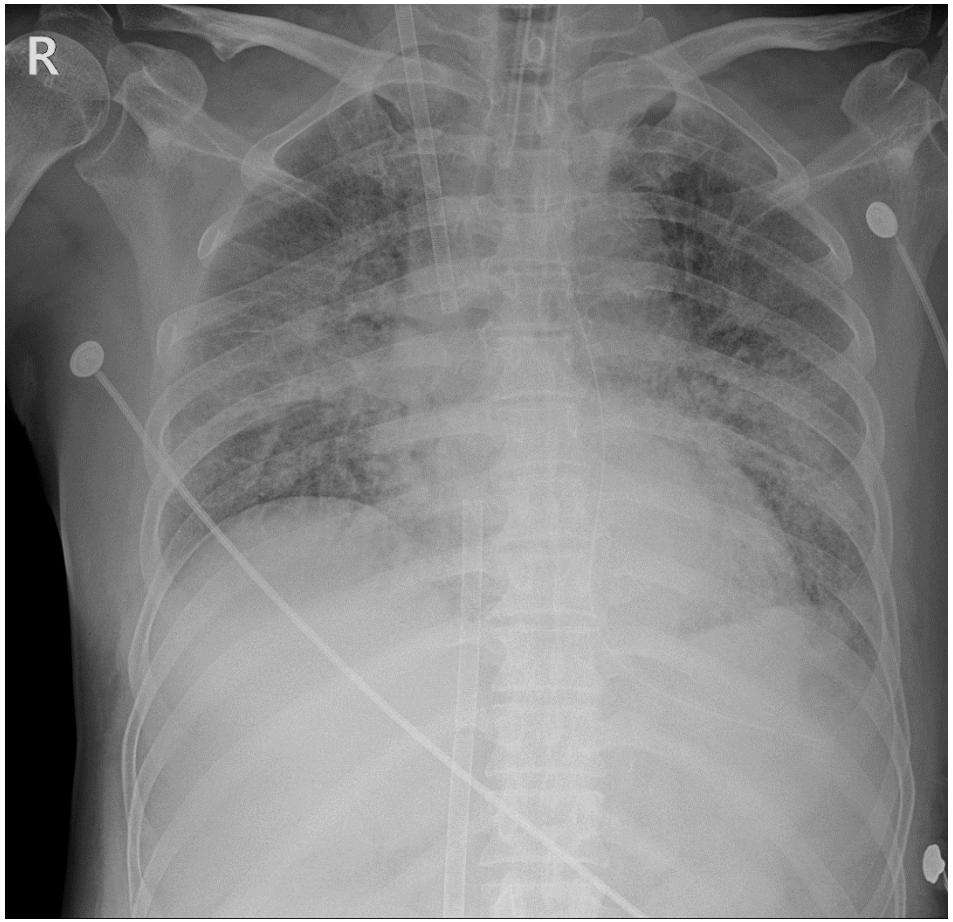




IVC collapse



recirculation



HT 170cm, 55kg

- VV ECMO 시작

Pump flow: 2800 RPM
Blood flow: 3.0 L/min
ECMO FiO2 1.0
Sweep gas: 3L

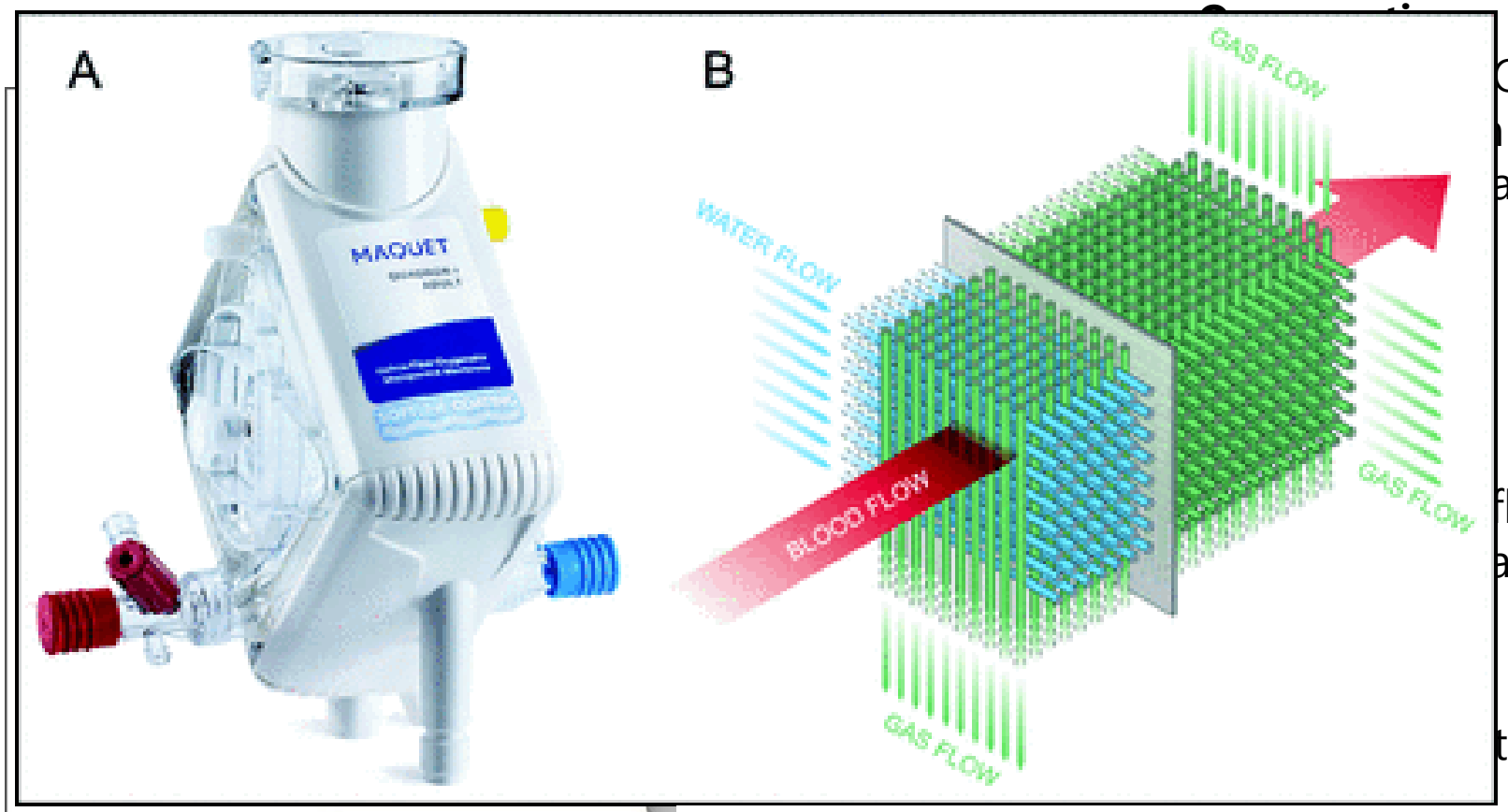
- Ventilator

PCV mode
FiO2: 0.35
PEEP: 10 cmH2O
Above PEEP: 10 cmH2O
RR: 12

- 객담 호흡기 바이러스 PCR 검사상 아데노바이러스 검출

Cidofovir, piperacillin/tazobactam, levofloxacin
Supportive management

Oxygenator (membrane)



Respir Care. 2018 Sep;63(9):1162-1173

O2
of delivered oxygen
ane capacity

flow
adient

tabolic demand (elevated oxygen
sepsis, fever, agitation, movement,

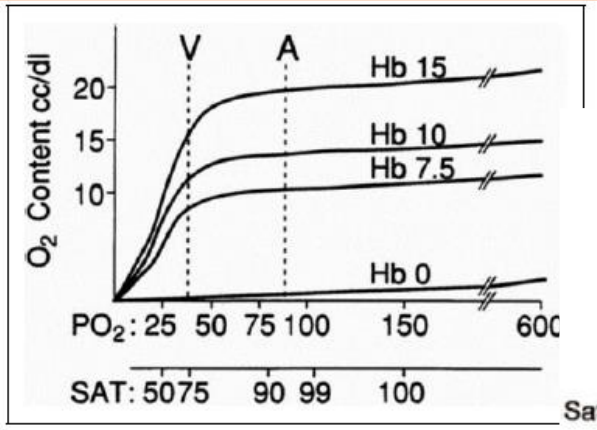
- Recirculation (Inlet oxygen saturation greater than 75% may suggest recirculation or cannula malposition)

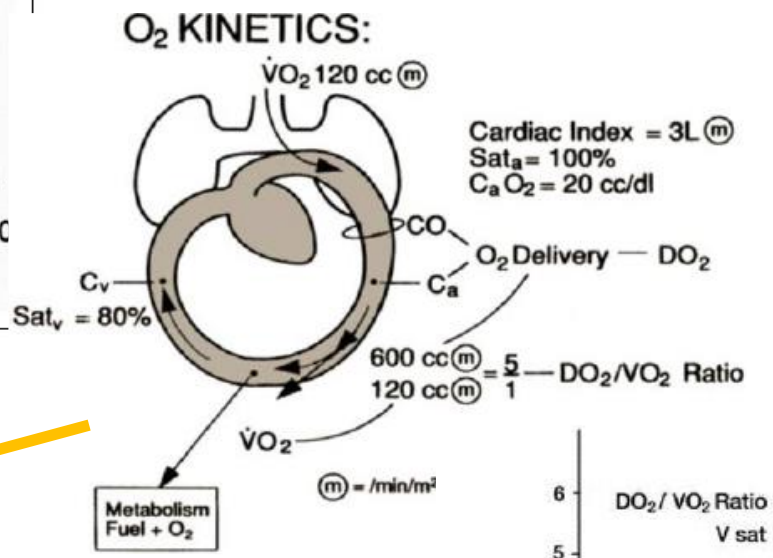
N Engl J Med 2011; 365:1905-1914

Oxygen in blood: Hb (g/dl) x sat (%) x 1.34ml/O_2/g + PO_2 (mmHg) x 0.003 (ml/mmHg/dL)

