Extra Corporeal Membrane Oxygenation updates (17/02/2024)

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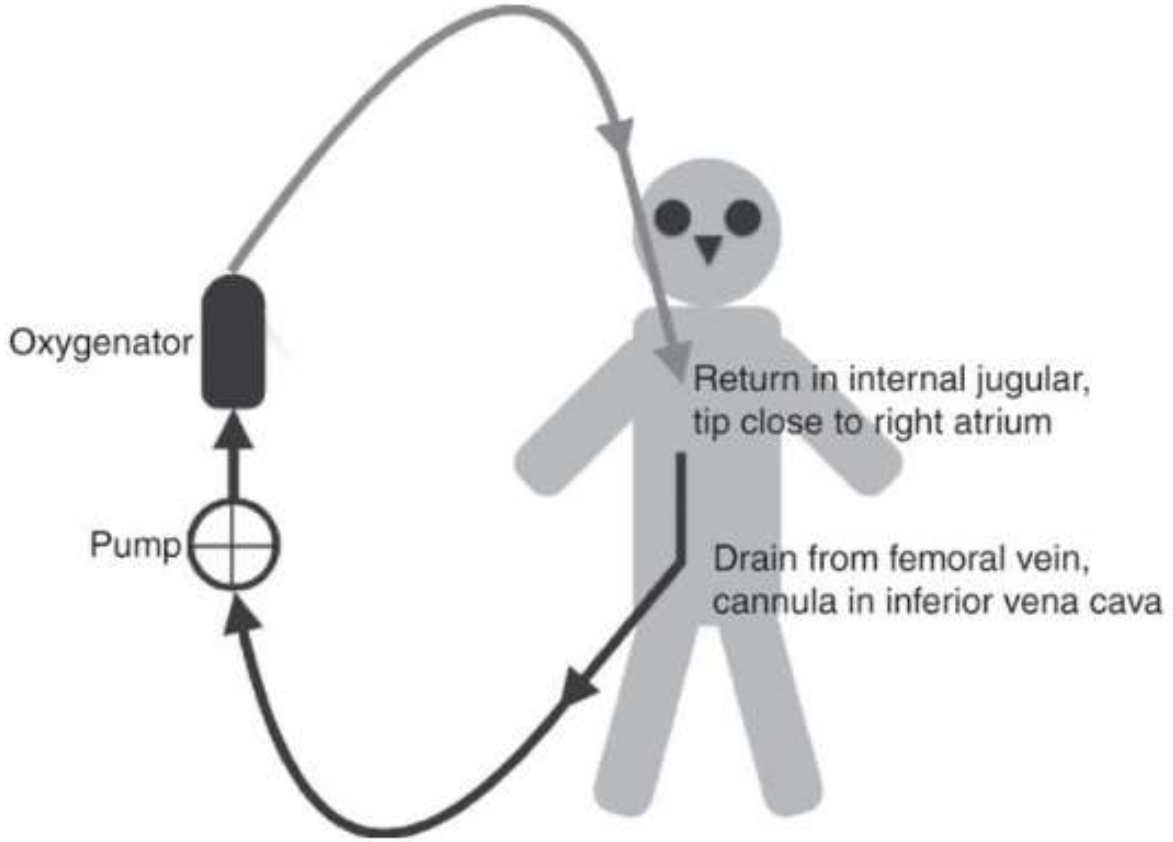
Introduction

- ECMO cis used for cardiac (veno-arterial bypass) or respiratory support
- VV -ECMO is hypoxemic respiratory failure
- For respiratory support, blood can be drained either from a venous vessel (veno- venous ECMO [VV-ECMO]) or from an arterial vessel (arteriovenous bypass)
- By 2020, the Extracorporeal Life Support Organization (ELSO) Registry had recorded >24,000 cases of adult respiratory ECMO use among 282 centers internationally
- **Components of ECMO circuit**
- A gas exchange unit, a pump to propel the blood, and Cannulas and tubing for vascular access

VV ECMO



Veno-venous ECMO circuit, with drainage from a cannula inserted in the femoral vein (tip in the inferior vena cava) and the return cannula inserted in the internal jugular vein (tip in the superior vena cava, next to the right atrium

ECMO circuit

- **Oxygenerators :**
- Hollow fiber oxygenators with a polymethylpentene membrane
- Higher gas transfer rates, and much lower resistance
- Gas, blood and heat exchange compartments are present in oxygenator
- **Pumps**
- Centrifugal pumps have a hole in the center of the rotor (Mendler design) and use both a magnetically suspended and a magnetically driven pump that eliminates stagnation, thrombosis, and heat production

ECMO circuit

- **Cannula**
- **Modern can**nulas have heparin coated surfaces to increase biocompatibility and reduce activation of the clotting cascade
- **Tubing**
- Polyvinylchloride, polyurethane, or silicon rubber

Recent updates

- ECMO and Prone Positioning
- Extracorporeal Cardiopulmonary resuscitation
- Extra corporeal carbon dioxide removal
- Septic shock
- Bridge to lung transplantation
- Toxicology
- ARDS and pregnancy

Indications for venovenous extracorporeal membrane oxygenation

- 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
- Hypercapnic respiratory failure (pH < 7.25), despite optimal conventional mechanical ventilation (respiratory rate 35 bpm and plateau pressure [Pplat] ≤ 30cm H_2O
- Ventilatory support as a bridge to lung transplantation or primary graft dysfunction following lung transplant

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

Common indications for venovenous extracorporeal membrane oxygenation

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

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

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 and 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 Pplat > 30 cm H2O and FiO2 > 90%

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

Initiating Extracorporeal Life Support for Adult Respiratory Failure

- **Rationale for ECLS in Respiratory Failure**
- Manage derangements in gas exchange using the artificial membrane lung thereby serving to bridge a patient with refractory hypoxemia and/or severe respiratory acidosis
- In ARDS, reduce the risk of ventilator induced lung injury by allowing the use of lower ventilator pressures, volumes and respiratory rates
- Resource intensive and High rate of device related complications

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

Initiating Extracorporeal Life Support for Adult Respiratory Failure

- Resource intensive and High rate of device related complications
- Initiating ECLS should be considered on a case-by-case basis as part of a specialized, multidisciplinary assessment
- Failed conventional therapies despite optimization and remain at high risk for death
- A potentially reversible cause of respiratory failure without comorbidities that limit short- term life expectancy,
- No contraindications to ECLS

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

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

- N = 180 study participants
- Randomly assigned (1:1) to receive mechanical ventilation or ECMO (VV - ECMO)
- Eligible patients were aged 18–65 years and had severe (Murray score >3·0 or pH <7·20) but potentially reversible respiratory failure
- Primary outcome was death or severe disability at 6 months after randomisation or before discharge from hospital
- 63% (57/90) in ECMO group survived to 6 months without disability compared with 47% (41/87) in conventional management (relative risk 0·69; 95% CI 0·05–0·97, p=0·03)

The Lancet. 2009 Oct17;374(9698):1351-63

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

	ECMO group (n=90)*	Conventional management group (n=90)	Relative risk (95% CI, p value)
Death or severe disability at 6 months	NA	NA	0·69 (0·05–0·97, 0·03)†
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

	ECMO group (n=90)*		Conventional management group (n=87)		Incremental cost-effectiveness ratio†
	Mean cost	Probability of survival to 6 months	Mean cost	Probability of survival to 6 months	
Scenario 1: base case‡	£73 979	0·63	£33 435	0·47	£250 162; US$404 268
Scenario 2: QALYs gained at 6 months with costs based on NHS tariffs§	£57 534	0·63	£36 688	0·47	£128 621; US$207 854

The Lancet. 2009 Oct17;374(9698):1351-63

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

- Randomised clinical trial, N = 249
- 124 patients received VV EMCO and 125 patients conventional mechanical ventilation (35 received rescue ECMO)
- Primary outcome - mortality at 60 days
- At 60 days, 44 patients (35%) in the ECMO group and 57 (46%) in the control group had died (relative risk, 0.76; 95% confidence interval [CI], 0.55 to 1.04; P = 0.09
- Hazard ratio for death within 60 days after randomization in the ECMO group, as compared with the control group, was 0.70 (95% CI, 0.47 to 1.04; P = 0.07)

