34th Annual Meeting
March 10–13 2022
Time to (Finally) Meet in the Sun

Bonita Springs
Thirty-Fourth Annual Meeting 2022

When Disaster Strikes: Intraoperative Dilemmas, My Worst Case, and How to Manage ECMO update

Joshua Sonett
Professor and Chief Thoracic Surgery
Director Price Center for Comprehensive Chest Care
Columbia University
New York-Presbyterian Hospital

NewYork-Presbyterian
Columbia University Irving Medical Center
Columbia
Columbia University Irving Medical Center

THE NEW SCHOOL

Please consider supporting those in need in Ukraine

Razom's Emergency Response is the SOS button that is pressed in times of need. We created this project to provide urgent help and support in face of an extreme and unforeseen situation in Ukraine. Today, the sovereign nation of Ukraine has to deal with the most horrendous and catastrophic emergency – a brutal invasion. Razom is responding to this by providing critical medical supplies and amplifying the voices of Ukrainians.

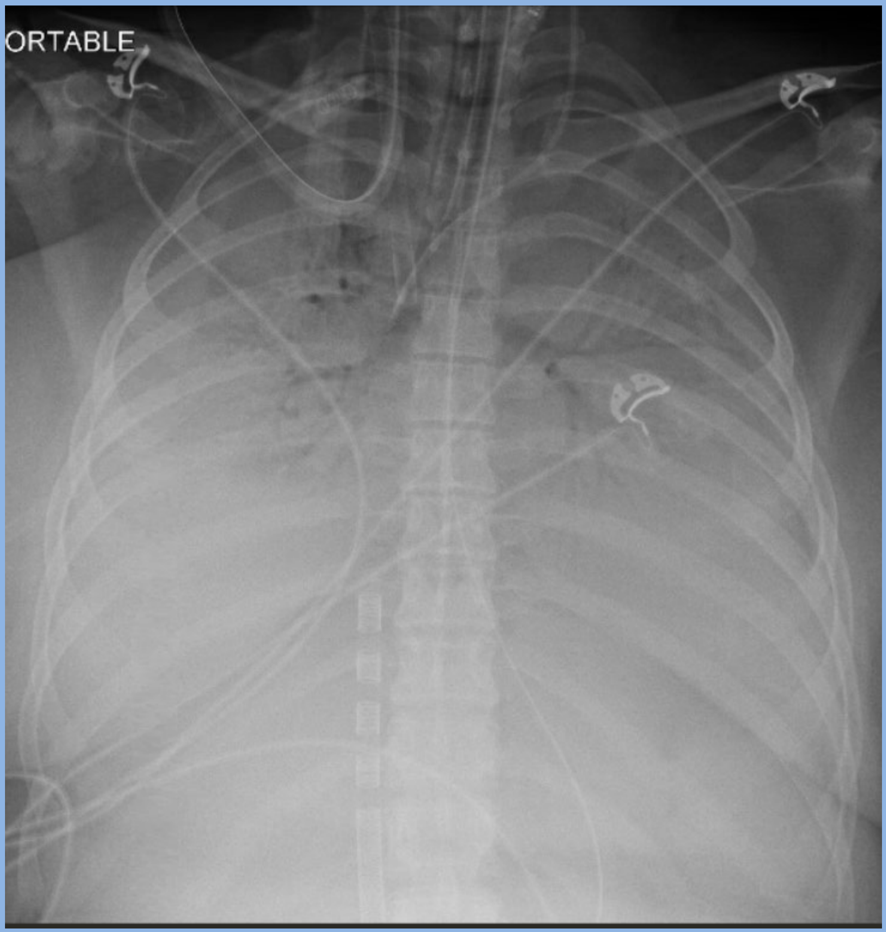
LEARN MORE

Ukrainian Charity, a 501 (c)(3) organization. **www.razomforukraine.org**

No Relevant financial Disclosure

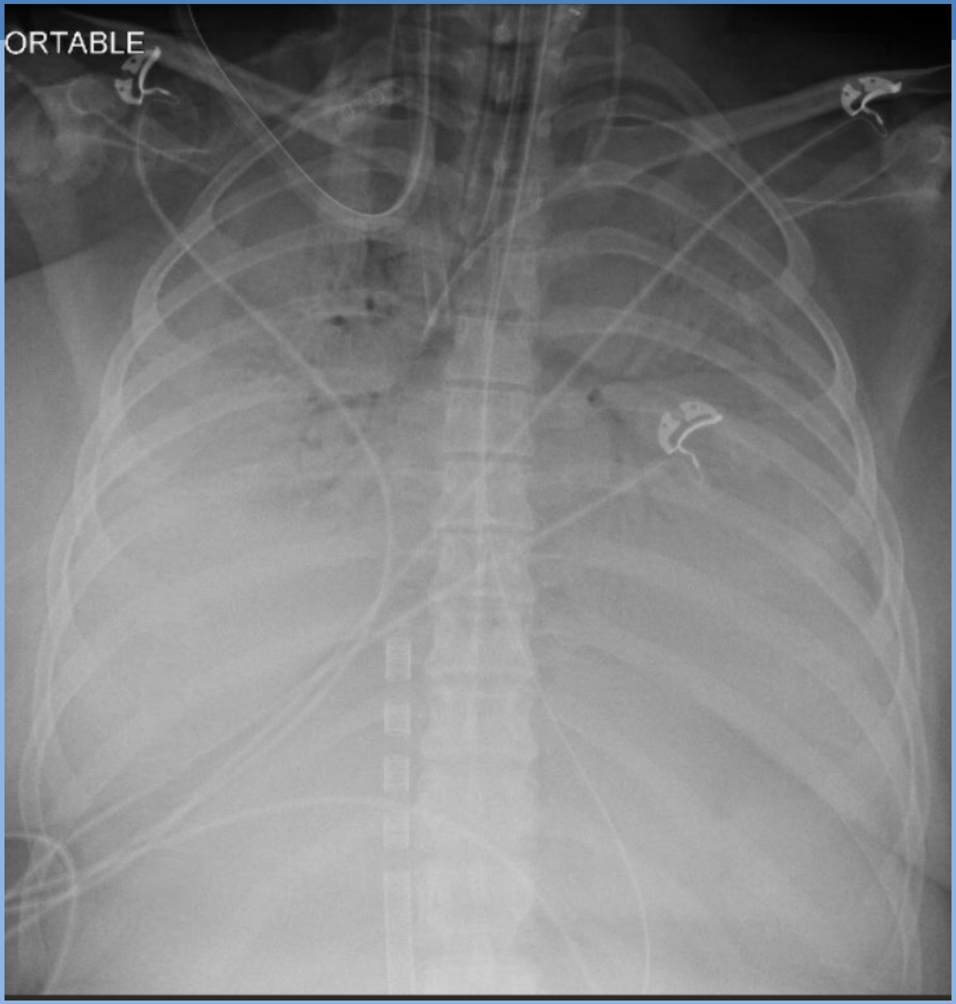
ECMO COVID FOURTH WAVE/DELTA
Dilema #1

- 31F 39 weeks pregnant. Presents to OSH in labor on 11/28/21
  - Symptomatic: 11/23
  - COVID positive: 11/26
  - vaccinated
- Emergent c section 11/29 secondary to worsening hypoxemic respiratory failure
- Admitted to ICU post op on HFNC
  - Remdesivir
  - Dexamethasone
  - Toci



Patient VU

- Intubated on 12/6
- VDR, iNO at 40
- Sedated, paralyzed, proned
- Cannulated-
- VV ECMO Fem-IJ on 12/6
- 20F fem-flex cannula in the RIJ and a 25F multiport sorin venous cannula
- **Transferred to Columbia on 12/9**



Patient VU

- **At OSH: Flows >6L, Pven -200s, saturations in the mid 90s**

- Once at Columbia: Decreased flows to 4.9L, Pven -130s, saturations in the mid to high 80s

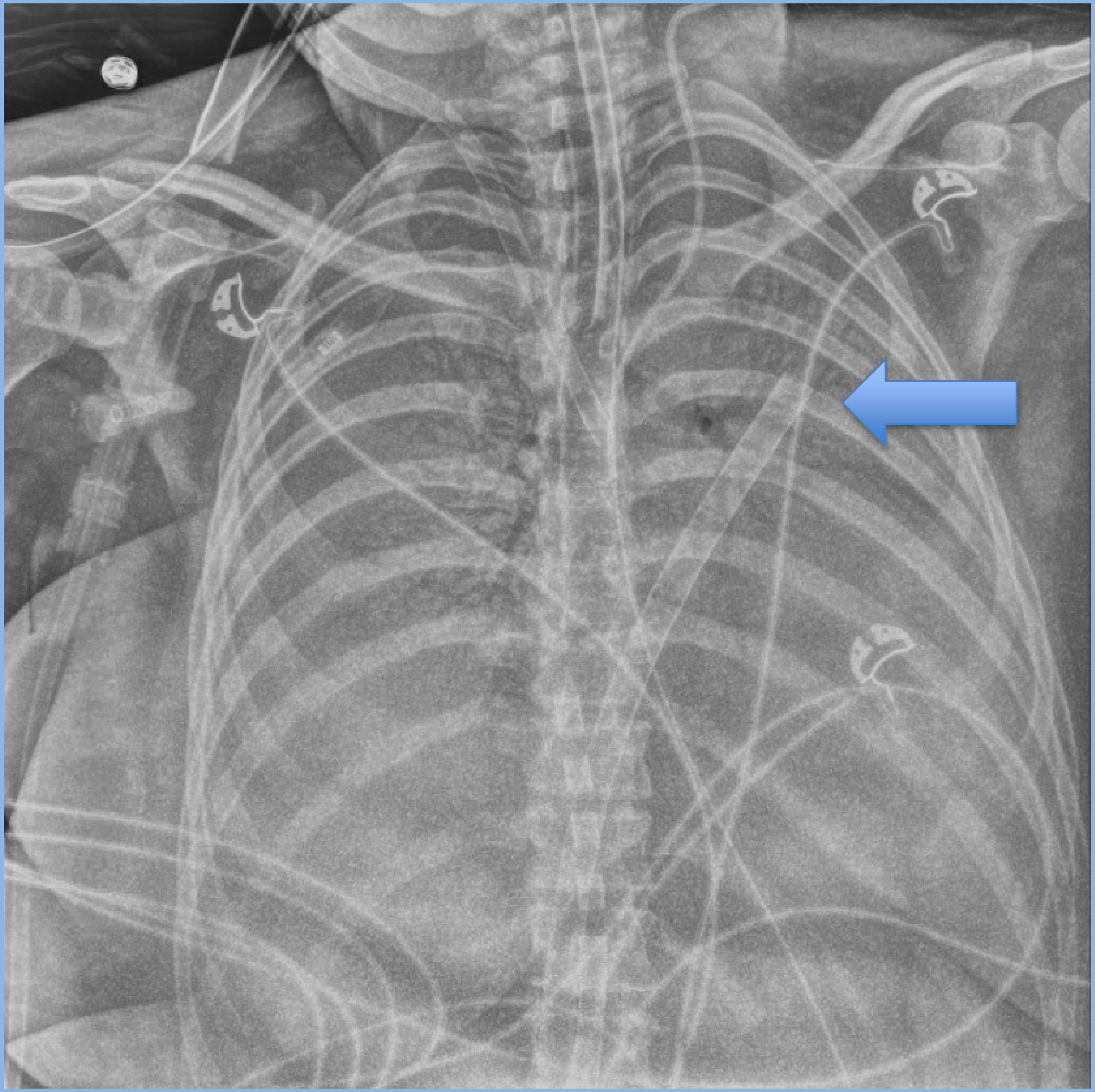
- **December 15th- patient becomes septic**,
  - LDH trending up (1228 from 1150)
  - Increasing pressors
  - Increasing AKI

- Decmber 16th- reconfigured from VV to VVV- addition of 29F drainage cannula via right femoral vein.

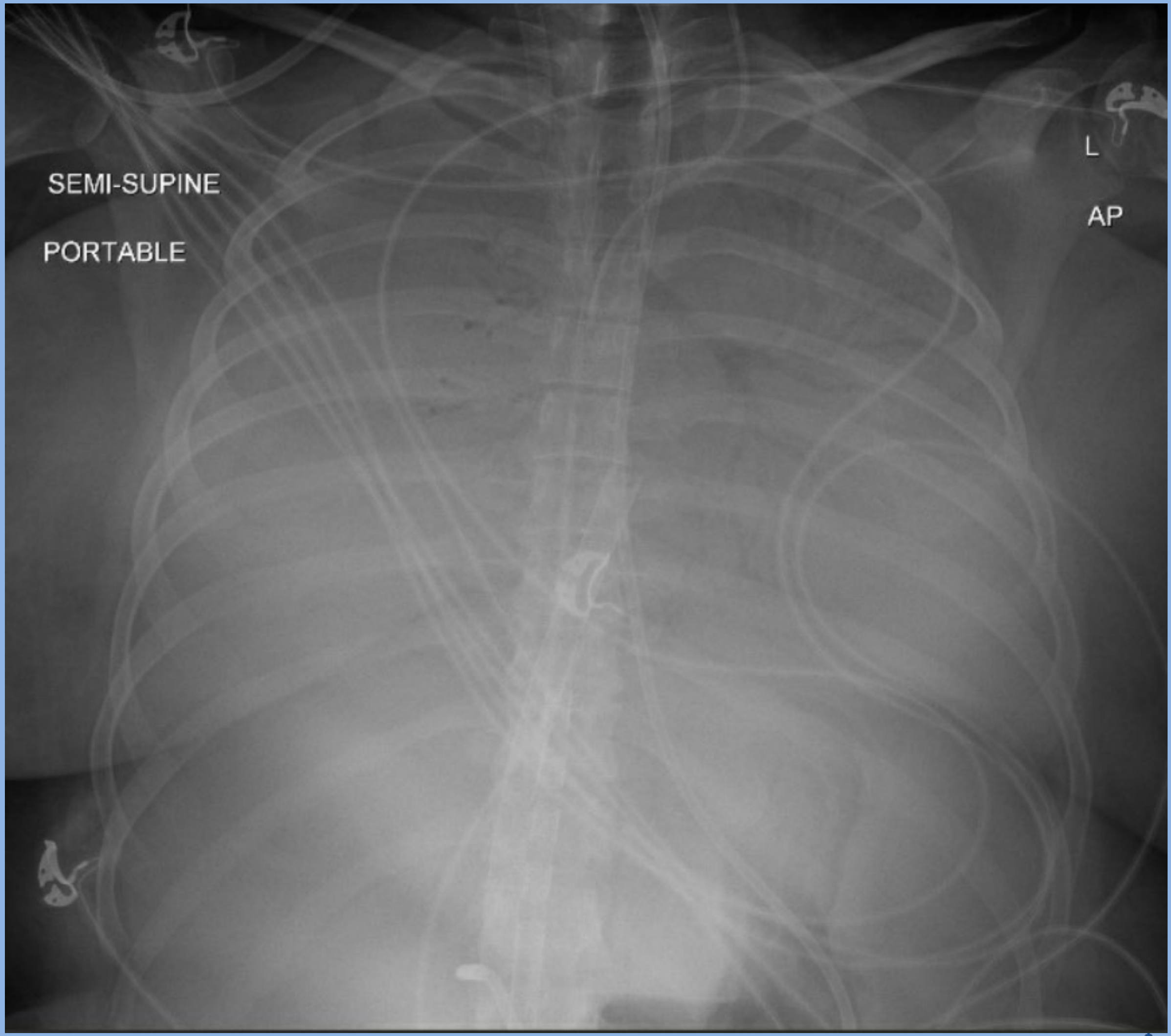
- Post reconfiguration- flows increased, saturation up to 100%, Pven -80s

NewYork-Presbyterian
Columbia University Irving Medical Center

COLUMBIA
COLUMBIA UNIVERSITY
IRVING MEDICAL CENTER



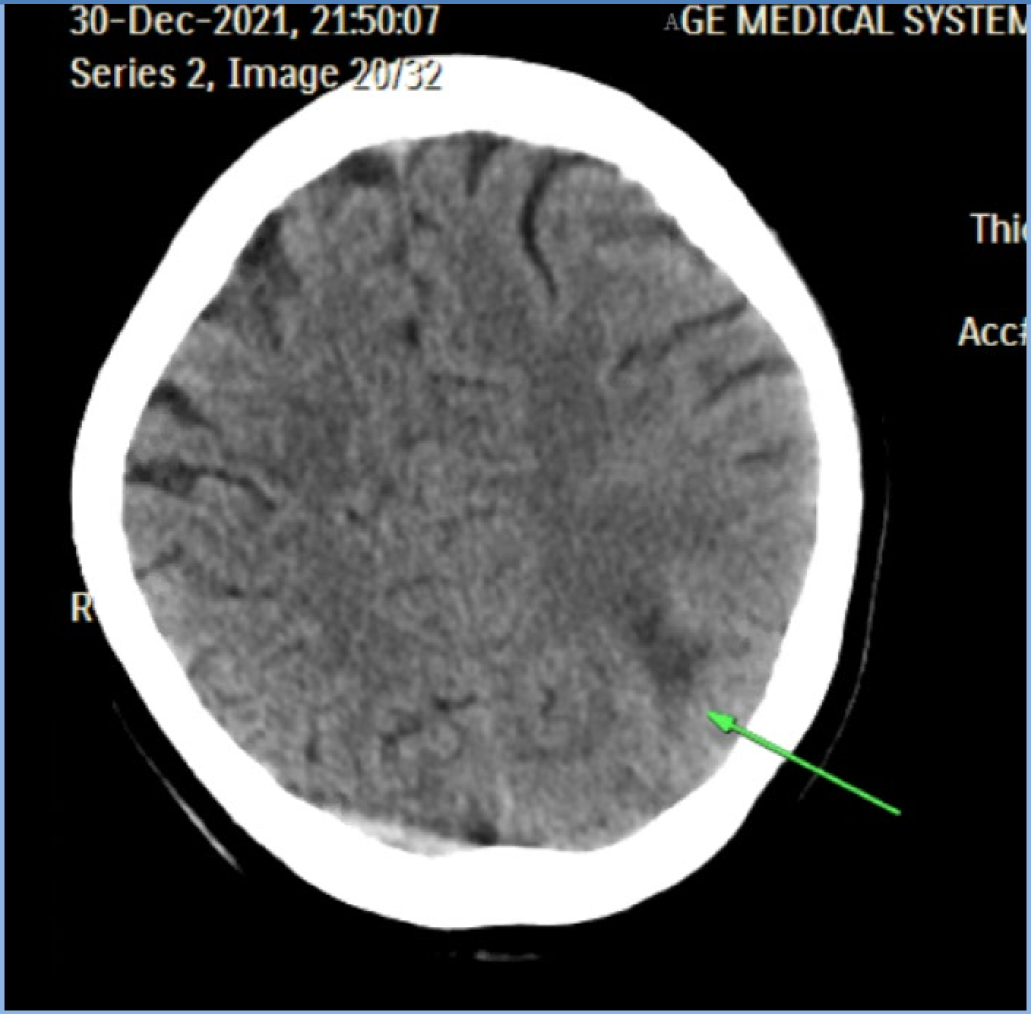
EXTUBATED



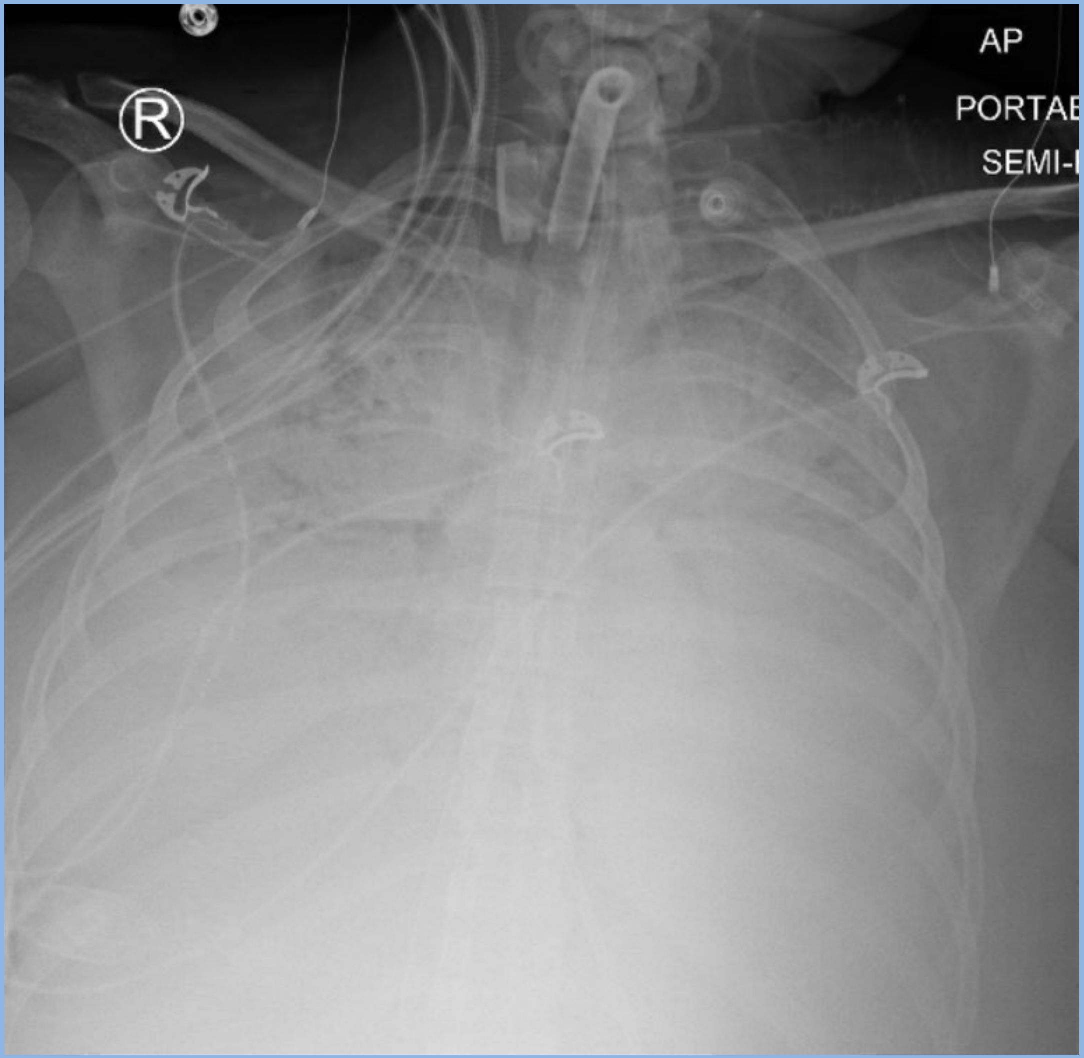
Stroke

- Decmber 29th- altered mental status and difficulty obtaining a neuro exam. Continuous EEG placed- asymmetric slowing

- Head CT with L parietal infarct



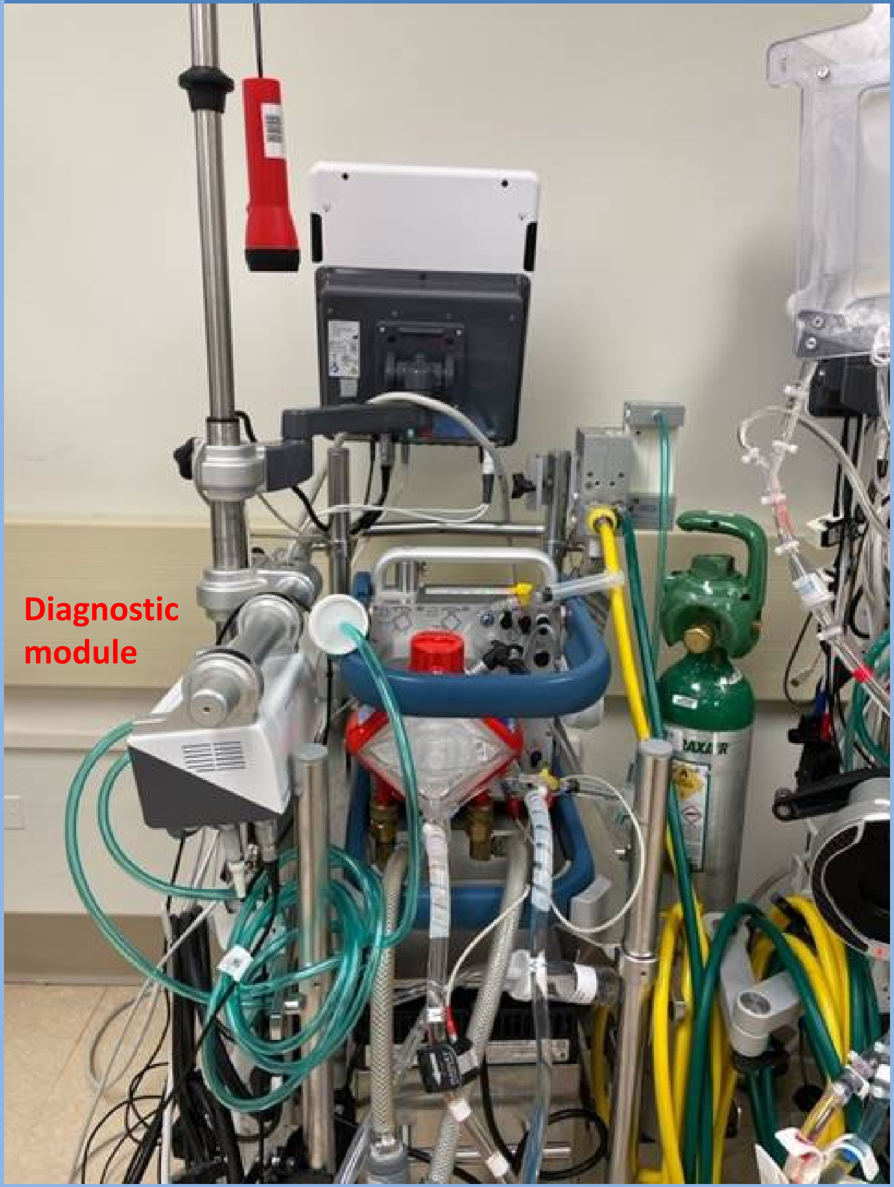
Jan 19

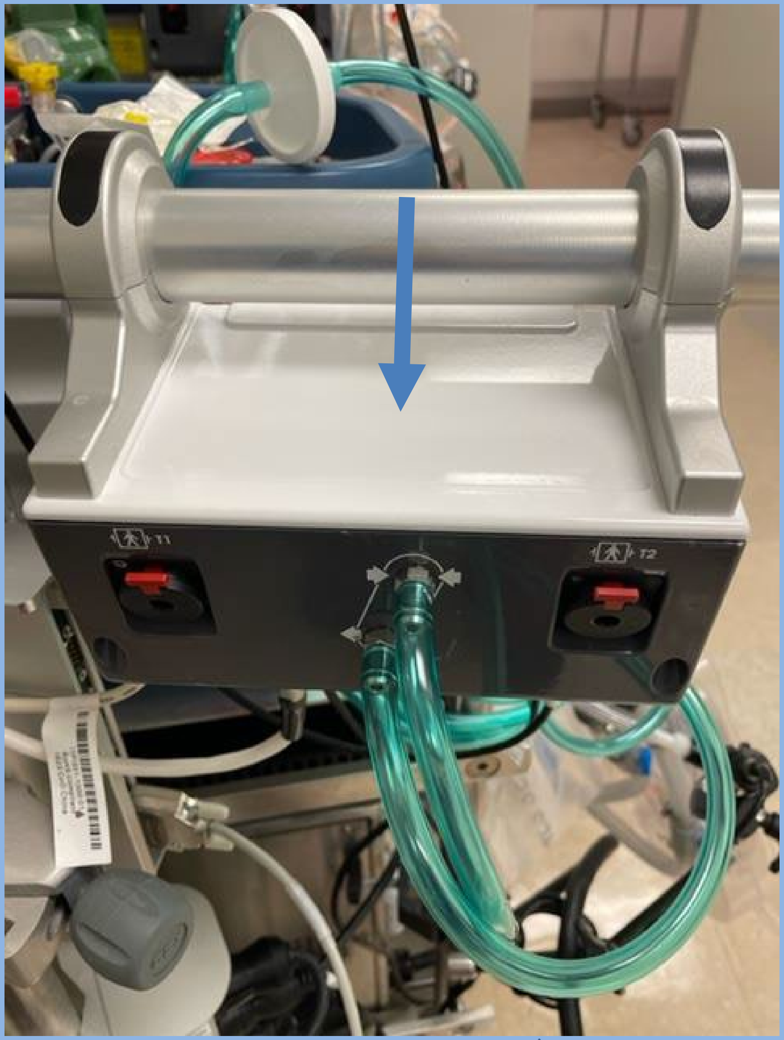


DRESS Syndrome

	1/27/2022 0244	
LIVER CHEMISTRIES:...		
PROTEIN, TOTAL	4.3	↓
ALBUMIN, SERUM/PLASMA	2.0	↓
GLOBULIN	2.3	
BILIRUBIN, TOTAL	1.2	
BILIRUBIN, DIRECT	0.8	↑
BILIRUBIN, INDIRECT	0.4	
AST	692	↑
ALT	461	↑
ALKALINE PHOSPHATASE	415	↑

HYPOXIC CODE





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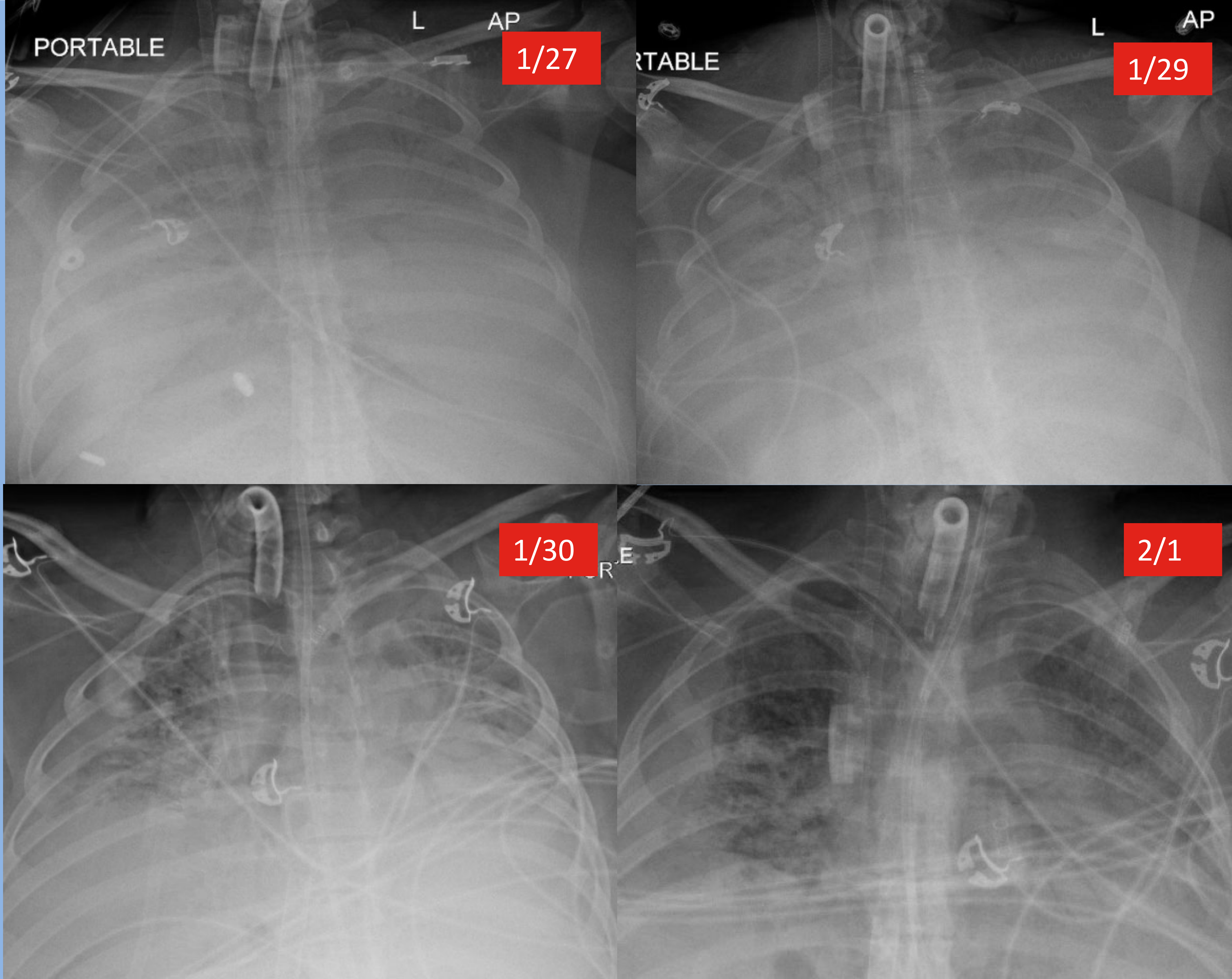
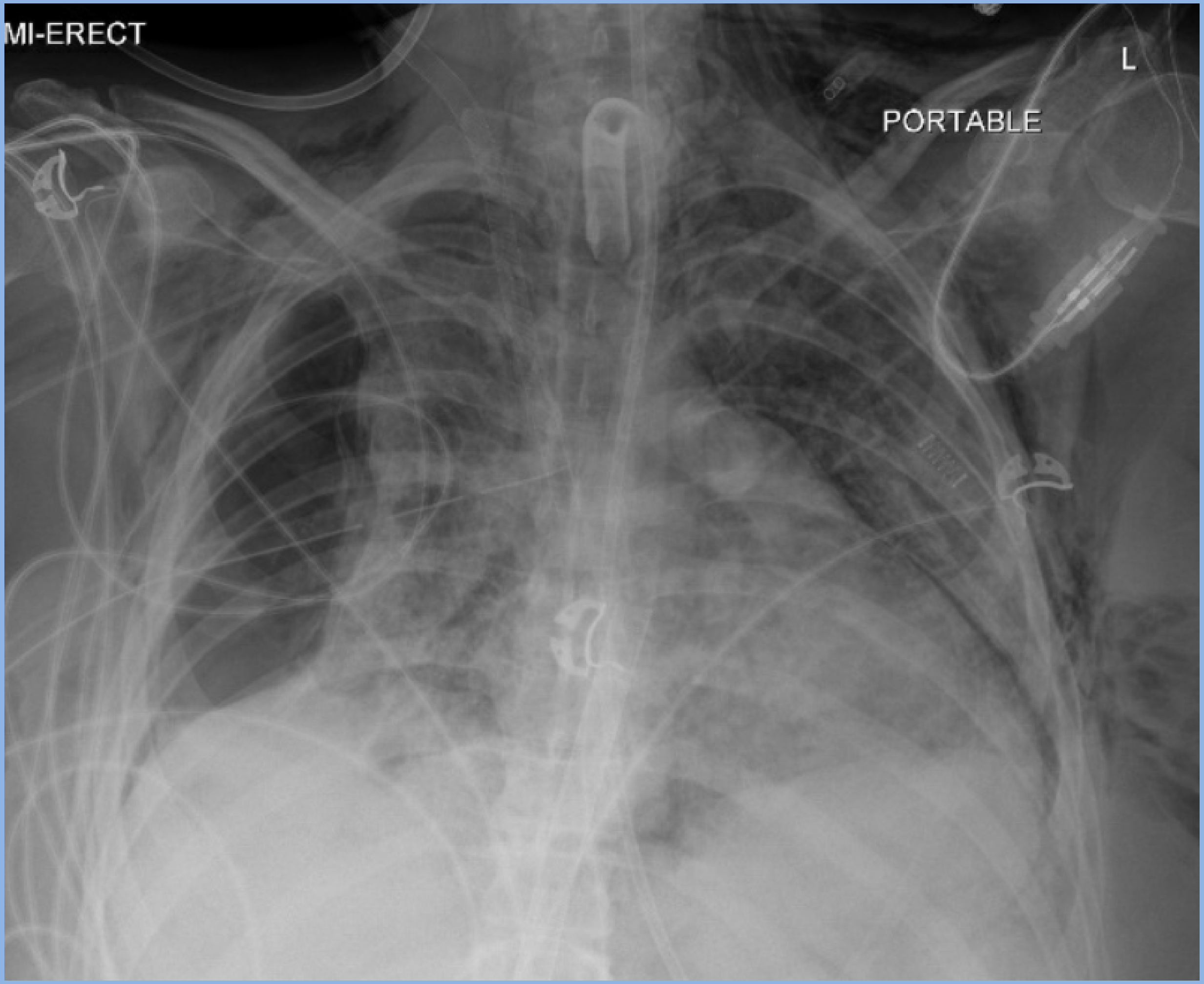
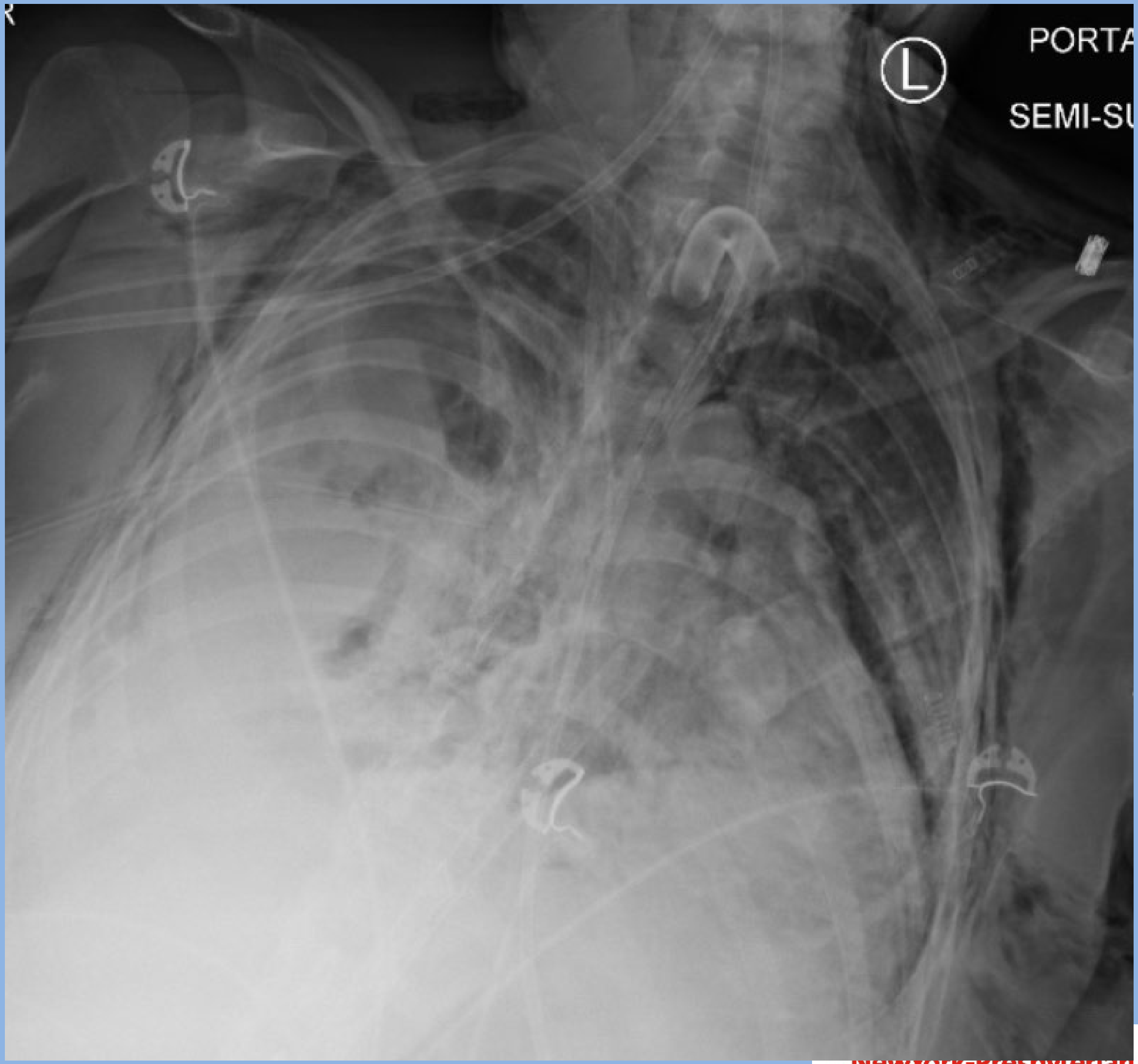