Hb 15인 성인, sat 100%
→ O_2 content 는 20ml/dL

Hb 7.5인 성인, sat 100%
→ O_2 content 는 10ml/dL

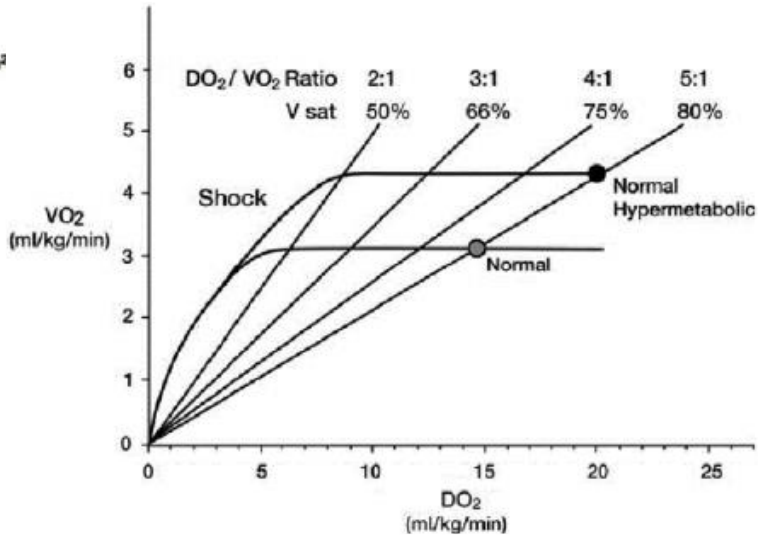




조직에 전달되는 oxygen 의 양은 (DO_2)
Cardiac output x 혈액내 산소량

30dL/min/m2 x 20ml/dL = 600ml/min/m2
정상 성인 휴식기 oxygen consumption
120ml/min/m2
→ DO_2: VO_2 = 5:1 유지

만약 VO_2 증가시 DO_2 를 증가시켜 유지하려고 함→ 유지 못하고 2:1 밑으로 떨어지면 anaerobic metabolism 발생 하며 시간이 지날수록 organ failure



J Intensive Care Med. 2017 May;32(4):243-248.

- The circuit and blood flow are planned for VO_2 at rest or during moderate

Mixing 2 Blood Flows in VV ECMO: Example 1

Using O_2 Content:

$$\frac{14 \times 4}{4 + F_2} + \frac{9 \times F_2}{4 + F_2} = 12.3 \text{ cc/dL}$$

$$\text{Cardiac Output} = \frac{4(14-9)}{(12.3-9)} = 6 \text{ L/min}$$

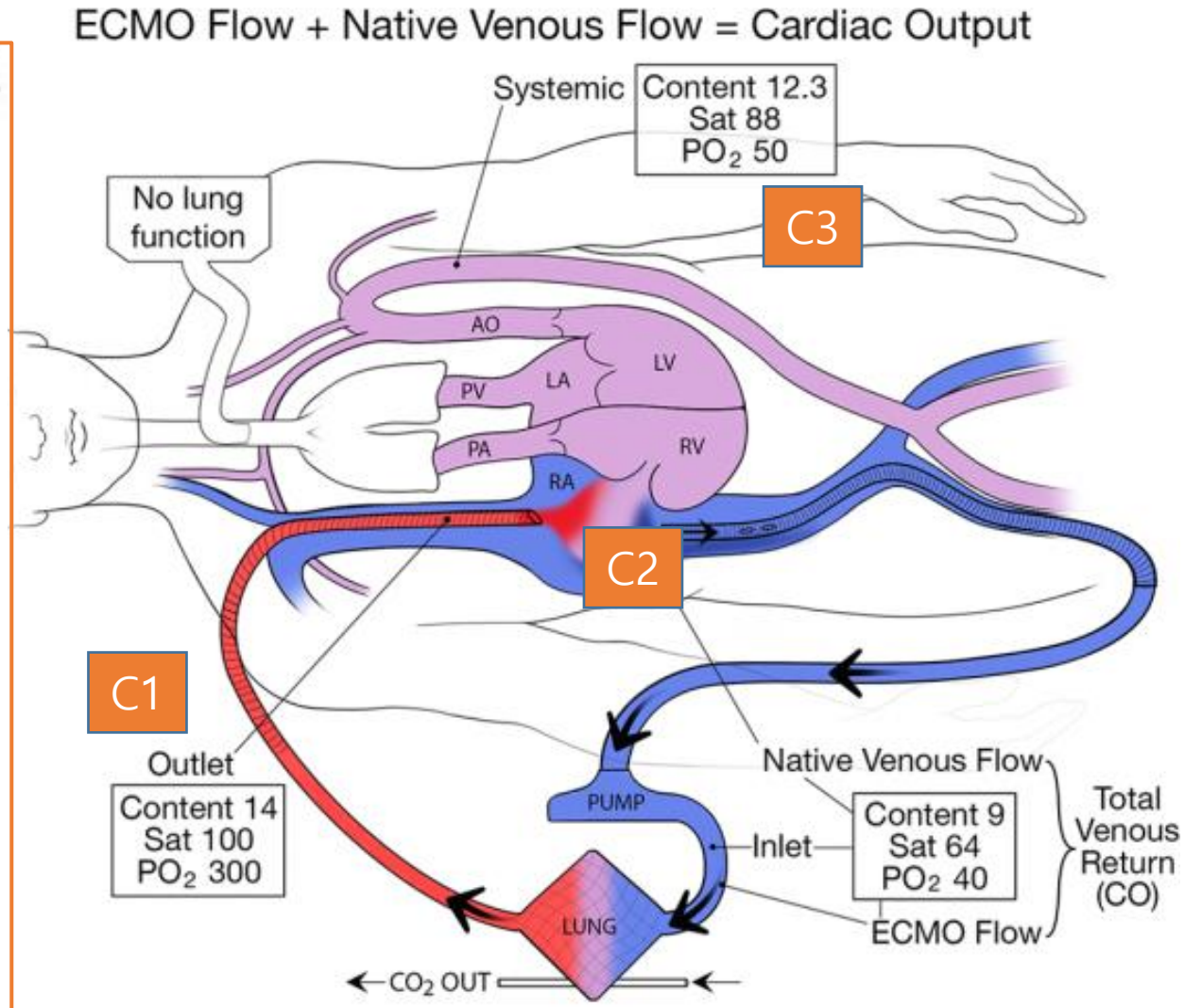
$$\text{Native Venous Flow} = 6 - 4 = 2 \text{ L/min}$$

Using O_2 Saturation:

$$\frac{100 \times 4}{4 + F_2} + \frac{64 \times F_2}{4 + F_2} = 90\%$$

$$\text{Cardiac Output} = \frac{4(100-64)}{(90-64)} = 6 \text{ L/min}$$

$$\text{Native Venous Flow} = 6 - 4 = 2 \text{ L/min}$$



J Intensive Care Med. 2017 May;32(4):243-248.

- ECMO flow: 4L/min = 40dL/min, systemic PO_2: 50mmHg, Sat:88%, Hb 10.5 g/dL, O_2 content 12.3ml/dL, Venous Sat: 64%
- oxygen consumption is 200 ml/min

→ Outlet O_2 content: 14ml/dL, inlet O_2 content : 9ml/dL

→Outlet – Inlet O_2 content, 14-9 = 5ml/dL

→그리고 ECMO flow 는 4L/min 이기 때문에

→공급되는 O_2 의 양은 5ml/dL x 4L/min = 200ml/min

→그런데 native venous flow 가 2L/min 임 (앞슬라이드 공식)

→총 cardiac output 은 6L = 60dL

→ECMO 에서 공급되는 산소 14ml/dL x 40dL/min / 60 = 9

→Venous content O_2 9/dL x 20dL/min /60 =3

→**DO_2 12.3 ml/dL x 60dl/min =738**

→**DO_2 / VO_2 ratio = 3.64**

Increased cardiac output

위에 환자에서 8L/min 로 cardiac output 증가시

- ECMO flow: 4L/min = 40dL/min, systemic PO_2: 45mmHg, Sat:84%, Hb 10.5 g/dL, O_2 content 11.5ml/dL, Venous Sat: 64%
- oxygen consumption is 200 ml/min→ but the systemic saturation and PO_2 are lower.
- The systemic oxygen delivery is 920 ml/min (11.5ml/dL x 80dL/min)
- DO_2 / VO_2 ratio = 4.6
- Oxygen consumption 이 변화가 없으면 fully aerobic metabolism이 유지됨. 그런데 sat monitoring 은 84% 로 check