New England Journal of Medicine. 2018 May 24;378(21):1965-75

ECMO to Rescue Lung Injury in Severe ARDS (EOLIA) study

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

New England Journal of Medicine. 2018 May 24;378(21):1965-75

ECMO to Rescue Lung Injury in Severe ARDS (EOLIA) study

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

New England Journal of Medicine. 2018 May 24;378(21):1965-75

Recent updates

- ECMO and Prone Positioning
- Extracorporeal Cardiopulmonary resuscitation
- Extra corporeal carbon dioxide removal
- Septic shock
- Bridge to lung transplantation
- Toxicology
- ARDS and pregnancy

ECMO - Prone positioning

Prone-Positioning for Severe Acute Respiratory Distress Syndrome Requiring Extracorporeal Membrane Oxygenation

- Retrospective, single center study and n = 294 study participants (received VV – ECMO)
- 64 had undergone prone positioning during ECMO
- Prone Positioning on ECMO considered for severe hypoxemia, extensive lung consolidation, or difficult ECMO- weaning
- Done with in 1st week of ECMO run and each sessions lasted for 16 hours
- Positive response respiratory system static compliance increased greater than or equal to 3mL/ cm H2O after 16 hours on PP

Crit Care Med. 2022 Feb 1;50(2):264-274

Baseline Characteristics of the Entire Study Cohort and After Propensity Score–Matching Analysis

Characteristic	Entire Cohort ($n = 298$)	Not Propensity-Score Matched			Propensity-Score Matched		
		PP-ECMO ($n = 64$)	No-PP-ECMO ($n = 234$)	p	PP-ECMO ($n = 59$)	No-PP-ECMO ($n = 59$)	Absolute Standardized Mean Difference
Age, yr	52 (40–61)	53 (45–61)	51 (39–60)	0.34	53 (46–61)	51 (45–59)	0.06
Male	203 (68)	43 (67)	160 (68)	0.98	40 (68)	42 (71)	0.02
Body mass index, kg/m^2	28.7 (24.5–31.5)	31.2 (27–38.7)	28.1 (24.2–33)	< 0.01	30.8 (26.5–37.9)	29.7 (26.1–35.3)	0.06
Simplified Acute Physiology Score II	69 (59–80)	67 (55–77)	70 (59–81)	0.04	67 (55–77)	64 (54–76)	0.04
Comorbidities							
Diabetes mellitus	57 (19)	16 (25)	41 (18)	0.24	16 (27)	11 (19)	0.20
Chronic kidney failure[a]	17 (6)	4 (6)	13 (6)	1	3 (5)	3 (5)	0.00
Ischemic cardiomyopathy	48 (16)	12 (19)	36 (15)	0.65	10 (17)	9 (15)	0.05
Chronic obstructive pulmonary disease or asthma	54 (18)	10 (16)	44 (19)	0.68	10 (17)	8 (14)	0.05
Immunocompromised status	83 (28)	18 (28)	65 (28)	1	16 (27)	17 (29)	0.04
Surgery in the last 7 d	40 (13)	7 (11)	33 (14)	0.65	7 (12)	4 (7)	0.10
Acute respiratory distress syndrome etiology							
Bacterial pneumonia	159 (53)	29 (45)	130 (56)	< 0.01	29 (49)	25 (42)	0.07
Viral pneumonia	63 (21)	23 (36)	40 (17)		18 (31)	20 (34)	
Other	76 (26)	12 (19)	64 (27)		12 (20)	14 (24)	
Pre-ECMO							
Sequential Organ Failure Assessment score	14 (10–17)	13 (9–16)	14 (10–17)	0.28	12 (8–16)	13 (9–17)	0.09
Mechanical ventilation-to-ECMO interval, d	4 (1–10)	4 (1–9)	4 (1–10)	0.52	4 (1–9)	4 (2–10)	0.04
Prone-positioning	196 (66)	55 (86)	141 (60)	< 0.01	50 (84)	48 (81)	0.04
Inhaled nitric oxide	156 (52)	32 (50)	124 (53)	0.78	29 (49)	31 (53)	0.07
Neuromuscular blockade	297 (99)	64 (100)	233 (99)	1	59 (100)	59 (100)	0.00
Corticosteroids	61 (20)	13 (20)	48 (21)	1	12 (20)	13 (22)	0.04
Pao_2/Fio_2, mm Hg	64 (53–70)	61 (54–70)	65 (53–70)	0.48	60 (55–70)	62 (55–70)	0.01
Vasopressors	221 (74)	44 (69)	177 (76)	0.34	41 (69)	42 (71)	0.04
Static compliance ECMO day 1, mL/cm H_2O	14 (8–23)	16 (11–24)	14 (7–23)	0.06	17 (10–24)	18 (8–25)	0.04

Crit Care Med. 2022 Feb 1;50(2):264-274

Pre prone-Positioning Characteristics, Mechanical Ventilation Settings, Respiratory Mechanisms, and Outcomes According to the Static Compliance Gain at the End of the Prone-Positioning Session

Parameter	Static Compliance Gain		p
	< 3 mL/cm H_2O (n = 30)	≥ 3 mL/cm H_2O (n = 34)	
Age, yr	51 (42–62)	56 (46–61)	0.58
Male sex	20 (67)	23 (68)	1.00
Simplified Acute Physiology Score II	68 (55–81)	66 (54–74)	0.41
Body mass index, kg/m^2	30.1 (25.4–40.3)	32.1 (29.3–38.1)	0.27
Cause of acute respiratory distress syndrome			
Viral pneumonia	9 (30)	14 (41)	0.54
Bacterial pneumonia	14 (47)	15 (44)	
Other	7 (23)	5 (15)	
Sequential Organ-Failure Assessment at ECMO cannulation	14 (10–16)	12 (9–16)	0.75
Pao_2/Fio_2 before ECMO, mm Hg	60 (54–70)	63 (53–72)	0.79
PP before ECMO	24 (80)	31 (91)	0.36
Intubation-to-ECMO interval, d	4 (1–9)	3 (1–9)	0.73
ECMO-start-to-first-PP interval, d	4 (1–13)	3 (2–6)	0.68
Before first PP			
Respiratory rate, cycles/min	20 (20–20)	20 (20–20)	0.88
Plateau pressure, cm H_2O	24 (24–26)	24 (24–28)	0.05
Positive-end expiratory pressure, cm H_2O	12 (12–13)	12 (12–15)	0.14
Driving pressure, cm H_2O	12 (12–14)	12 (12–14)	0.76
Tidal volume, mL/kg predicted body weight	2.5 (1.5–4.0)	3.2 (2.8–4.9)	0.08
Respiratory system static compliance, mL/cm H_2O	15 (10–20)	17 (13–28)	0.33
Fio_2, %	40 (32–50)	40 (40–60)	0.22
Fmo_2, %	100 (80–100)	100 (83–100)	0.78
ECMO flow, L/min	5.1 (4.4–5.9)	5.1 (4.6–5.5)	0.93
Sweep-gas flow, L/min	7 (4–9)	6 (4–8)	0.79
At the end of the PP session			
Respiratory system static compliance, mL/cm H_2O	14 (8–20)	26 (20–32)	< 0.01
Compliance gain, mL/cm H_2O	0 (−0.8–0.8)	6.2 (3.5–10.3)	< 0.01
$\Delta Pao_2/Fio_2$,[a] mm Hg	6 (−24 to 59)	44 (−15 to 77)	0.20
ΔPco_2,[a] mm Hg	1 (−3 to 3)	−2 (−6 to 2)	0.10

Crit Care Med. 2022 Feb 1;50(2):264-274

Extracorporeal Membrane Oxygenation-Related Complications and Outcomes of the Propensity-Matched Population