PORTABLE
L
AP
1/27
L
AP
1/29
1/30
2/1

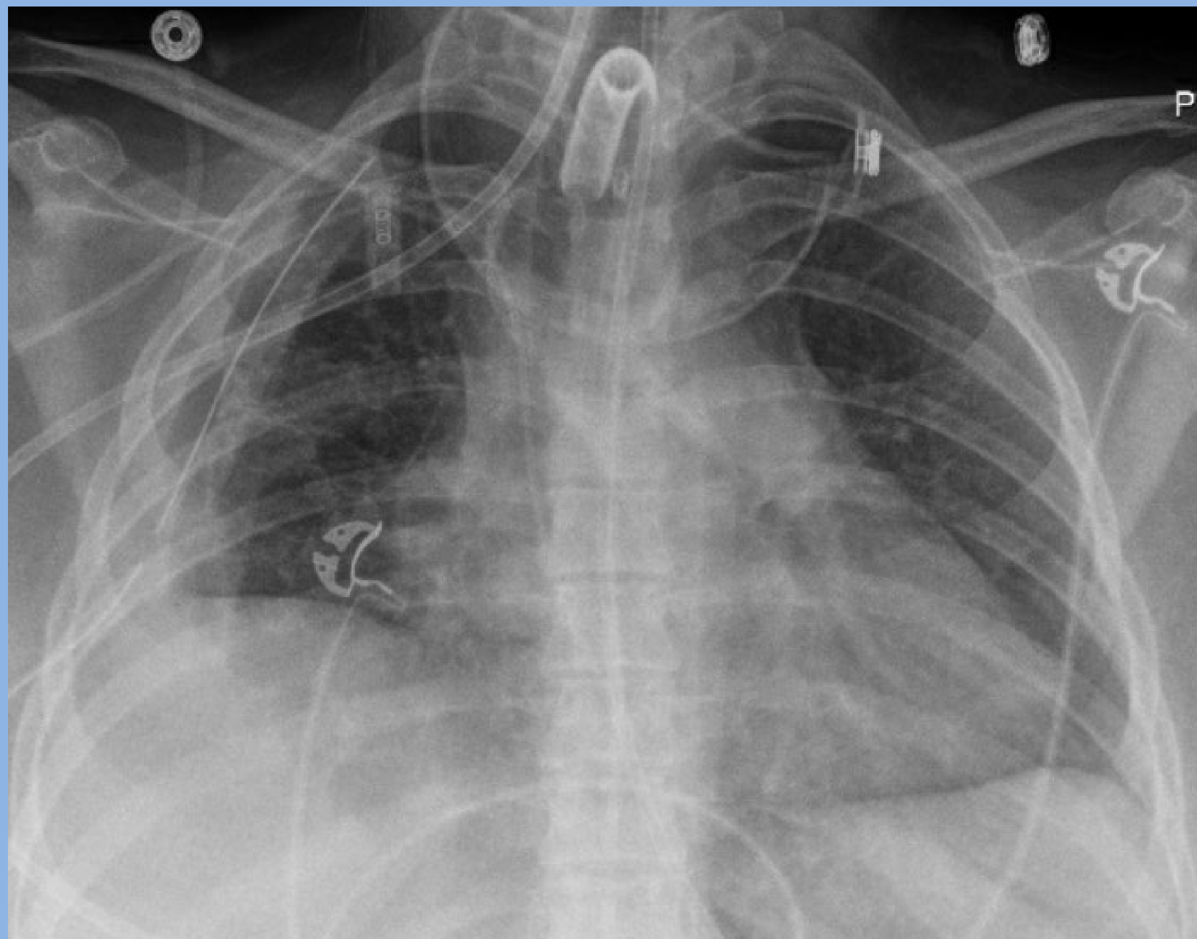
2/11



2/11



Off ECMO now in rehab after 73 day ECMO run



ECMO 2022

- ECMO COVID
  - CU experience
  - Chicago experience
  - World
- ECMO Non Covid/ARDS
  - Operative support
- ECMO Infrastructure
  - Team
  - Q/A
- ECMO Evolution

ECMO FIRST WAVE

ASAIO Journal 2021

Extracorporeal Membrane Oxygenation for Coronavirus Disease 2019: Crisis Standards of Care

Cara Agerstrand,* Richard Dubois,† Koji Takeda,‡ Nir Uriel,§ Philippe Lemaitre,‡ Justin Fried,§ Amirali Masoumi,§ Eva W. Cheung,¶ Yuji Kaku,‡ Lucas Witer,‡ Peter Liou,† Claire Gerall,|| Rafael Klein-Cloud,|| Darryl Abrams,* Jennifer Cunningham,* Purnema Madahar,* Madhavi Parekh,* Briana Short,* Natalie H. Yip,* Alexis Serra,* James Beck,# Michael Brewer,# Kenmund Fung,# Dana Mullin,# Roy Oommen,‡ Bryan Payne Stanifer,‡ William Middlesworth,|| Joshua Sonett,‡ and Daniel Brodie*

Surgical Director ECMO	Medical Director ECMO	Perfesion lead ECMO
Philippe Lemaitre	Cara Agerstrand Dan Brodie	Dana Mullin

ECMO COVID COLUMBIA

Sonett circa march 2020/ ecmo transport

ECMO FIRSt WAVE

Table 1. Demographic Information

Study Population	n = 22
Age (years)	52 (19–68)
Male sex	18 (82)
Body mass index (kg/m^2)	28.2 (21.3–55.0)
Comorbidities	
Obesity	10 (45.5)
Diabetes mellitus	7 (31.8)
Hypertension	5 (22.7)
Asthma	4 (18.1)
Coronary artery disease	1 (4.5)
Postpartum status	1 (4.5)
None	*7 (31.8)*
SARS-CoV-2 RT-PCR positive	22 (100)

Data are reported as number (%) or median (range).

SARS-CoV-2 RT PCR, severe acute respiratory syndrome coronavirus 2 reverse transcription-polymerase chain reaction.

Table 2. Pre-ECMO Characteristics

Study Population	n = 22
Indications for ECMO*	
ARDS	21 (95.4)
Cardiogenic shock†	7 (31.8)
Barotrauma	5 (22.7)
Admission to cannulation (days)	9 (1–23)
Intubation to cannulation (days)	3.5 (1–10)
Transport on ECMO	12 (54.5)
Pre-ECMO conditions	
Shock	22 (100)
Acute kidney injury requiring renal replacement therapy‡	10 (45.5)
Thrombus (intracardiac or pulmonary embolism)§	6 (27.3)
Pneumothorax/barotrauma	5 (22.7)
Cardiac arrest	4 (18.2)
Pre-cannulation ABG	
Ph	7.23 (7.08–7.38)
$PaCO_2$ (mmHg)	67 (36–100)
PaO_2:FIO_2 (mmHg)	63 (49–100)
Pre-ECMO mechanical ventilation	
Respiratory rate (breaths per minute)	34 (18–38)
Tidal volume (ml)	400 (200–600)
PEEP (cm H_2O)	15 (10–20)
FIO_2 (%)	100 (80–100)
End-inspiratory plateau pressure (cm H_2O)	36 (21–50)
Neuromuscular blocking agent	21 (95.5)
Prone positioning	8 (36.4)
Inhaled nitric oxide	4 (18.2)
Pre-Cannulation Illness Severity Score	
APACHE II	31 (20–36)
SAPS II	67 (43–81)

ECMO FIRST WAVE

Table 3. ECMO Characteristics

Study Population	n = 22
ECMO configuration	
Venovenous	15 (68.2)
Venoarterial-venous	6 (27.3)
Venoarterial	1 (4.5)
ECMO circuit parameters*	
Blood flow rate (LPM)	4.4 (3–5.6)
Sweep gas flow rate (LPM)	6.4 (3–12)
Complications	
Oxygenator failure (number of patients)	12 (54.5)
Number of oxygenator failures (total)	24
Time to oxygenator failure (days)	10 (3-46)

Data are reported as number (%) or median (range).

*Blood flow and sweep gas flow rates 24 hours following ECMO cannulation.

ARDS, acute respiratory distress syndrome; ECMO, extracorporeal membrane oxygenation; LPM, liters per minute.

Table 4. Clinical Outcomes

Study Population	n = 22
Survival to	
Decannulation	16 (72.7)
ICU discharge	12 (54.5)
Hospital discharge	12 (54.5)
ECMO duration (days)	24.5 (7–74)
ECMO duration of survivors (days)*	23 (7–74)
Complications	
Bleeding requiring transfusion	13 (59.1)
Oxygenator failure	12 (54.5)
Pneumothorax	5 (22.7)
Hemolysis	3 (13.6)
Cerebrovascular accident	2 (9.1)
Cannula site infection	1 (4.5)

Data are reported as number (%) or median (range).
*Patients surviving to ECMO decannulation.
ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit.

- Most up to date is over 40 patients with 60 percent survival to discharge.

Finish Line: Mile 26.2

ECMO Covid/ Chicago

Extracorporeal membrane oxygenation with right ventricular support in COVID-19 patients with severe acute respiratory distress syndrome

Check for updates

Antone J. Tatooles, MD, Asif K. Mustafa, MD, PhD, Devang J. Joshi, MD, and Pat S. Pappas, MD

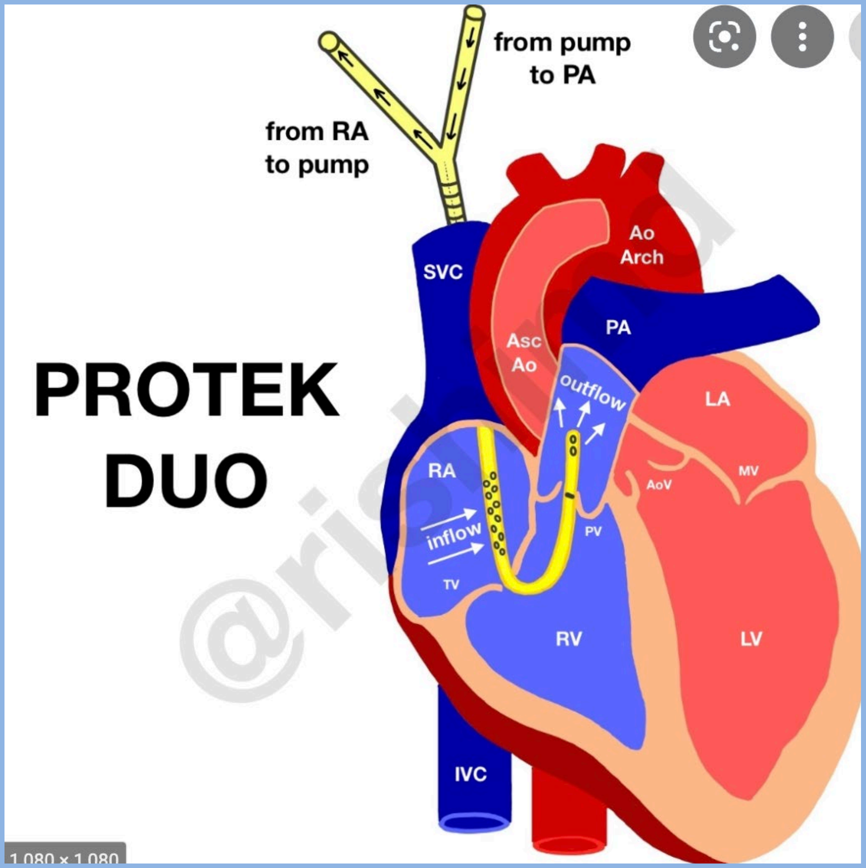
Video clip is available online.

From *left* to *right*: Drs Antone J. Tatooles, Asif K. Mustafa, Devang J. Joshi, and Pat S. Pappas

JTCVS Open 2021;8:90-6

Department of Cardiovascular and Thoracic Surgery, Rush University Medical Center, Chicago, Ill; and Cardiothoracic and Vascular Surgical Associates, SC, Advocate Christ Medical Center, Oak Lawn, Ill

ECMO Covid/ Chicago



Mustafa AK, Alexander PJ, Joshi DJ, Tabachnick DR, Cross CA, Pappas PS, et al. Extracorporeal membrane oxygenation for patients with COVID-19 in se-vere respiratory failure. JAMA Surg. 2020;155:990-2

FIRST 40 patients survival to discharge 82%

<u>MECHANICAL VENT LESS THAN 2 WEEKS</u>

RA_PA support
Aggressive Extubation
Aggressive Anticoagulaiton

ECMO Covid/ Chicago

136/140 patients who have completed their hospital course
75% were extubated from the ventilator

<u>67% decannulated from ECMO and discharged alive</u>.

The average time for mechanical ventilation was 23.5 days +/- 5
ECMO was 48.4 +/- 4.9 days.

The average age was 46.9 years;
The average body mass index (BMI) was 34.3
.

<u>Tracheostomy in only 13% of patients.</u>

ECMO Covid/world

Review Article

ECMO in COVID-19 Patients: A Systematic Review and Meta-analysis

Pietro Bertini, MD, PhD[*], Fabio Guarracino, MD[*],
Marco Falcone, MD, PhD[†], Pasquale Nardelli, MD[‡],
Giovanni Landoni, MD[‡,!,1], Matteo Nocci, MD[§],
Gianluca Paternoster, MD, PhD[||]

<u>ECMO COVID Survival 61 Percent</u>

consistent with previous prospective studies of covid ards
EOLIA ANS CESAR

ECMO 2022
Prevailing Thoughts

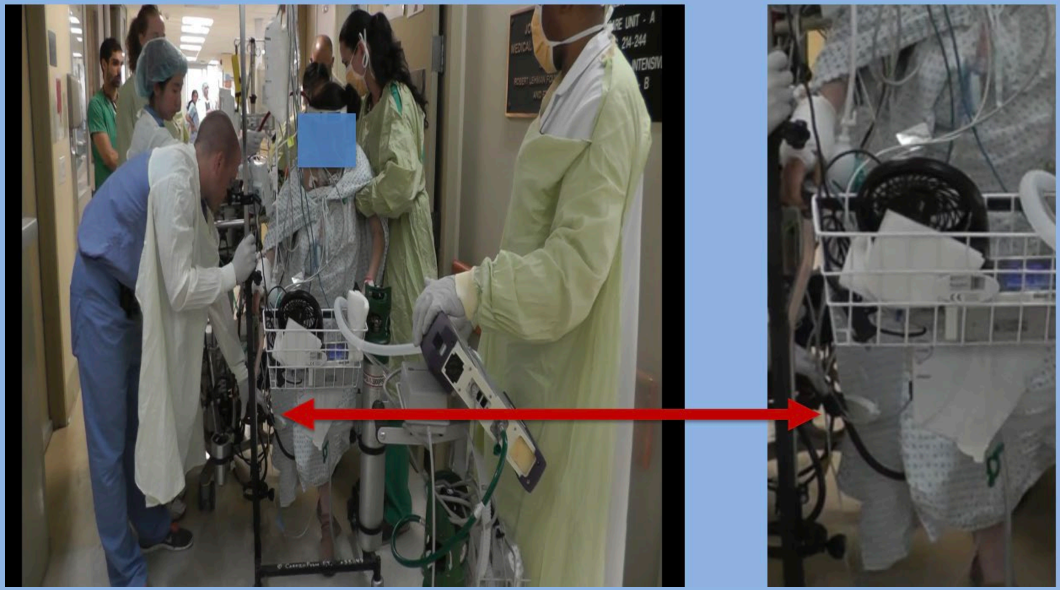
Optimize Support

Ambulate

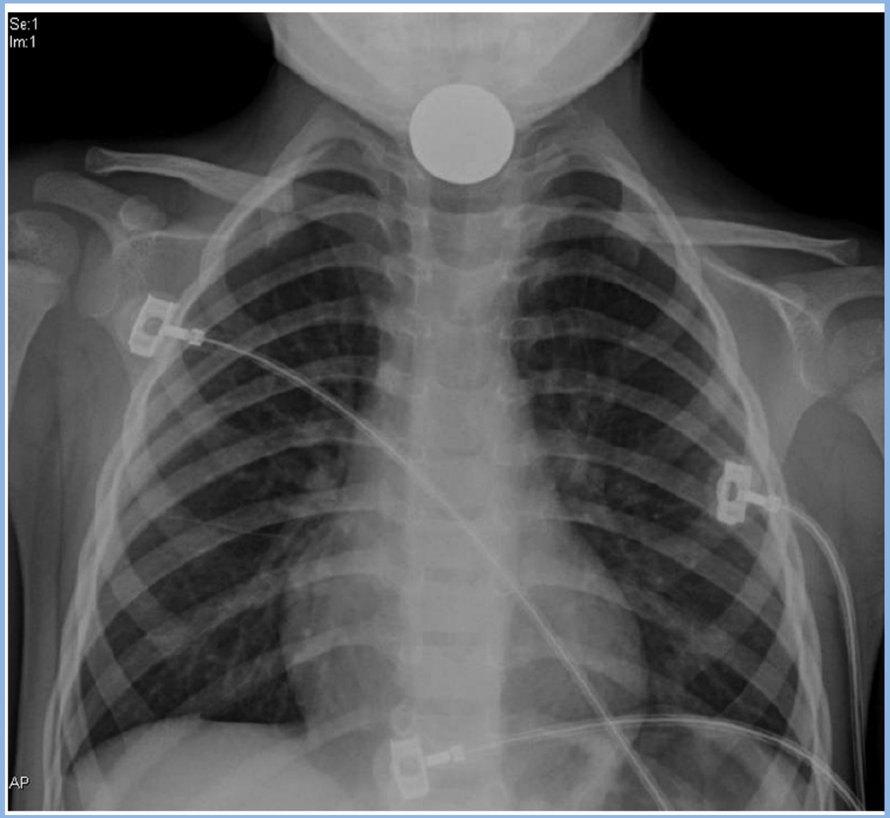
Extubate

Ambulation

RIGHT FEMORAL
VENOUS CANULATION

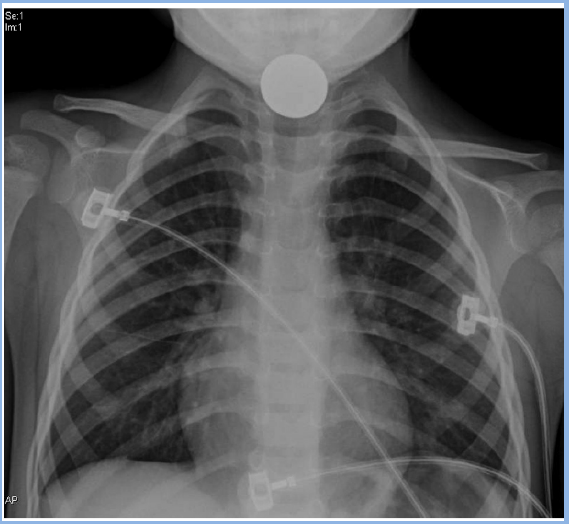


Dilemma



2 Year old presents to Emergency room with coin lodged in esophagous

Case presentation



Pediatric Esophageal Foreign body extraction device was used to attempt to remove coin

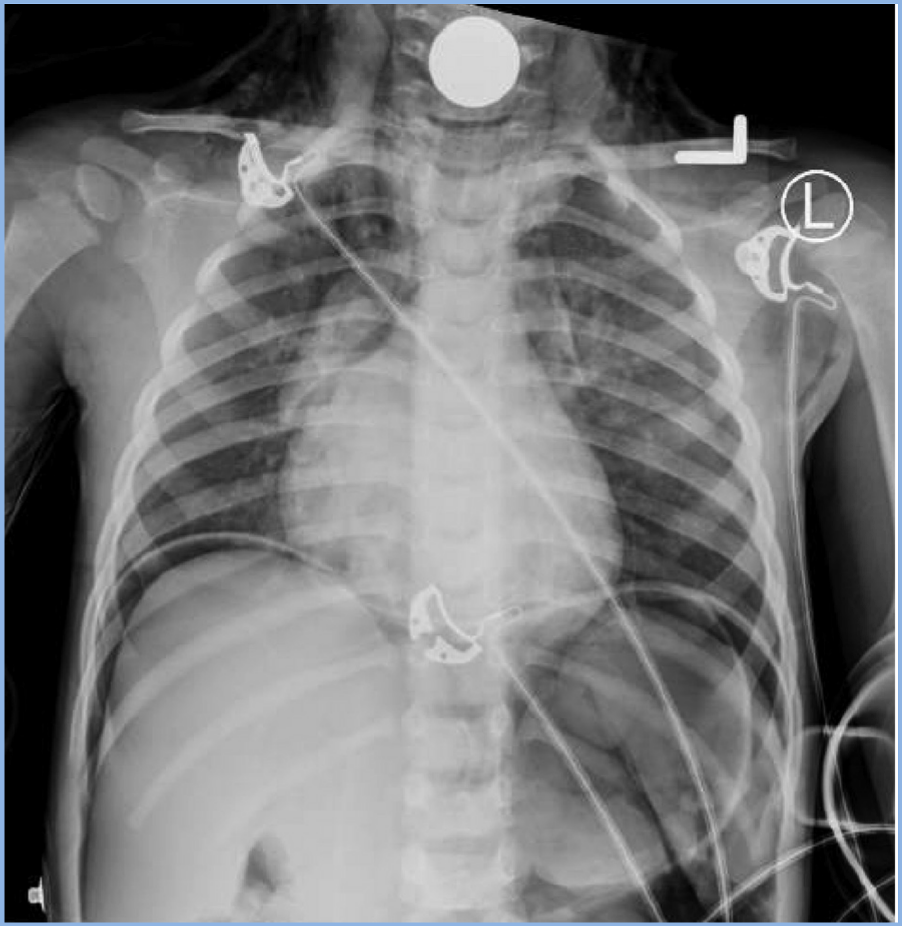
Case presentation

Coin in Place
Blood tinged sputum
Rapid subcutaneous emphysema
neck, chest , abdomen

Intubated in ER

Brought to Operating Room
Rigid Esophagoscope used to remove
Bronch Revealed tracheal laceration

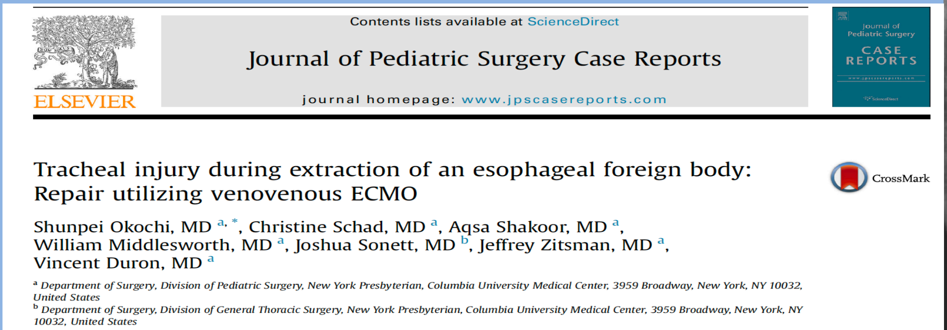
In PICU decompensation
Bilateral Pneumothorax
Difficulty ventilating
Repeat bronch ,complete separation of membranous airway trachea to rul



ECMO and You

A 19F double lumen cannula was placed via Seldinger technique into the right internal jugular vein under ultrasound guidance and position in the right atrium confirmed with fluoroscopy.

Tear repaired primarily right chest


Contents lists available at ScienceDirect

Journal of Pediatric Surgery Case Reports

journal homepage: www.jpscasereports.com

ELSEVIER

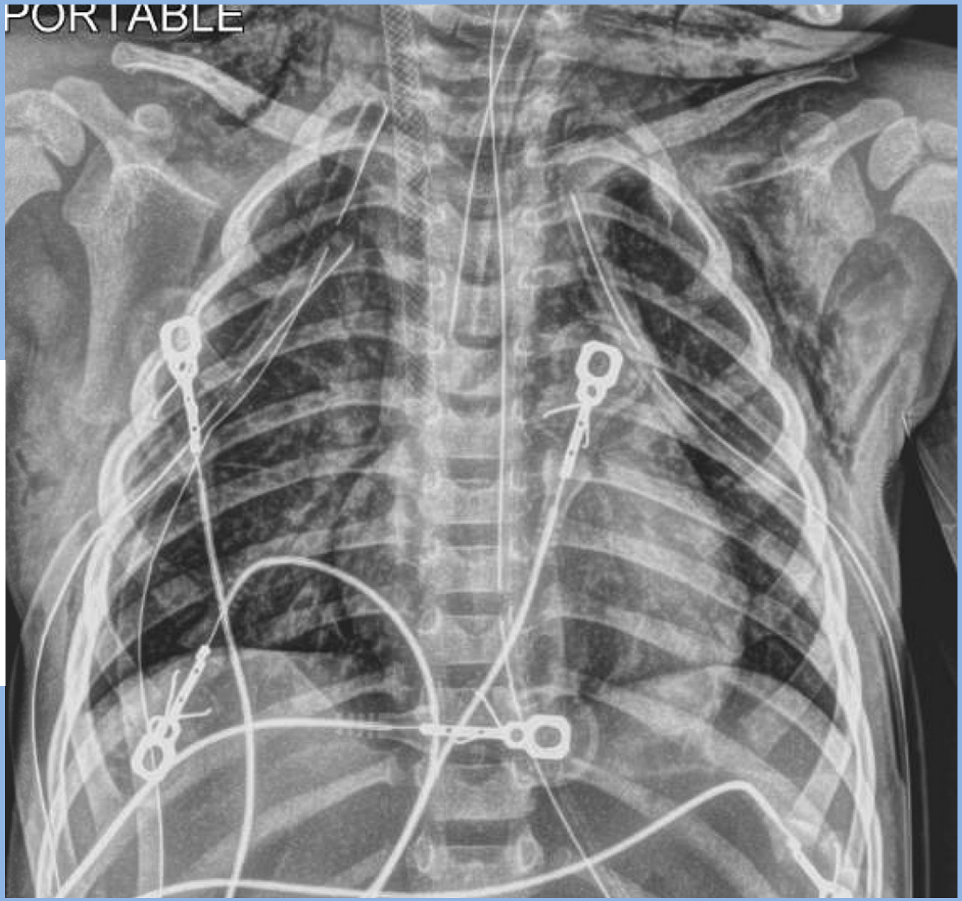
CrossMark

Tracheal injury during extraction of an esophageal foreign body: Repair utilizing venovenous ECMO

Shunpei Okochi, MD [a,*], Christine Schad, MD [a], Aqsa Shakoor, MD [a], William Middlesworth, MD [a], Joshua Sonett, MD [b], Jeffrey Zitsman, MD [a], Vincent Duron, MD [a]

[a] Department of Surgery, Division of Pediatric Surgery, New York Presbyterian, Columbia University Medical Center, 3959 Broadway, New York, NY 10032, United States

[b] Department of Surgery, Division of General Thoracic Surgery, New York Presbyterian, Columbia University Medical Center, 3959 Broadway, New York, NY 10032, United States



ECMO
Beyond ARDS

- TRANSPLANT
  - 10 percent of transplant in US ARE BRIDGED with ECMO
  - ECMO support during and post transplant now "routine"
  - Prophylactic ?

- Status Asthmaticus
- Pregnancy support
  - Safe Pre and Post
- OR Support
  - Airway surgery

Tracheal injury during extraction of an esophageal foreign body: Repair utilizing venovenous ECMO

CrossMark

Shunpei Okochi, MD [a,*], Christine Schad, MD [a], Aqsa Shakoor, MD [a], William Middlesworth, MD [a], Joshua Sonett, MD [b], Jeffrey Zitsman, MD [a], Vincent Duron, MD [a]

Extracorporeal lung support for tracheoesophageal fistula surgical repair with free flap

C. Bauer[1], P. Jacquenod[1], C. Fuchsmann[2], P. Philouze[2]
[1]Service d'Anesthésie Réanimation, Hôpital de la Croix-Rousse, Hospices Civils de Lyon, Lyon, France; [2]Service de Chirurgie ORL, Hôpital de la Croix-Rousse, Hospices Civils de Lyon, Lyon, France

Bronchoscopy-guided intervention therapy with extracorporeal membrane oxygenation support for advanced cancer metastasis to the central airway

A case report

Wei Yu, MD, Pengcheng Zhou, MD[*], Keling Chen, MB, Wenjun Tang, MD, Qianming Xia, MD, PhD,

Original Article

Multivariate Analysis of Risk Factor for Mortality and Feasibility of Extracorporeal Membrane Oxygenation in High-Risk Thoracic Surgery

Do Hyung Kim, MD,[1] Jong Myung Park, MD,[2] Joohyung Son, MD,[1] and Sung Kwang Lee, MD[1]

Extracorporeal membrane oxygenation in pregnancy: a bridge to delivery and pulmonary recovery for COVID-19-related severe respiratory failure

Ophelia Yin, MD, Michael Richley, MD, Joseph Hadaya, MD, Jenny Mei, MD, Thalia Mok, MD, Mariam Fahim, MD, Ilina D. Pluym, MD, Rashmi Rao, MD, Courtney Martin, MD, Christina S. Han, MD, Peyman Benharesh, MD, Yalda Afshar, MD PhD

Extracorporeal Carbon Dioxide Removal in the Treatment of Status Asthmaticus

Bianca J. Bromberger, MD[1]; Cara Agerstrand, MD[2]; Darryl Abrams, MD[2]; Alexis Serra, MPH[2]; Dana Apsel, MS, CCP[3]; Yuliya Tipograf, MD[1]; Mark E. Ginsburg, MD[4]; Michael I. Ebright, MD[4]; B. Payne Stanifer, MD[4]; Roy Oommen, MD[4]; Matthew Bacchetta, MD, MBA[5]; Daniel Brodie, MD[2]; Joshua R. Sonett, MD[4]

Intraoperative support with venovenous extracorporeal membrane oxygenation for complex thoracic oncologic resection

Flávio Pola dos Reis[1], Andre Nathan Costa[2], Leticia Leone Lauricella[1], Ricardo Mingarini Terra[1], Paulo Manoel Pêgo-Fernandes[1]

Intraoperative veno-venous extracorporeal lung support in thoracic surgery: a single-centre experience[†]

Bassam Redwan[a], Stephan Ziegeler[b], Stefan Freermann[a], Liane Nique[b], Michael Semik[a], Mahyar Lavae-Mokhtari[c], Thomas Meemann[b], Nicolas Dickgreber[c] and Stefan Fischer[a,*]

Review Article

Extracorporeal support in airway surgery

Konrad Hoetzenecker[1], Walter Klepetko[1], Shaf Keshavjee[2], Marcelo Cypel[2]

Conclusions

In the vast majority of cases, airway surgery can be safely performed by experienced teams without the need for ECLS. However, there are instances where airway control is predictably very difficult or near impossible, or where loss of airway control can suddenly occur. ECLS is an important tool in the armamentarium of the thoracic surgeon to facilitate extended airway surgery or endoscopic airway manipulation in critical obstructions.

J Thorac Dis 2017;9(7):2108-2117

ECMO INTRA-OP

- Veno – Venous
  - FEM IJ
  - Fem-Fem
- High flow low Heperan
  - 3000 bolus to canulate
  - No further anticoagulation

ECMO QUALITY

Isn't Limb as Precious as Life ...