Decreased Hb

Hb 이 10.5 에서 8로 감소될 경우

- outlet O_2– inlet O_2 content = 10.7-9 =1.7
- 1.7 x 40으로 68ml/min 밖에 공급을 못해 총 DO_2 는 588 ml/min 으로 감소
- DO_2/VO_2 ratio of 2.9
- 그리고 시간이 지나면 inlet O_2 content 는 5.7 로 감소 (VO_2sat 50%) → systemic sat 75% 그러나 out O_2-inlet O_2 content 는 10.7-5 = 5.7 로 다시 증가
- DO_2 는 542로 감소 → DO_2/VO_2 ratio 는 2.7
- 아직 2배를 넘는 상태로 systemic Sat: 75% 로 유지

Increased metabolic rate

- oxygen consumption is 250 ml/min 으로 증가시
- Catheter size 고려시 flow 4L 이상 어렵다면 O_2 supply 는 200ml/min 에 한계

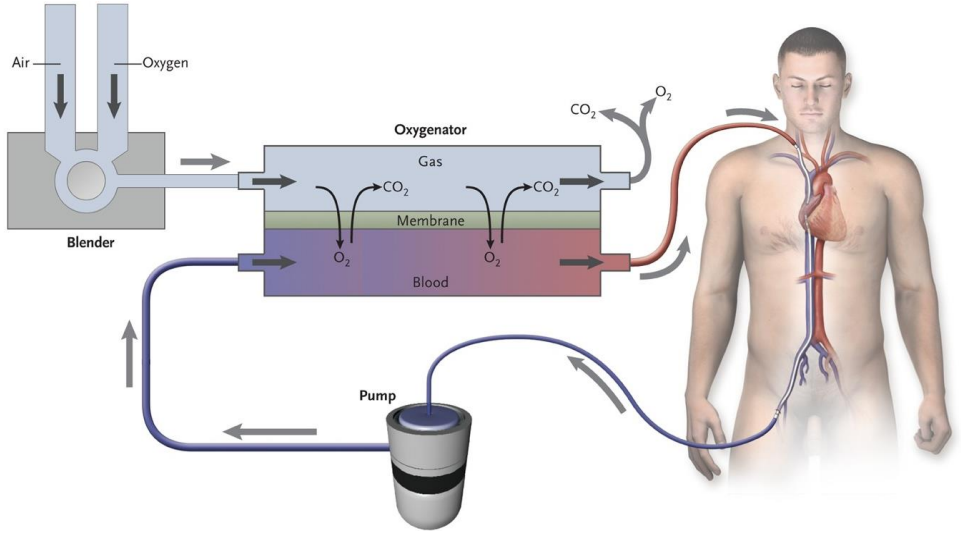
→ 분당 50ml 의 산소가 떨어짐 → venous sat 감소됨.

- Outlet O_2 content 는 동일 inlet O_2 content 는 감소
- outlet – inlet O_2 content 는 5보다 증가됨.
- 그러나 native venous flow 의 sat 감소로 전신 sat 감소
- Inlet O_2 content 7.5 까지 감소되면 14 -7.5 =6.5 → 6.5 x 40 =260

→ Steady state: 62% and PaO_2 35 mm Hg 유지

DO_2= 523 VO_2=250 DO_2/VO_2 ratio: 2.1 → anaerobic metabolism and will lead to multiple organ failure

CO_2 exchange



Sweep gas flow 상향

oxygenator 의 CO_2 감소

Diffusion gradient 증가

CO_2 제거 증가

N Engl J Med 2011; 365:1905-1914

Initial extracorporeal support management

- ECMO blood flow required for adequate oxygenation support→ >2L start, 50-80ml/kg per minute in adult
- Sweep gas: 1:1 start sweep at 2 LPM, and blood flow at 2 LPM, and titrate ventilator

Ventilator

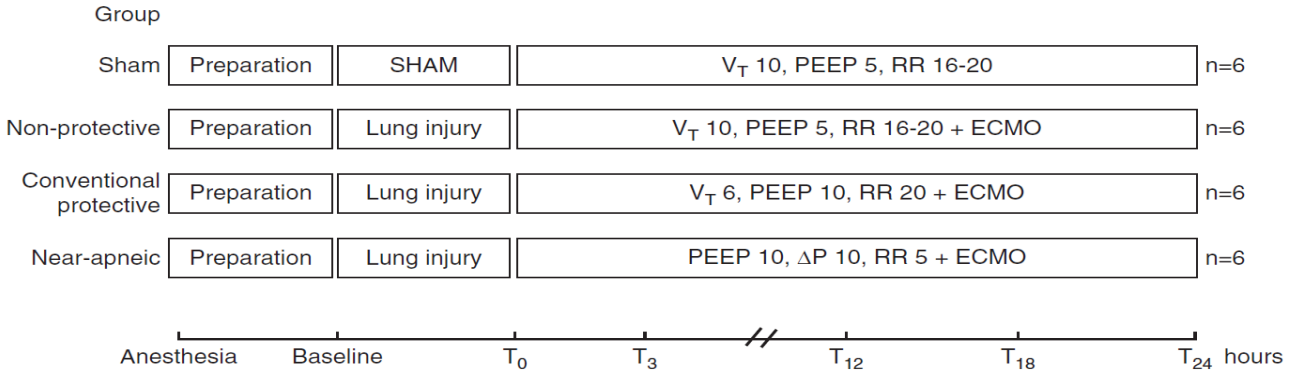
- Optimal ventilator strategy in patients with severe ARDS undergoing ECMO is not well define
- Ventilator settings should be chosen to limit ventilator-induced lung injury

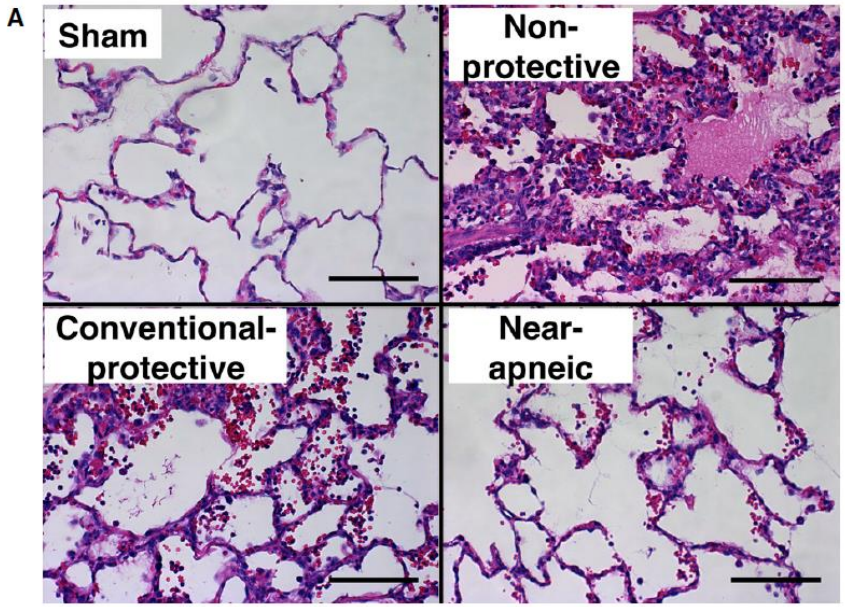
Parameter	Acceptable Range	Recommendation	Comments
Inspiratory plateau pressure (P_{plat})	≤30 cm H_2O	<25 cm H_2O	Further reductions in P_{plat} below 20 cm H_2O may be associated with less VILI and improved patient outcomes[24–26]
PEEP	10–24 cm H_2O	≥10 cm H_2O	Reductions in P_{plat} and tidal volume may lead to atelectasis without sufficient PEEP; PEEP can be set according to various evidence-based methods (*e.g.*, ARDSNet PEEP-F_iO_2 table or Express trial strategy) while maintaining the P_{plat} limit[27]
RR	4–30 breaths/min	4–15 breaths/min (set RR) or spontaneous breathing	CO_2 elimination is being provided primarily by VV ECMO, reducing the need for high minute ventilation (which may be associated with more VILI)
FiO_2	30–50%	As low as possible to maintain saturations	Oxygenation is being provided primarily by VV ECMO, reducing the need for high F_iO_2 from the ventilator unless required to maintain adequate oxygenation

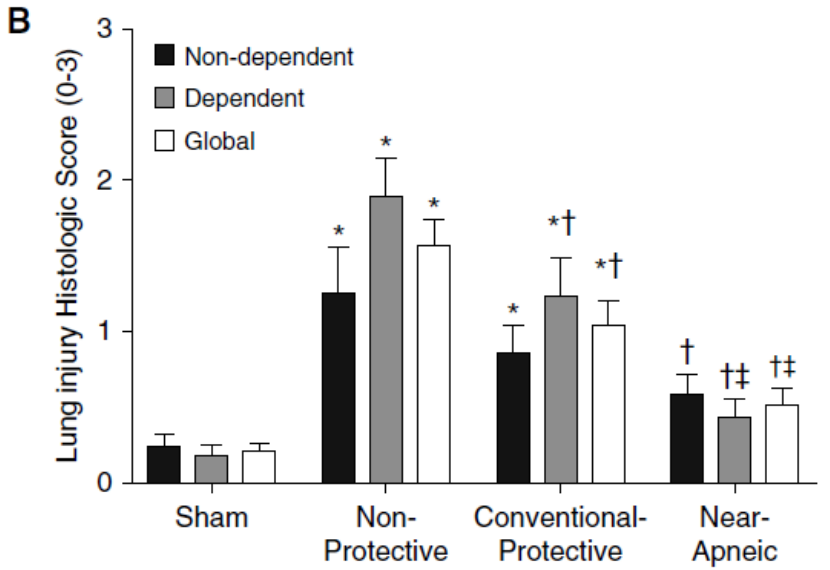
	CESAR[2]		EOLIA[1]
Ventilatory mode	PCV	V-AC	APRV
Set parameter	10 cm H_2O above PEEP	V_T for P_{plat} ≤ 24 cm H_2O	P_{high} ≤ 24 cm H_2O
PEEP (cm H_2O)	10	≥10	≥10
Respiratory rate (breaths/min)	10	10–30	Spontaneous
FiO_2	0.30	0.30–0.50	0.30–0.50

ASAIO J. 2021 Jun 1;67(6):601-610.