Parameter	Nonmatched Cohort			Propensity-Score Matched		
	PP-ECMO ($n = 64$)	No-PP-ECMO ($n = 234$)	p	PP-ECMO ($n = 59$)	No-PP-ECMO ($n = 59$)	p
Complications						
Accidental decannulation	0 (0)	5 (2)	0.52	0 (0)	2 (3)	0.48
Cannula bleeding	16 (25)	52 (22)	0.76	15 (25)	16 (27)	1
Cannula-site infection	17 (27)	89 (38)	0.12	16 (27)	25 (42)	0.12
Ventricular arrhythmia	2 (3)	17 (7)	0.36	2 (3)	6 (10)	0.27
Gas embolism	2 (3)	1 (0.4)	0.23	2 (3)	1 (2)	0.23
Cardiac arrest	3 (5)	27 (12)	0.19	3 (5)	9 (15)	0.13
Outcomes						
Tracheostomy	19 (30)	101 (43)	0.07	18 (31)	28 (47)	0.09
ECMO duration, d	16 (9–29)	11 (4–30)	0.01	15 (8–31)	15 (7–30)	0.66
ICU length of stay, d	38 (27–60)	25 (11–43)	< 0.01	37 (25–60)	27 (17–49)	0.04
90-d probability of being weaned-off ECMO and alive (95% CI)	0.75 (0.62–0.84)	0.49 (0.43–0.55)	< 0.01	0.75 (0.61–0.84)	0.54 (0.41–0.66)	0.03
90-d probability of being weaned-off mechanical ventilation and alive (95% CI)	0.64 (0.51–0.75)	0.46 (0.4–0.53)	0.05	0.62 (0.46–0.74)	0.52 (0.39–0.65)	0.35
90-d mortality	13 (20)	113 (48)	< 0.01	12 (20)	25 (42)	< 0.01

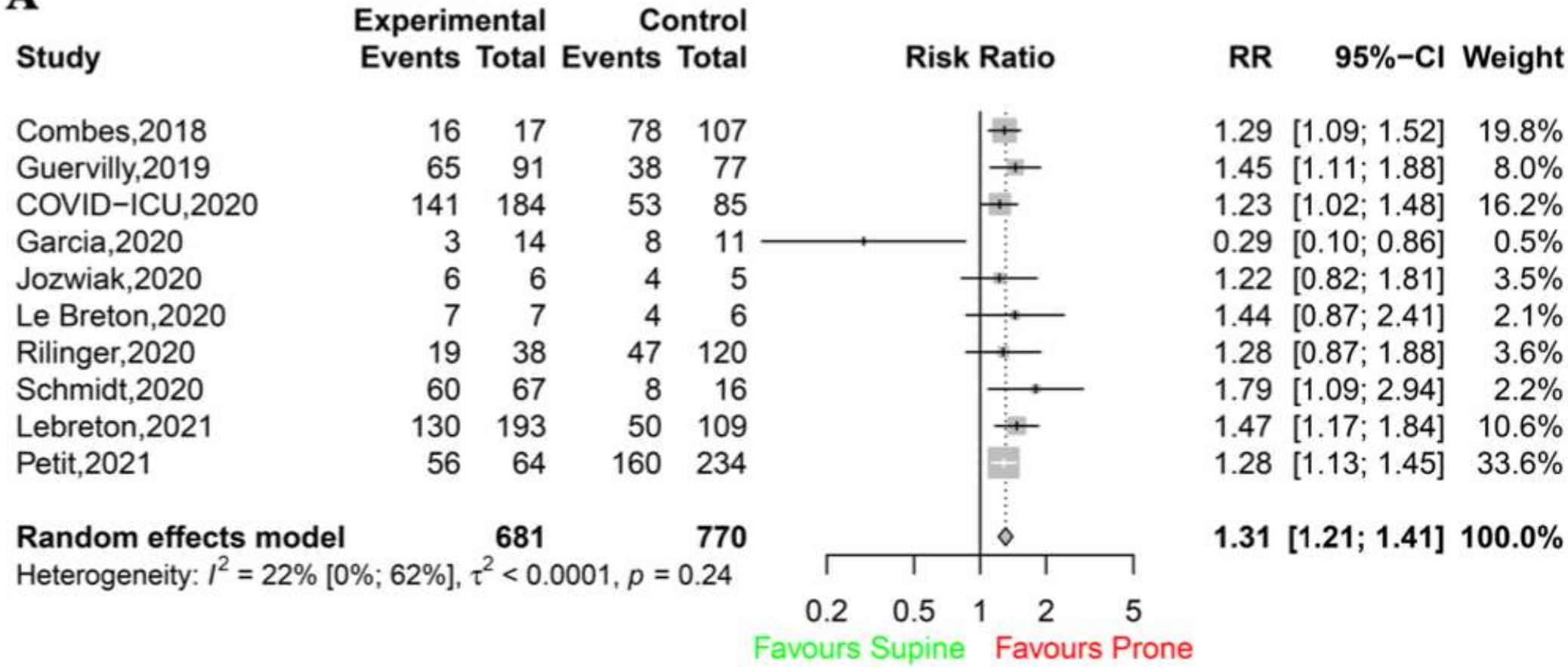
Crit Care Med. 2022 Feb 1;50(2):264-274

Effect of prone positioning on survival in adult patients receiving venovenous extracorporeal membrane oxygenation for acute respiratory distress syndrome: a systematic review and meta-analysis

- 13 studies
- N = 1836 study participants
- Primary outcome to compare 28-day survival in vvECMO patients with Prone Positioning to vv ECMO patients without prone positioning
- Pneumonia – cause of ARDS
- Proning showed a significant improvement in 28-day survival (503 out of 681 patients in the PP group [74%; 95% CI 71–77] vs. 450 out of 770 patients in the control group [58%, 95% CI 55–62]; RR 1.31 [95% CI 1.21–1.41]; *I*2 22% [95% CI 0–62%]; $P < 0.0001$)

Intensive Care Med (2022) 48:270–280

A



Intensive Care Med (2022) 48:270–280

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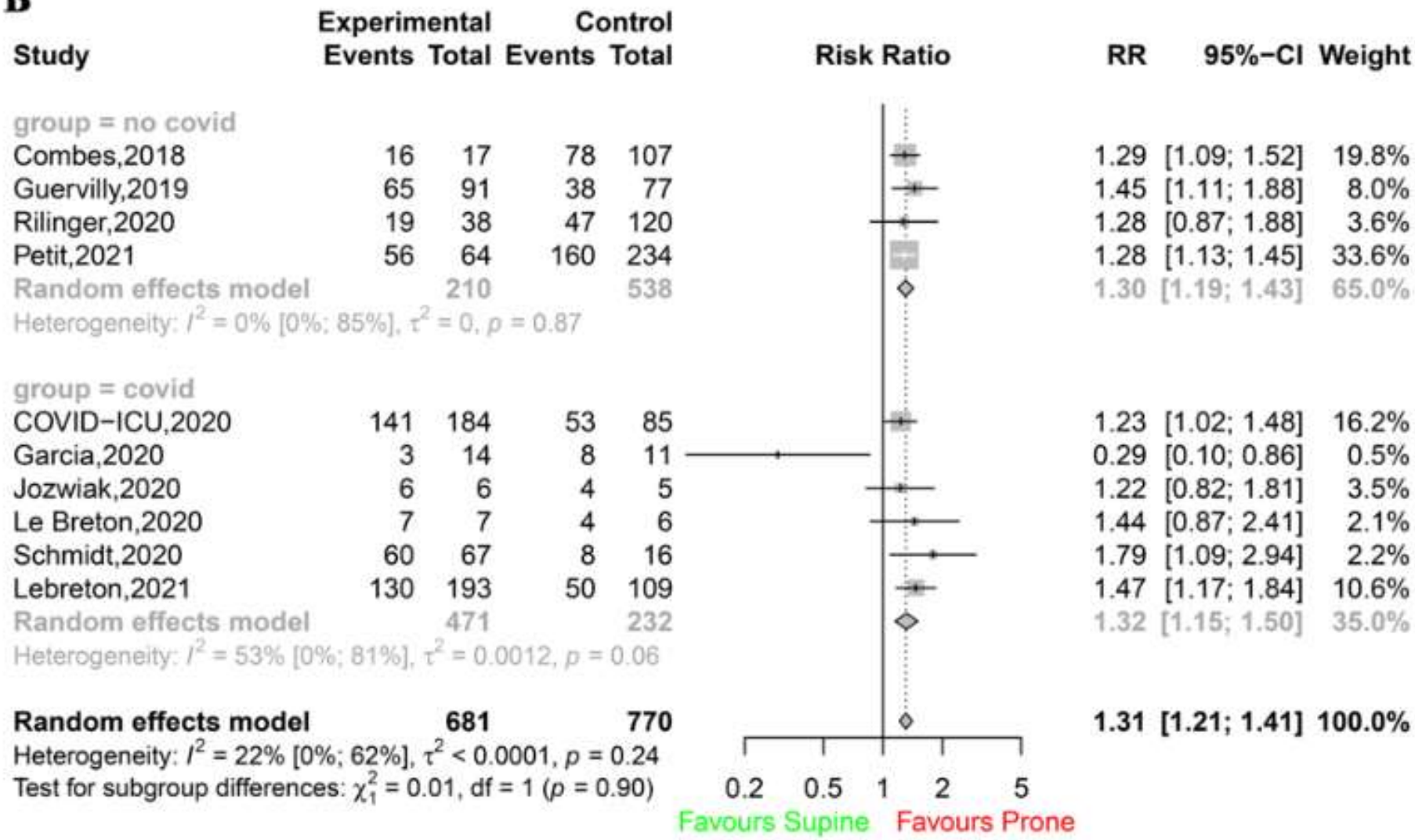