ALWAYS MONITER DISTAL PERFUSION WITH NIR
DISTAL PERFUSION CATH IF COMPROMISED

new on the ECMO horizon
Equipment

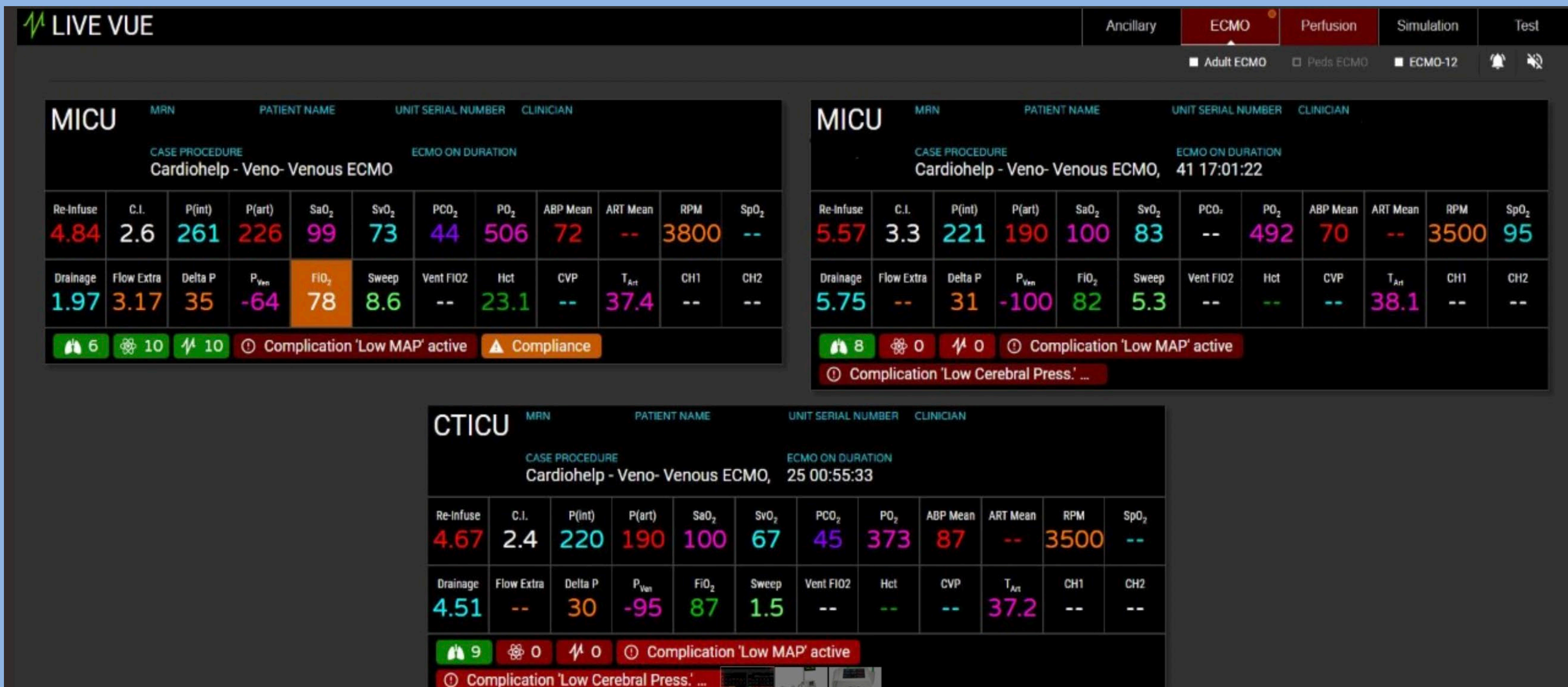
- **New Cannulas- multiport peripheral cannulas made from Elaston** (less thrombogenic), longer insertion lengths
- **New dual lumen VV** cannula options
- **New vascular access devices- offers bidirectional flow** (to reduce limb ischemia and distal perfusion insertion)
- **New circuitry with different coatings to prevent thrombosis are on the horizon**
- **New circuits with smaller priming volumes**
- **New flow dynamics. Moving to more cylinder shaped oxygenators to prevent stasis**
- **multiple flow probes for measuring flows in multiple lines on hybrid ECMO or with distal perfusion lines**.
- New Digital oxygenator blenders here and more to come in the future.

new on the ECMO horizon AI/QI?/Safety/Learning

- **Remote monitoring**
  - collecting real time data and displayed in a useful way for the clinician. **.**
- **Dashboards can be used displaying certain parameters**
  - to be monitored to watch trends and real time values for anticoagulation, labs, ECMO parameters such as RPM, blood flow, circuit pressures and circuit saturations.
- <u>**Artificial intelligence with smart coupling of alarms**</u> t
  - Alert the clinician that something is happening and try to catch the event early. For example, if the cvp increases a %, arterial blood pressure decreases %, HR increases, circuit negative pressure increases- could alert the clinician that there is a possible tamponade physiology.
- <u>**Troubleshooting decision trees**</u>
  - in electronic format that can help the bedside clinican to troubleshoot certain conditions.
- <u>**Oxygenator health critical scoring-**</u>
  - to help guide the clinician and monitor oxygenator performance


250
40
210
78.4
99.9
37.0
BATT

Remote Monitoring



Institutional ECMO Quality

- Pediatric ECMO
- Adult Pulmonary ECMO
  - Non-Transplant'
  - Transplant
- Cardiac ECMO

MICU: Pulmonary ECMO/Bridge to Transplant

CTICU: Post Transplant/Cardiac

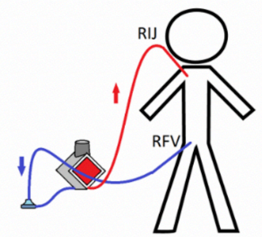
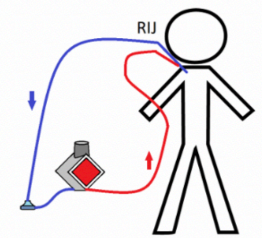
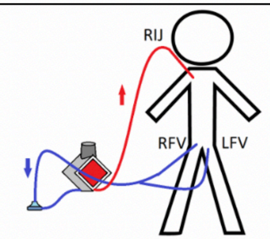
NP's Beside

Perfusion Supervision

EMCO PROGRAM
"CLIFF NOTES FOR TEAM"

	V-V ECMO	V-A ECMO
Purpose	Lung Support	Heart & Lung Support
Cannulation Site	Femoral Vein & Internal Jugular Dual Lumen Internal Jugular	Femoral Vein & Femoral Artery Internal Jugular & Axillary Artery Right Atrium & Aorta Internal Jugular & Carotid Artery
Types of patients	Cystic Fibrosis ARDS Bridge to Lung Transplant	Cardiac Arrest Failure to wean off bypass Post Heart Transplant Acute MI
Weaning	Wean FiO2 Wean Sweep Turn off Sweep	Wean Flow
Problems	If patient pO2 is low despite maxing out vent settings, may need to add an extra arterial line, converting to V-A-V ECMO If need higher flow, may add an extra venous line to increase drainage	For fem-fem patients, if heart is ejecting and patient pO2 is low despite maxing out vent settings, may need to add an extra venous line, converting to V-A-V ECMO

V-V ECMO

	Types of Patients: ARDS, Bridge to recovery, V-V ECMO transport from outside hospital Cannulas: FV – Biomedicus Venous (21 or 23 fr) IJ – EOPA (18 or 20 fr) Blood Gas Management: Treat patient ABG *If patient pO2 is low, may need to add an extra arterial line, converting to V-A-V
	**Need fluoro for cannulation** Types of Patients: Cystic Fibrosis, Bridge to lung transplant Cannulas: Avalon Dual Lumen (27 or 31 fr) Blood Gas Management: Treat patient ABG *If patient pO2 is low, may need to add an extra arterial line, converting to V-A-V
	**Converted from FV-IJ VV ECMO due to the need for more drainage for higher flow** Types of Patients: Patients on V-V ECMO who needed more drainage for higher flow Cannulas: FV – Biomedicus (21 or 23 fr) IJ – EOPA (18 or 20 fr) Blood Gas Management: Treat patient ABG

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Membrane Lung Dysfunction Lecture

Not Completed

LV distension on ECMO

Complete

Cardiovascular Pharmacology

Not Completed

Surgical Approaches to PA HTN

Complete

PHTN ECMO MODEL

ECMO Quality

#encrypt #phi ECMO Complications/Events

K

kef9019@nyp.org
Sat 2/5/2022 1:12 AM

To: Fung, Kenmond; Mullin, Dana Apsel; Kirtane, Ajay J.; Agerstrand, Cara L.; Berman-Rosenzweig, Erika S. **+23 others**

ECMO Complications/Events

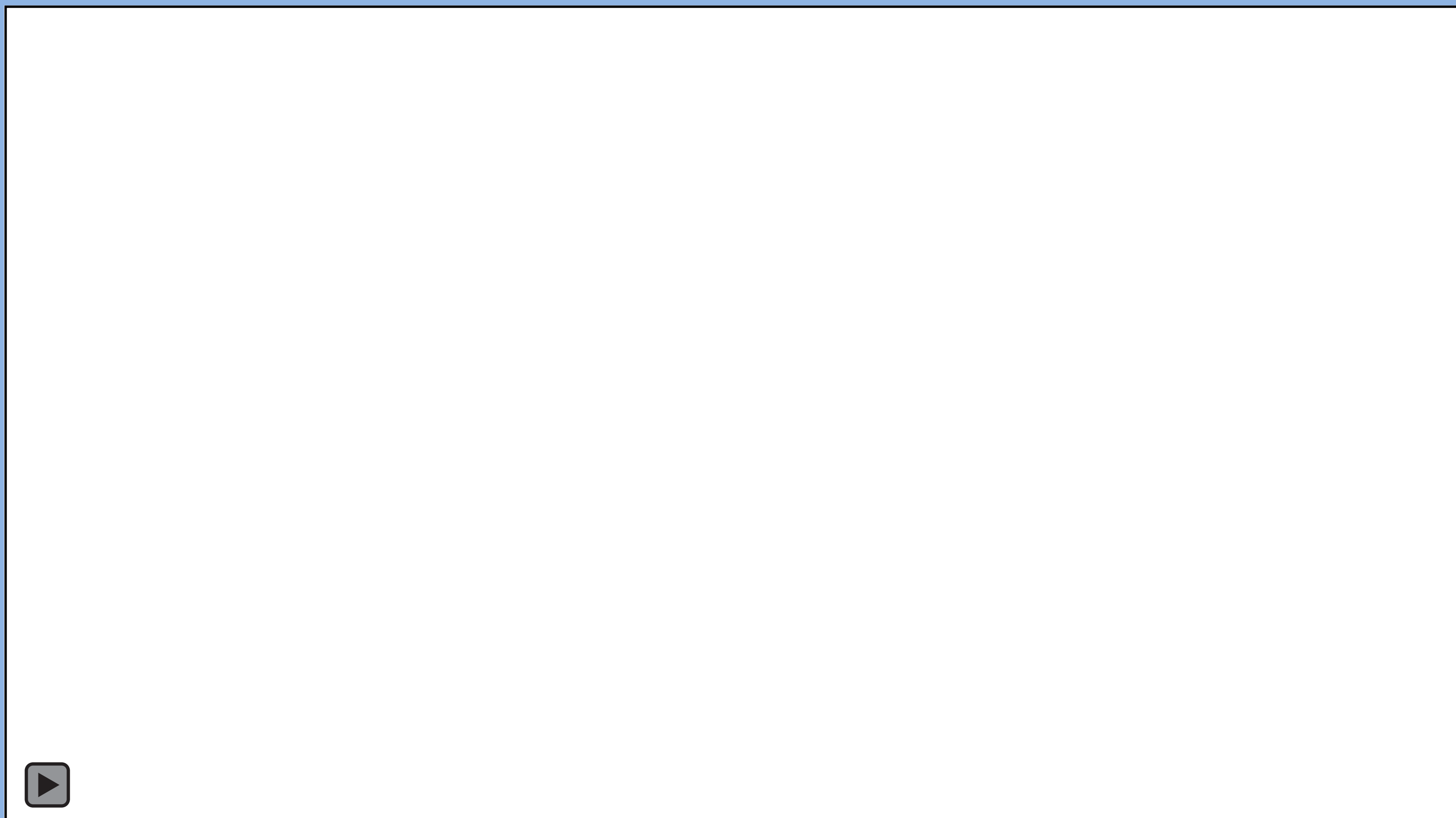
Date	[redacted]	Name	Location	Complication	Perfusionist
2022-02-04 12:46:03	[redacted]	KIMBERLY KUDLO	MICU 230	Oxygenator Failure - Oxy Change Out - Gas Exchange Impairment	[redacted]
2022-02-01 07:00:00	[redacted]	Baby boy Kelly	9 North - 923	Oygenator Failure - Oxy Change Out - Thrombus/ Increase Delta Pressure	[redacted]
2022-01-27 00:33:12	[redacted]	VICTORIA URGO	MICU 228	Oxygen Delivery Failure - Gas Line Disconnect	[redacted]
2022-01-25 09:52:41	[redacted]	VICTORIA URGO	MICU 228	Circuit Thrombosis - Clots: Tubing Most fibrin located along drainage 25; some fibrin on drainage 29 near Y	[redacted]
2022-01-25 00:01:00	[redacted]	VICTORIA URGO	MICU 228	Circuit Thrombosis - Clots: Pump Head	[redacted]
2022-01-18 11:03:44	[redacted]	VICTORIA URGO	MICU 228	Oxygenator Failure - Oxy Change Out - Thrombus / Increase Delta Pressure	[redacted]
2022-01-17 15:20:00	[redacted]	RAIZY FLOHR	9 Central - 903	Oygenator Failure - Oxy Change Out - Thrombus/ Increase Delta Pressure	[redacted]
2022-01-15 20:13:37	[redacted]	KIMBERLY KUDLO	MICU 230	Patient Event - Pneumothorax	[redacted]
2022-01-12 07:11:50	[redacted]	PATRICIA SCALISE	CTICU 8	Circuit Thrombosis - Clots Pre-pigtail	[redacted]
2022-01-08 13:51:38	[redacted]	KIMBERLY KUDLO	MICU 230	Oxygenator Failure - Oxy Change Out - Thrombus / Increase Delta Pressure	[redacted]
2022-01-06 05:59:00	[redacted]	ANTHONY MENDOZA	9 Tower - 906	Oygenator Failure - Oxy Change Out - Thrombus/ Increase Delta Pressure	[redacted]
2022-01-02 07:34:21	[redacted]	KIMBERLY KUDLO	MICU 230	Circuit Thrombosis - Clots: Other Post oxy 3, 9, 12 o'clock	[redacted]
2021-12-31 11:26:14	[redacted]	VICTORIA URGO	MICU 228	Circuit Thrombosis - Clots: Other Hemolysis	[redacted]
2021-1 [illegible]	[redacted]	GINA WELLS	CTICU 2	Circuit Thrombosis - Clots: Post-pigtail	[redacted]

Screenshot

ECMO

- ECMO now commonly used at a diversity of Institutions
- New compact and ”packaged” units will continue to Evolve to expand ”entry”
- Growing comfort and decreased morbidity enable ECMO as an operative tool
- Institutional guidelines, Q/A, teaching will be critical to uniform results and safety

ECMO Revolution and Corona Virus slide circa 2020



No Relevant financial Disclosure

Pandemic Resource Allocation

Less than 70 years old
Intubated less than 7 days

Lesson learned time, time , time

Rationale is different for each disease

BTT

Increase transplantability

ARDS

Reduce barotrauma

Reduction sedation

COPD / Asthma

Avoid hyperinflation

Decrease sedation

Improve weaning

Patients appropriate for extubation

- ✓ Awake
- ✓ Cooperative
- ✓ Good cough
- ✓ Medically appropriate
- ✓ Room on oxygenation
- ✓ Able to control tachypnea with sweep
- ✓ Consider risk of ECMO vs. MV removal
    - Bleeding / coagulopathy

Bilvalrudin vs. Heparin?

No RCTs exist

3 retrospective observational studies

58 patients - 40 bilvalrudin vs. 18 heparin

Heparin had more aPTT variation (26% vs. 11%, $p<0.001$)

Bleeding (NS)

pRBC transfusions (NS)

Mortality (NS)

Sanfilippo F, et al. J Intensive Care Med, 2017

Modern ECMO Experience

Low-dose anticoagulation protocol is favored

aPTT 40-60 seconds

Variables	Median (IQR) (N = 38)
Hemoglobin, g/dL	8.2 (7.9–8.7)
pRBCs transfused	
Total per patient	
Units	1 (0–3)
Volume, mL	250 (0–750)–300 (0–900)
Per day of ECMO support	
Units	0.11 (0–0.33)
Volume, mL	27.8 (0–83.3)–33.3 (0–100)
aPTT, s	46.5 (40.8–50.8)

Occlusive DVT 11.8%

No circuit changed

Agerstrand C, et al. Ann Thoracic Surg, 2015

HELP-ECMO

Ultra-low level anticoagulation?

31 patient RCT, unblinded

22 VV / 9 VA

aPTT 50-70s vs. <45s

ECMO duration: 9 days

NO difference in thrombotic or bleeding complications

McQuilten Z, et al. Blood J, 2016

Right parameter to monitor? PTT/Xa/TEG

No consensus in monitoring parameter or target ranges

Significant areas of uncertainty and variations in practice

ECMO /Beyond ARDS
Lung Transplant

- **Lung Transplant**
  - ECMO vs CPB
  - **ECMO Bridge to Transplant now routine**
    - Ambulation and extubation key
    - Currently 10 Percent of US Transplants
- ECMO in Lung Transplant

  no support ►

  Support as needed►

  “Prophylactic”

  PHTN

  All

Columbia Experience using ECMO as a Bridge to Lung Transplantation

72 Patients

2007-2016

LAS 91.2

VV 45 (62.5)

VA 23 (31.9)

VVA 3 (4.2)

Central 1 (1.4)

50 (69.4%) ambulated

Post-transplant Survival

1-year 90%

2-year 84%

Biscotti, et al. Ann Thorac Surg 2017

Dilemma
ECMO and ECMO Transport
Pandemic

- ECMO Call Center
- ECMO Medical Attending/NP
- ECMO Team
  - 24/7 zoom discussion
  - Medical assessment and decision making
- Nursing Capability Triage
- Hospital Capability Triage

Old Slides

COLUMBIA | COLUMBIA UNIVERSITY IRVING MEDICAL CENTER

NewYork-Presbyterian
The University Hospital of Columbia and Cornell

Biomarker Multiplex Immunoassay in Covid-19 Patients Requiring Extracorporeal Membrane Oxygenation (ECMO)

Alexey Abramov MD[1], Richard Dubois MD[1], Andrew Thornton MD[1], Danielle Feldhaus MD[2]
Philippe Lemaitre MD PhD[1], Cara Agerstrand MD[3], Renu Nandakumar PhD[4],
Joshua Sonett MD[1], Daniel Brodie MD[3], Bryan P. Stanifer MD[1]

[1] Department of Surgery, Division of Thoracic Surgery, Columbia University Irving Medical Center, New York NY
[2] Department of Surgery, Hackensack Meridian Health Palisades Medical Center, Edison NJ
[3] Department of Medicine, Division of Pulmonary, Allergy and Critical Care Medicine, Columbia University Irving Medical Center, New York NY
[4] Irving Institute for Clinical and Translational Research, Columbia University Irving Medical Center, New York NY

STSA 68th ANNUAL MEETING
Atlanta, GA
Nov. 3–6, 2021

Methods

- **Clinical Data**
  - Retrospective cohort study including all SARS-CoV-2 positive patients with refractory respiratory failure cannulated to ECMO from March 1st, 2020 through June 1st, 2021

- **Primary outcome:** In-hospital mortality
- **Secondary outcomes:** Demographics, hospital and ECMO course, laboratory values

- **Biomarker Multiplex Immunoassay**
  - Blood was collected near time of cannulation (within 24hrs) centrifuged and stored at -80C for future analysis
  - Cytokines in human serum samples were measured using Human XL Cytokine Premixed Kit (R&D Systems, MN) and the Luminex 200 platform (Luminex Corp, Austin, TX)

- R Project for Statistical Computing (Vienna, Austria) was used for statistical analysis

Figure 1

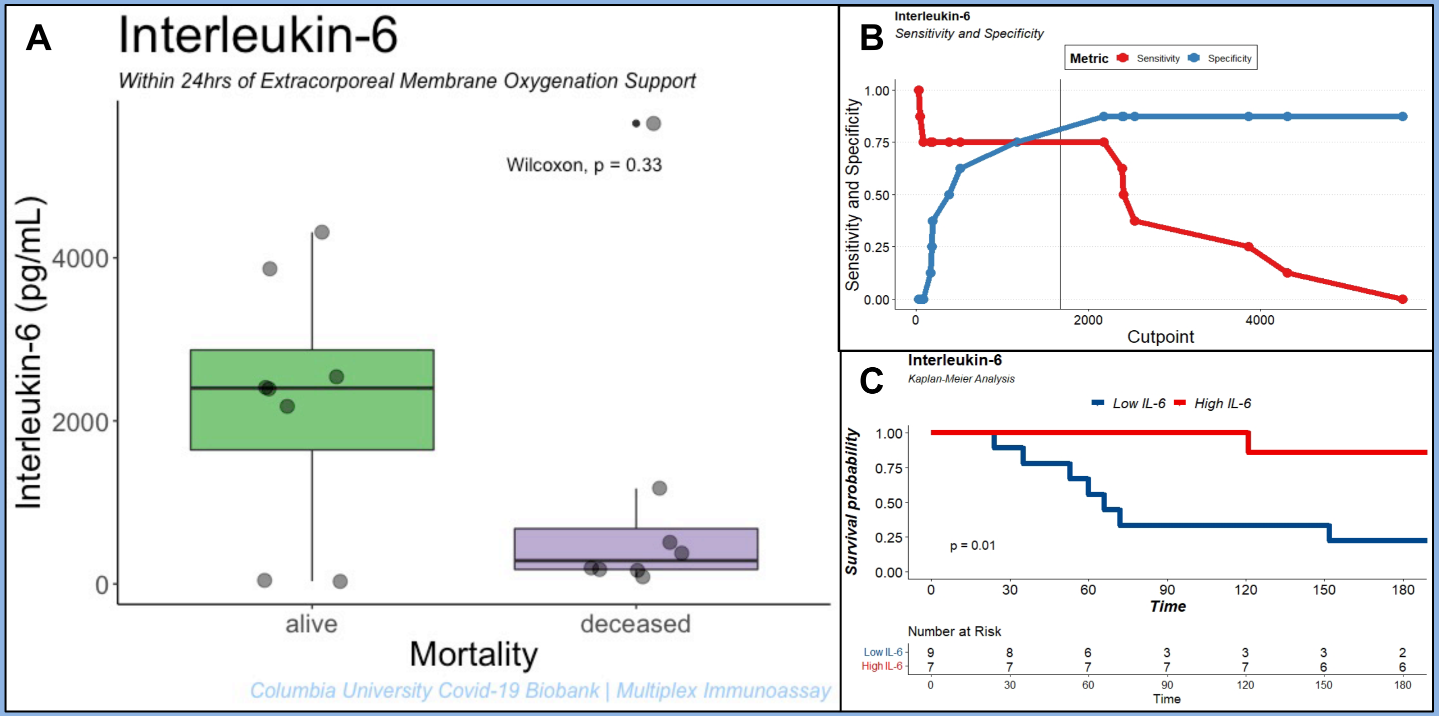
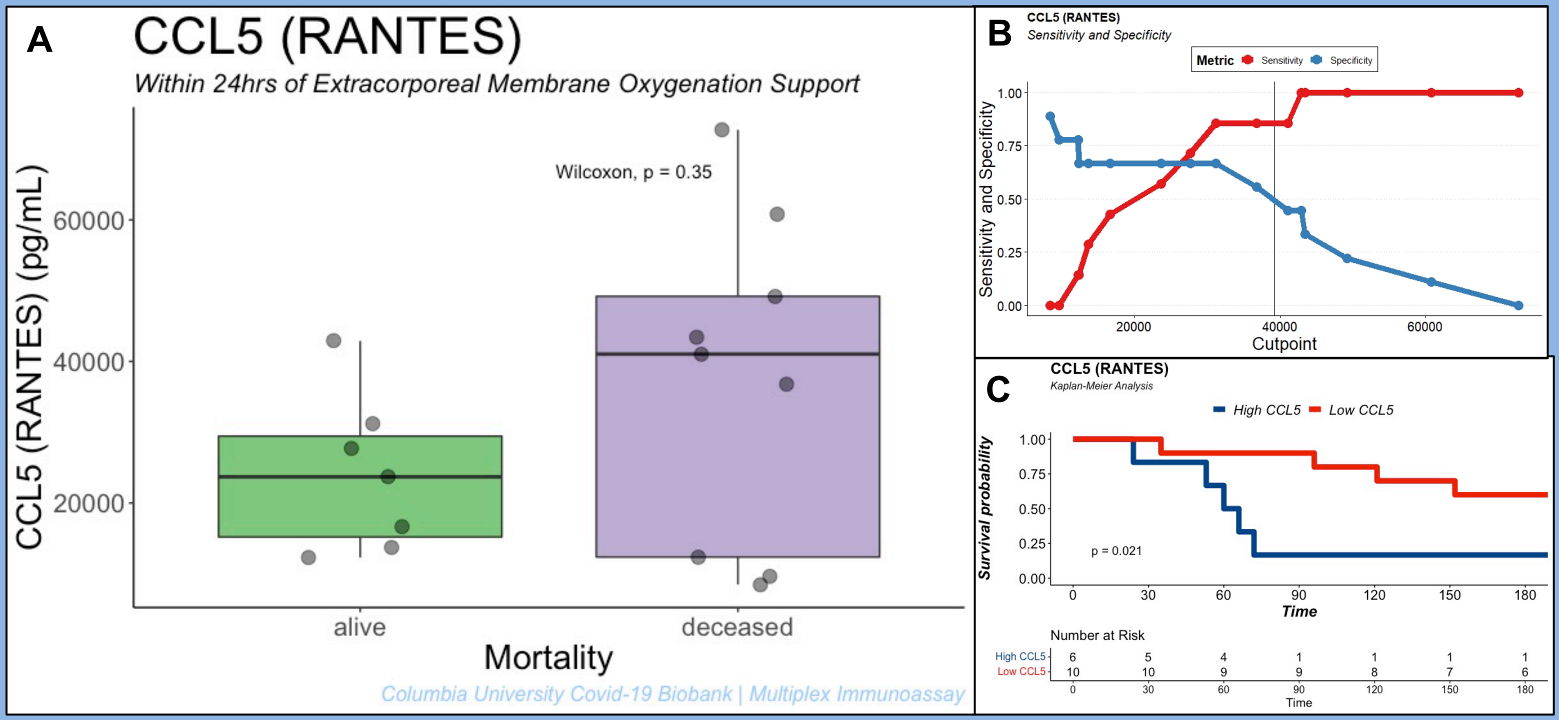

A
Interleukin-6
Within 24hrs of Extracorporeal Membrane Oxygenation Support
Wilcoxon, p = 0.33
Interleukin-6 (pg/mL)
4000
2000
0
alive
deceased
Mortality
Columbia University Covid-19 Biobank | Multiplex Immunoassay
B
Interleukin-6
Sensitivity and Specificity
Metric
Sensitivity
Specificity
Sensitivity and Specificity
1.00
0.75
0.50
0.25
0.00
0
2000
4000
Cutpoint
C
Interleukin-6
Kaplan-Meier Analysis
Low IL-6
High IL-6
Survival probability
1.00
0.75
0.50
0.25
0.00
p = 0.01
0
30
60
90
120
150
180
Time
Number at Risk
Low IL-6 9 8 6 3 3 3 2
High IL-6 7 7 7 7 7 6 6
0
30
60
90
120
150
180
Time

Figure 2



A
CCL5 (RANTES)
Within 24hrs of Extracorporeal Membrane Oxygenation Support
Wilcoxon, p = 0.35
CCL5 (RANTES) (pg/mL)
60000
40000
20000
alive
deceased
Mortality
Columbia University Covid-19 Biobank | Multiplex Immunoassay
B
CCL5 (RANTES)
Sensitivity and Specificity
Metric Sensitivity Specificity
Sensitivity and Specificity
1.00
0.75
0.50
0.25
0.00
20000
40000
60000
Cutpoint
C
CCL5 (RANTES)
Kaplan-Meier Analysis
High CCL5 Low CCL5
Survival probability
p = 0.021
0 30 60 90 120 150 180
Time
Number at Risk
High CCL5 6 5 4 1 1 1 1
Low CCL5 10 10 9 9 8 7 6
Time

Conclusions

Among patients with Covid-19 critical illness with refractory respiratory failure requiring ECMO support, **higher IL-6** and **lower CCL5 (RANTES)** cytokine levels at time of cannulation were associated with **improved survival.**

ECMO 2020 First Wave

History of Present Illness:

HISTORY / 24 HOUR EVENTS: 53 yo male with no significant past medical history presented to Lawrence Hospital on 3/31 with fever/cough/ SOB found to be COVID positive and hypoxic requiring NRB ultimately requiring intubation on 4/4 now s/p VV ECMO cannulation and transferring to MICU for acute hypoxic respiratory failure/ARDS 2/2 to COVID.

Mr Teodulo was admitted to the floor initially for hypoxia requiring NRB with increasing 02 requirements. He started on 4/4 he was intubated for progressive hypoxia and tachypnea and was transferred to OSH CCU. He had refractory hypoxia requiring paralysis ultimately proned on 4/7 for 12 hours for a P/F < 150. He remained hypoxic with sats in the low 80's and when supine had worsening hypotension with increased pressor requirements. He was on phenylephrine and vasopressin. Gave 20 mg Lasix w 100 cc urine output. He completed a five day course of azithromycin and hydroxychloroquine. Prior to cannulation pH 7.16/82/58, sats in 70's, phenylephrine @ 300, vasopressin @ 6. He was cannulated to VV ECMO with abg 7.37/39/137 ACVC 20/350/50%/18. Tidal volumes further decreased to 300 and RR to 15 with ECMO flows at 3 and sweep 3. OSH labs notable for Cr. 1.18 (0.72), TG 556, WBC 11.7, Fibrinogen >1000, Ddimer 1151, LDH 881.

MICUA: Pt arrived to MICUA on VV ECMO on vasopressin @ 2.4 and phenylephrine @ 150. Paralysis off. Propofol to Versed d/t triglyceride>500. Vent adjusted: 10/280/50%/15.

Operative Report

Date of Surgery: 4/8/2020

Preoperative Diagnosis: Acute respiratory distress syndrome (ARDS) due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)

Postoperative Diagnosis: Same as preoperative diagnosis

Procedure: Veno-venous Extracorporeal Membrane Oxygenation (ECMO) Cannulation

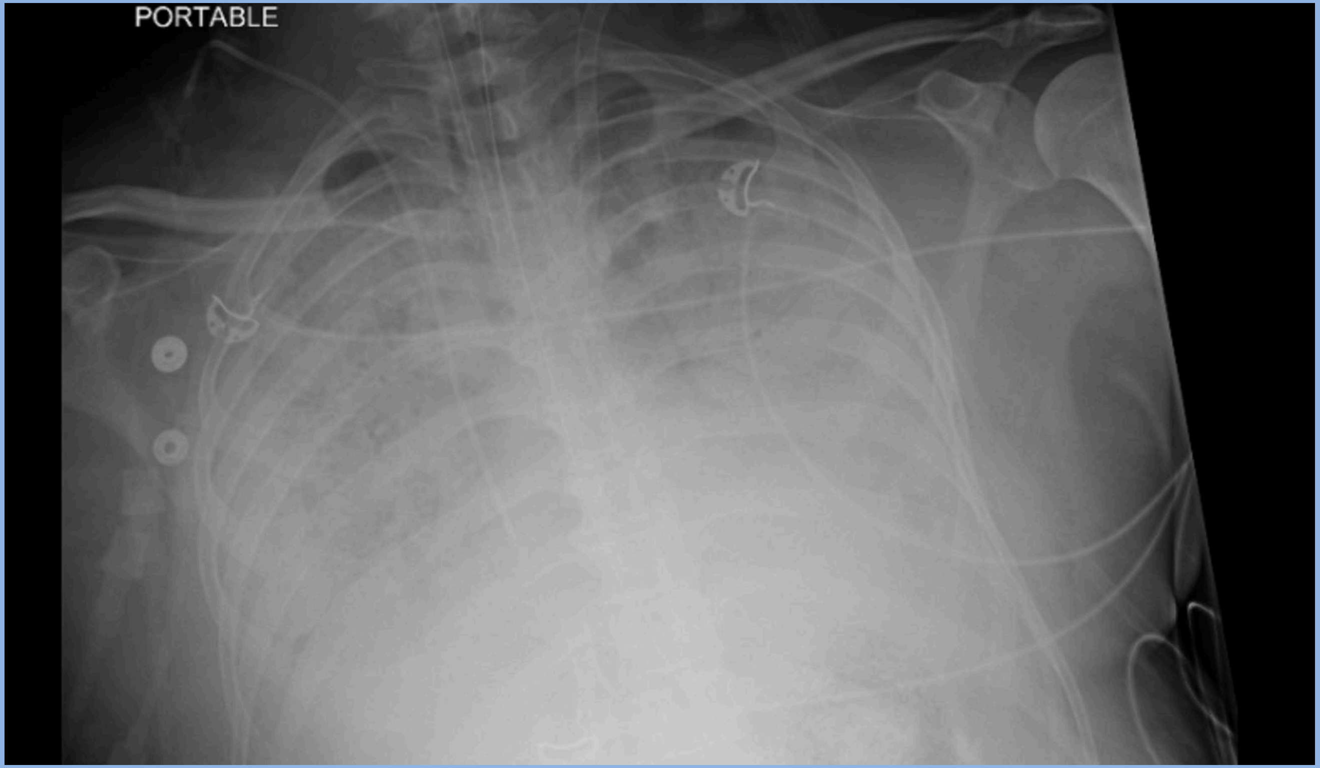
Surgeon(s):
Philippe Lemaitre, MD, PhD

Assistants: Richard DuBois, MD

Anesthesia: General anesthesia

Drainage Cannulation: 25Fr RFV multiport

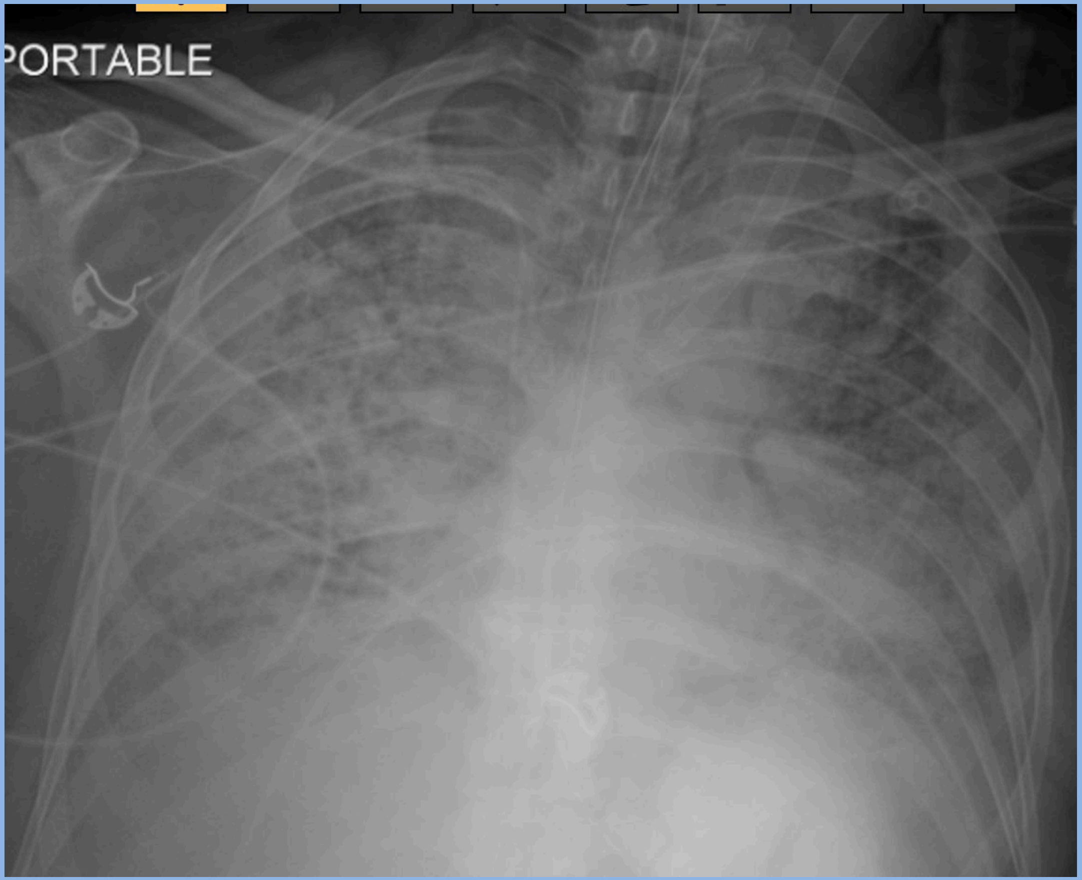
Reinfusion Cannulation: 20Fr LIJ EOPA



ECMO Surgical Fellow Progress Note

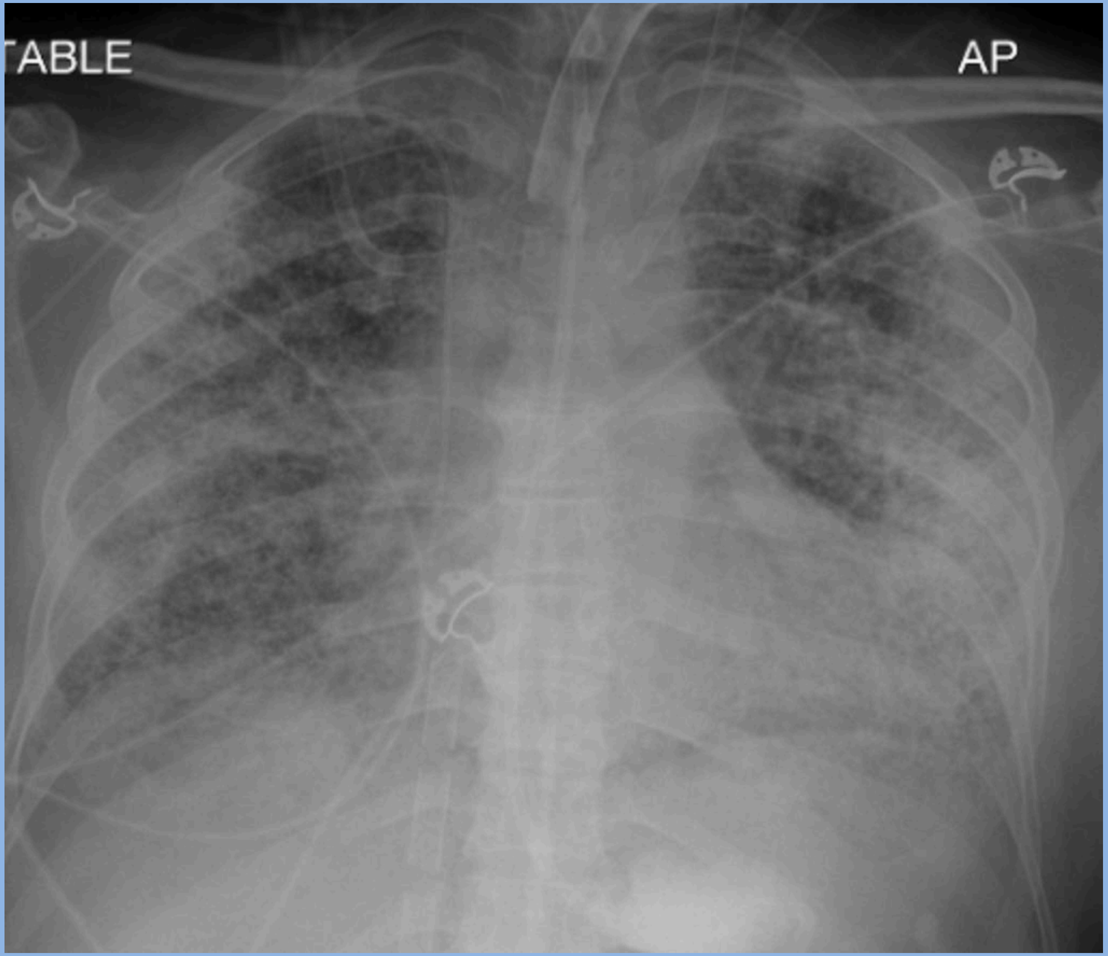
Diagnosis: ARDS/COVID19
Cannulation Date: 4/8/2020
Days on ECMO: 31
Configuration: VV (25Fr RFV muliport --> 20Fr LIJ EOPA)