Near-Apneic Ventilation Decreases Lung Injury and Fibroproliferation in an Acute Respiratory Distress Syndrome Model with Extracorporeal Membrane Oxygenation

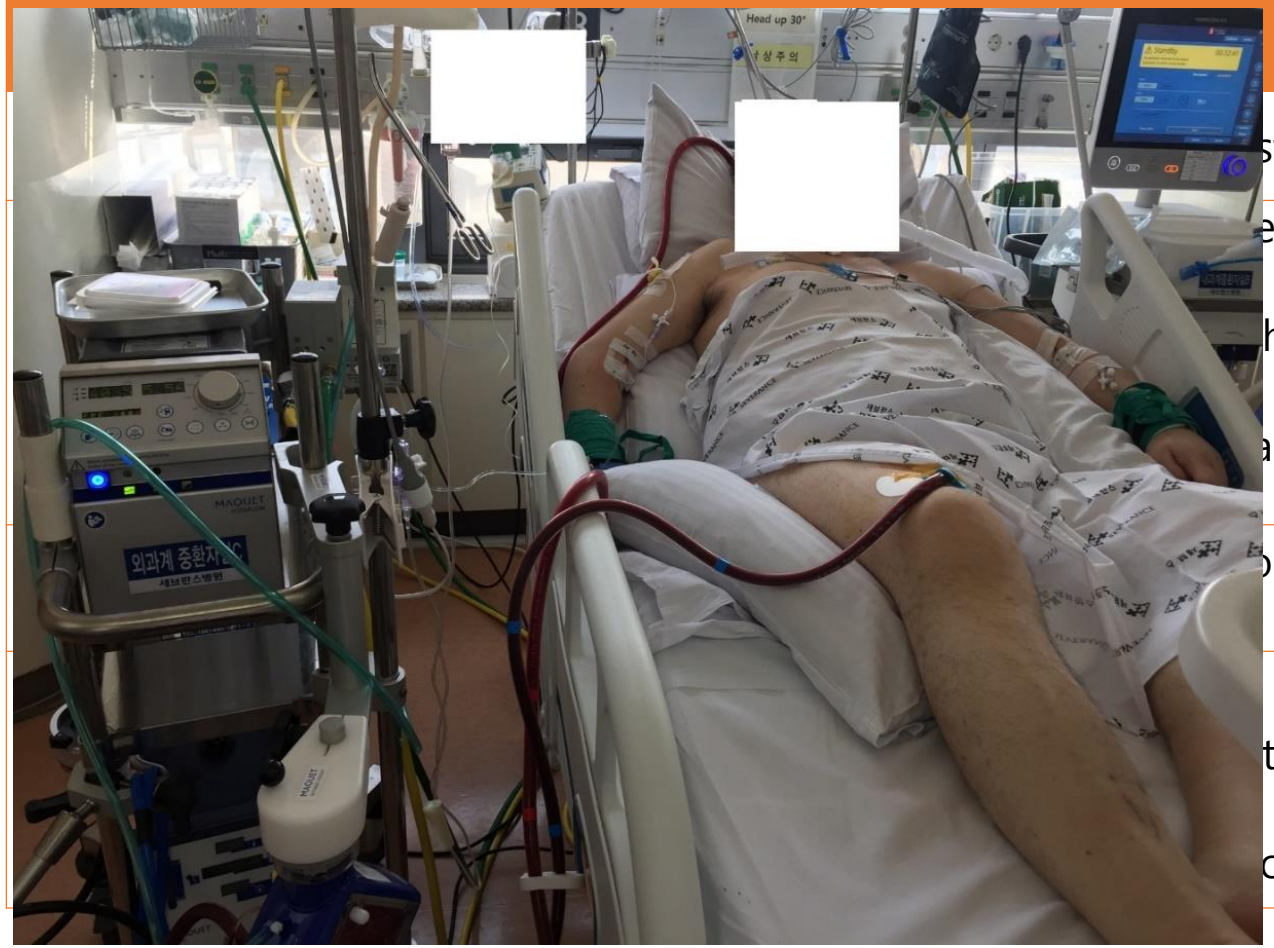


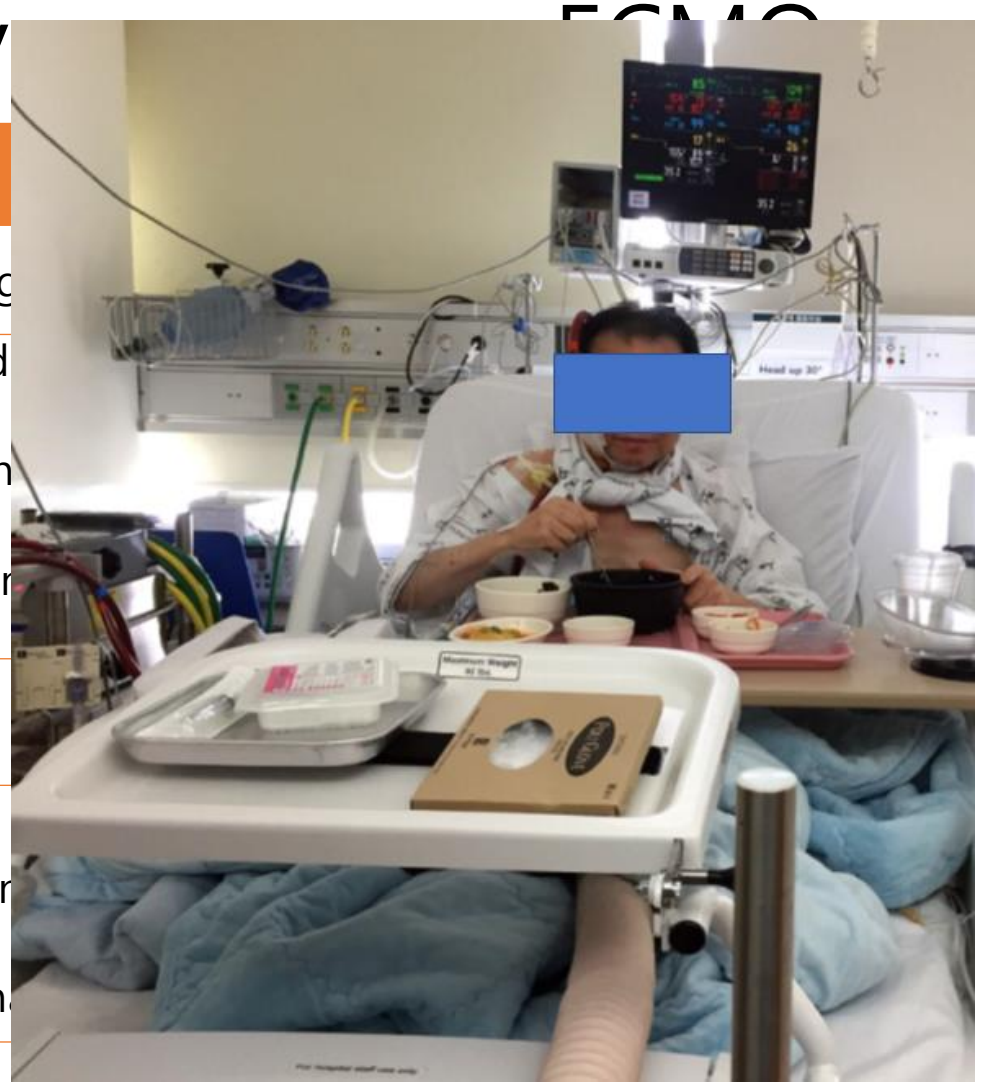


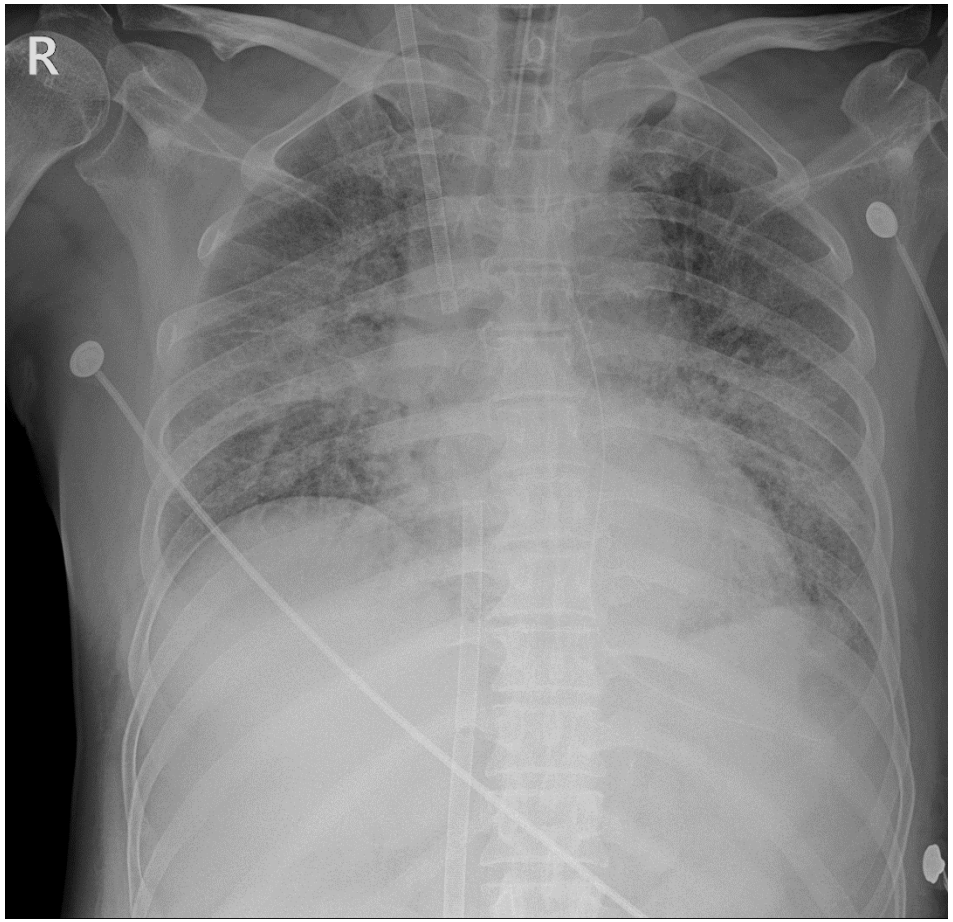