Intensive Care Med (2022) 48:270–280

Extracorporeal Cardiopulmonary Resuscitation in Adult Patients

- ECPR is the application of rapid- deployment VA ECMO to provide circulatory support in patients with cardiac arrest in whom conventional CPR (CPR) is unsuccessful in achieving sustained return of spontaneous circulation (ROSC)
- ECPR can provide precious time for diagnosis, therapy, and recovery.
- ECPR is a time-sensitive, complex intervention that requires teamwork, clearly defined roles optimal logistics, and well-trained health care providers

Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial

- Phase 2, randomised clinical trial, single centre, open-label,
- Adaptive, safety and efficacy of ECMO
- 30 randomly assigned to standard ACLS treatment (n=15) or to early ECMO-facilitated resuscitation (n=15)
- Initial OHCA rhythm of ventricular fibrillation or pulseless ventricular tachycardia, no ROSC after three defibrillation shocks and estimated transfer time to the emergency department shorter than 30 min

- **OHCA – Outside Hospital cardiac arrest**

Lancet 2020; 396: 1807–16

Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial

- Primary outcome survival to hospital discharge
- Secondary outcomes were safety, survival, and functional assessment at hospital discharge and at 3 months and 6 months after discharge

Lancet 2020; 396: 1807–16

	ECMO-facilitated resuscitation (n=15)		Standard ACLS treatment (n=15)		Risk difference or p value
	Number of patients with data	Patients	Number of patients with data	Patients	
Primary outcome (95% CrI)					
Survival to hospital discharge	14	6 (43%, 21·3–67·7)	15	1 (7%, 1·6–30·2)	36% (3·7–59·2; posterior probability= 0·9861)
Secondary outcomes (95% CI)					
Survival to 3 months	14	6 (43%, 21·3–67·7)	15	0 (0·0–20·4)	0·0063
Survival to 6 months	14	6 (43%, 21·3–67·7)	15	0 (0·0–20·4)	0·0063
CPC score at discharge	6	2·5 (0·5)	1	4	NA
CPC score at 3 months	6	1·16 (0·4)	0	NA	NA
CPC score at 6 months	6	1·16 (0·4)	0	NA	NA
mRS score at discharge	6	3·8 (0·7)	1	5	NA
mRS score at 3 months	6	2 (1·2)	0	NA	NA
mRS score at 6 months	6	1·3 (0·8)	0	NA	NA

Lancet 2020; 396: 1807–16

Effect of Intra-arrest Transport, Extracorporeal Cardiopulmonary Resuscitation, and Immediate Invasive Assessment and Treatment on Functional Neurologic Outcome in Refractory Out-of-Hospital Cardiac Arrest

A Randomized Clinical Trial

- Single-centre, randomized clinical trial
- N = 256 patients (witnessed OHCA of presumed cardiac origin without return of spontaneous circulation)
- To determine whether an early invasive approach in adults with refractory OHCA improves neurologically favorable survival
- Regular advanced cardiac life support was continued on-site in the standard strategy group (n = 132)

- **OHCA – Outside Hospital cardiac arrest**

Jama. 2022 Feb 22;327(8):737-47

Effect of Intra-arrest Transport, Extracorporeal Cardiopulmonary Resuscitation, and Immediate Invasive Assessment and Treatment on Functional Neurologic Outcome in Refractory Out-of-Hospital Cardiac Arrest

A Randomized Clinical Trial

- Invasive strategy group (n = 124), mechanical compression was initiated, followed by intra-arrest transport to a cardiac center for ECPR and immediate invasive assessment and treatment
- Primary outcome - survival with a good neurologic at 180 days after randomization.
- Secondary outcomes included neurologic recovery at 30 days and cardiac recovery at 30 days (defined as no need for pharmacological or mechanical cardiac support for at least 24 hours

Jama. 2022 Feb 22;327(8):737-47

Table 2. Primary and Secondary Outcomes in a Study of Intra-arrest Transport, Extracorporeal Cardiopulmonary Resuscitation, and Immediate Invasive Assessment and Treatment in Refractory Out-of-Hospital Cardiac Arrest

	No. (%)			
	Invasive strategy (n = 124)	Standard strategy (n = 132)	Absolute difference, % (95% CI)	*P* value
Primary outcome				
Survival with minimal or no neurologic impairment at 180 d[a]	39 (31.5)	29 (22.0)	9.5 (−1.3 to 20.1)	.09
Secondary outcomes				
Survival with minimal or no neurologic impairment at 30 d[a]	38 (30.6)	24 (18.2)	12.4 (1.9 to 22.7)	.02
Cardiac recovery at 30 d[b]	54 (43.5)	45 (34.1)	9.4 (−2.5 to 21)	.12

Jama. 2022 Feb 22;327(8):737-47

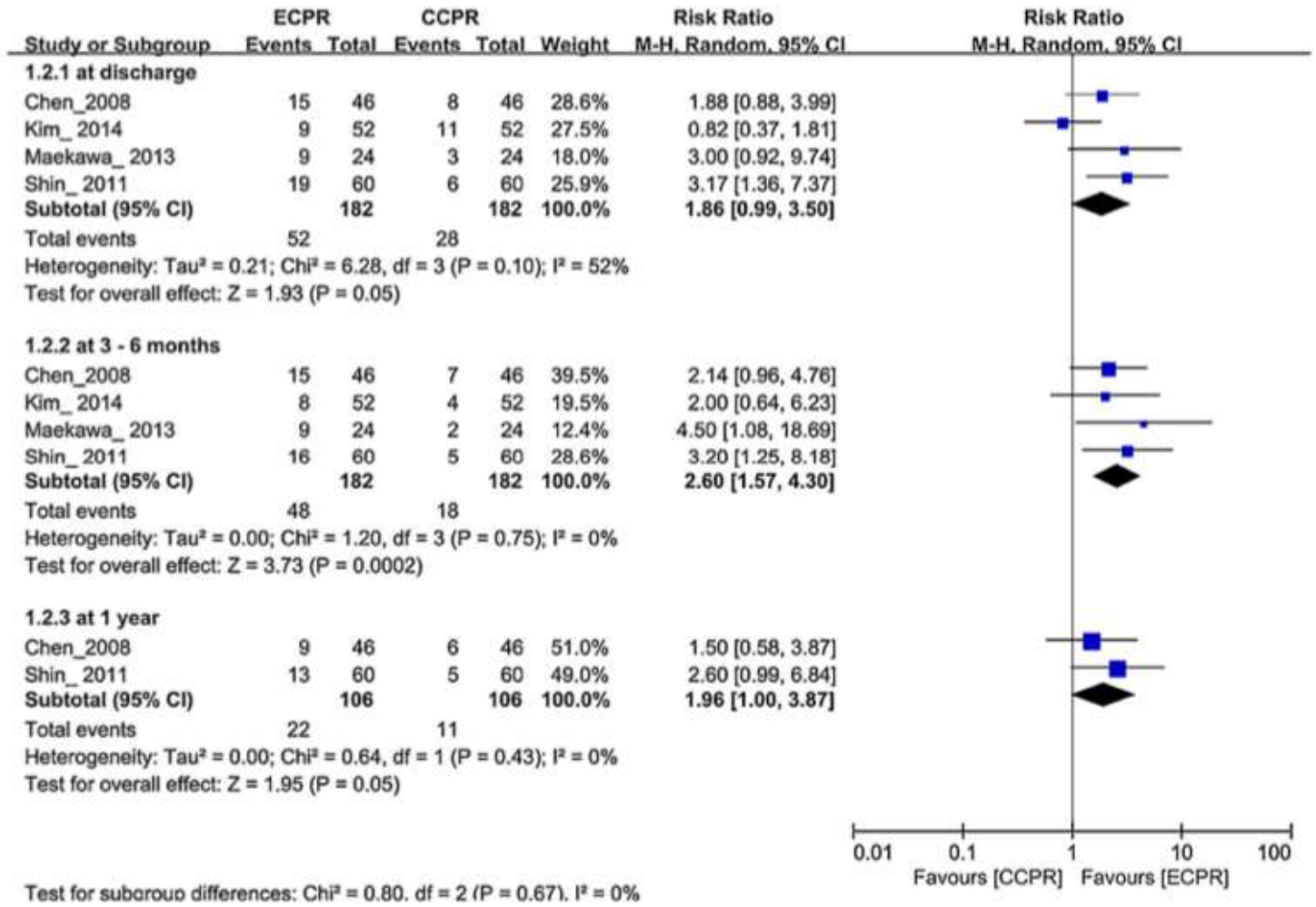
Comparing extracorporeal cardiopulmonary resuscitation with conventional cardiopulmonary resuscitation: A meta-analysis☆