24 hour events:
- TV improved despite being 1L positive



ECMO Surgical Fellow Progress Note

Diagnosis: ARDS/COVID19
Cannulation Date: 4/8/2020
Days on ECMO: 43
Configuration: VV (25Fr RFV muliport --> 20Fr LIJ EOPA)

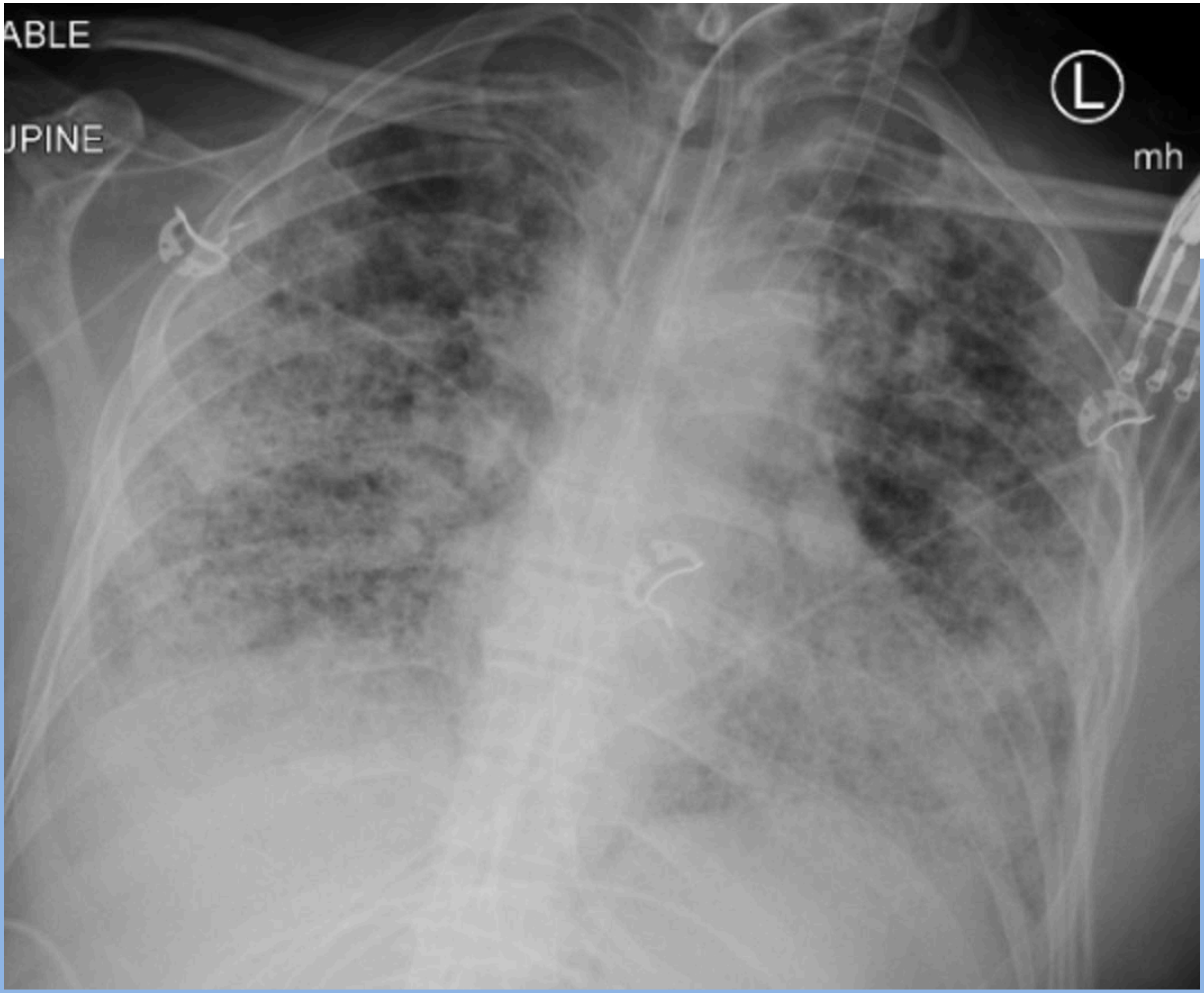


ECMO Surgery Progress Note

Diagnosis: ARDS/COVID19
Cannulation Date: 4/8/2020
Days on ECMO: 58
Configuration: VV (25Fr RFV muliport --> 20Fr LIJ EOPA)

24 hour events:
-sweep weaned to 1
-RR remains in 30s
-may trial off sweep today

Vitals:

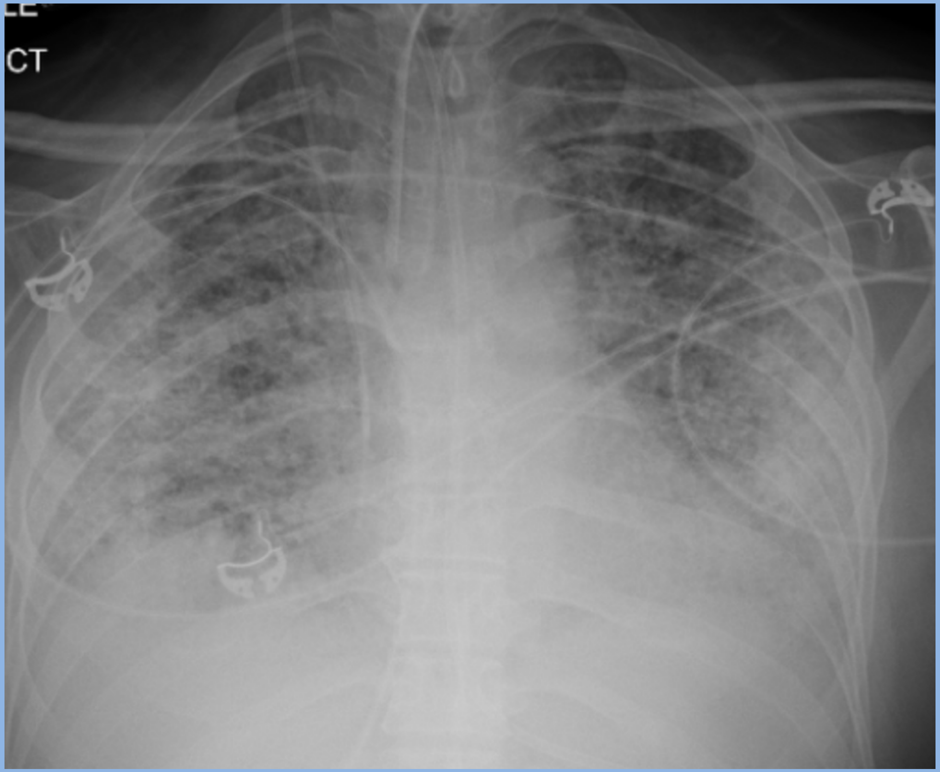


MICU Attending Progress Note

Hospital Admit Date: 4/8/2020 3:32 PM
ICU Length of Stay: 72d 21h 10m
ICU Indication: COVID ARDS

Isolation: Droplet, Contact, Klebsiella aerogenes (MDR), COVID-19

24hr/Interval Events:
-Off pressors
- Oxygenator swapped out yesterday for poor post-oxygentor gas indicating that it was failing
- Weaning sweep
- On minimal sedation this morning his pupils were ~7 mm in diameter round but not reactive to light on my exam
- given that he is on anticoagulation and aware of the complexity of his care the decision was made to send him for a non-contrast CT head
- He had a CT head showing a 1.6 x 1.1 x 1.1 cm acute intraparenchymal hemmorhage
- In the process of getting the head CT and transferring from head CT gurney to transport stretcher L IJ ECMO drainage canula was dislodged. This was noted immediately, canula were clamped, pressure was held at the L IJ and team was called including myself, fellow, CT surgery, anesthesia.
- In this setting patient lost approximately 500 cc blood, he was stabilized and returned to the MICU.
- Given the intraparenchymal hemmorhage and the requirement for anticoagulation with ECMO, the ECMO team has limited enthusiasm for putting him back on circuit but would rather prefer to manage him on the vent.



Milstien Hospitalist Attending Progress Note

Interval Events:

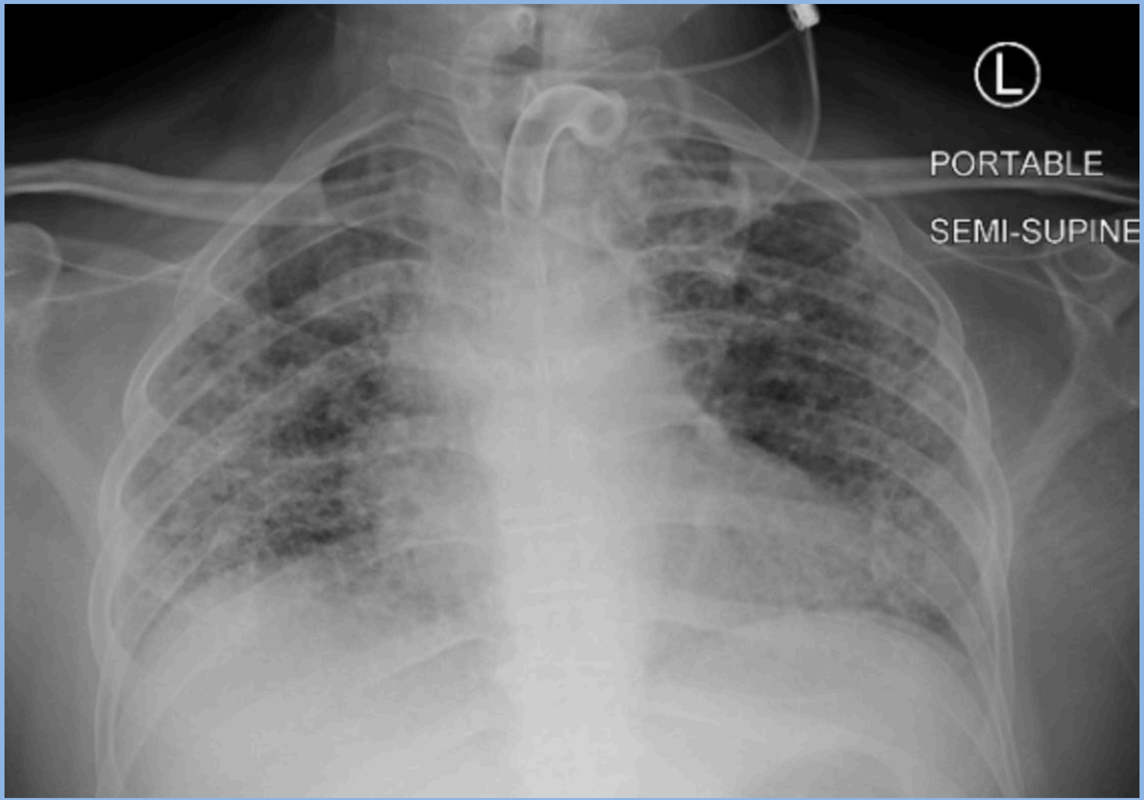
Had a haircut today

Sat comfortably in chair, able to return to bed with assistance

Extensive discussion with patient, wife, daughter re: post-discharge care

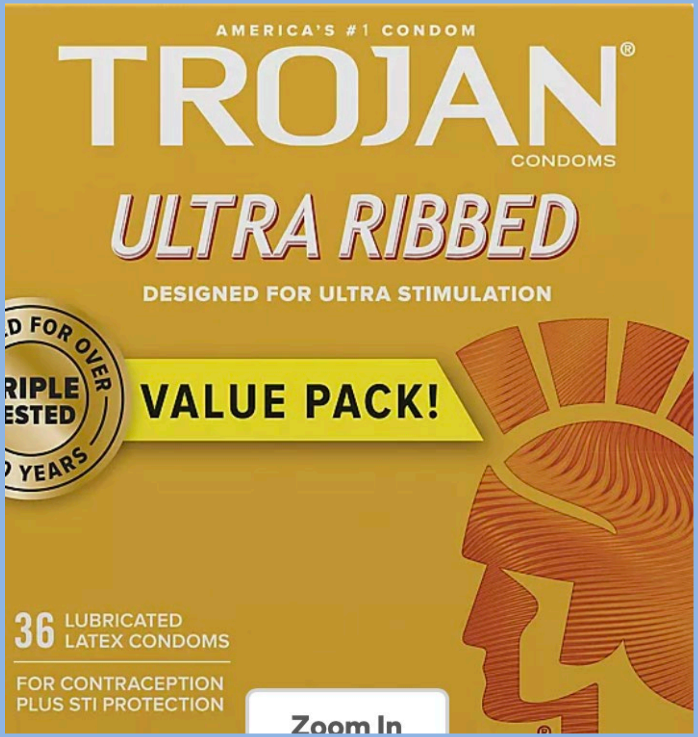
Medications:

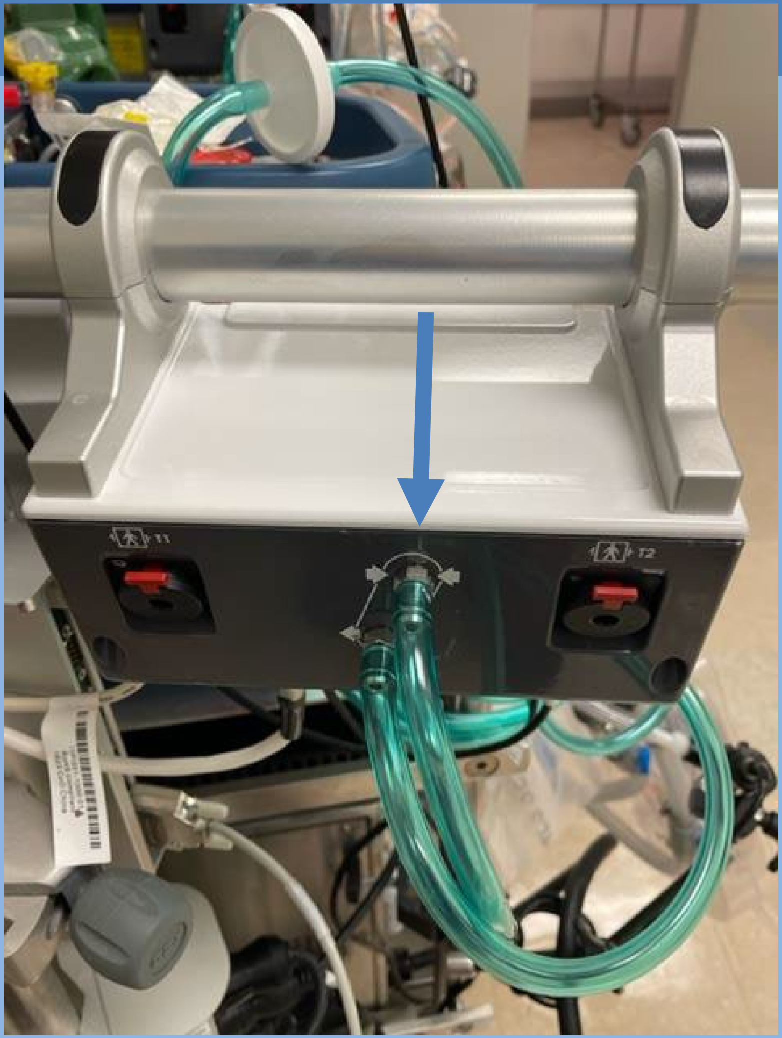
Medications



5 months in hospital

Discharge day


AMERICA'S #1 CONDOM
TROJAN
CONDOMS
ULTRA RIBBED
DESIGNED FOR ULTRA STIMULATION
VALUE PACK!
36 LUBRICATED LATEX CONDOMS
FOR CONTRACEPTION PLUS STI PROTECTION
Zoom In



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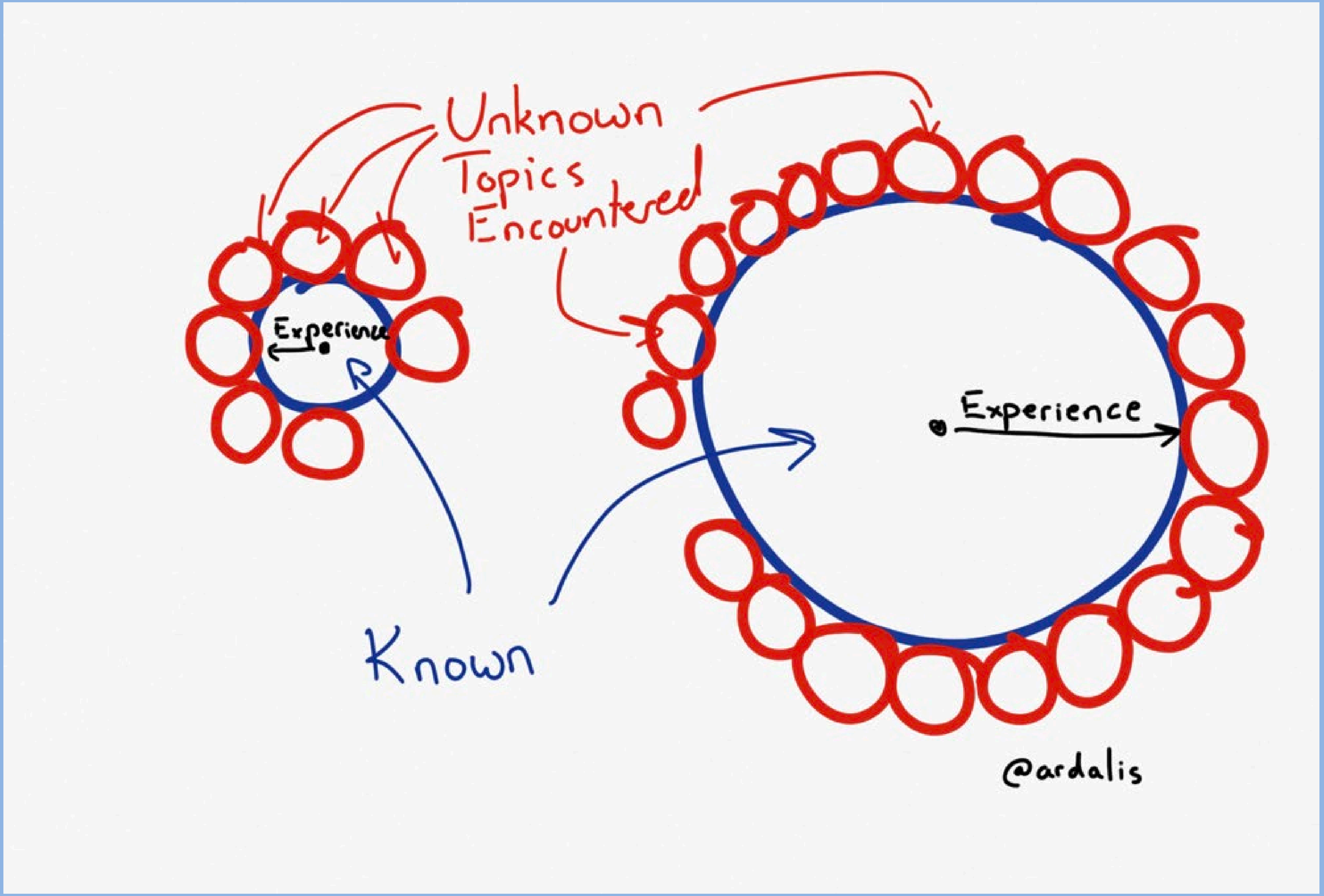
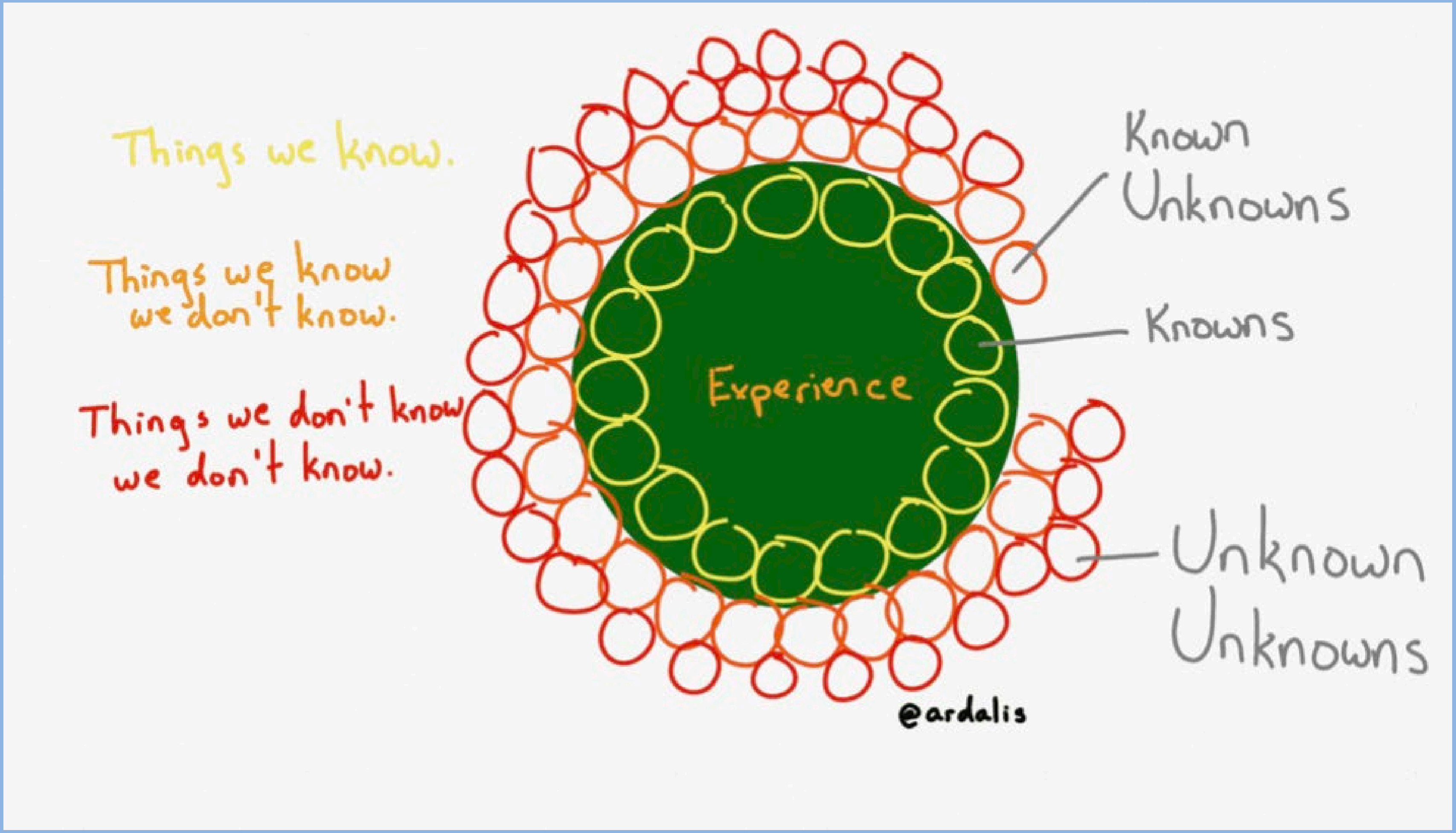
ECMO 2022



Unknown
Topics
Encountered
Experience
Experience
Known
@ardalis

ECMO 2022



Things we know.
Things we know we don't know.
Things we don't know we don't know.
Experience
Known Unknowns
Knowns
Unknown Unknowns
@ardalis

The Lancet · Saturday 12 August 1967

ACUTE RESPIRATORY DISTRESS IN ADULTS

TABLE II—RESPIRATORY DATA

Case	Respiratory support	Frequency (min.$^{-1}$)	$\dot{V}_E$(l./min.)	S_{aO_2}	$P_{IO_2}-P_{aO_2}$ gradient (mm. Hg)	P_{aCO_2} (mm. Hg)	pH	Compliance (l./cm. water)
1	Nasal oxygen (8 l./min.)	40	16·0	85	..	45·0	7·360	0·016
2	Bennett respirator (P.R.I.) (100% oxygen) ..	28	16·8	72	..	62·0	7·245	0·016
3	Bennett respirator (P.R.I.) (100% oxygen) ..	48	..	78	..	40·0	7·410	..
4	Bennett respirator (P.R.I.) (100% oxygen) ..	48	..	73	..	47·0	7·330	..
5	Engstrom respirator (70% oxygen) ..	48	8·0	85	..	63·0	7·270	..
6	Room air	36	14·4	84·4	..	37·0	7·338	0·017
7	Oxygen mask (3 l./min.)	64	..	79	..	22·0	7·420	..
8	Room air	44	20·0	41	536 (100% oxygen)	29·5	7·395	0·009
9	Bennett respirator (vol.) (80% oxygen) ..	20	8·0	84	320 (100% oxygen)	57·5	7·270	0·016
10	Nasal oxygen (7 l./min.)	48	48·0	87	..	30·5	7·420	0·019
11	Bennett respirator (P.R.I.) (40% oxygen) ..	36	25·2	74	..	29·5	7·480	0·017
12	Bennett respirator (P.R.I.) (40% oxygen) ..	34	12·8	72	220 (100% oxygen)	30·0	7·450	0·013

In view of the similar response of the lung to a variety of stimuli, a common mechanism of injury may be postulated. The loss of lung compliance, refractory cyanosis, and microscopic atelectasis point to alveolar instability as a likely source of trouble. The inability to

Microscopic appearance of the lungs was consistent in the 5 patients who died early in the course of the illness. Striking features were hyperæmia, dilated engorged capillaries, and areas of alveolar atelectasis (fig. 3). Interstitial and intra-alveolar hæmorrhage and œdema were also common (fig. 4). Alveolar macrophages were numerous. A striking finding was the presence of hyaline membranes

MEDICAL PROGRESS

ACUTE RESPIRATORY FAILURE IN THE ADULT (Third of Three Parts)

H. Pontoppidan, M.D., B. Geffin, M.D., and E. Lowenstein, M.D.

Patient	Ventilation Mode	Minute Ventilation (L/min)	Tidal Volume (L)[a]	PEEP (cm H_2O)	Auto-PEEP (cm H_2O)	Peak Inspiratory Pressure (cm H_2O)	Mean Airway Pressure (cm H_2O)
1	SIMV/AC	14/21	0.8/0.8	15/15	NA	70/67	30/33
2	AC/SIMV	24/27	1/0.85	5/15	17/20	56/60	34/30
3	SIMV/SIMV	13/11	0.75/0.75	5/5	NA	67/77	16/16
4	SIMV/SIMV	10/11	0.8/0.8	7/10	NA	65/75	NA
5	SIMV[b]	21	0.6	15	14	80	38
6	SIMV/SIMV	15/12	0.95/0.95	15/10	0/0	54/54	19/17
7	SIMV/SIMV	11/16	0.9/1	10/15	NA	53/47	26/24
8	AC/AC	23/22	0.75/0.75	12/15	NA	55/57	26/28
9	AC/AC	11/11	0.6	12/12	NA	52/55	24/32
10	AC/AC	17/17	0.7	20/16	NA	75/50	NA
11	NA[c]						
12	SIMV/SIMV	9/6	1/1	5/5	0/0	32/28	15/9
13	AC/AC	12/9	0.38/0.38	14/14	NA	80/80	30/28

PROLONGED EXTRACORPOREAL OXYGENATION FOR ACUTE POST-TRAUMATIC RESPIRATORY FAILURE (SHOCK-LUNG SYNDROME)

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.