Am J Respir Crit Care Med. 2019 Mar 1;199(5):603-612.

Endotracheal extubation in patients with respiratory failure receiving v







환자 발열

Sat 이 84% 까지 감소

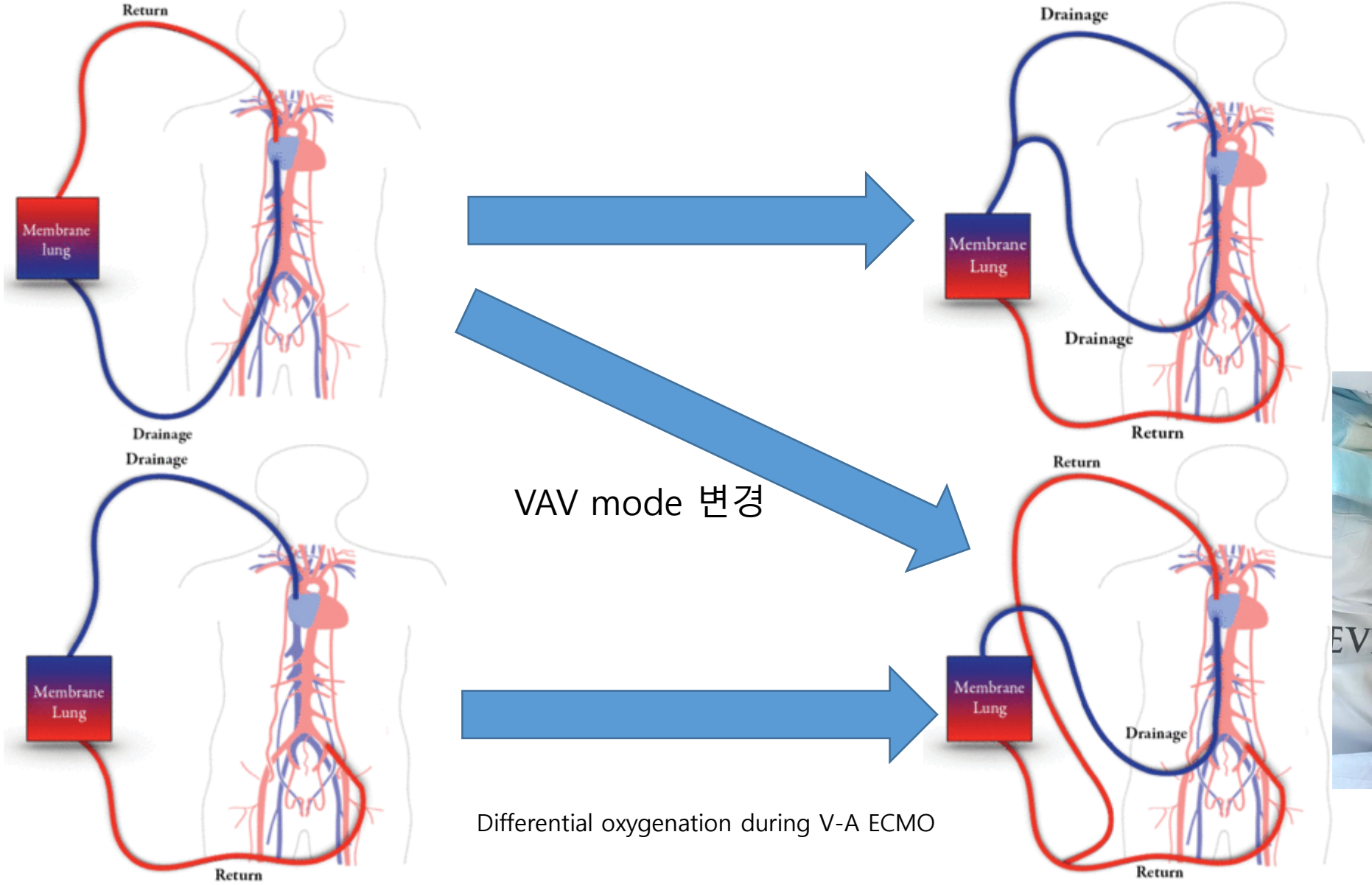
- ECMO blood flow: 4L/min 까지 증가

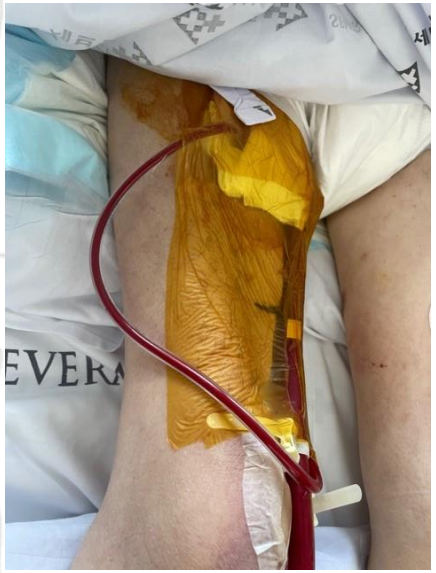
→

- 혈압 떨어지고 회복되지 않음.