Su Jin Kim[a], Hyun Jung Kim[b], Hee Young Lee[c], Hyeong Sik Ahn[b], Sung Woo Lee[a,*]

- 10 studies in meta analysis
- Observational studies
- Primary outcome – survival at hospital discharge and good neurological outcome at discharge
- Other outcomes - (survival outcome at 3–6 months after discharge , at over 1 year and good neurologic outcome at, at 3–6 months, at over 1 year in comparative groups)

resuscitation.2016.01.019

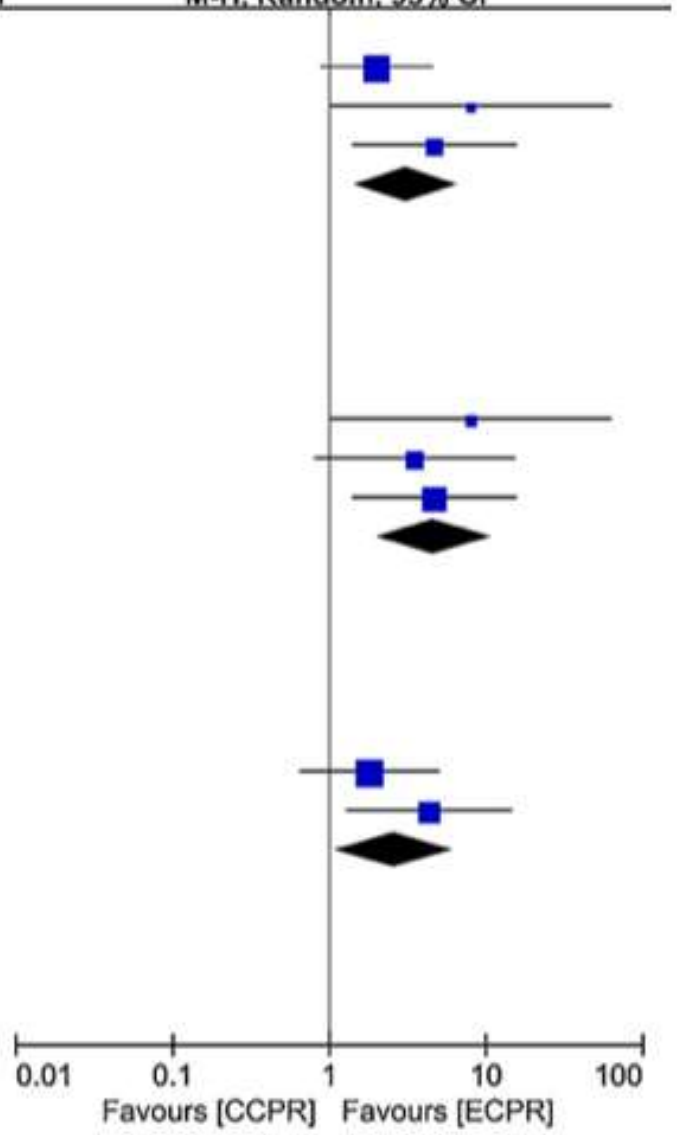
Forest plot of studies reporting survival outcomes



resuscitation.2016.01.019

Forest plot of studies reporting a good neurological outcomes

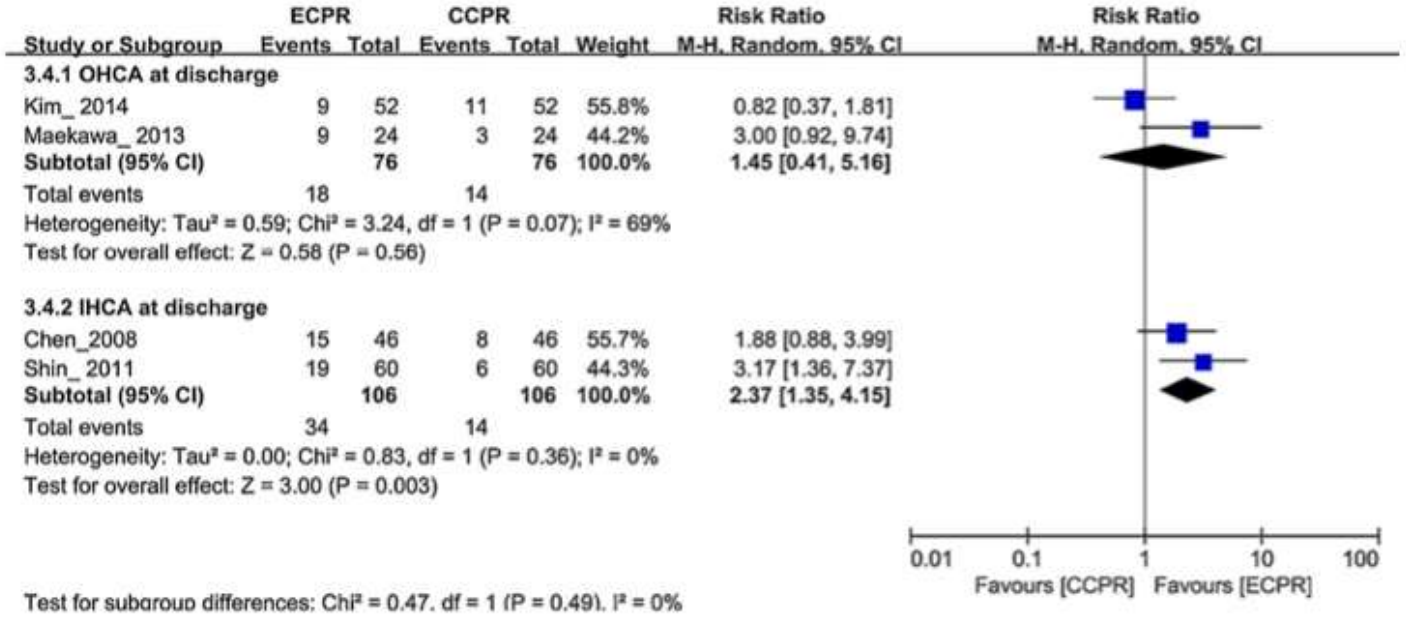
Study or Subgroup	ECPR Events	ECPR Total	CCPR Events	CCPR Total	Weight	Risk Ratio M-H, Random, 95% CI
2.1.1 at discharge						
Chen_2008	14	46	7	46	55.5%	2.00 [0.89, 4.50]
Kim_ 2014	8	52	1	52	12.6%	8.00 [1.04, 61.71]
Shin_ 2011	14	60	3	60	31.8%	4.67 [1.41, 15.41]
Subtotal (95% CI)		**158**		**158**	**100.0%**	**3.12 [1.46, 6.66]**
Total events	36		11			
Heterogeneity: Tau² = 0.10; Chi² = 2.49, df = 2 (P = 0.29); I² = 20%						
Test for overall effect: Z = 2.94 (P = 0.003)						
2.1.2 at 3 - 6 months						
Kim_ 2014	8	52	1	52	17.0%	8.00 [1.04, 61.71]
Maekawa_ 2013	7	24	2	24	33.1%	3.50 [0.81, 15.16]
Shin_ 2011	14	60	3	60	49.9%	4.67 [1.41, 15.41]
Subtotal (95% CI)		**136**		**136**	**100.0%**	**4.65 [2.00, 10.81]**
Total events	29		6			
Heterogeneity: Tau² = 0.00; Chi² = 0.42, df = 2 (P = 0.81); I² = 0%						
Test for overall effect: Z = 3.57 (P = 0.0004)						
2.1.3 at 1 year						
Chen_2008	9	46	5	46	57.0%	1.80 [0.65, 4.96]
Shin_ 2011	13	60	3	60	43.0%	4.33 [1.30, 14.43]
Subtotal (95% CI)		**106**		**106**	**100.0%**	**2.63 [1.11, 6.21]**
Total events	22		8			
Heterogeneity: Tau² = 0.07; Chi² = 1.22, df = 1 (P = 0.27); I² = 18%						
Test for overall effect: Z = 2.20 (P = 0.03)						