Hill JD, Bramson M. NEJM, 1972
Photo courtesy of Robert Bartlett, MD

1979

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;
Robert J. Fallat, MD; Robert H. Bartlett, MD; L. Henry Edmunds, MD; Alan H. Morris, MD;
E. Converse Peirce II, MD; Arthur N. Thomas, MD; Herbert J. Proctor, MD; Philip A. Drinker, PhD;
Philip C. Pratt, MD; Anna Bagniewski, MA; Rupert G. Miller, Jr, PhD

NHLBI-sponsored prospective RCT
Conventional MV alone vs. ECMO with MV

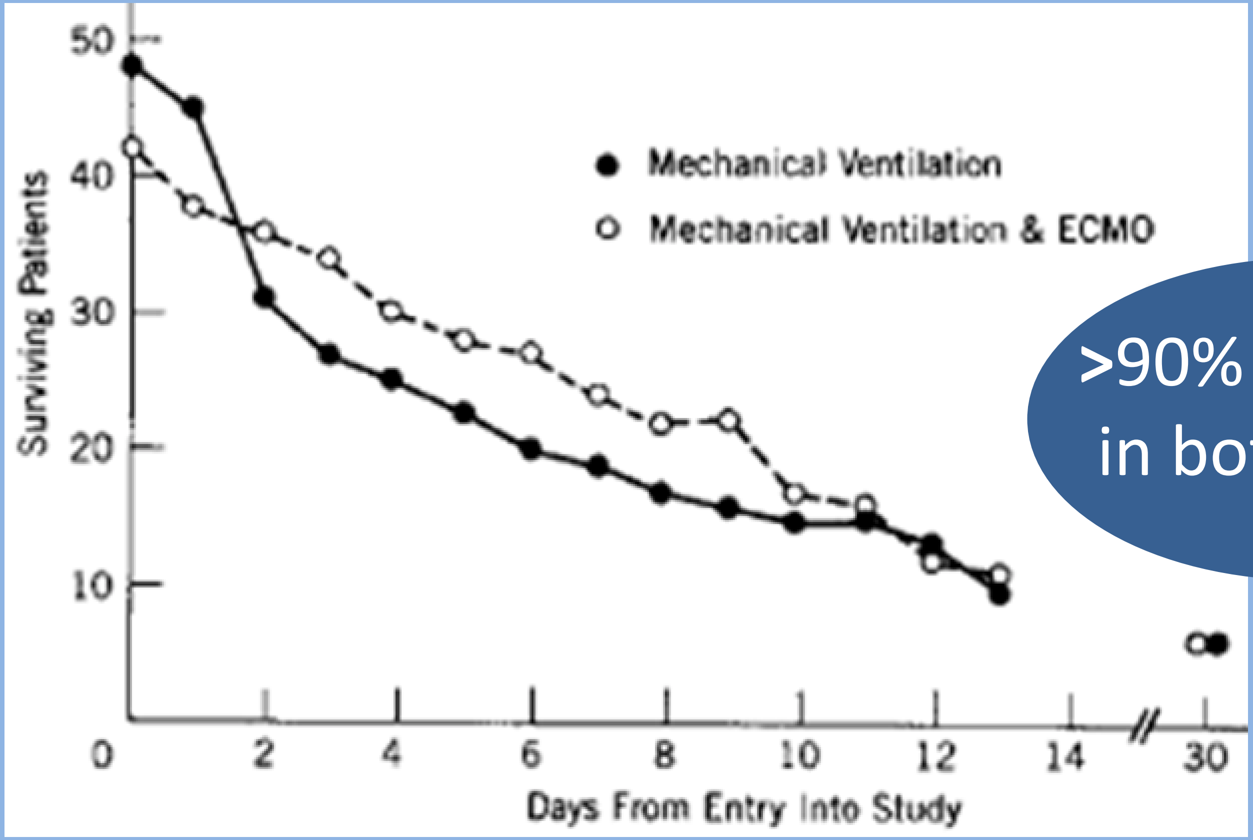
90 patients   P:F < 50
9 centers

Zapol WM, et al. JAMA 1979

Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure

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

(*JAMA* 242:2193-2196, 1979)



>90% mortality in both groups

Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure

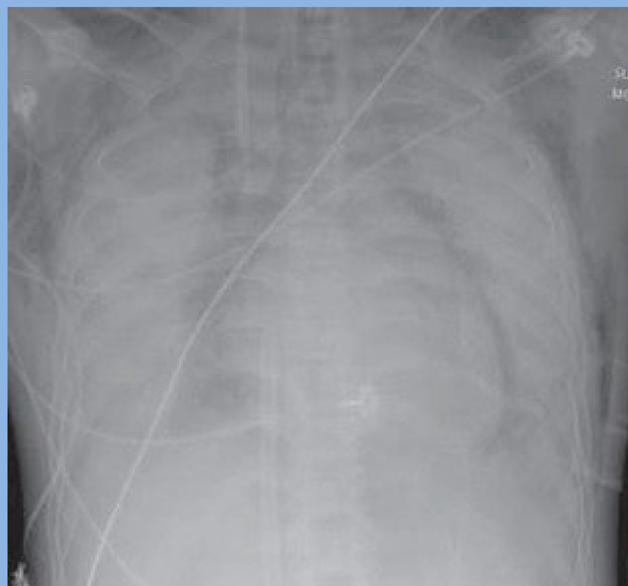
Warren M. Zapol, MD; Michael T. Snider, MD, PhD; J. Donald Hill, MD;

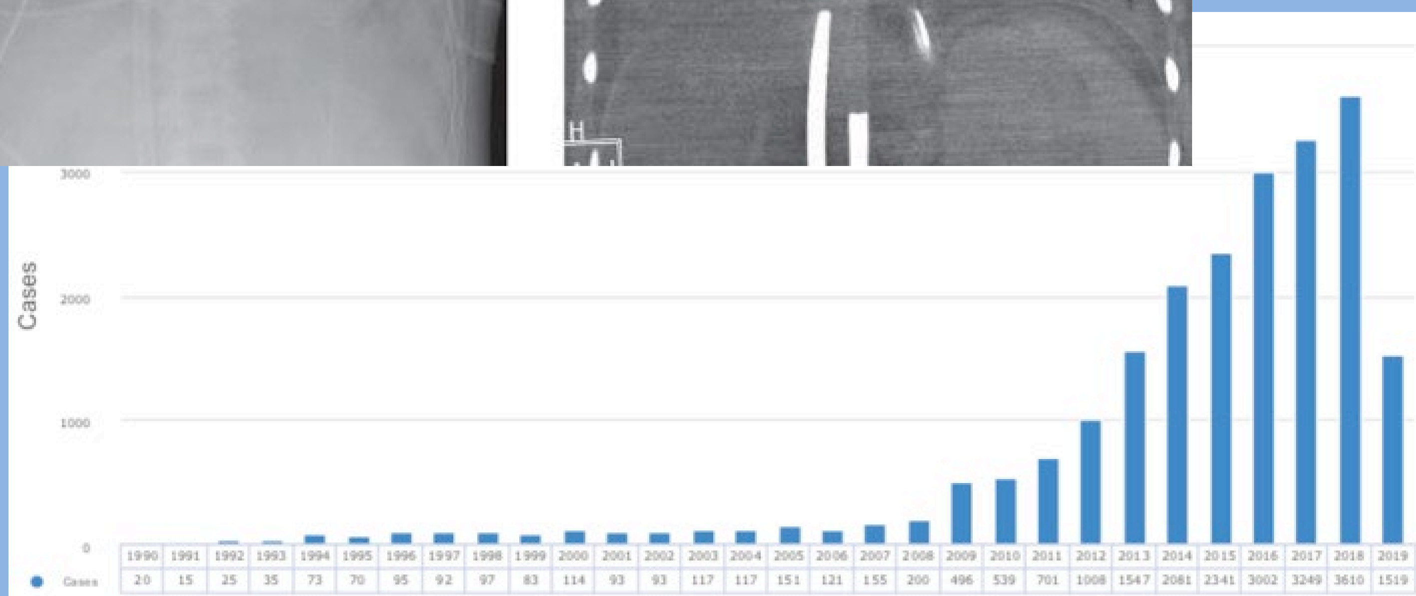
(*JAMA* 242:2193-2196, 1979)

Limitations

- ✓ Minimal ECMO experience
- ✓ VA configuration
- ✓ Early ECMO technology
- ✓ High levels of anticoagulation
- ✓ Fixed 5d run
- ✓ Injurious MV strategies

Modern VV Era





Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome

The Australia and New Zealand Extracorporeal Membrane Oxygenation (ANZ ECMO)

JAMA. 2009;302(17):1888-1895

15 ICUs in Australia & New Zealand
ECMO for H1N1-associated ARDS

68 patients
Median age 34
Median P:F 56

Observational

Davies A, et al. JAMA 2009
Davies A, et al JAMA 2010

Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome

The Australia and New Zealand Extracorporeal Membrane Oxygenation (ANZ ECMO)

JAMA. 2009;302(17):1888-1895

15 ICUs in Australia & New Zealand
ECMO for H1N1-associated ARDS

ELSO Registry Data

67% survival H1N1

68 patients
Median age 34
Median P:F 56

75% Survival with ECMO

Davies A, et al. JAMA 2009
Davies A, et al JAMA 2010

Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome

The Australia and New Zealand Extracorporeal Membrane Oxygenation (ANZ ECMO)

JAMA. 2009;302(17):1888-1895

Limitations

- ✓ Retrospective
- ✓ Observational
- ✓ No control
- ✓ Young patients with H1N1 influenza

CESAR Trial

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

RCT
180 adults (18-65y)
Severe respiratory failure
Murray score > 3 or pH < 7.2

Peek G, et al. Lancet 2009

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

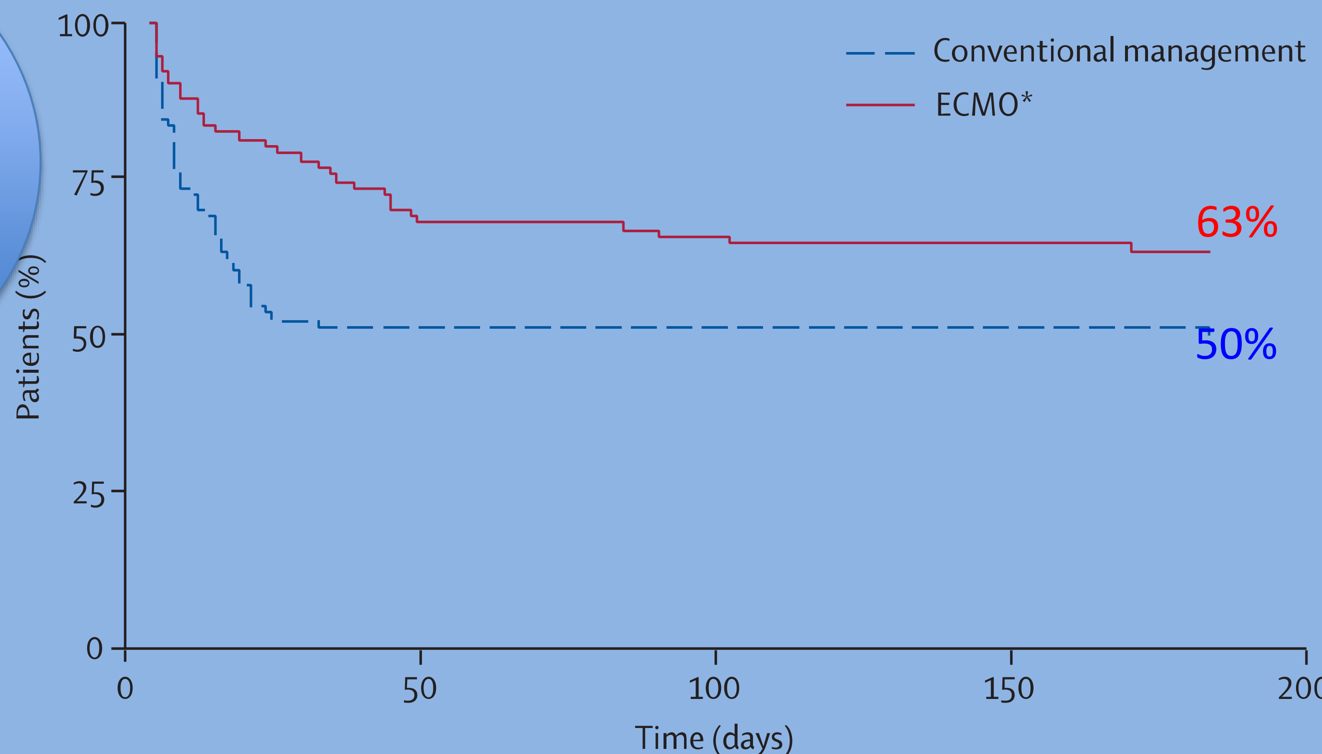
Lancet 2009; 374: 1351–63

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

Disorder leading to study entry		
Hypoxia†	85 (94%)	87 (97%)
Murray score	3·5 (0·6)	3·4 (0·3)
PaO_2/FiO_2 (mm Hg^{-1})	75·9 (29·5)	75·0 (35·7)
Positive end-expiratory pressure (cm H_2O)	13·7 (9.6)	14·2 (9·4)
Lung compliance (mL/cm H_2O)	27·4 (12·2)	25·3 (8·0)
Chest radiograph (quadrants infiltrated)	3·5 (0·7)	3·7 (0·6)
Uncompensated hypercapnoea†	5 (6%)	3 (3%)
pH	7·1 (0·1)	7·1 (0·1)

6-month survival

Primary outcome:
Survival without severe disability
ECMO: 63%
Convent: 47%
p=0.03



Patients at risk					
Conventional management	90	45	44	44	0
ECMO*	90	61	59	58	0

Figure 2: **Kaplan-Meier survival estimates**

Peek G, et al. Lancet 2009

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

Lancet 2009; 374: 1351–63

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

Limitations

✓ No MV protocol in control group

- Any LTVV: 90% vs. 70% (p=<0.001)
- Days at LTVV: 23 vs. 15 days (p=<0.001)

✓ Not all patients received ECMO

- 19% of patients in ECMO arm did not receive ECMO

✓ No transport on ECMO

- 6% of patients in ECMO arm died during transport

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

Lancet 2009; 374: 1351–63

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

CESAR Conclusion

Referral to an ECMO center improves outcomes as part of a standard management protocol for patients with severe ARDS

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 MAY 24, 2018 VOL. 378 NO. 21

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*

EOLIA

Multinational RCT

Adults with very severe ARDS

Intubated <7 days

n=249

Combes A, et al. NEJM, 2018

Randomization

Conventional Management

- Lung protective ventilation
  - VT 6 cc/kg IBW
  - Pplat 28-30 cmH_2O

- iNO, proning, paralysis

ECMO

- Ultra lung protective ventilation
  - RR 10-30
  - PEEP ≥10 cm H_2O
  - FIO_2 30-60%
  - Pplat ≤24 cm H_2O

Combes A, et al. NEJM, 2018

Inclusion criteria for EOLIA

✓ Diagnosis of ARDS

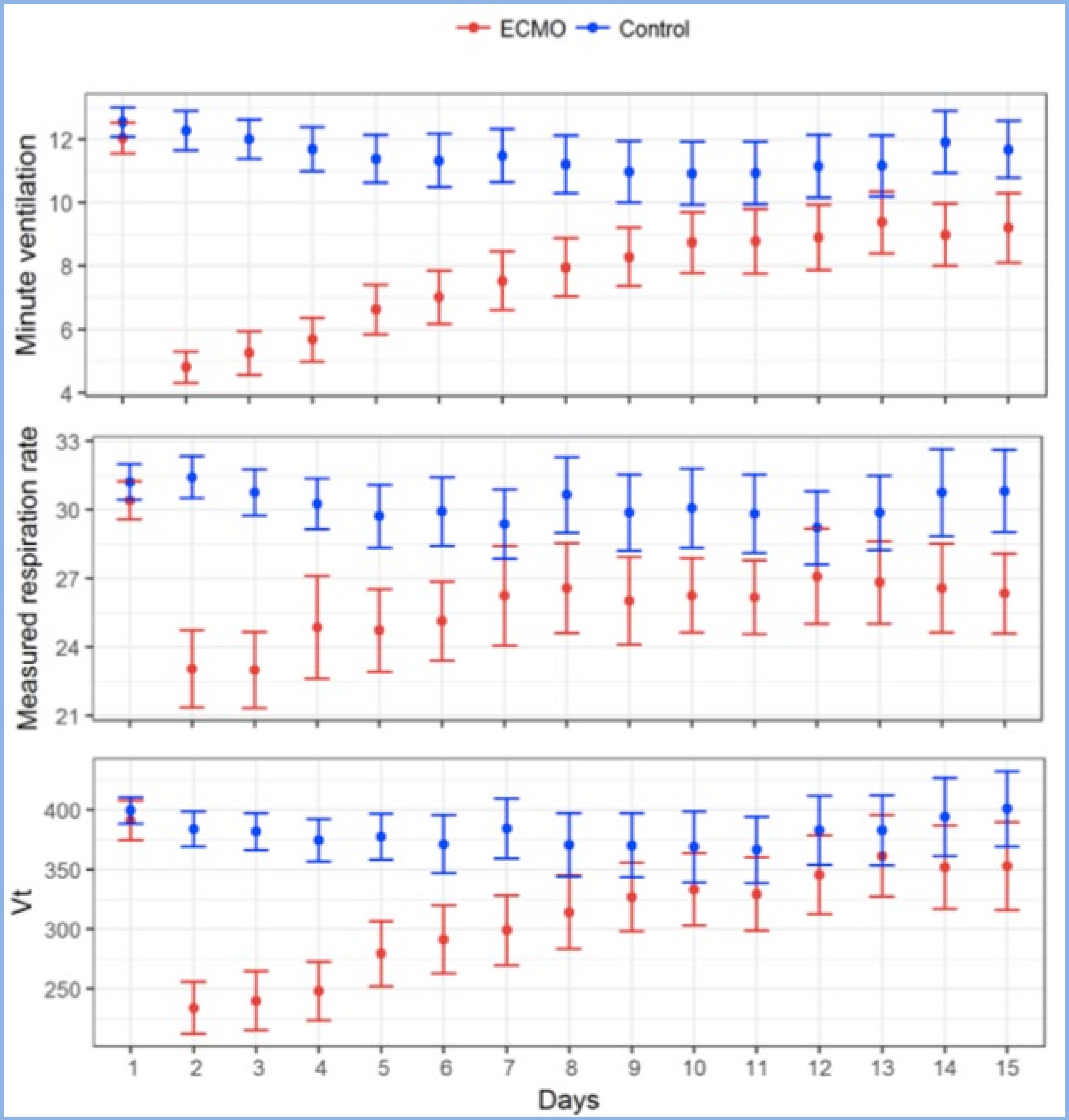
✓ Intubated <7 days

✓ ABG criteria

- PaO_2:F_IO_2 <80 for 6 hours
- PaO_2:F_IO_2 <50 for 3 hours
- pH <7.25 with $PaCO_2$ ≥ 60 mmHg

for 6 hours with RR of 35 and Pplat ≤ 32 cm H_2O

Combes A, et al. NEJM, 2018



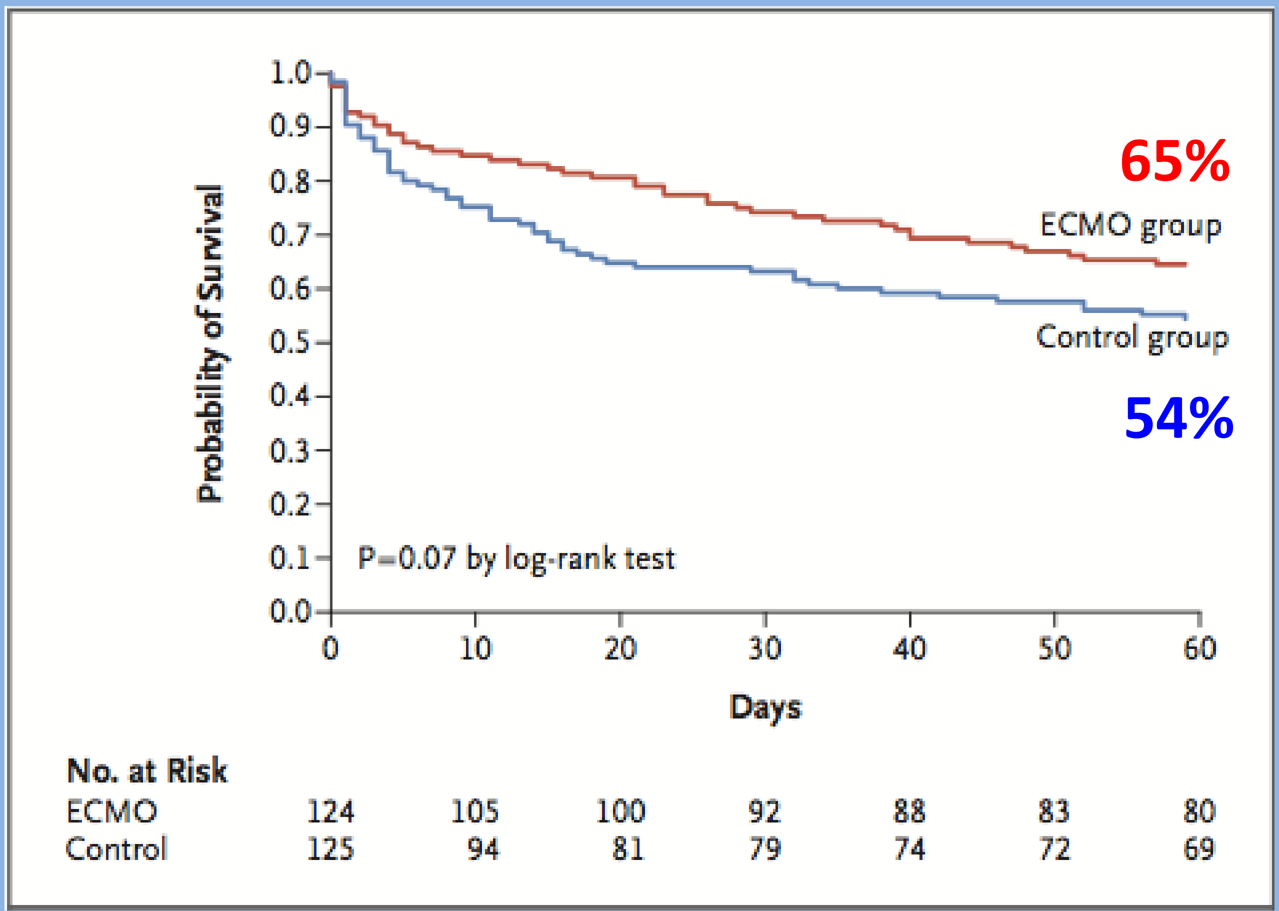
Combes A, et al. NEJM, 2018

Did EOLIA work?

The trial was stopped early for futility

To reach their primary outcome of 20% reduction in mortality

EOLIA
Primary outcome: 60 Day Survival

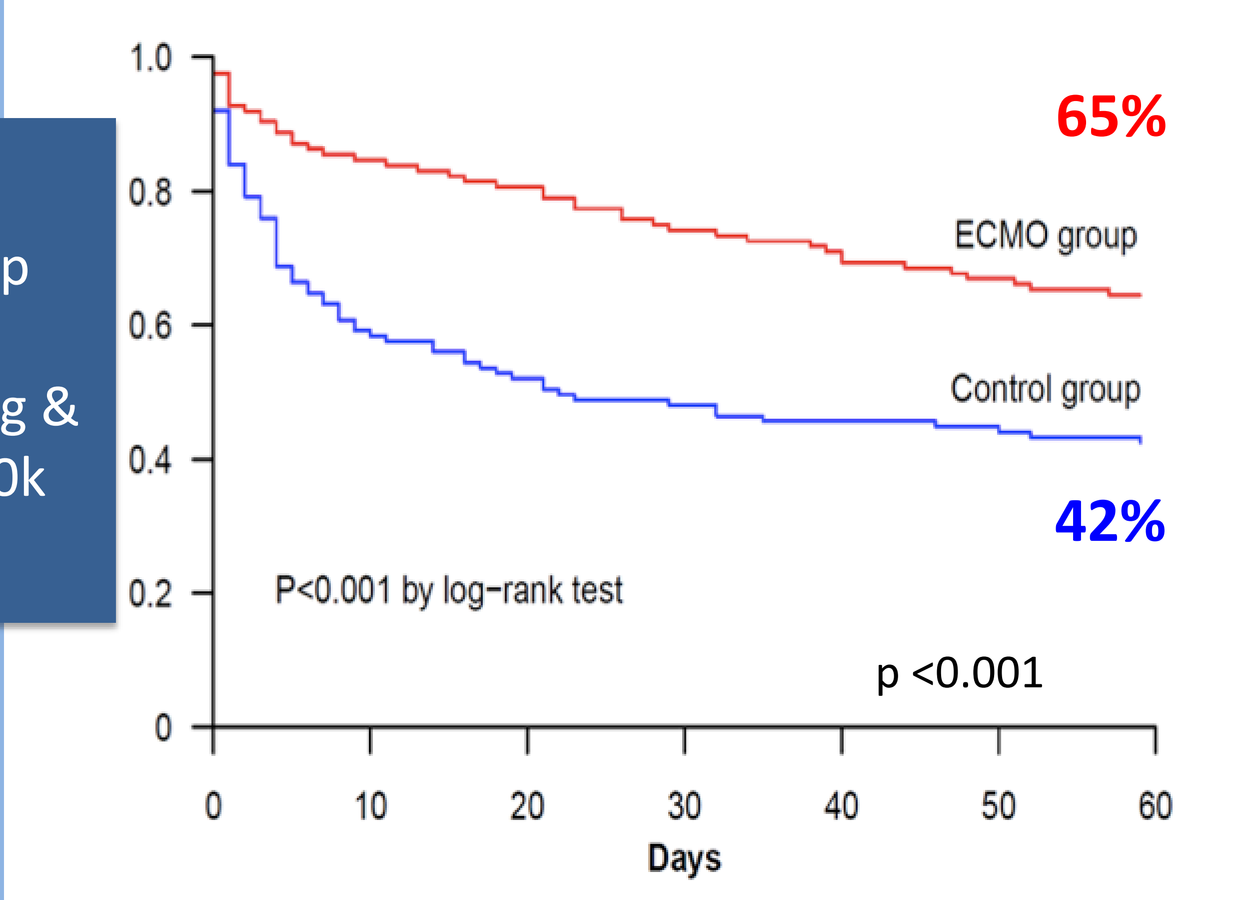


Combes A, et al. NEJM, 2018

Secondary Outcome:
Risk of Death or Treatment Failure

ECMO group

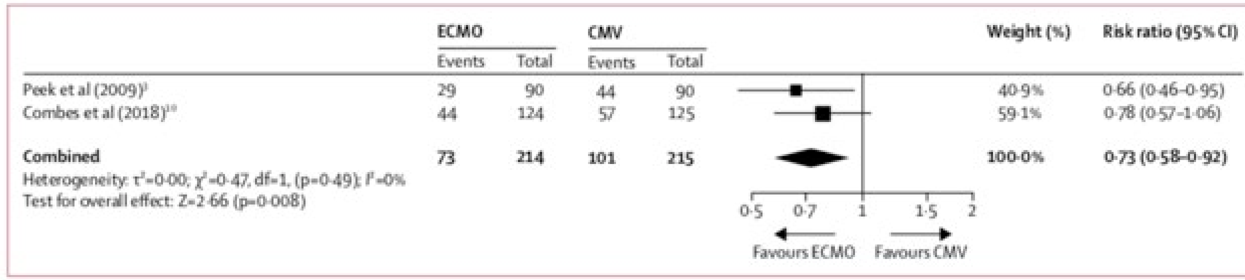
More bleeding & platelets <20k



Combes A, et al. NEJM, 2018

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

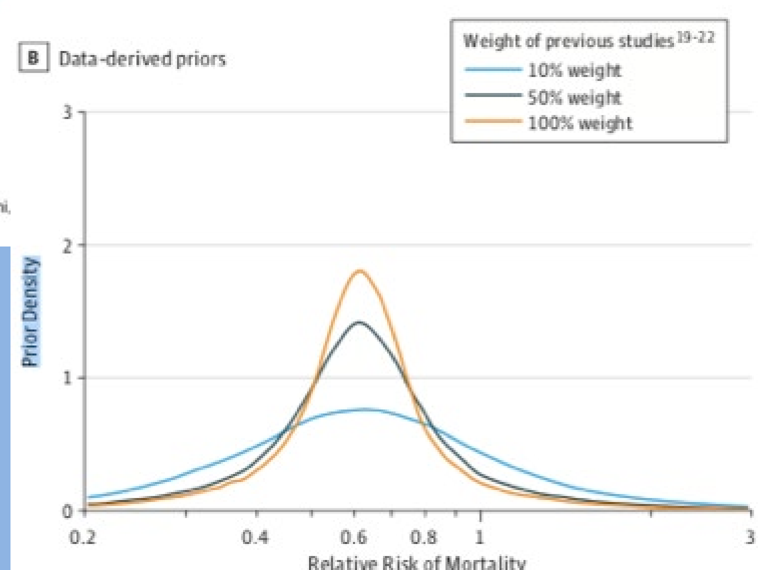
Laveena Munshi, Allan Walkey, Ewan Goligher, Tai Pham, Elizabeth M Uleryk, Eddy Fan



JAMA | Special Communication | CARING FOR THE CRITICALLY ILL PATIENT

Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome and Posterior Probability of Mortality Benefit in a Post Hoc Bayesian Analysis of a Randomized Clinical Trial

Ewan C. Goligher, MD, PhD; George Tomlinson, PhD; David Hajage, MD, PhD; Duminda N. Wijeysundera, MD, PhD; Eddy Fan, MD, PhD; Peter Jüni, Daniel Brodie, MD; Arthur S. Slutsky, MD; Alain Combes, MD, PhD



Munshi L, et al. Lancet, 2019
Goligher E, et al. JAMA, 2018

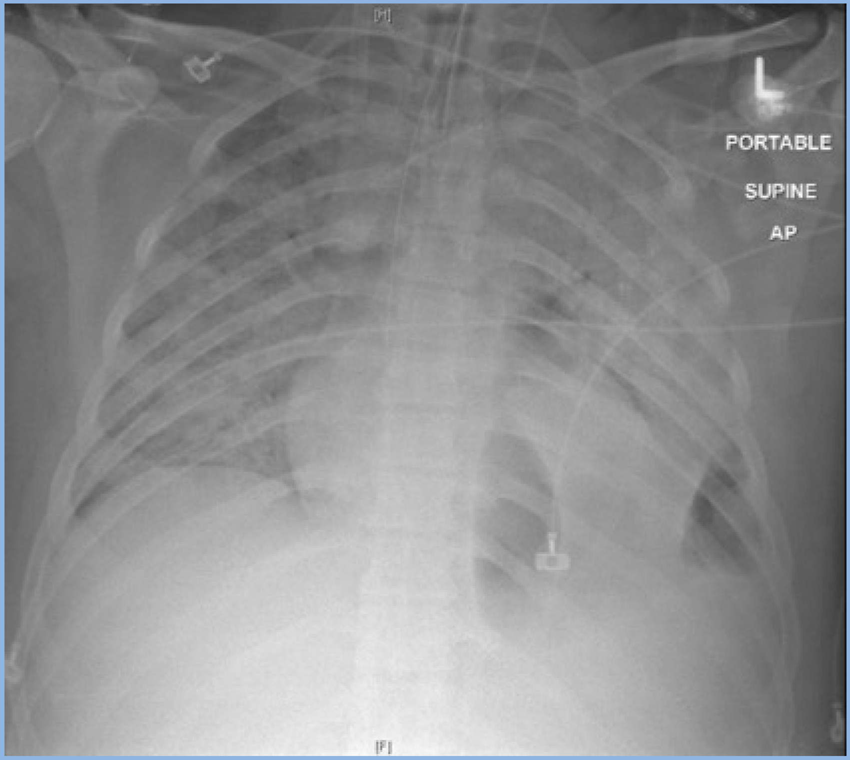
Mechanical Ventilation

25 year-old man with PNA and ARDS cannulated onto VV ECMO

Pre-ECMO ABG

ABG: pH 7.05 / $PaCO_2$ 85 / PaO_2 57

AC/PC: RR 35 / P_I 32 / PEEP 15 / F_IO_2 100%



25 year-old man with PNA and ARDS cannulated onto VV ECMO

ECMO Settings

Blood Flow: 4.5 LPM

RPM: 3250

Sweep: 4 LPM

F_DO_2: 100%

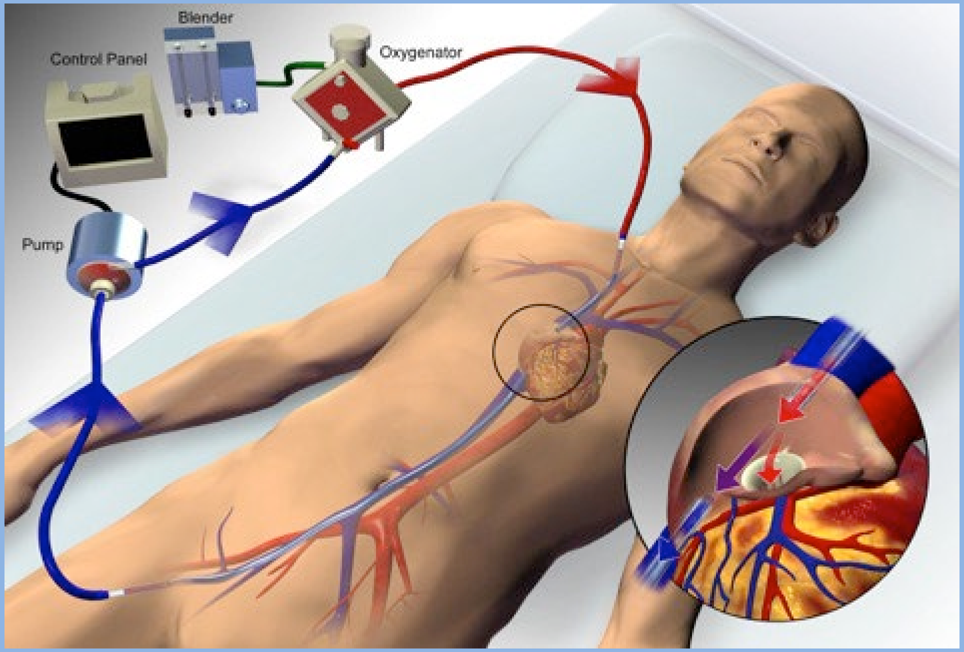
Pre-Ox Sat: 74%

Drainage P: 22

Delta P: 18

Line Pressures: 158/140

ECMO Configuration



ABG: 7.38 / 46 / 110

Agerstrand C, et al. ASAIO, 2014
Courtesy of COACH, with permission from CollectedMed.com

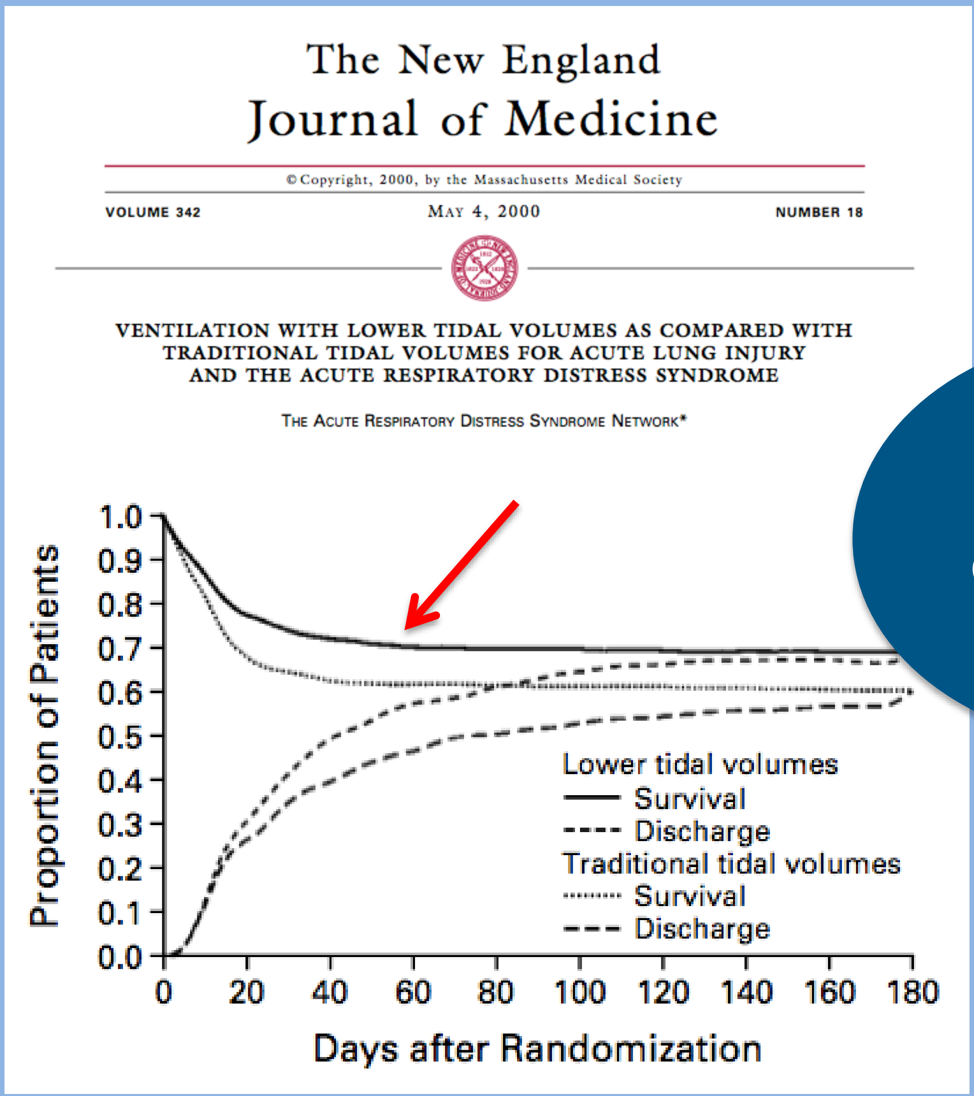
Incremental decrease in ventilator over several hours to target settings

What are target settings?