→ 심초음파

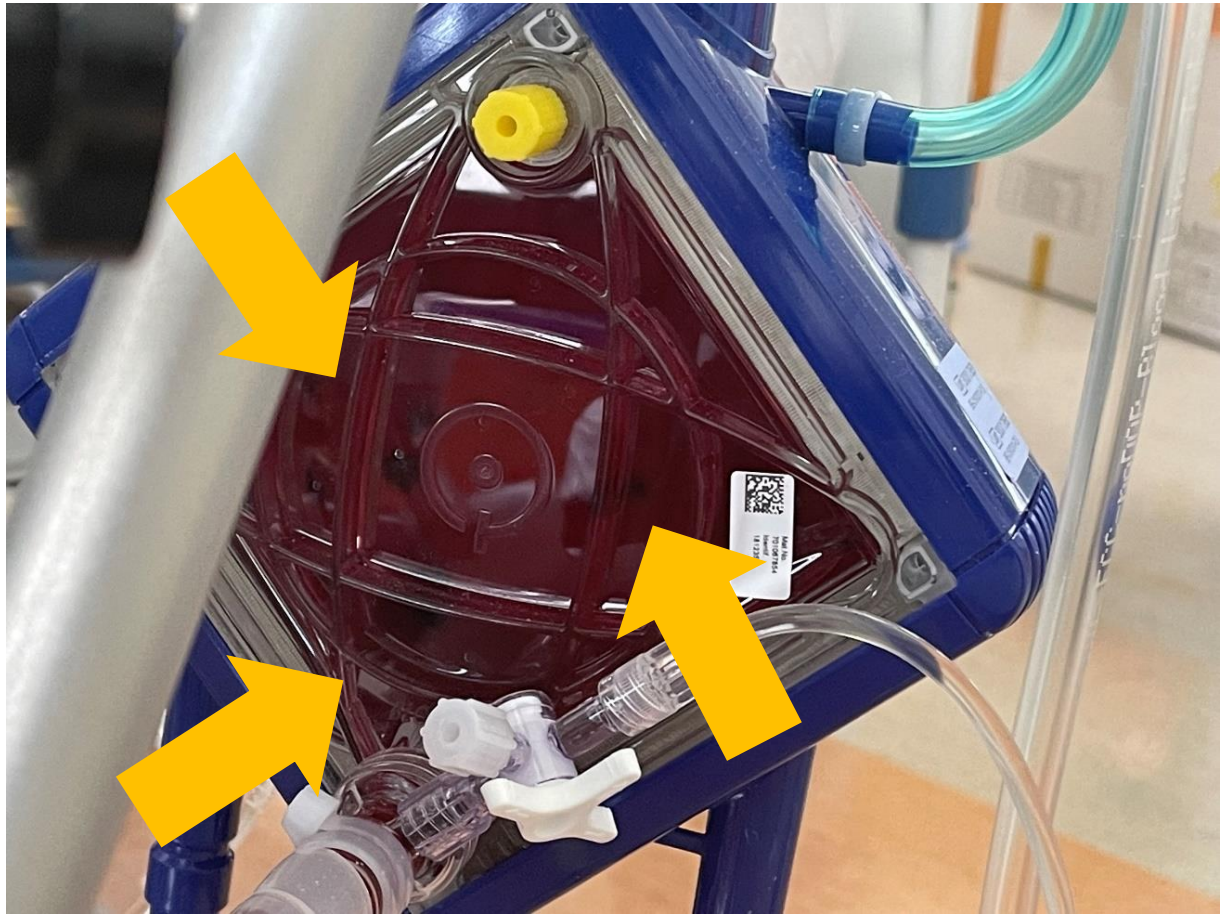
- TTE: Global hypokinesia, EF = 15%





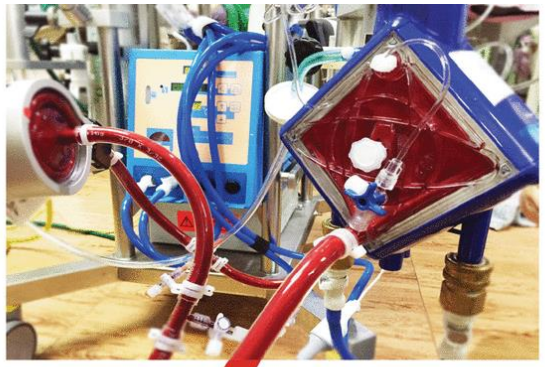
Differential oxygenation during V-A ECMO

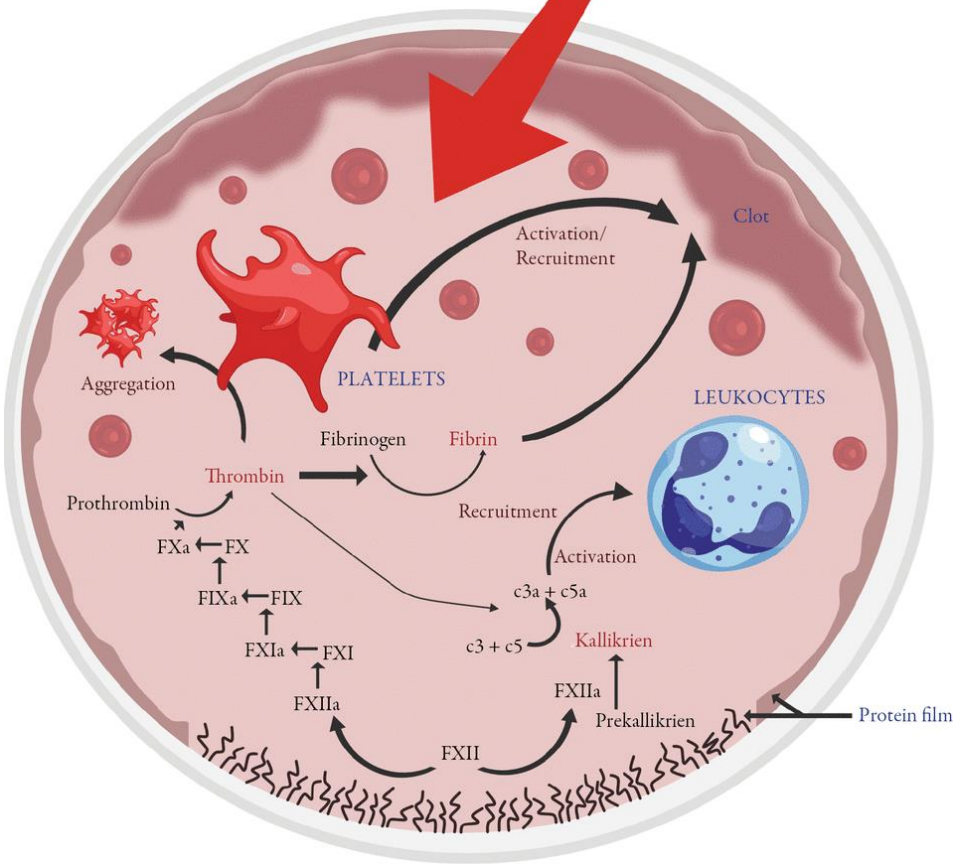
Extracorporeal Membrane Oxygenation: An Interdisciplinary Problem-Based Learning Approach, Maybauer, Marc, Oxford University Press 2022



Membrane thrombus
and decreased ECMO blood flow

Emergency ECMO circuit change





Several inflammatory and coagulative processes that occur when the patient's blood meets the foreign surface of the extracorporeal circuit.

Systemic inflammatory response and thrombosis

In order to suppress hemostatic activation and prevent thrombosis

→

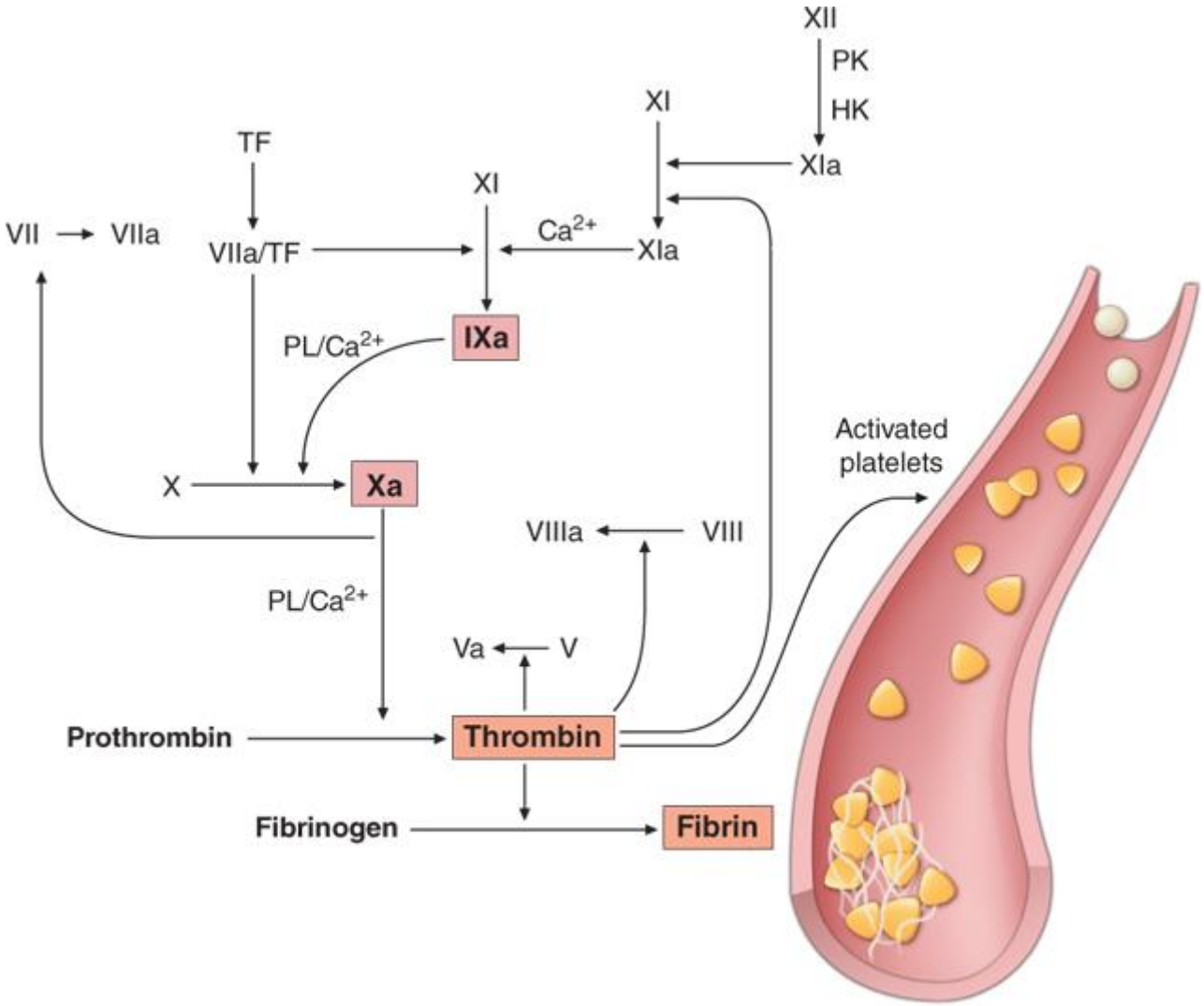
Anticoagulation

Extracorporeal Membrane Oxygenation: An Interdisciplinary Problem-Based Learning Approach, Maybauer, Marc, Oxford University Press 2022

Drug	Advantages	Disadvantages
Unfractionated heparin	Familiarity with use Easy to antagonize (protamine)	Not linear anticoagulation effect Dependency from AT III levels Risk of HIT induction
Direct thrombin inhibitors	Independent from AT III levels Good dose response No HIT induction Mainly renal clearance (Bivalirudin) Mainly Hepatic Clearance (**Argatroban**)	Ceiling effect in aPTT (Bivalirudin) May interfere on INR (Argatroban) No antagonist available