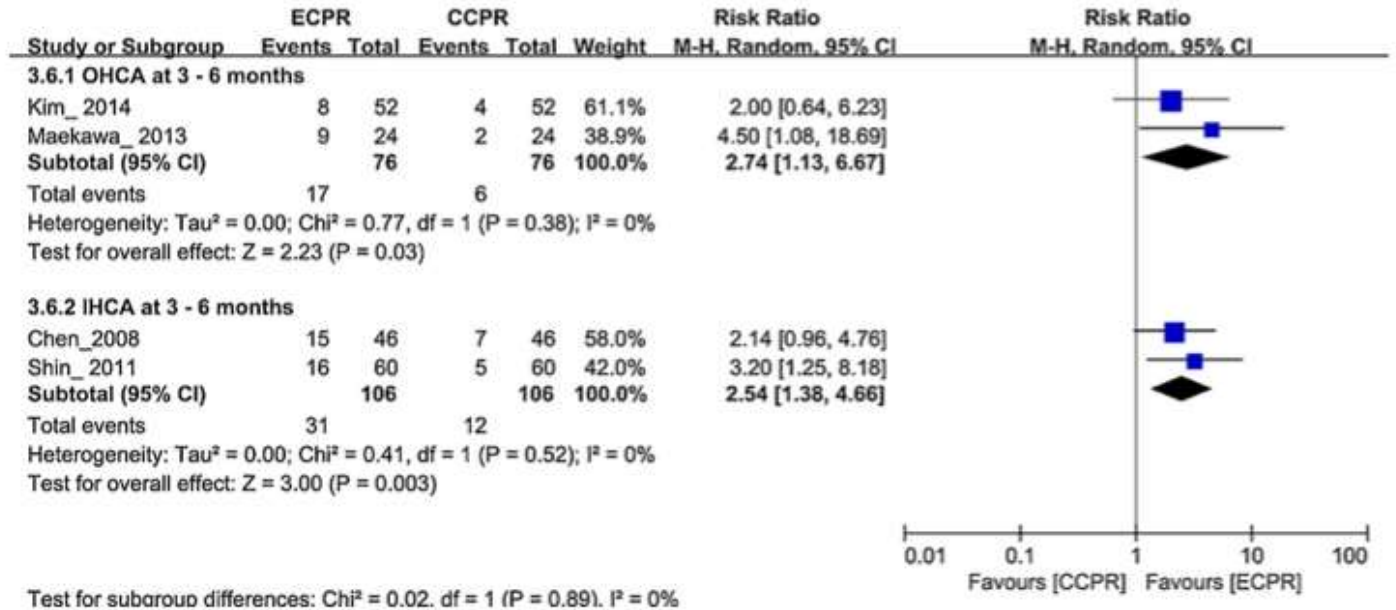
Test for subgroup differences: Chi² = 0.92, df = 2 (P = 0.63), I² = 0%

resuscitation.2016.01.019

A. Forest plot of studies reporting survival to discharge in OHCA and IHCA



B. Forest plot of studies reporting survival at 3-6 months after arrest in OHCA and IHCA



Extracorporeal Carbon Dioxide Removal

Extracorporeal Carbon Dioxide Removal

- Primary aim of ECCO2R is the direct removal of CO2 from blood
- Respiratory failure, including the support of ultra-low tidal volumes in ARDS
- Expedite weaning in patients with chronic obstructive pulmonary disease (COPD)
- Alternative to invasive mechanical ventilation (IMV) in patients with exacerbations of chronic pulmonary diseases
- Bridge to recovery (BTR) or a bridge to transplantation (BTT)

JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

Effect of Lower Tidal Volume Ventilation Facilitated by Extracorporeal Carbon Dioxide Removal vs Standard Care Ventilation on 90-Day Mortality in Patients With Acute Hypoxemic Respiratory Failure

The REST Randomized Clinical Trial

- Multicentre randomized trial
- N = 412 patients
- Randomized to receive lower tidal volume ventilation facilitated by extracorporeal carbon dioxide removal for at least 48 hours (n = 202) or standard care with conventional low tidal volume ventilation (n = 210)
- Primary outcome - all-cause mortality 90 days
- Secondary outcomes included ventilator-free days at day 28 and adverse event rates.

Jama. 2021 Sep 21;326(11):1013-23

Table 2. Primary, Secondary, and Other Clinical Outcomes in a Study of Lower Tidal Volume Facilitated by Extracorporeal Carbon Dioxide Removal in Patients With Acute Hypoxemic Respiratory Failure

Outcome	No. (%)		Difference (95% CI)	Risk ratio (95% CI)	*P* value
	$ECCO_2R$	Ventilation alone			
Primary					
90-d mortality	83 (41.5) [n = 200]	81 (39.5) [n = 205]	2.0% (−7.6% to 11.5%)	1.05 (0.83 to 1.33)	.68
Adjusted analysis[a]				1.12 (0.90 to 1.40)	.29
Sensitivity analysis to adjust for site effect[b]			1.8% (−7.7% to 11.3%)	1.04 (0.83 to 1.31)	.72
90-d mortality in cohort who initiated $ECCO_2R$[c]	80 (43.5) [n = 184]	80 (39.2) [n = 204]	4.3% (−5.5% to 14.1%)	1.11 (0.87 to 1.41)	.39
90-d mortality excluding the first 2 patients at each site who initiated $ECCO_2R$[d]	48 (37.8) [n = 127]	81 (39.5) [n = 205]	−1.7% (−12.5% to 9.0%)	0.96 (0.72 to 1.27)	.76
Secondary					
Ventilator-free days from randomization to day 28, mean (SD)[e]	7.1 (8.8) [n = 199]	9.2 (9.3) [n = 206]	−2.1 (−3.8 to 0.3)		.02
Duration receiving ventilation in survivors, mean (SD), d[f]	18.0 (13.6) [n = 121]	17.4 (31.3) [n = 137]	0.7 (−5.4 to 6.7)		.83
Need for ECMO to day 7	12 (6) [n = 202]	6 (3) [n = 210]	3.1% (−0.9% to 7.0%)	2.08 (0.80 to 5.43)	.13
28-d mortality	76 (38) [n = 200]	74 (36) [n = 207]	2.3% (−7.1% to 11.6%)	1.06 (0.82 to 1.37)	.64
ICU length of stay to death or discharge, median (IQR), d[g,h]	14 (7 to 26) [n = 202]	13 (7 to 22) [n = 210]			.67
Hospital length of stay to death or discharge, median (IQR), d[g,h]	22 (8 to 39) [n = 193]	18 (9 to 35) [n = 201]			.65

Jama. 2021 Sep 21;326(11):1013-23

Table 3. Adverse Events in a Study of Lower Tidal Volume Facilitated by Extracorporeal Carbon Dioxide Removal in Patients With Acute Hypoxemic Respiratory Failure

	$ECCO_2R$ (n = 202)		Ventilation alone (n = 210)	
Adverse event	No. of events	No. (%) of patients	No. of events	No. (%) of patients
Adverse events[a]	168	106 (52.5)	61	48 (22.9)
Related to study intervention[a,b]	65	51 (25.3)	0	0
Serious adverse events[c,d]	70	62 (30.7)	20	18 (8.6)
Related to study intervention[b]	22	21 (10.4)	0	0
Adverse events of specific interest				
Bleeding at other site (excluding intracranial hemorrhage)	18	17 (8.4)	3	3 (1.4)
Intracranial hemorrhage	10	10 (5.0)	2	2 (1.0)
Device failure causing adverse event	9	9 (4.5)	0	0
Bleeding at cannula site	8	8 (4.0)	0	0
Infectious complications[e]	7	7 (3.5)	1	1 (0.5)
Heparin-induced thrombocytopenia	4	4 (2.0)	0	0
Hemolysis	3	3 (1.5)	0	0
Ischemic stroke	1	1 (0.5)	3	3 (1.4)
Serious adverse events of specific interest[f]				
Bleeding at other site (excluding intracranial hemorrhage)	6	6 (3.0)	1	1 (0.5)
Intracranial hemorrhage	9	9 (4.5)	0	0
Infectious complications[e]	5	5 (2.5)	0	0
Device failure causing serious adverse event	2	2 (1.0)	0	0
Heparin-induced thrombocytopenia	1	1 (0.5)	0	0
Ischemic stroke	1	1 (0.5)	3	3 (1.4)