“Lung Rest”

Shift the work from the patient to the circuit

ARDSnet ARMA study


The New England
Journal of Medicine

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VOLUME 342 MAY 4, 2000 NUMBER 18

VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

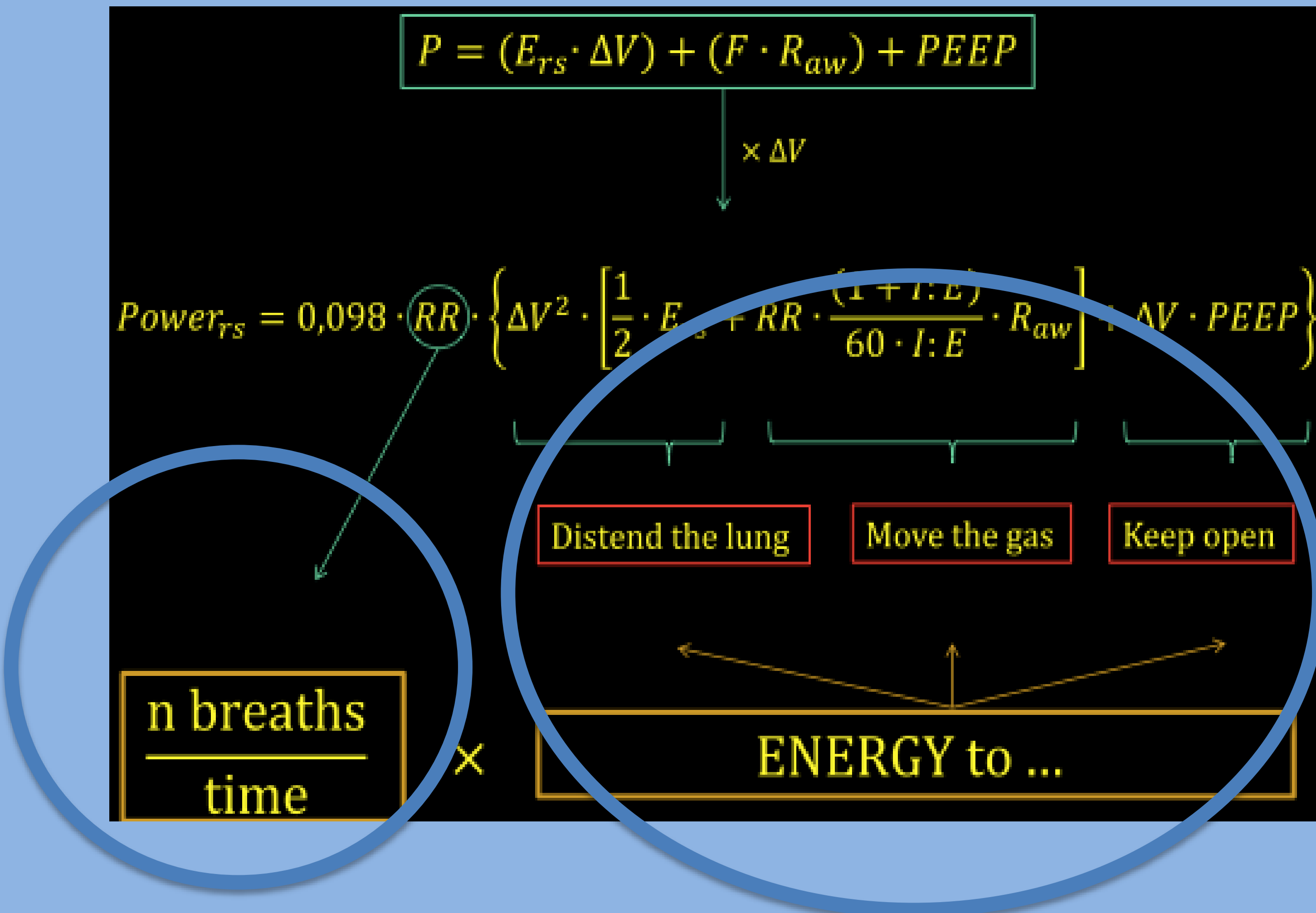
THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*

LTVV Mortality:
31%

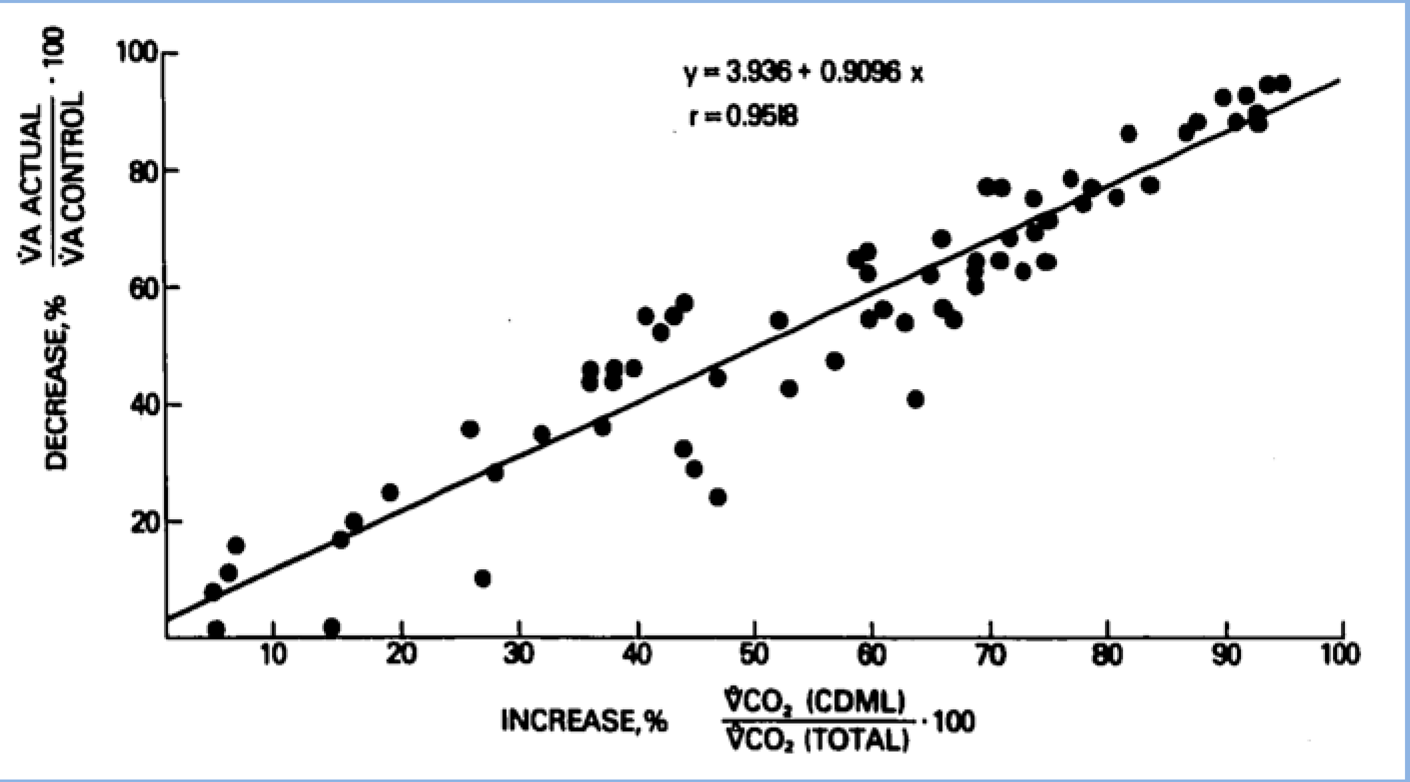
Conventional TV
Mortality:
40%

ARDSnet, NEJM 2000

Mechanical Power



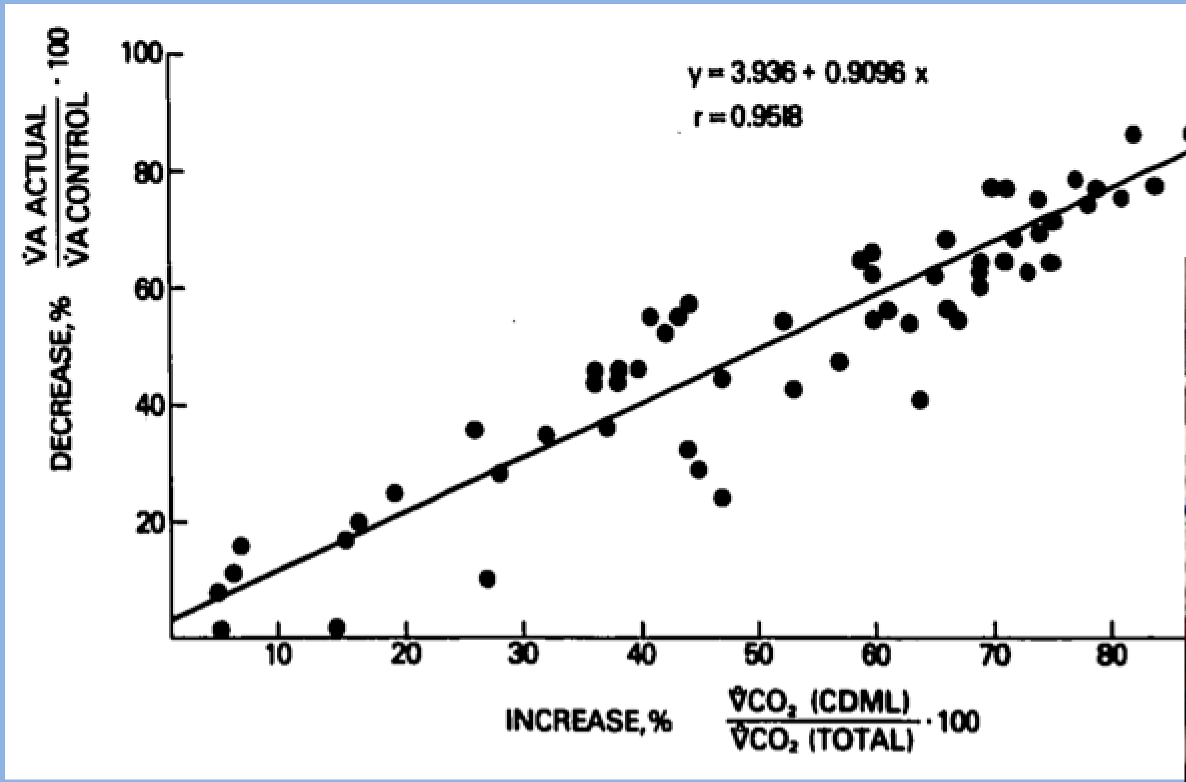
Gattinoni L, et al. Critical Care, 2017

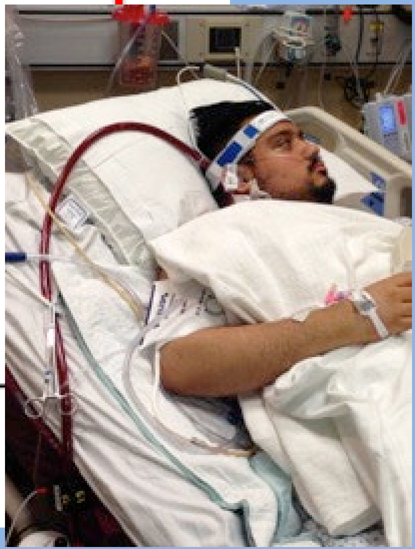


As CO_2 removal increased via the membrane lung, alveolar ventilation decreased proportionally (TV & RR both decreased)

As CO_2 removal neared 100% of CO_2 production, alveolar ventilation ceases

Kolobow T, et al. Anesthesiology, 1977



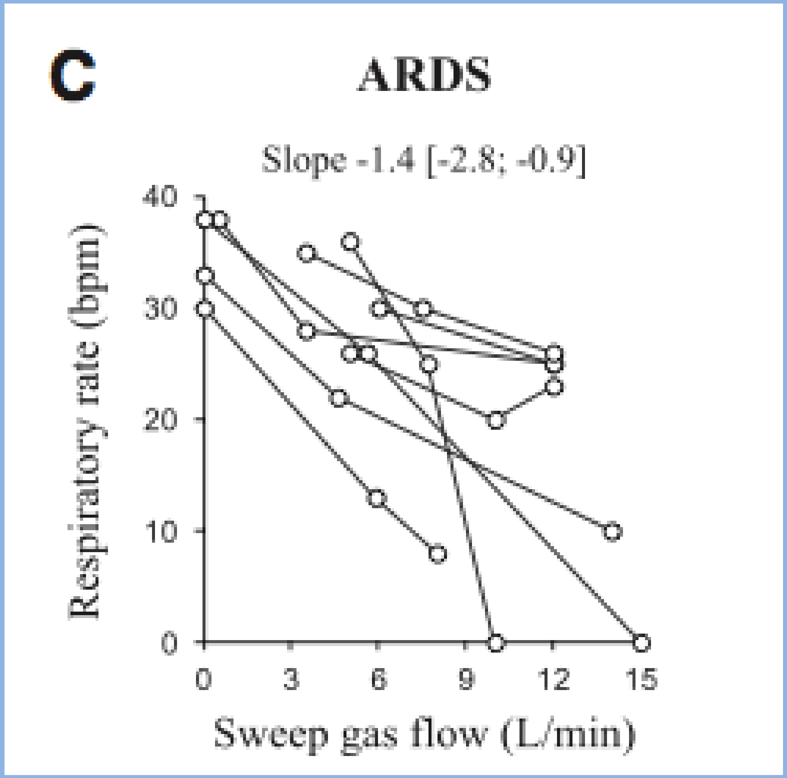


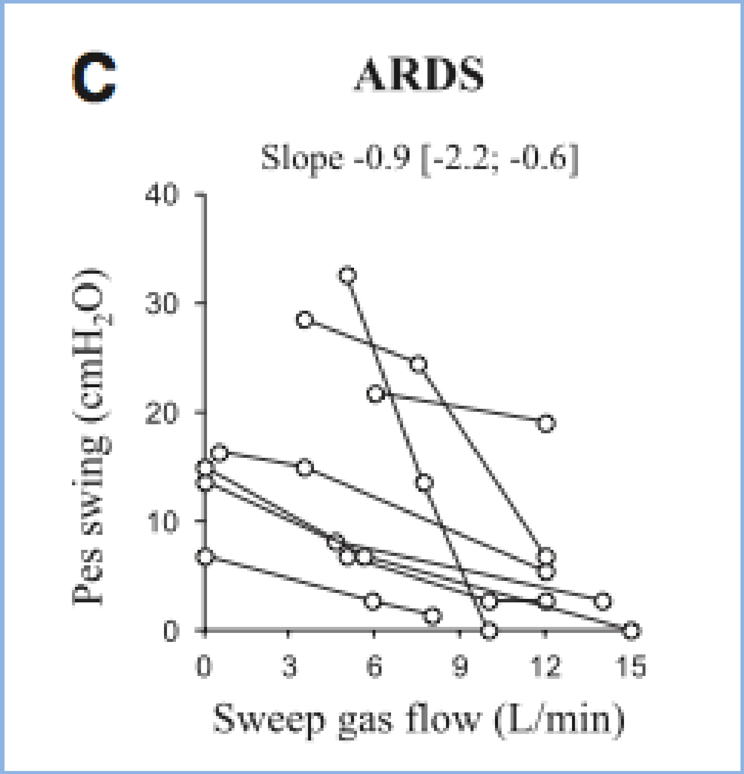
As CO_2 removal increased via the membrane lung, alveolar ventilation decreased proportionally (TV & RR both decreased)

As CO_2 removal neared 100% of CO_2 production, alveolar ventilation ceases

Kolobow T, et al. Anesthesiology, 1977

Decreased respiratory effort in ARDS





Crotti S, et al. Anesthesiology, 2017

Transition of respiratory effort from the patient to the circuit

Parameter	Low Support	High Support
Sweep gas (L/min)	2.5	11.9
RR (breaths/min)	33	15
pH	7.46	7.49
$PaCO_2$ (mmHg)	37	34
CO_2 removal (mL/min)	83	226

At high sweep:

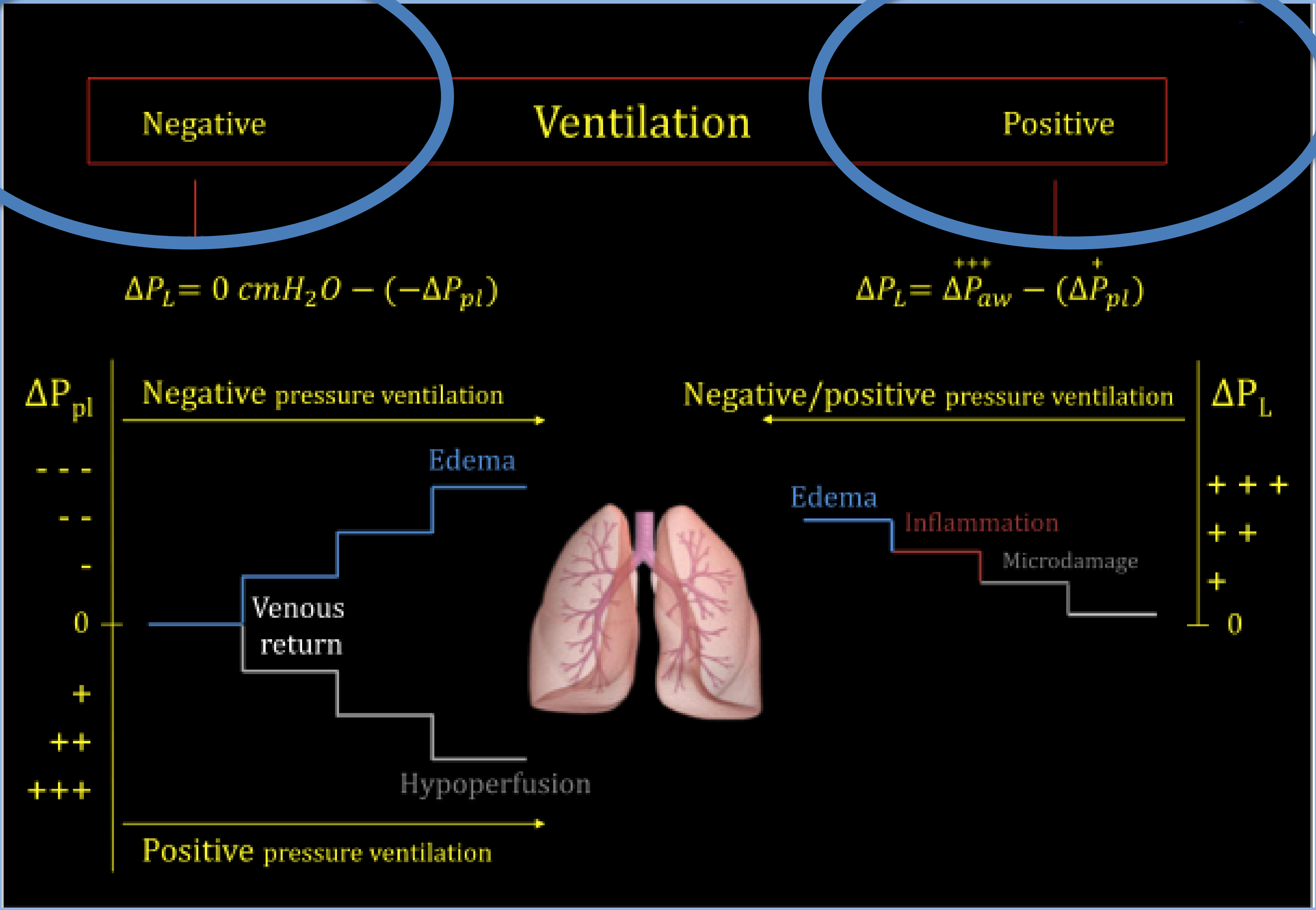
-Decreased PaO_2
-Increased shunt fraction

Crotti S, et al. Anesthesiology, 2017

Spontaneous breathing does not necessarily mean prevention of lung injury

…Ventilation-associated lung injury

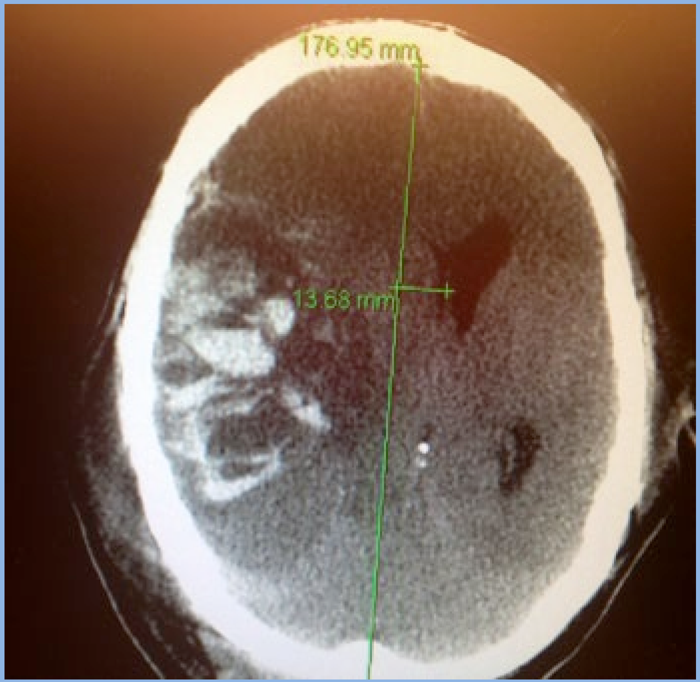
Crotti S, et al. Anesthesiology, 2017

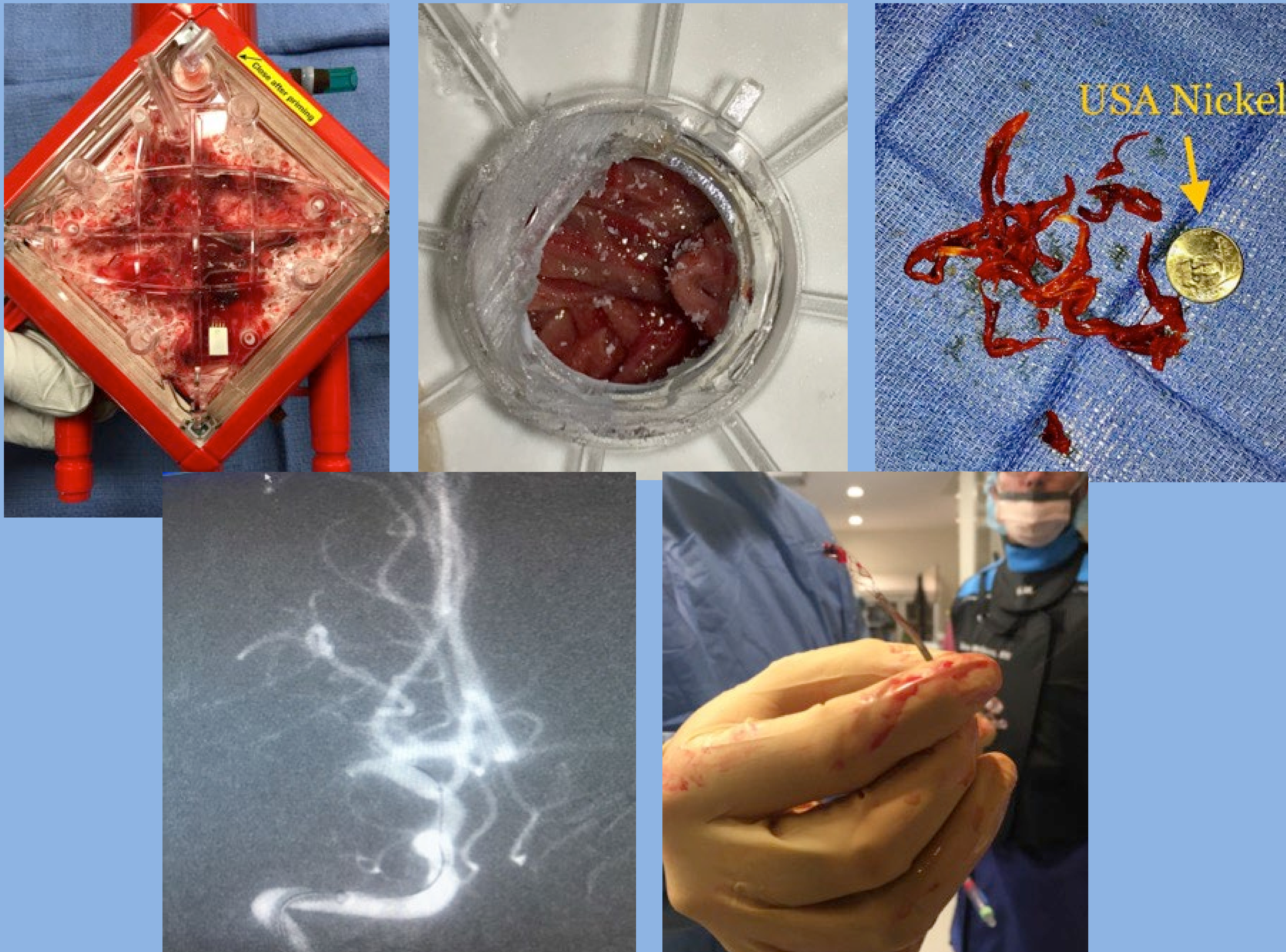


Gattinoni L, et al. Critical Care, 2017

Anticoagulation

Bleeding complications are the most common complications reported during ECMO




USA Nickel

Activated Clotting Time (ACT)

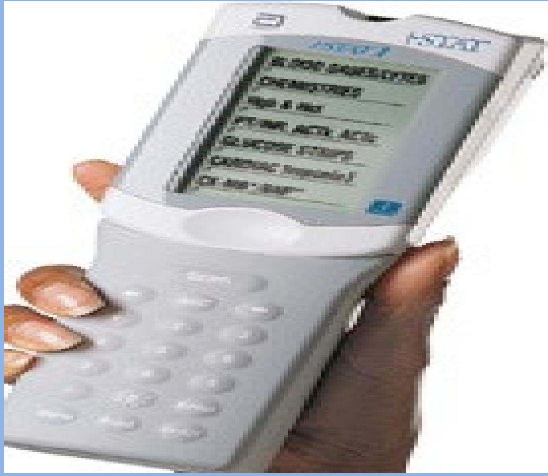
Historically most used test

Developed 1966, used in cardiopulmonary bypass

Point of Care Test (POC)

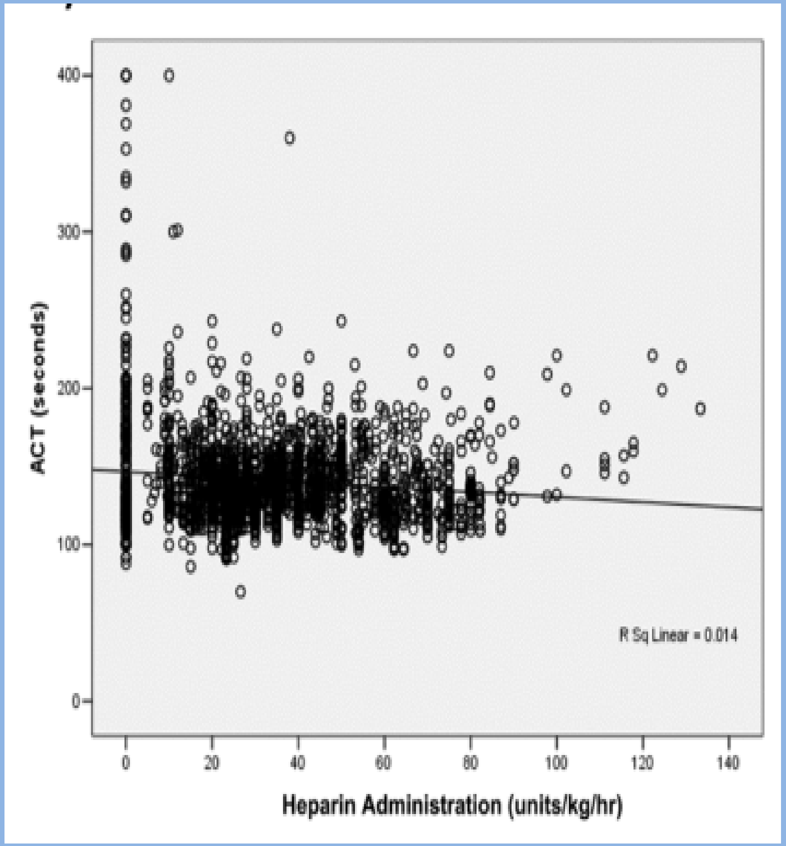
Whole blood sample

Sample	Range
Normal	90-120 s
CPB	>480 s
ECMO	180-220 s



ACT is affected by multiple factors, making is less reliable as a measurement of coagulation status

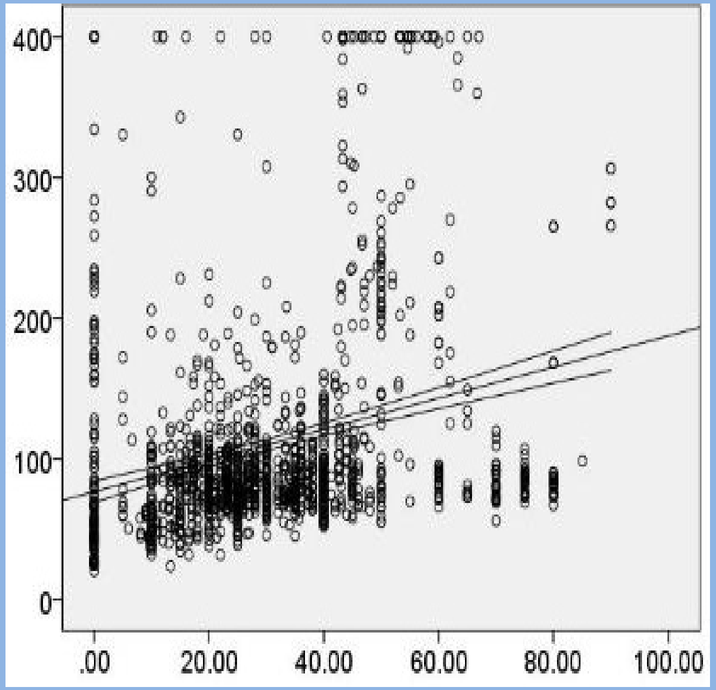
- Platelet count & function
- Factor Deficiencies
  - VIII, IX, X, XI, XII, fibrinogen
- Elevated D-dimer
- Lupus anticoagulant
- Oral anticoagulants
- Hypothermia
- Hemodilution
- Patient age
- Type of machine



Maul T, et al. PCCM 2012

Activated Partial Thromboplastin Time (aPTT)

- Prolonged by
  - >20-40% factor deficiency
  - Acquired clotting factor inhibitors
  - LAC
  - Warfarin



- Shortened by
  - Acute phase reactants

Maul T, et al. PCCM, 2012

ACT vs. aPTT in Adult ECMO patients n=46

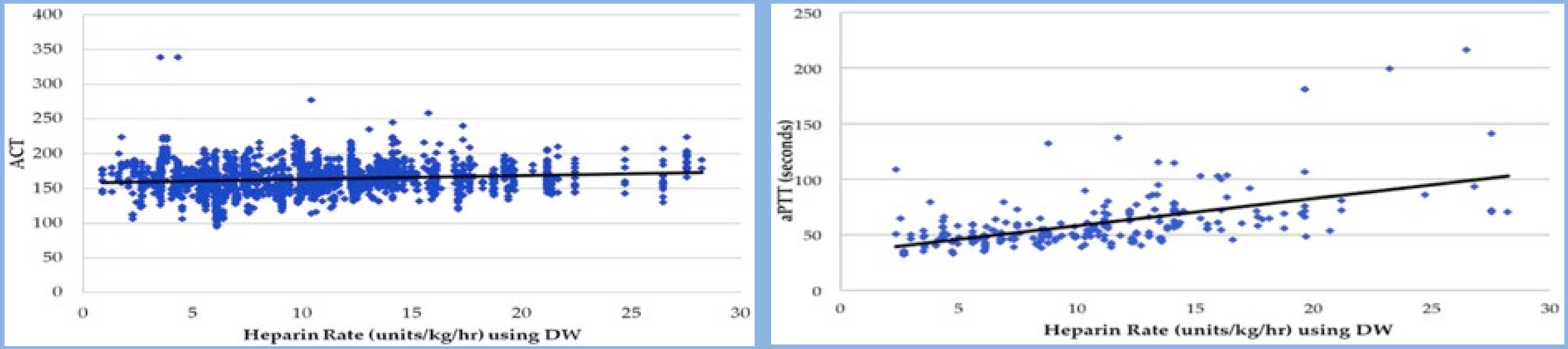


Table 3. Pearson product-moment correlation coefficient for heparin rate and either ACT or aPTT.

Heparin rate	Correlation coefficient for ACT and heparin rate	Correlation coefficient for aPTT and heparin rate
Heparin rate (units/hr)	0.11	0.43
Heparin rate (units/kg/hr) IBW	0.12	0.52
Heparin rate (units/kg/hr) DW	0.14	0.55
Heparin rate (units/kg/hr) ABW	0.14	0.54

IBW: ideal bodyweight, DW: dosing weight, ABW: actual bodyweight.

Tallah S, et al. Perfusion, 2014

The "Gold Standard" for Heparin Measurement: Anti-Factor Xa

Anti-factor Xa levels measure the heparin-antithrombin complex thus are specific to the anticoagulation effect of heparin

Considered more accurate than other testing modalities.

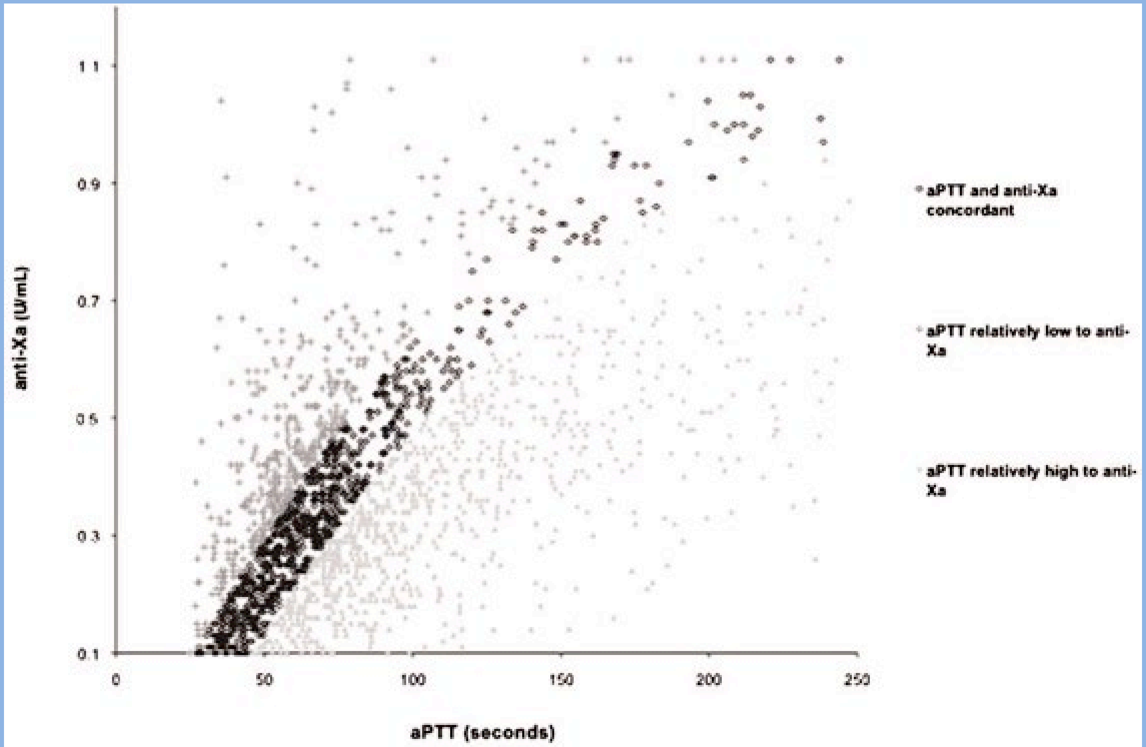
Not affected by other coagulopathies

Price E, et al. Annals Pharmacotherapy, 2013

The "Gold Standard" for Heparin Measurement: Anti-Factor Xa

Frequently discordant with aPTT in 42% of 2300 data pairs
Associated increased mortality

- Therapeutic range 0.3-0.7 u/mL
- Often lower target 0.1-0.3 u/mL



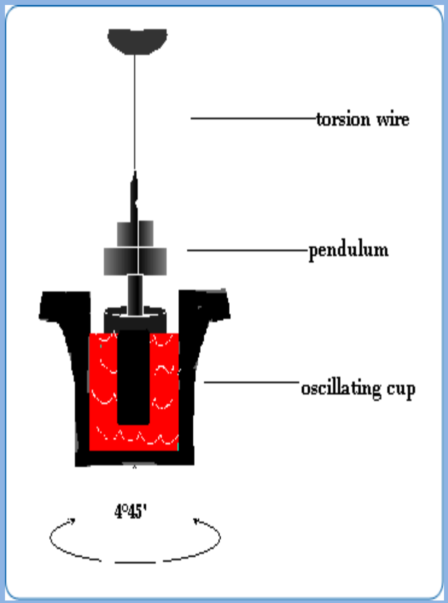
Price E, et al. Annals Pharmacotherapy, 2013

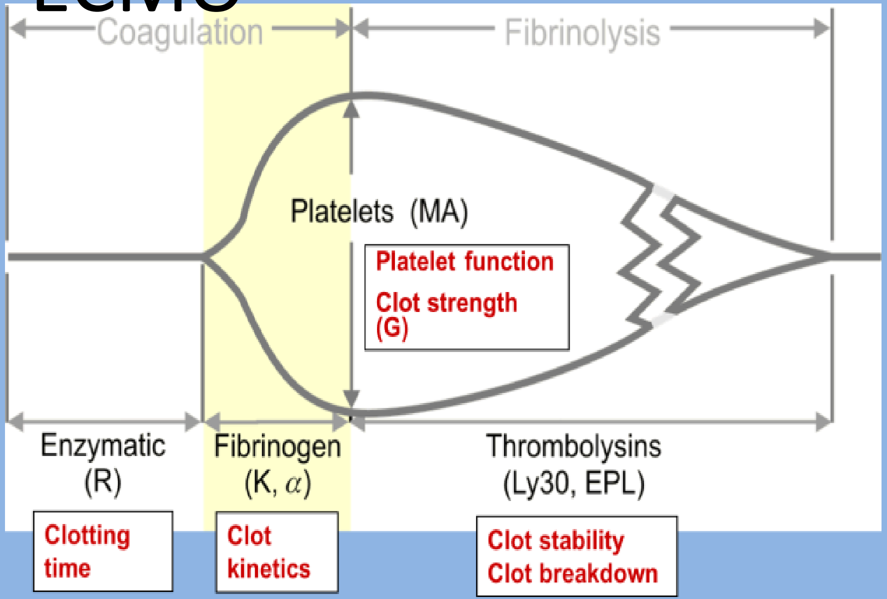
Viscoelastic testing
TEG or ROTEM

More recently being used during ECMO support

Measure total hemostatic function

Validity & clinical impact not well-studied in ECMO





Modern ECMO Experience

Low-dose anticoagulation protocol is favored

EOLIA

aPTT 40-55 s

-or -

Anti-Xa 0.2-0.3

Cannula thrombosis 14%

Circuit changed 28%

No ischemic CVA

Combes A, et al. NEJM, 2018

Modern ECMO Experience

Low-dose anticoagulation protocol is favored

aPTT 40-60 seconds

Variables	Median (IQR) (N = 38)
Hemoglobin, g/dL	8.2 (7.9–8.7)
pRBCs transfused	
Total per patient	
Units	1 (0–3)
Volume, mL	250 (0–750)–300 (0–900)
Per day of ECMO support	
Units	0.11 (0–0.33)
Volume, mL	27.8 (0–83.3)–33.3 (0–100)
aPTT, s	46.5 (40.8–50.8)

Agerstrand C, et al. Ann Thoracic Surg, 2015

Modern ECMO Experience

Low-dose anticoagulation protocol is favored

aPTT 40-60 seconds

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Volume, mL	27.8 (0–83.3)–33.3 (0–100)
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Agerstrand C, et al. Ann Thoracic Surg, 2015

Systematic review of anticoagulation for VV ECMO

	Bleeding	Thrombosis
Overall	16%	53%
aPTT (n = 199)	19%	27%
aPTT > 60 (n=43)	56%	7%
aPTT <60 (n=56)	8%	32%

Role of anticoagulation unclear
Limited by retrospective, observational design
& patient heterogeneity

Sklar M, et al. AATS, 2016

What about physical rehabilitation of patients on ECMO?