Coagulation Test	Advantages	Disadvantges
ACT	Bedside Easy monitoring Point of care Whole blood test	Different devices and ranges Less accurate for ECMO (lower anticoagulation than during cardi ac surgery)
aPTT	Consolidated use, accurate Easy interpretation	Time consuming, Not available as point of care, Inter-laboratory variance
Anti-Xa assay	Very sensitive to UFH effects	Time consuming, Bilirubin and free haemoglobin interference, Not available as point of care

Extracorporeal Membrane Oxygenation: An Interdisciplinary Problem-Based Learning Approach, Maybauer, Marc, Oxford University Press 2022



Source: Joseph Loscalzo, Anthony Fauci, Dennis Kasper, Stephen Hauser, Dan Longo, J. Larry Jameson: Harrison's Principles of Internal Medicine, 21e

Role of Antithrombin III

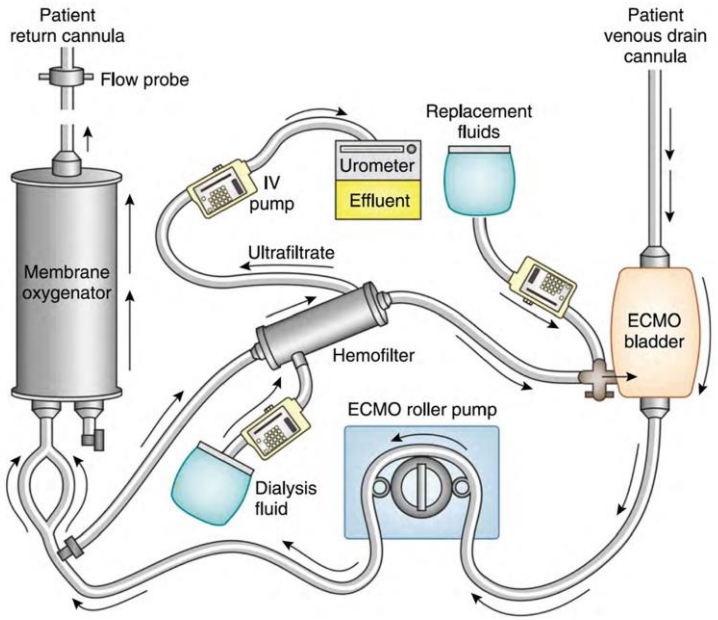
→ low ACT values despite UFH anticoagulation at increasing dosages
→ **AT III level 확인 및 replacement 고려**

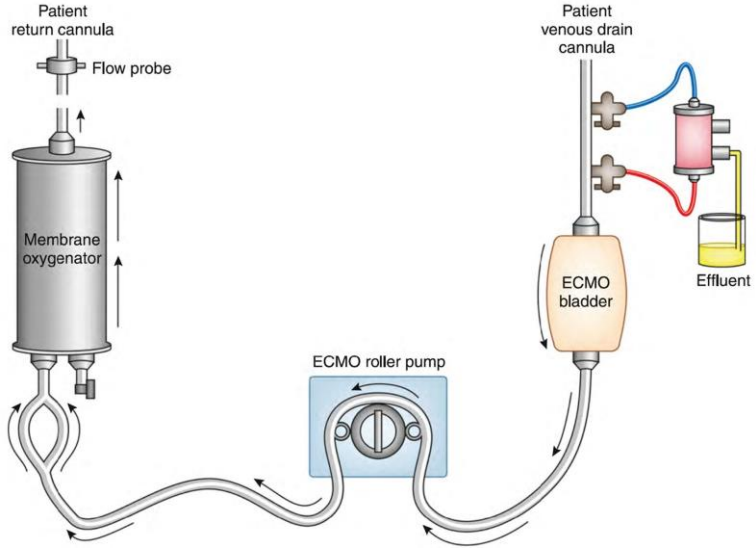
Heparin induced thrombocytopenia
- Thrombocytopenia
- time of the fall in platelet count
- thrombosis or other sequelae
- other potential causes of thrombocytopenia

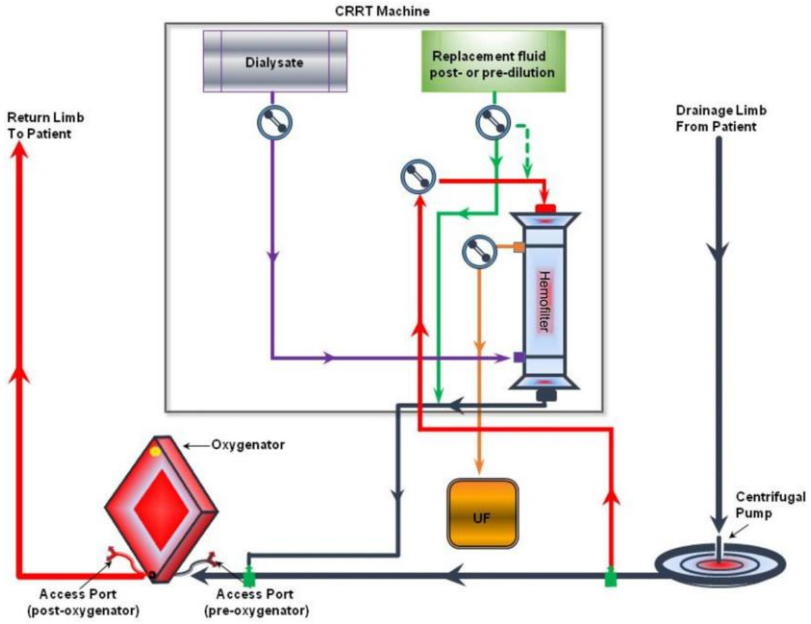
→ 4Ts (platelet count, timing, thrombosis, other causes) 를 확인하여 의심.
→ Heparin 대신 Argatroban 사용

Harrison's Principles of Internal Medicine 21e

Acute kidney injury during ECMO







syndrome characterized by a rapid decline in renal excretory function, leading to a constellation of cl inical features, including retention of nitrogenous waste products, extracellular volume imbalance an d accumulation of metabolic acids and electrolytes

ASAIO J. 2022 May 1;68(5):611-618.

Alterations in Renal Perfusion

- Renal perfusion pressure = renal artery press (MAP)- renal ve nous press (CVP)

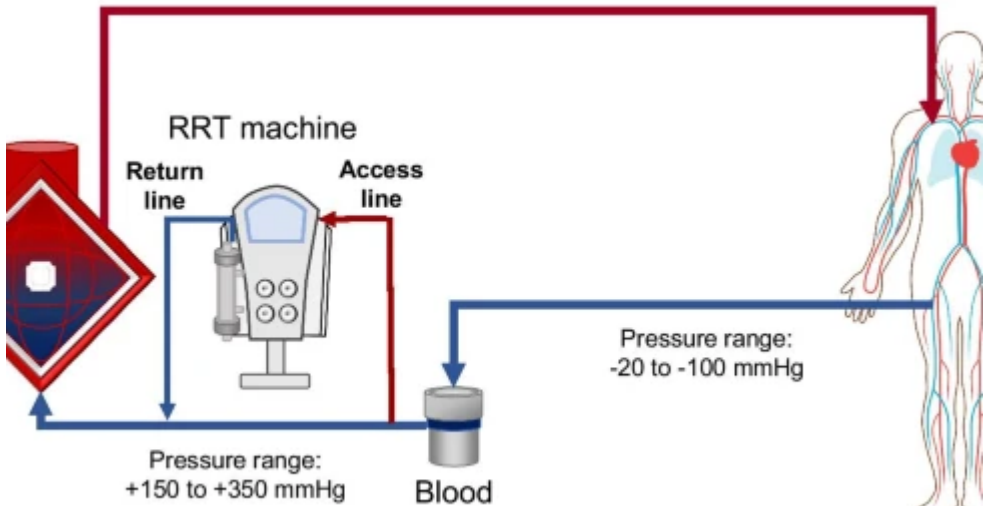
Changes to the Renal Microcirculation

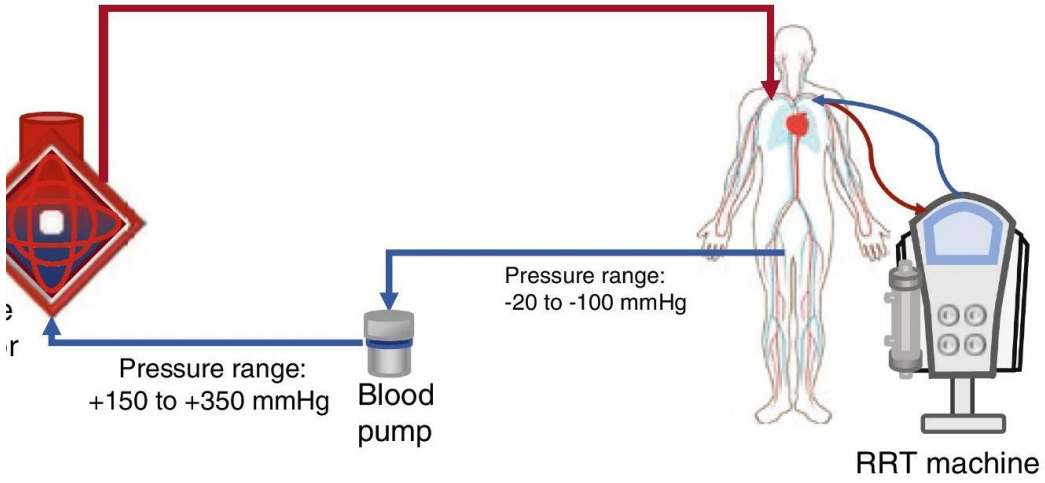
- sepsis or shock or ischemia of the renal microvasculature, disr uption of the NO and ROS homeostasis is common