Jama. 2021 Sep 21;326(11):1013-23

Extracorporeal Carbon Dioxide Removal in the Treatment of Status Asthmaticus

- Retrospective observational study
- Medical ICU n = 26
- Status asthmaticus
- All patients cannulated onto VV ECCO2R
- 50% males
- All survived to discharge

Crit Care Med 2020; 48:e1226–e1231

TABLE 2. Patient Data Before and After Extracorporeal Carbon Dioxide Removal Initiation

Variables	Pre-$ECCO_2R$	24 hr After $ECCO_2R$ Initiation	*p*
Vitals			
Heart rate (beats/min)	110 ± 31.8	99 ± 17.5	0.09
Systolic blood pressure (mm Hg)	126 ± 14.2	135 ± 27.6	0.13
Mean arterial pressure (mm Hg)	82 ± 12.4	90 ± 17.9	0.07
Oxygen saturation (%)	99 (96–100)	100 (97–100)	0.28
Use of vasopressors	17 (65)	2 (8)	< 0.05
Ventilator settings and measurements			
Tidal volume (cc)	400 (350–473)	255 (170–370)	< 0.05
Tidal volume (cc/kg)	5 (4–6)	3 (2–5)	< 0.05
Respiratory rate (breaths/min)	13 (10-16)	8 (5-10)	<0.05
F_{IO_2} (%)	50 (40-70)	40 (40-60)	0.12
Set PEEP (cm H_2O)	5 (5-7)	5 (5-5)	0.14
Intrinsic PEEP (cm H_2O)	13 (9–14)	6 (5–7)	< 0.05
Peak pressure (cm H_2O)	53 (45–63)	36 (27–44)	< 0.05
Plateau pressure (cm H_2O)	20 (16–25)	18 (16–19)	< 0.05
Arterial blood gas			
pH	7.13 (6.97–7.20)	7.42 (7.39–7.45)	< 0.05
P_{CO_2} (mm Hg)	93 (71–128)	43 (38–48)	< 0.05
P_{O_2} (mm Hg)	136 (95–206)	134 (85–202)	0.32
P_{O_2}-to-F_{IO_2} ratio	248 (181–350)	–	–
Lactate (mmol/L)	1.5 (0.8–2.6)	1.2 (0.9–1.8)	0.07
$ECCO_2R$ parameters			
Blood flow (L/m)	–	3.2 ± 0.6	
Sweep (L/m)	–	5.8 ± 2.9	

Crit Care Med 2020; 48:e1226–e1231

Clinical outcomes of patients on Veno venous Extracorporeal Carbon Dioxide Removal

Outcomes	Median (Interquartile Range) or *n* (%)
Survival to discharge	26 (100)
Extubated during $ECCO_2R$	20 (77)
Never extubated during $ECCO_2R$	6 (23)
Hospital LOS (d)	11 (8–13)
ICU LOS (d)	8 (6–10)
Time on $ECCO_2R$ (d)	3 (2–6)
Time on mechanical ventilation (d)	4 (2–5)

Complications During or Post extracorporeal Carbon Dioxide Removal

Complication	*n* (%)
Pneumothorax	2 (8)
Bleeding requiring transfusion	4 (15)
DVT	12 (46)
DVT related to $ECCO_2R$ cannula	6 (23)
Groin hematoma post-$ECCO_2R$	1 (4)
Ventilator-associated pneumonia	6 (23)

Crit Care Med 2020; 48:e1226–e1231

The feasibility and safety of extracorporeal carbon dioxide removal to avoid intubation in patients with COPD unresponsive to noninvasive ventilation for acute hypercapnic respiratory failure (ECLAIR study): multicentre case–control study

- Multicentre study – five centres
- Case control study
- N = 25 study participants
- Intubation was avoided in 14 out of all 25 ECCO2R patients (56.0 %)
- No difference in 30day and 90day mortality between case and control groups

Intensive Care Med (2016) 42:1437–14

Clinical course	$ECCO_2R$ group ($n = 25$)	Control group ($n = 25$)	p value
Days on $ECCO_2R$	8.5 (1.0–27.0)	N/A	N/A
Days on IMV	8.3 (0–60.0)	13.7 (1.0–52.0)	0.02*
Tracheotomy	9.0 (36.0)	15.0 (60.0)	0.09*
Days on NIV during $ECCO_2R$	4.6 (0–22.0)	N/A	N/A
Mode of NIV used during $ECCO_2R$	A-NIV 12.0 % C-NIV 8.0 % Mix-NIV 44.0 %	N/A	N/A
Length of stay			
Days in ICU	28.9 (8.0–100.0)	24.0 (2.0–66.0)	0.09*
Days in hospital	36.9 (9.0–100.0)	37.0 (12.0–248.0)	0.49*
Mortality *n* (%)			
28-day mortality	4.0 (16.0)	3.0 (12.0)	0.68
Hospital mortality	6.0 (24.0)	3.0 (12.0)	0.28
90-day mortality	7.0 (28.0)	7.0 (28.0)	1.0

Intensive Care Med (2016) 42:1437–14

$ECCO_2R$-associated adverse events and bleeding/ thromboembolic complications

Adverse events (*n*)	$ECCO_2R$ group	Control group
Major $ECCO_2R$-associated adverse events	14	N/A
Major bleeding	11	2*
Pulmonary haemorrhage	2	–
Bleeding from tracheostomy	2	1
Haematothorax	2	–
Bleeding from gastric ulcer	1	–
Bleeding from rectal ulcer	1	–
Bleeding from oesophageal varices	–	1
Retroperitoneal haematoma	1	–
Dislodged sealing cap of DLC	1	–
Cannula insertion site	1	–
Device-related	3	N/A
Air detection in the circuit	1	–
Extracorporeal clotting	2	–
Minor $ECCO_2R$-associated adverse events	11	N/A
Minor bleeding/thrombosis	10	10
Haematuria	3	1
Cannula insertion site	2	–
Intracerebral bleeding (small)	–	1
Epistaxis	2	–
Haemorrhagic pleural effusion	1	–
Tracheobronchial haemorrhage	1	3
Bleeding from ileostomy	1	–
Inguinal haematoma	–	1
Intramuscular bleeding lower limb	–	1
Postoperative wound bleeding	–	1
Bleeding from tracheostomy	–	1
Thrombosis inferior vena cava and renal vein		1
Device-related	1	N/A
Disconnection of sweep gas tubing	1	–

ECMO IN SEPTIC SHOCK

ECMO in septic shock

- Use of ECLS for adult septic shock has demonstrated that peripheral ECMO for distributive shock is generally associated with poor outcomes
- In adult patients with refractory septic cardiomyopathy, ECLS may have an important role

Venoarterial extracorporeal membrane oxygenation as mechanical circulatory support in adult septic shock: a systematic review and meta-analysis with individual participant data meta-regression analysis

- 14 observational studies
- N = 468 patients
- Pooled survival 36.4% (95% confidence interval [CI]: 23.6%–50.1%)
- Survival among patients with left ventricular ejection fraction (LVEF) < 20% (62.0%, 95%-CI: 51.6%–72.0%) significantly higher than those with LVEF > 35% (32.1%, 95%-CI: 8.69%–60.7%, *p* = 0.05)