ECMO in the modern era…

- ✓ Advances in circuit technology
- ✓ Innovative cannulation techniques
- ✓ New exercise equipment/cannula security devices
- ✓ Evolving approach to ICU management

Extracorporeal membrane oxygenation as a bridge to pulmonary transplantation

Charles W. Hoopes, MD,[a] Jasleen Kukreja, MD,[b] Jeffery Golden, MD,[c] Daniel L. Davenport, PhD,[a] Enrique Diaz-Guzman, MD,[d] and Joseph B. Zwischenberger, MD[a]

U. Kentucky and UCSF

31 patients bridged 2003-2012

Pulmonary fibrosis 42%

CF 20%

pHTN 16%

ECMO duration: 13.6 days (2-53 days)

19 / 31 (61.2.%) ambulatory

Hoopes, et al. JTCVS, 2013

Extracorporeal membrane oxygenation as a bridge to pulmonary transplantation

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Hoopes, et al. JTCVS, 2013

Feasibility and Safety of Early Physical Therapy and Active Mobilization for Patients on Extracorporeal Membrane Oxygenation

Youngjun Ko,* Yang Hyun Cho,† Yun Hee Park,‡ Hyun Lee,§ Gee Young Suh,§¶ Jeong Hoon Yang,¶‖
Chi-Min Park,¶# Kyeongman Jeon,§¶ and Chi Ryang Chung¶

62 physical therapy sessions

7 VV via dual site cannulation (Fem-IJ)

1 VA via central cannulation (RA-aorta)

Mean age 56

3 bridge to recovery, 5 bridge to transplant

Ko, et al. ASAIO, 2015

Feasibility and Safety of Early Physical Therapy and Active Mobilization for Patients on Extracorporeal Membrane Oxygenation

Youngjun Ko,* Yang Hyun Cho,† Yun Hee Park,‡ Hyun Lee,§ Gee Young Suh,§¶ Jeong Hoon Yang,¶‖
Chi-Min Park,¶# Kyeongman Jeon,§¶ and Chi Ryang Chung¶

Study endpoints were safety during PT and
PT interruptions due to instability

3 sessions (5%) stopped due to tachycardia or tachypnea
No clinically significant adverse events

Ko, et al. ASAIO, 2015

Candidates for Ambulatory ECMO

Bridge to transplantation or bridge to recovery patients

- ✓ Awake
- ✓ Cooperative
- ✓ Stable airway or extubated
- ✓ Hemodynamically stable
- ✓ No active bleeding
- ✓ Well-supported on ECMO

In our first 100 ECMO patients…

35 received active physical therapy - 19 BTT, 16 BTR

VVDL 23 (66%), VV 8 (23%), VA 4 (11%)

66% were extubated

51% ambulated

Median distance: 175 feet (4 – 2800 feet)

No patient or circuit complications

Abrams, et al. Critical Care 2014

Columbia Experience using ECMO as a Bridge to Lung Transplantation

72 Patients

2007-2016

LAS 91.2

VV 45 (62.5)

VA 23 (31.9)

VVA 3 (4.2)

Central 1 (1.4)

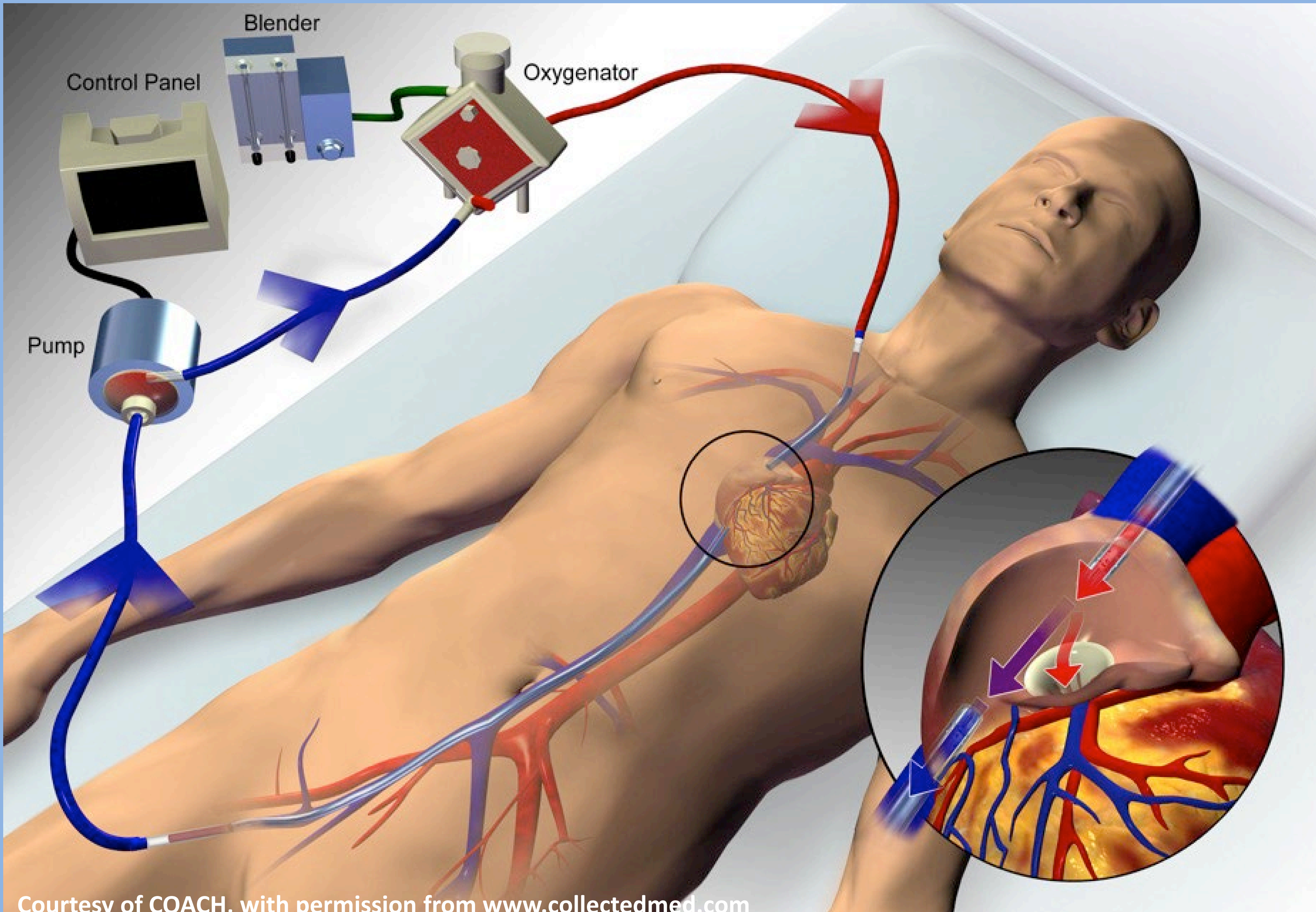
50 (69.4%) ambulated

Post-transplant Survival

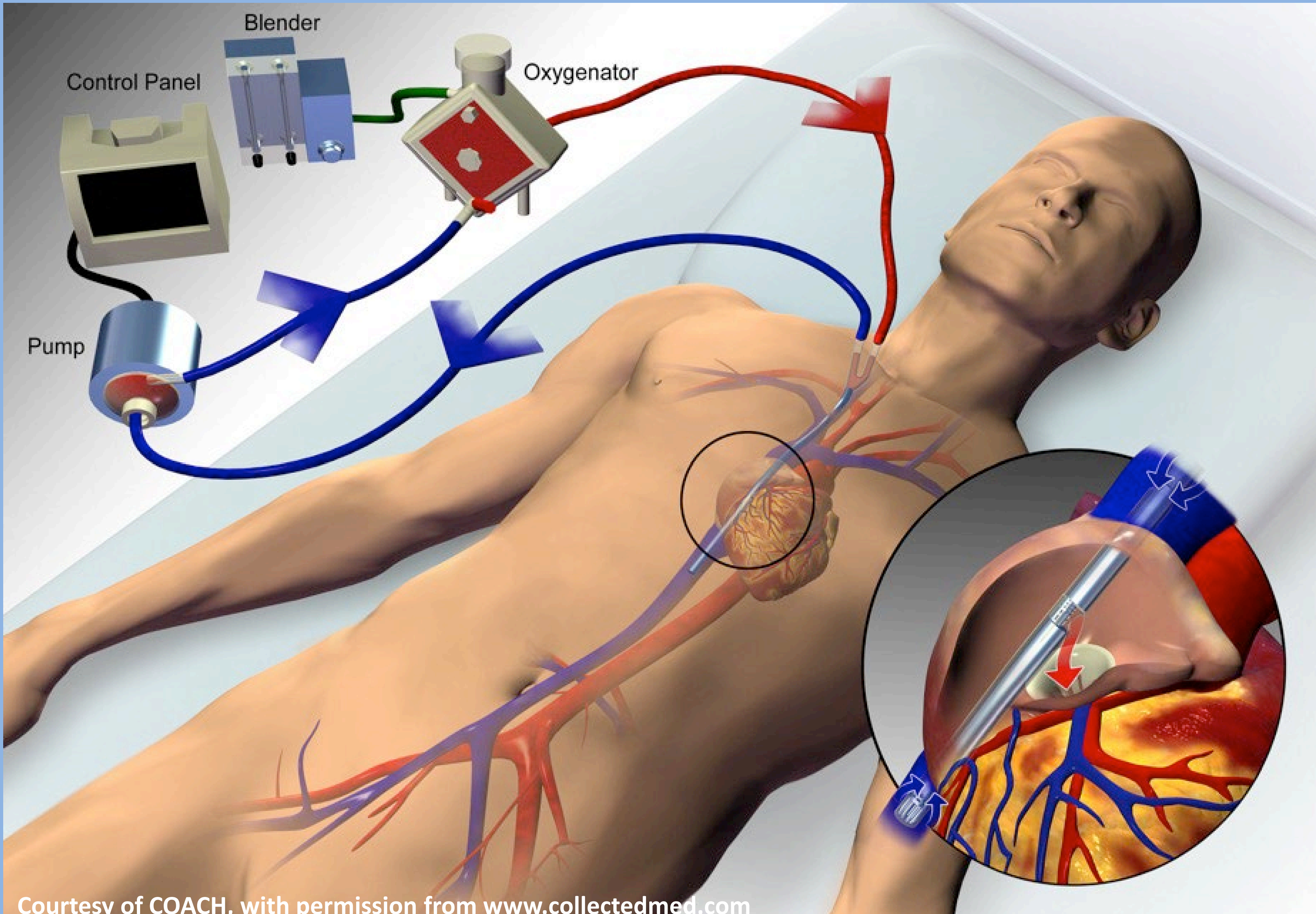
1-year 90%

2-year 84%

Biscotti, et al. Ann Thorac Surg 2017



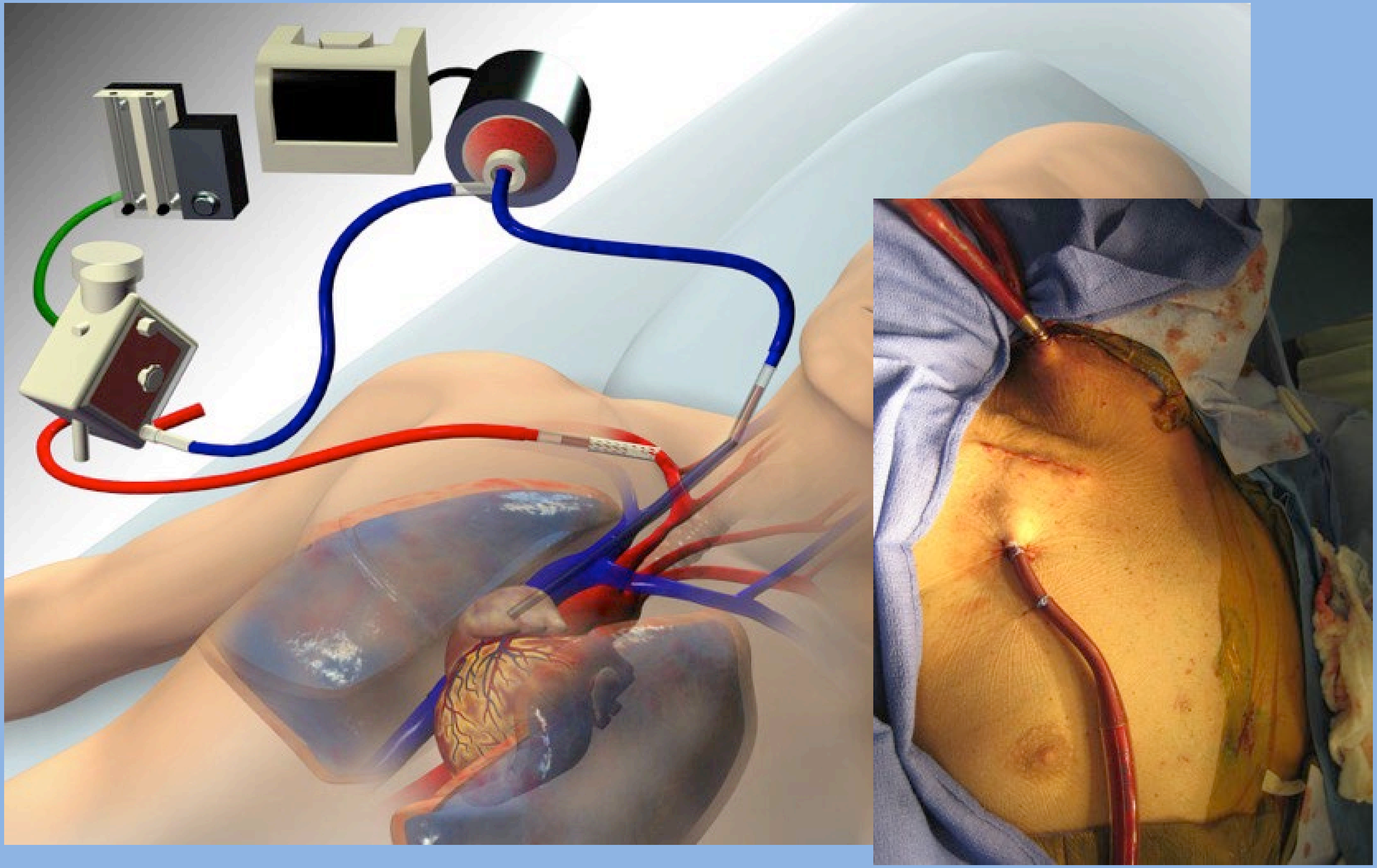
Agerstrand, et al. ASAIO 2014



Agerstrand, et al. ASAIO 2014

Venoarterial ECMO

V-A ECMO Subclavian Artery Cannulation

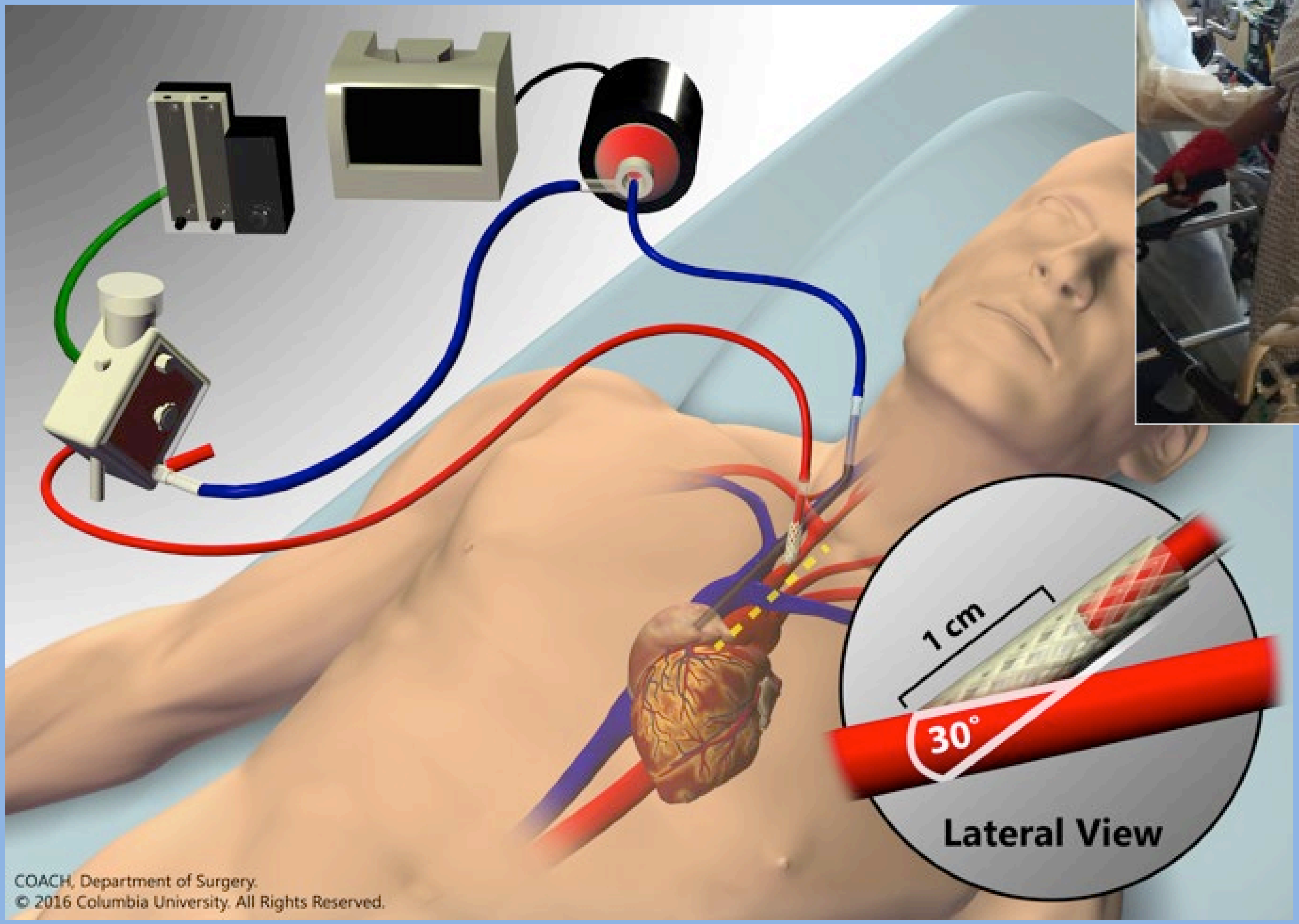


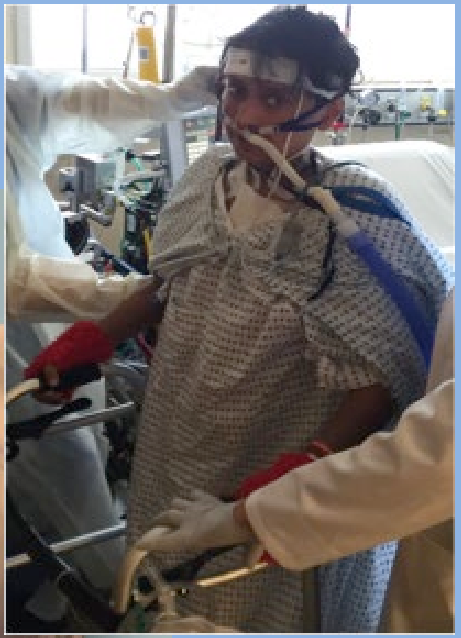
With permission of www.collectedmed.com


ELEVATORS


Infusable
2.3
50
700
5
2

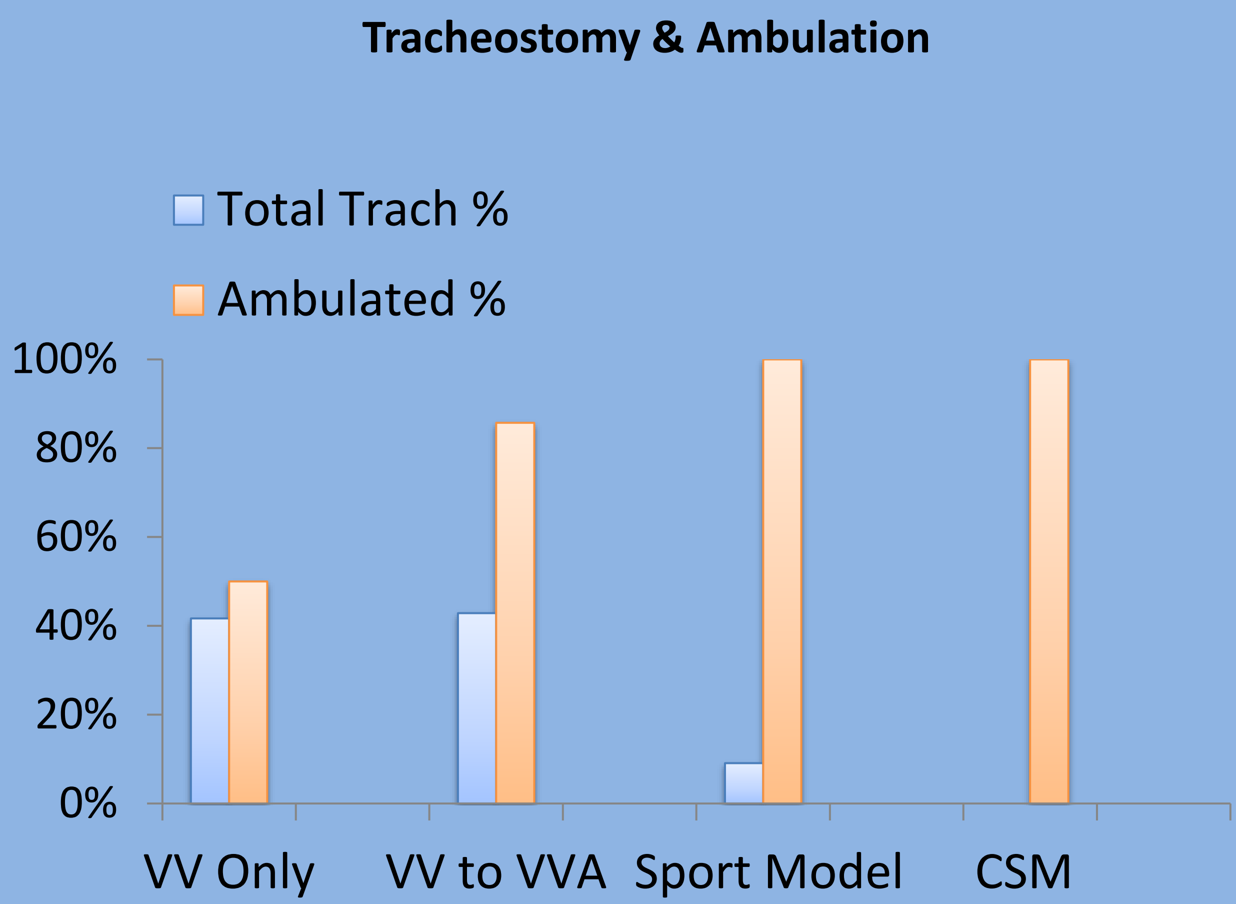
V-A ECMO: Innominate Artery Cannulation
“Central Sport Model”





Chicotka, et al. ASAIO 2016

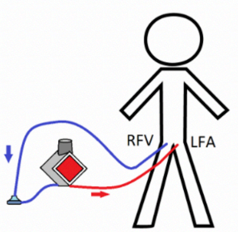
BTT Patients with ILD



EMCO PROGRAM
"CLIFF NOTES FOR TEAM"

V-A ECMO

Fem-fem V-A



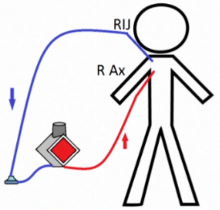
Types of Patients:
Emergent Cardiac Arrest, Failure to wean off bypass

Cannulas:
FV – Biomedicus Venous (21 or 23 fr)
FA – Biomedicus Arterial (15 or 17 fr)
Distal Perfusion – Biomedicus (8 or 10 fr)

Blood Gas Management:
If patient's heart is ejecting, treat post-oxy gas. Patient's ABG should be treated with ventilator setting changes.

*If patient pO2 is low, may need to add an extra venous line, converting to V-A-V

"Sports Model"

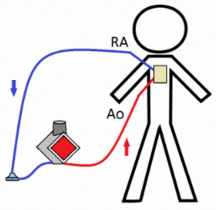


Types of Patients:
Bridge to lung transplant patients, pulmonary hyptertension

Cannulas:
IJ – Biomedicus Arterial (23 fr)
connection is ½"
Ax – EOPA (18 or 20 fr)

Blood Gas Management:
Treat patient ABG

Central V-A



Types of Patients:
Failure to wean off Bypass patients

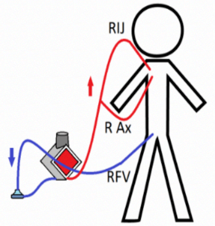
Chest is open

Cannulas:
RA – Malleable Lighthouse
Ao – EOPA (18 or 20 fr)

May need LV vent to decompress LV

Blood Gas Management:
Treat patient ABG

V-A-V ECMO

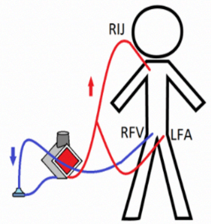


Converted from FV-IJ VV ECMO by adding Ax cannula

Types of Patients:
Patients on V-V ECMO that needed an additional arterial cannula due to low pO2

Cannulas:
FV – Biomedicus Venous (21 or 23 fr)
IJ – EOPA (18 or 20 fr)
Ax – EOPA (18 or 20 fr)

Blood Gas Management:
Treat patient ABG

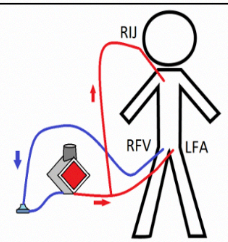


Converted from FV-IJ VV ECMO by adding FA cannula

Types of Patients:
Patients on V-V ECMO that needed an additional arterial cannula due to low pO2

Cannulas:
FV – Biomedicus Venous (21 or 23 fr)
IJ – EOPA (18 or 20 fr)
FA – Biomedicus Arterial (15 fr)

Blood Gas Management:
Treat patient ABG



Converted from fem-fem VA ECMO by adding IJ cannula

Types of Patients:
Patients on fem-fem V-A ECMO that has heart ejection but poor lung functions, resulting in low pO2 in upper body**

Cannulas:
FV – Biomedicus Venous (21 or 23 fr)
FA – Biomedicus Arterial (15 or 17 fr)
IJ – EOPA (18 or 20 fr)

Blood Gas Management:
Treat patient ABG

Troubleshooting

Problems	Solutions
Low Flow	• Check for cannula kinking • Check for cannula positioning
Venous Line Chattering	• Come down on the flow and go back up, cannula may be stuck against the vessel wall • Patient may need more volume
Arterial Blood is Dark	• Check Oxygen line connections, the oxygen line may have fallen off • Blender may be broken, put the oxygen line on an oxygen tank • Check wall gas source
Arterial cannula fell out Arterial line disconnected	• Clamp arterial line and arterial cannula!!! (otherwise patient will exsanguinate!) • Call surgeon!
Venous cannula fell out Venous line disconnected	• Clamp venous line, arterial line, and venous cannula!! • Call surgeon! • Before re-initiate ECMO, may need to de-air the circuit!
ECMO alarming SIG	• Need more ultrasonic gel ("goop") for rotaflow • Come off ECMO (clamp arterial and venous line), turn RPM to 0, remove rotaflow, and put more goop

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ECMO in the Field: The New Logistics of Pump and Run

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ECMO Fellow

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Associate Professor of Surgery
Director of Adult ECMO
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Disclosures

- No financial disclosures to report

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Background

- Extracorporeal membrane oxygenation (ECMO) can be a salvage therapy for cardiac or respiratory failure[1,2]
  - Venoarterial (VA) ECMO
    - Bridge to recovery
    - LVAD insertion
    - Transplantation
  - Venovenous (VV) ECMO
    - Bridge to recovery
    - Transplantation
- ECMO management at specialized centers
  - ~200 ECMO centers in the world
  - Referral and transport in "hub and spoke" configuration[3-5]

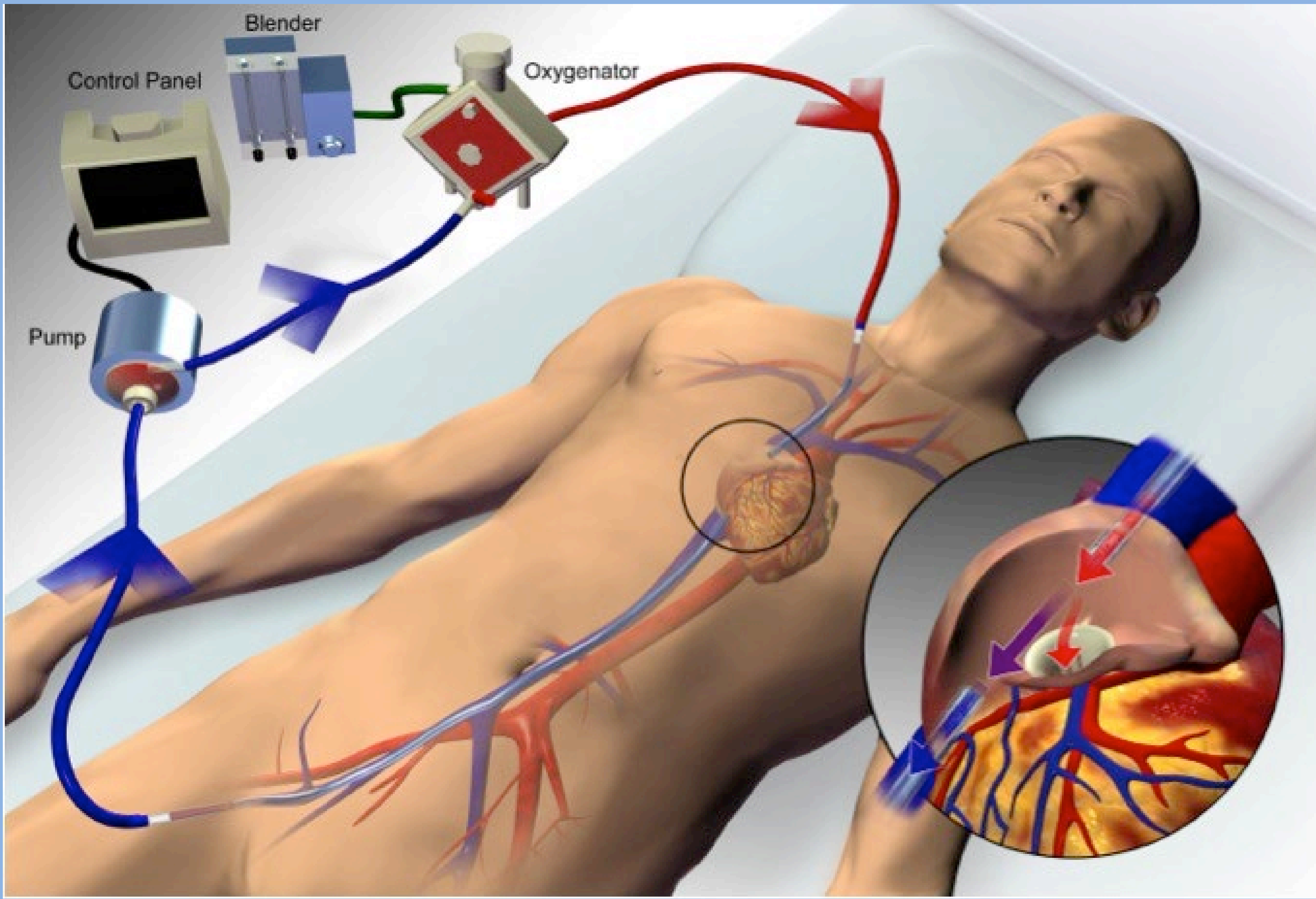
1. Abrams D, et al. *JACC,* 2014; 63:2769-78
2. Brodie D, et al. *NEJM,* 2011; 365:1905-14
3. Wagner K, et al. *Perfusion,* 2008; 23:101-6
4. Javidfar J, et al. *ASAIO J,* 2011; 57:421-5
5. Bryner B, et al. *Ann Thorac Surg*, 2014; 98(4): 1363-70

Cannulation for Field Transport

- Simple is always better than complex
  - Select what meets physiologic needs
    - Remember Aero MedEvac can further compromise O_2 levels
- Durable to withstand transition zones
  - Bed to stretcher
  - Stretcher to ambulance/aircraft
  - Ambulance/aircraft to ambulance/aircraft
    - "Tail-to-tail" transfer
  - Ambulance to ICU
  - Stretcher to ICU bed