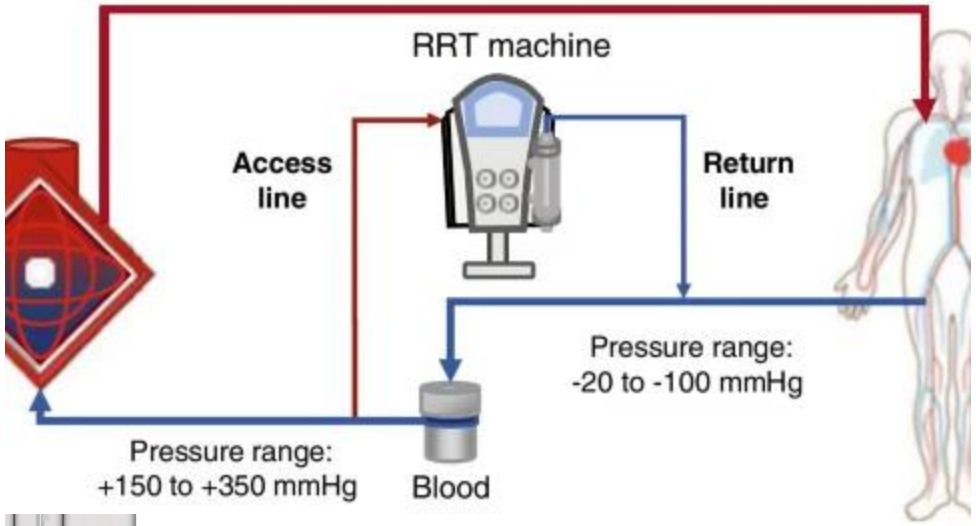
Secondary Renal Parenchymal Cell Death

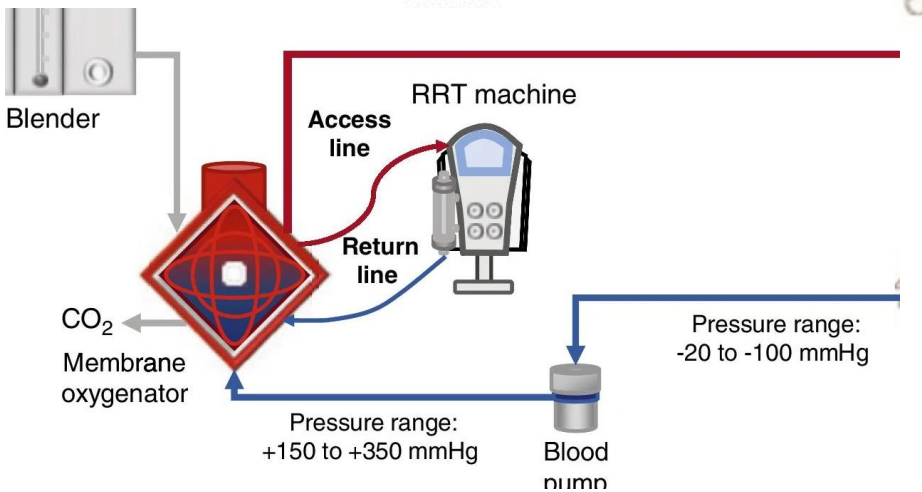
- microemboli and microthrombi formation within the renal vas culature

Incorporation of an External CRRT Device Into the ECMO Circuit







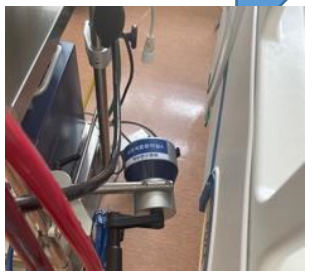


Crit Care. 2021 Aug 31;25(1):313

Troubles

Troubles persist from insertion to wean

- Difficult or failed cannulation
- Vessel injury
- Limb ischemia
- Cannula site bleeding
- Active bleeding on various vessel
- Heparin induced thrombocytopenia
- Thrombosis
- Air embolism
- Membrane rupture



- Cannula withdrawal
- Pump failure
- Chattering of catheter
- Progress right heart dysfunction or pulmonary hypertension
- Wean failure
- pneumothorax
- Etc.

Incidence of complications	n=100 (%)
Complication, any	56 (56.0)
Major bleeding	38 (38.0)
Cannulation site bleeding	11 (11.0)
Pulmonary hemorrhage	10 (10.0)
Internal bleeding*	9 (9.0)
Gastrointestinal bleeding	8 (8.0)
Intracranial hemorrhage	4 (4.0)
Thrombotic event	20 (20.0)
Oxygenator thrombosis	8 (8.0)
Deep vein thrombosis	8 (8.0)
Pulmonary artery thromboembolism	4 (4.0)
Cerebral infarction	3 (3.0)
Renal replacement therapy	20 (20.0)
Blood stream infection	11 (11.0)
Bacteremia	10 (10.0)
Fungemia	3 (3.0)
Bacteremia and fungemia	2 (2.0)
Machine failure	4 (4.0)
Lower limb ischemia	3 (3.0)
Number of complications	
None	44 (44.0)
1	20 (20.0)
2	26 (26.0)
3	9 (9.0)
4	1 (1.0)

Unpublished data

Initiating a Weaning Trial

	Intubated Patients	Non-intubated Patients
Oxygenation	▪ F_iO_2 consistently ≤ 60% ▪ PEEP ≤ 10 cm H_2O ▪ P_aO_2 ≥ 70 mm Hg	▪ P_aO_2 ≥ 70 mm Hg on no more than a moderate amount of supplemental O_2 (example: ≤6 LPM NC or facemask, or ≤ 40 LPM with F_iO_2 ≤ 0.3 on high-flow nasal cannula)
Ventilation	▪ Tidal volume ≤ 6 mL/kg PBW ▪ Plateau pressure ≤ 28 cm H_2O ▪ Respiratory rate ≤ 28 bpm ▪ ABG demonstrates acceptable pH and P_aCO_2 based on the patient's clinical condition without excessive work of breathing	▪ ABG demonstrates acceptable pH based on the patient's clinical condition without excessive work of breathing
Imaging	Chest radiograph demonstrates improvement in appearance	

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Approach to Weaning from VV ECMO

Step	Purpose	Process
1	Reduce FDO_2	▪ Stepwise reduction in FDO_2 from 1.0 to 0.21 in decrements of approximately 20%. ▪ Maintain acceptable SpO_2 > 92% or P_aO_2 of at least ≥ 70 mm Hg ▪ ABG as clinically indicated
2	Reduce sweep gas	▪ Stepwise reduction in sweep gas flow rate by 0.5–1 L/min to goal of 1 L/min ▪ Check ABG with each decrement in sweep gas flow rate ▪ Maintain acceptable pH based on the patient's clinical condition without excessive work of brea thing
3	Off-sweep gas Challenge	▪ If patient able to tolerate discontinuation of ECMO, trial off sweep gas for 2–3 hours or longer. ▪ Monitor SpO_2 ▪ Check ABG off sweep gas after allotted time
4	Prepare for Decannulation	▪ Notify surgeon or whomever decannulates. ▪ Confirm off-sweep gas ABG demonstrates PaO_2 ≥ 70 mm Hg and acceptable pH based on the patient's clinical condition without excessive work of breathing ▪ *Nil per os/nothing by mouth* status ▪ Active blood type (ABO) and antibody screen in the case of significant blood loss ▪ Prepare to give sedation depending on patients' predecannulation sedation status. ▪ Hold heparin for at least 1 hour before decannulation. ▪ Trendelenburg position if jugular vein cannula ▪ Close cannulation site with a suture, apply slight compression dressing and observe carefully ▪ Check for deep vein thrombosis after 24 hours

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study	Date	Type	N	Findings	Limitations
ELSO	2019	REG	>21,000	Cumulative registry with 69% and 59% survival after ECMO and to hospital discharge/transfer, respectively, for *over all adult pulmonary failure*	**1.1.** Retrospective analysis **2.2.** No control group
EOLIA (Combes et al.)	2018	RCT	124	**1.1.** Lower mortality at 60 days in ECMO (35%) compared to control group (46%) **2.2.** Composite treatment failure, death or crossover to ECMO, at 60 days in control group (58%)	**1.1.** Results difficult to interpret due to 28% control group crossover into ECMO group **2.2.** Trial was stopped prematurely at 75 % maximum calculated sample size due to ethical concerns of futility
H1N1(Zangrillo et al.)	2013	MAA	266	**1.1.** Majority (94%) received V-V access **2.2.** Mortality in hospital and to 90 days after discharge ranged from 8% to 65%; overall estimated pooled in-hospital mortality 28%	**1.1.** Retrospective analysis **2.2.** No studies with control group or randomization included
ANZ-ECMO influenze investigators, Davies, et al.	2009	COH	68	**1.1.** Majority (93%) received V-V access **2.2.** Mortality in-hospital 23% in the ECMO group compared to 13% in the control group	**1.1.** Retrospective analysis **2.2.** No randomization, criteria for ECMO initiation not reviewed **3.3.** ECMO cohort more likely to have vasopressor requirements
CESAR (Peek et al.)	2009	RCT	68	Six-month survival without disability higher in the ECMO referral (63%) compared to the control group (47%)	No standardized management in control group

Thank you for your time and your attention !!!