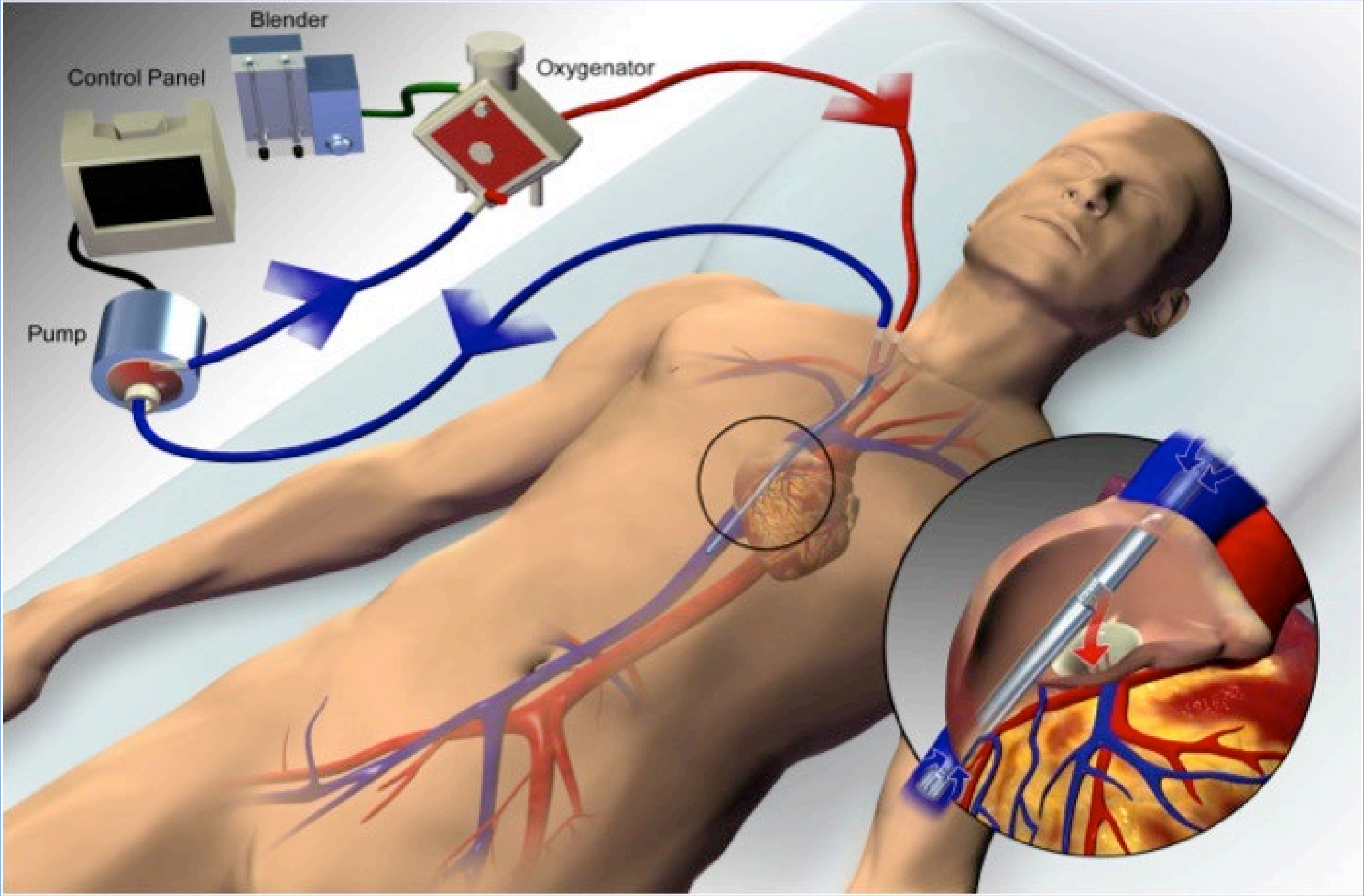
Dual Site VV ECMO: Simple

Easy to teach, easy to execute, minimal gear



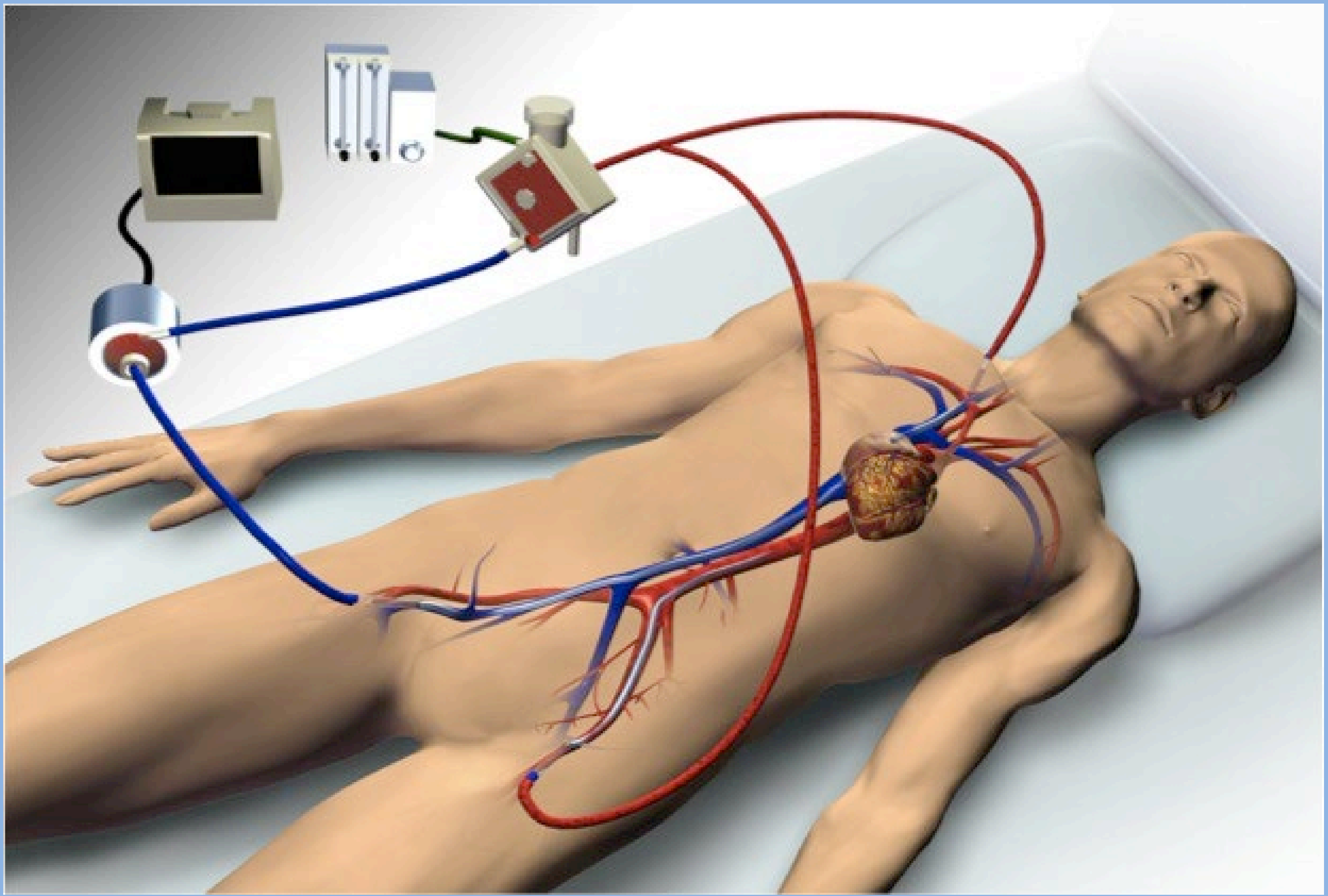
Single Site VV ECMO: Complex

Consider for patients with traumatic amputations



VVA ECMO: Slightly more complex

Required for combined cardiopulmonary/hemodynamic issue



Indications

- Hypoxemic respiratory failure
- Hypercapnic respiratory failure
- Respiratory failure as a bridge to transplant
- Severe bronchopleural fistulas
- Failure to wean from cardiopulmonary bypass
  Heart failure
- Massive pulmonary embolism
- Cardiac failure
- Cardiac arrest

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Indications:
Hypoxemic Respiratory Failure

- PaO_2:FiO_2 <80
- Acute Lung Injury Score (ALIS) 3-4
  - PaO_2:FiO_2: >300 (0) → <100 (4)
  - CXR: 1 pt per quadrant involvement
  - PEEP: ≤5 (0) → ≥15 (4)
  - Compliance: ≥80 (0) →≤19 (4)

Reflective of the Berlin Definition. JAMA 2012

- Consider for P:F < 150 or ALIS 2-3
  - May be appropriate for rapid worsening to avoid delays in initiation
- ***Reversible*** causes
  - Do Not Provide a Bridge to Nowhere

Relative Contraindications

- Mechanical ventilation with high inflation pressures (Pplat > 30 cm H_2O) or high O_2 concentrations (FiO_2> 0.8) for ≥7 days
- Advanced age >65
- Weight > 150 kg OR BMI > 60
- Severe medical co-morbidities
- Severely immunocompromised host
- Malignancy with limited life expectancy

Absolute Contraindications

- Documented irreversible brain injury
- Irreversible multi-system organ failure or other futile condition
- Prolonged cardiac arrest
- Contraindications to anticoagulation
  - Recent or expanding CNS hemorrhage
  - Active hemorrhage
- Inability to receive blood products

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Role of ECMO Transport Teams

- Extend ECMO care to patients at smaller hospitals or soldiers in field
- Patients gain access to complex tertiary care
- Facilitate the safe transfer of critically ill patients to specialized centers of care

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Why ECMO Transport?

- Provides a higher level of care
  - Community hospitals
  - Support your medical services
  - Support your cardiothoracic services

- Use will continue to grow
  - Technological improvements
    - Smaller, more reliable equipment
  - Successful programs will attract more referrals as experience leads to improved outcomes
  - Cost improvements

ECMO Transport: What does it Provide?

- Regionalization of care
  - Concentration of expertise in managing the "very sick"
  - CESAR Trial hinted at the advantage of concentrated expertise
    - Concentrated expertise comes in all forms: ICU mgmt, surgery, etc.
  - Military applications: Move severely injured soldiers out of the combat theater

- Is it safe?
  - Review of the literature suggests it is safe
    - May be only successful programs publish their results
    - Do you cannulate at point of care?
      - Emergency privileges

Columbia Service Line Model

- Any successful regional program must provide a *service!!!*
  - Consultancy
    - Medical-surgical consultants
- Service line model vs Procedural model
  - Surgeons like to do procedures
  - Referrals want more than a procedure
    - Want advice on management that might obviate need for ECMO transport

Service Line Model

- Center for Acute Respiratory Failure
  - ARDS, COPD exacerbation, PE, heart failure, etc
- Service line contact number
- Consult service
  - Standardized In-take form
  - Review by ECMO attending (Pulm ICU)
  - Review by Surgeon led transport team

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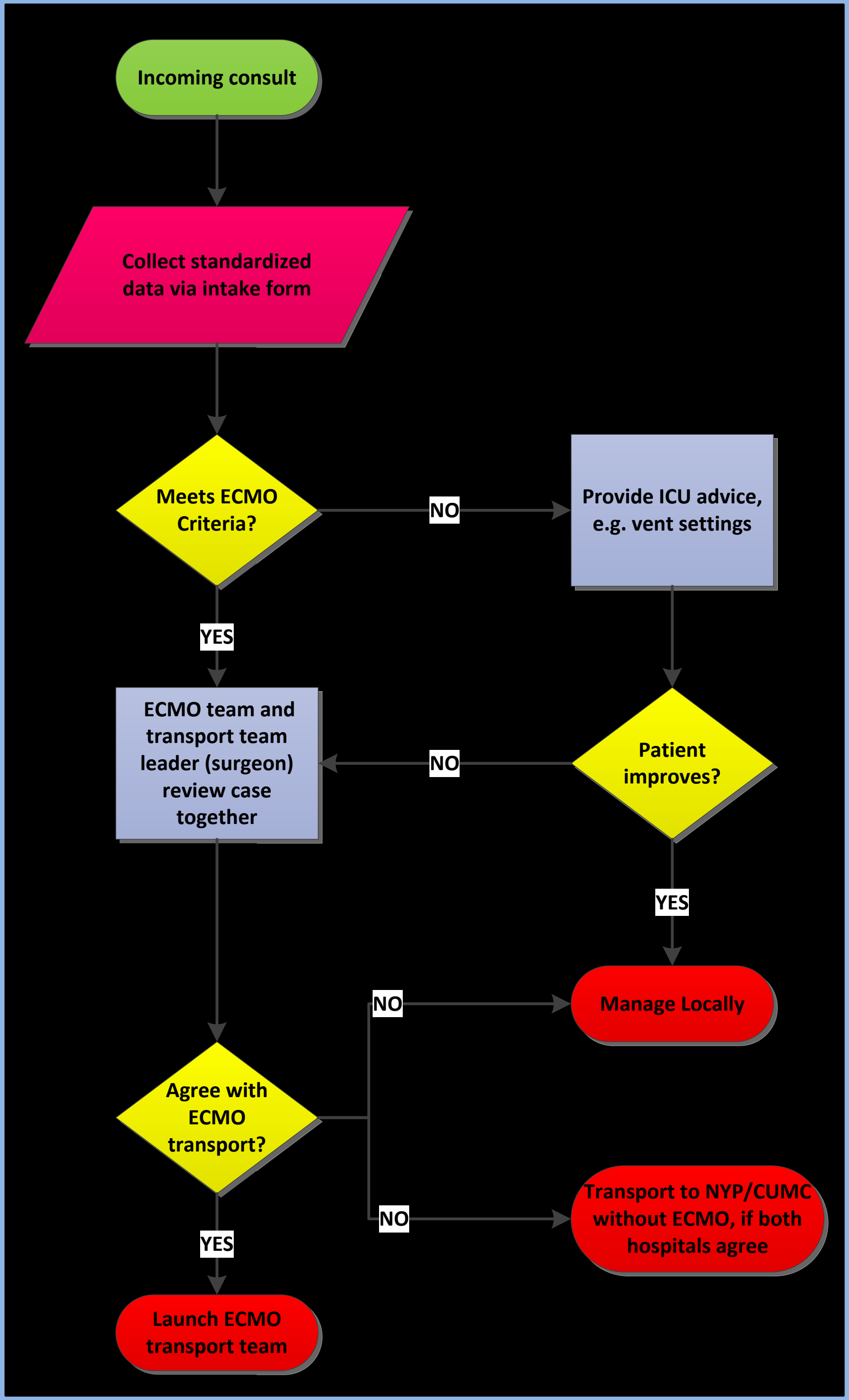
Maintain consultancy role

- Smarter decision
- Relationship building
- Ensure proper care of patient



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The Ideal Regional Center

- Expert personnel
  - Surgery
  - Intensive care
  - Nursing
  - Perfusion
  - Available 24/7: Consult services

The Ideal Regional Center

- Advanced disease management programs
  - Heart failure
    - Heart transplant, VAD
  - Lung failure
    - Acute: ALI/ARDS, Pulmonary embolism
    - Chronic lung disease program: ILD, Lung Tx
- Transport capability

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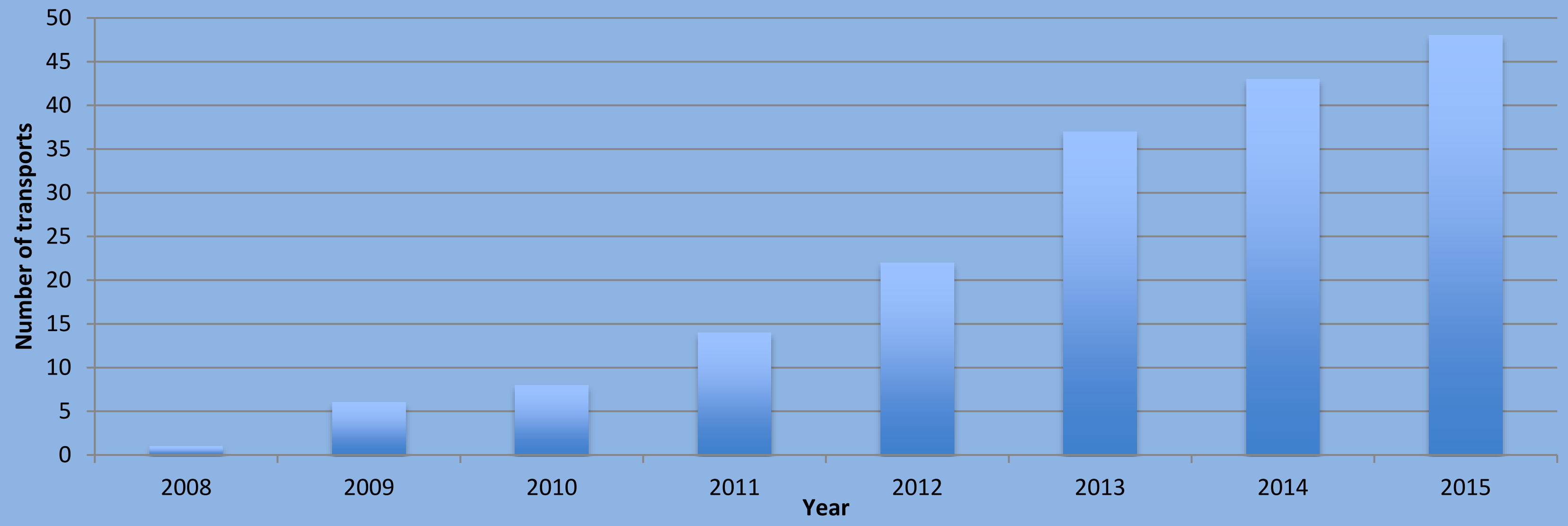
Columbia ECMO Transport Service

Columbia Experience

- Performed 203 safe ECMO transports
  - First transport September 2008
    - Increasing yearly volume
    - 48 Transports in 2015



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Transports: Personnel

- Longer distances
  - Aeromedical transports
  - International transport
- 5 dedicated ECMO intensivists
- 5 surgeons

- Dedicated ECMO fellow
- Nurse practitioners with advanced ECMO training
- Dedicated medical and surgical ICU’s
- Dual site cannulation
- Compact circuit/pump/oxygenator
- Liberalized exclusion criteria

Personnel & Training: Train for Success

- Dedicated team members
  - Not ad hoc
- Training programs/certifications
  - Courses: ELSO, STS, AATS
- Ongoing training
  - Recurrent/scheduled
- Drills
- Simulation

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Protocol for ECMO Transport

- Consult called via institution-wide transfer center
  - Intake and patient optimization
  - Patient accepted if deemed unstable for transport
  - Coordination of surgeons, perfusionists, ambulance, operating privileges

- Consulting hospital responsibilities
  - Central venous catheter (LIJ)
  - Arterial line (radial)
  - Bedside ultrasound
  - Vascular surgical tray

Protocol at Patient Bedside

- Sedation
  - Benzodiazepine and opioid infusions
  - Neuromuscular blockade
- Cannulation
  - Percutaneous Seldinger technique
  - Existing CPB cannulation
  - Single site
  - Dual site
  - Heparin bolus
- Circuit selection
  - Centrifugal pump and polymethylpentene oxygenator
  - Integrated pump/oxygenator system

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Protocol at Bedside: Prior to Transport

- Patient management
  - Ventilator adjustments
    - Peak airway pressures <35cm H_2O
    - Respiratory rate <20 breaths/minute
    - Target pH 7.35-7.45
    - Minimal PEEP adjustments
  - Neuromuscular blockade
- Transport equipment
  - Generator
  - Two Oxygen tanks
  - Hand Crank

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Ground vs Air MedEvac

- Ground
  - Steady state partial pressures
    - Unless you are driving over mountain ranges
- Air
  - Partial pressures are dynamic, i.e. a function of the altitude
    - Higher altitude is more efficient for planes but bad for patient oxygenation
  - Device flow shifts when taking off and landing
    - 200 – 500 cc per minute

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Physiologic Stresses of Flight and Extended Travel Distance

- Decreased partial pressure of oxygen
  - Know your rated cabin pressure
- Barometric pressure changes
- Thermal changes: patients can easily lose heat
- Decreased humidity – increased fluid requirements from insensible losses

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Physiologic Stresses of Flight and Extended Travel Distance

- Noise:
  - Difficult to communicate; disturbs the patient
- Vibration:
  - Things fall apart if you shake them enough
- Gravitational forces:
  - Acceleration & deceleration
- Long range transport:
  - Wear & tear on the staff
- Oxygen Capacity: Are the tanks big enough?

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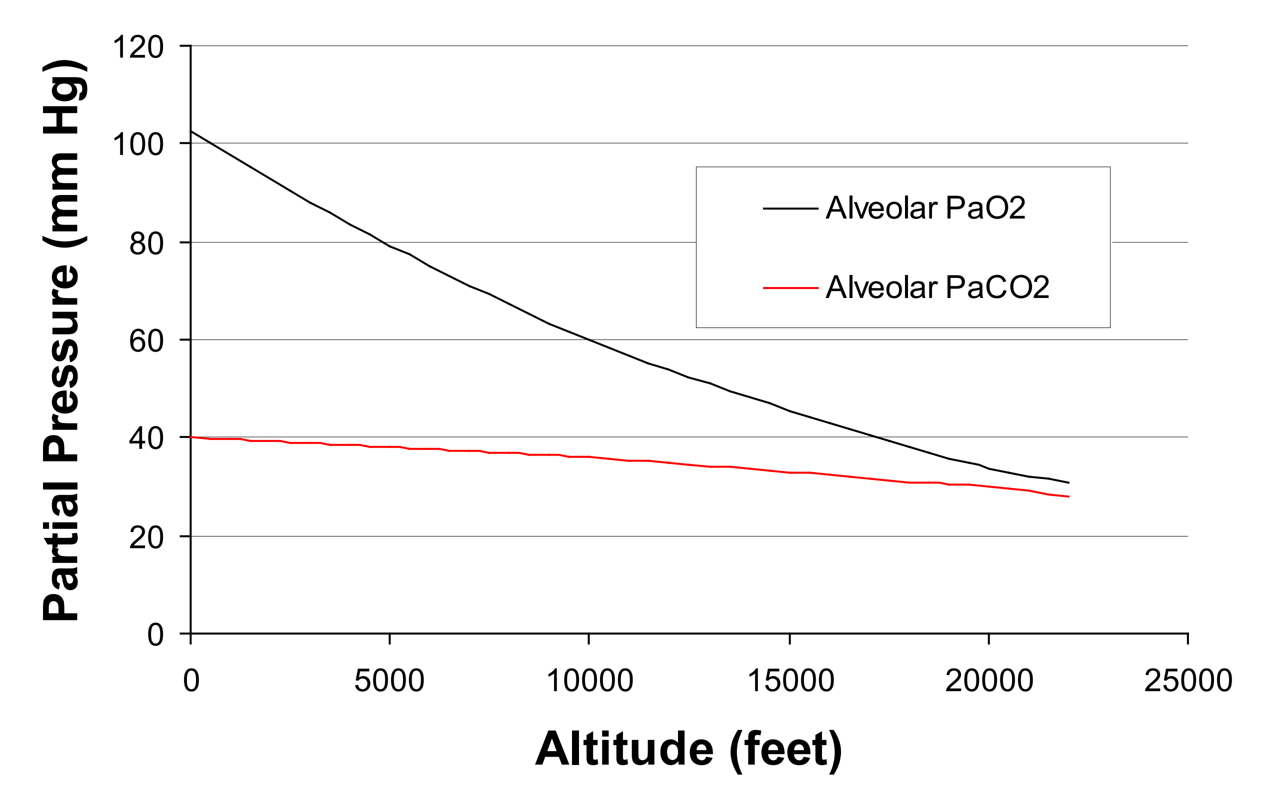
PaO2 of 100 at sea level equates to a PaO2 of 60 at 10,000 feet



Oxygenator Function Declines at Altitude

- Boyle's Law and Dalton's Law (partial pressure O2 available)
- Real life example courtesy of LTC Eric Osborn

– Sea level	ABG	post oxygenator	7.43/44/**290**
	patient		7.39/52/48
– 7500 ft	ABG	post oxygenator	7.42/49/**119**
– 3am	patient		7.36/61/39
– Iowa City 700ft	ABG	post oxygenator	7.44/36/**285**
– 530am	patient		SVO2 68%, O2 Sat 82%

Example courtesy of LTC Eric Osborn (US Army)

Complications & Management

- Columbia experience: 3 complications
  - Console pump failure
  - Decannulation at Bedside transition
  - Oxygenator failure

- Back up pump, Hand crank
- Rapid clamp out of circuit and re-cannulation
- Oxygenator swap out

PREPARE & TRAIN

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ECMO in the Austere Environment

Far Forward Position in Afghanistan

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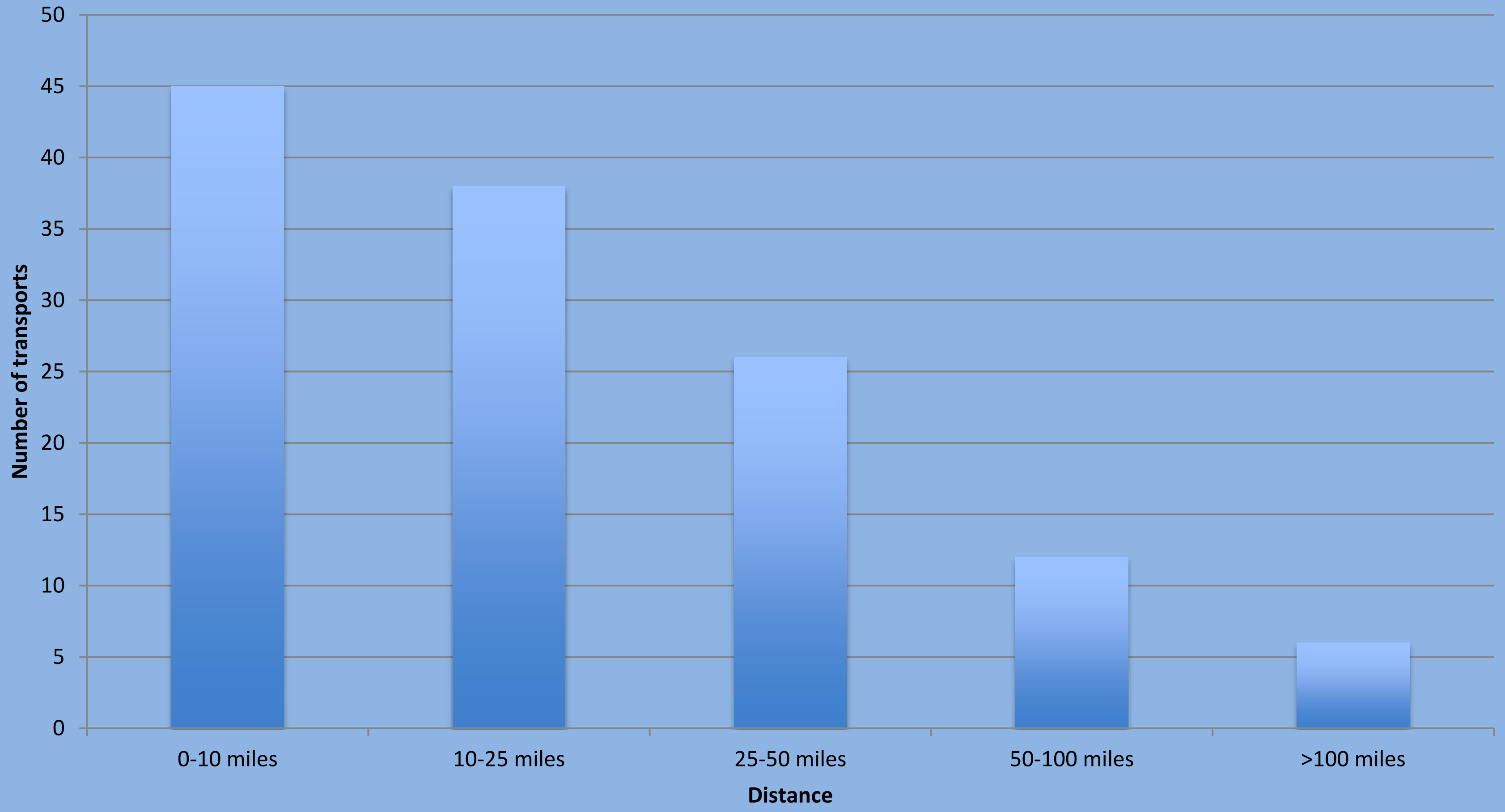
Transport Distance



Factors Affecting Survival

- Age and APACHE II Score correlate with decreased survival
- No correlation with survival
  - P:F
  - Mechanical ventilation time prior to ECMO
  - Transport Distance

Univariate Analysis	p-value	
	All patients	*Respiratory Failure*
Age	**<0.0001**	**0.001**
BMI	0.638	0.973
Sex	0.223	0.831
APACHE II Score	**0.041**	**0.039**
Pre-ECMO P:F	0.319	0.436
Pre-ECMO pH	1.000	0.924
Intubation to ECMO (days)	0.248	0.118
Transport Distance	0.207	0.22

U. of Michigan Experience

- 20 years of ECMO transport experience
  - 221 patients
    - 79 pediatric
    - 142 adults
  - Reason for support
    - Respiratory: 180
    - Cardiac: 41
  - Mode of ECMO
    - Venoarterial: 114
    - Venovenous: 107

Bryner et al. Ann Thorac Surg, 2012

U. of Michigan Experience

- Travel Distance:
  - Survivors: 191 km
  - Nonsurvivors: 182 km
- Travel Time:
  - Survivors: 1.4h
  - Nonsurvivors: 1.7h
- Survival to Discharge:
  - Adult: 55%
  - Pediatric: 71%
  - Neonatal: 72%

Bryner et al. Ann Thorac Surg, 2012

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U. of Michigan Experience

- Complications
  - Missing Item: 23
  - Electrical complication: 39
  - Patient care complications (cardiac arrest): 9
  - Delay in travel: 8
  - Circuit issue: 20
  - Inadequate flow: 20
  - Death: 1

Bryner et al. Ann Thorac Surg, 2012

U. of Michigan Experience

- Conclusions:
  - Transport requires requires an immense institutional commitment
  - Transport itself can be successful (99.5% survival)
  - Transport does not confer a survival disadvantage compared to non-transport ECMO
  - Be prepared to manage complications

Bryner et al. Ann Thorac Surg, 2012

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Stockholm Experience

- Over 700 Patients transported from 1998
  - 80 to 90 per year
- 59% by aircraft
  - 4 to 8357 miles
- Reported Results from last 3 years
  - 288 ECMO transports
  - 1 death
  - 27% Complication rate

Broman et al. Critical Care, 2015

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Stockholm Experience

- Transport team:
  - Critical Care physician
  - ECMO ICU Nurse
  - Cannulating Surgeon
- Comparable Survival to in-house ECMO

Broman et al. Critical Care, 2015

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Combat Transport Experience

TABLE 2. Patient and Injury Characteristics, ECLS Use, and Outcomes

Patient	Age, y	Primary Injury	Pulmonary Injury	ISS	AIS Score (Chest)	APACHE II Score	ECLS Device	ECLS Duration, d	Outcome
1	24	Blast injury with bilateral lower-extremity amputations	Blast-related bilateral pulmonary contusions, pneumonia	13	3	N/A	PECLA	12	Survived
2	23	Blast injury with traumatic brain injury	No primary lung injury	22	0	34	PECLA	8	Survived
3	33	Blast injury with left lower-extremity amputation	Blast-related bilateral pulmonary contusions, wound sepsis	34	3	37	PECLA	9	Died
4	23	Blast injury with traumatic brain injury	Blast-related bilateral pulmonary contusions	17	1	26	PECLA	8	Survived
5	19	Gunshot to right chest	Right pneumonectomy	33	4	29	PECLA	18	Survived
6	20	Motor vehicle collision with spinal cord injury	Bilateral pulmonary contusions	33	5	24	ECMO	7	Survived
7	29	Blast injury with traumatic brain injury	Bilateral pulmonary contusions, aspiration	34	3	31	ECMO	8	Survived
8	25	Gunshot to right chest	Right pulmonary contusion	9	3	20	ECMO	7	Survived
9	22	Gunshot to right chest	Right pneumonectomy	34	5	21	ECMO	13	Survived
10	21	Gunshot to left chest	Left pulmonary contusion	14	3	12	ECMO	6	Survived

AIS, Abbreviated Injury Scale; APACHE, Acute Physiology and Chronic Health Evaluation; ISS, Injury Severity Score; N/A, not available.

Bein et al. J Traum Acute Care Surg 2012

Equipment: Civilian

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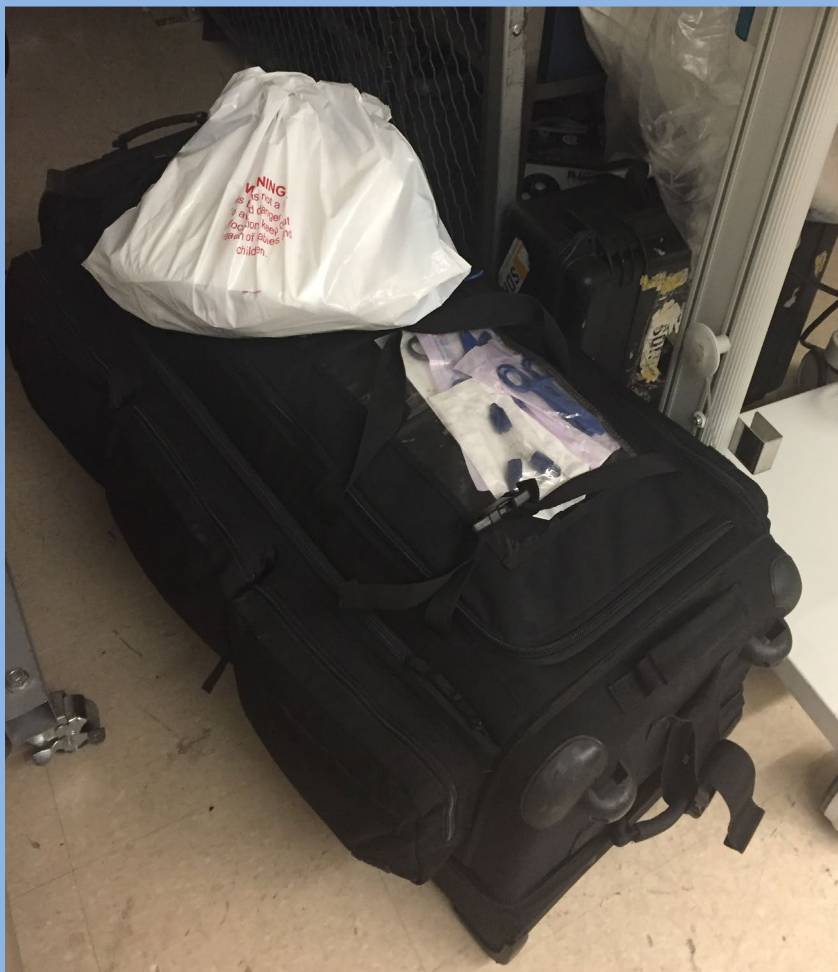
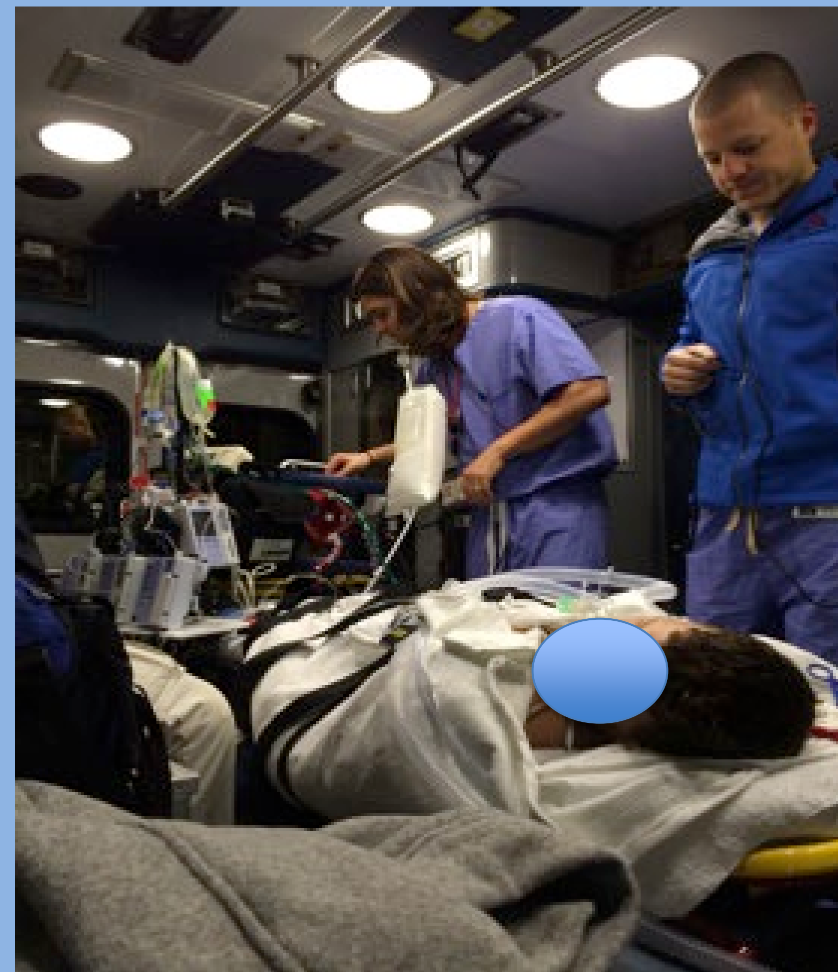
Equipment: Civilian



‘Go Bag’ and Emergency Supply Bag



Ambulance Transport

Conclusions

- ECMO transport is safe and feasible
  – Technological advances in equipment
  – Improved clinician experience

- Cannulation strategy
  – Simple is always better than complex
  – Physiologic needs of the patient
  – Physiologic demands of transport
    - High altitude vs ground transport
  – Multiple securing sutures

Conclusions

- Intra-transport monitoring & management
  - Transition points are high risk for mishaps
  - Distribution of responsibilities for each team member
  - Team leader and proper communication
- Preparation for complications
  - Critical back up equipment as needed
- Military MedEvac vs. Civilian
  - Increased complexity: combat zone, polytrauma
  - Greater equipment & personnel redundancy

Conclusions

- Success is built on foundation
  - Personnel selection
  - Standardized protocols
    - Patient selection
    - Transport equipment
  - Training
    - Baseline and on-going
      - Wet drills
  - AAR (After Action Reviews)
    - Continuous improvement process

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- EMS team