Ling et al. Crit Care (2021) 25:246

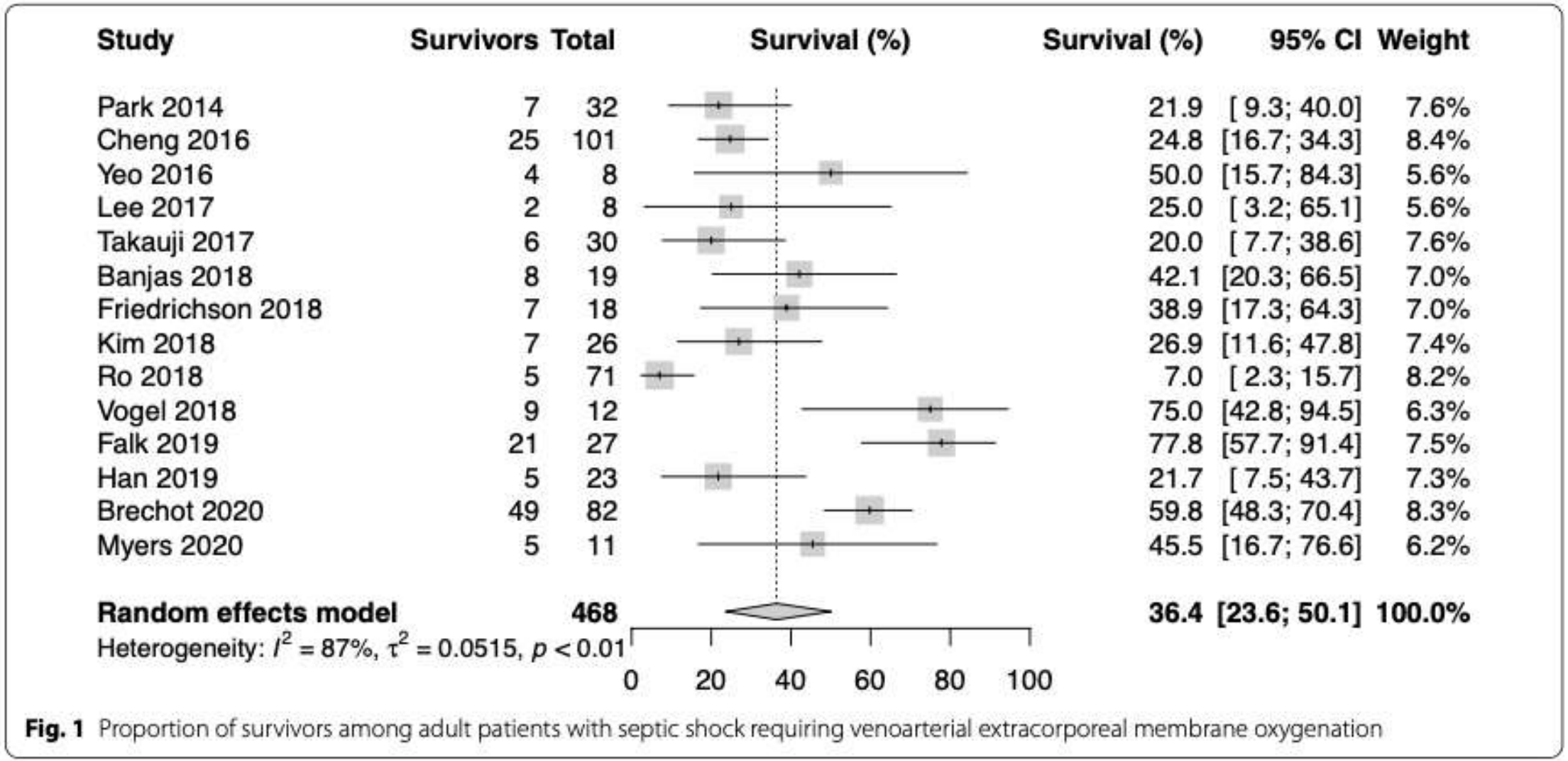


Fig. 1 Proportion of survivors among adult patients with septic shock requiring venoarterial extracorporeal membrane oxygenation

Ling et al. Crit Care (2021) 25:246

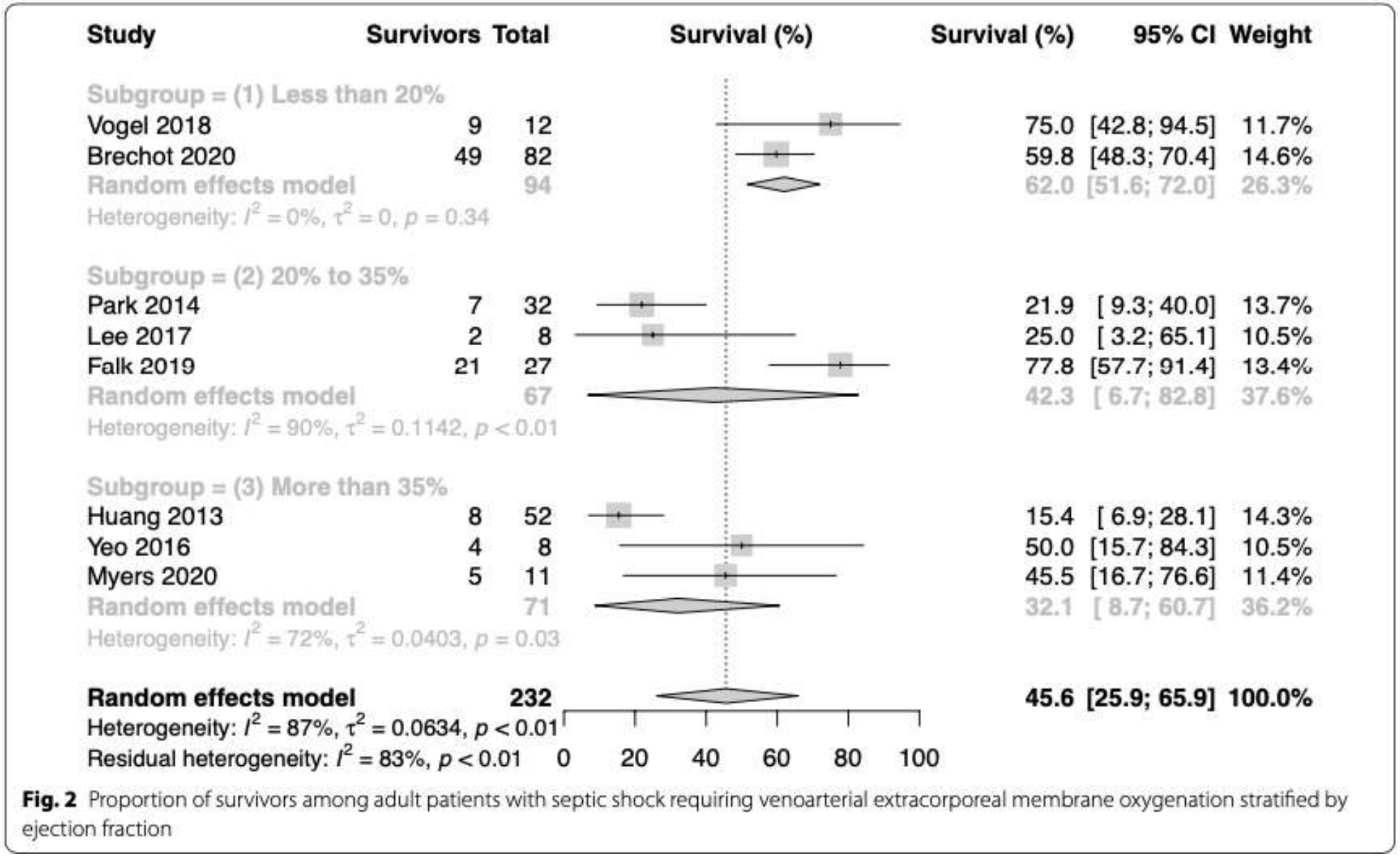


Fig. 2 Proportion of survivors among adult patients with septic shock requiring venoarterial extracorporeal membrane oxygenation stratified by ejection fraction

Ling et al. Crit Care (2021) 25:246

Subgroup		Pooled survival (%)	95% CI (%)
Geographical region ($p < 0.001$)	Asia	19.5	13.0 to 26.8
	Europe and North America	57.8	44.8 to 70.3
Presence of CPR ($p = 0.55$)	CPR	Survival = 24.4% (21 of 86)	
	No CPR	Survival = 27.3% (54 of 144)	
LVEF ($p = 0.09$)	< 20%	62.0	51.6 to 72.1
	20 to 35%	42.3	6.70 to 82.8
	> 35%	32.1	8.70 to 60.7
Serum lactate ($p = 0.20$)	< 5 mmol/l	50.5	29.8 to 71.2
	> 5 mmol/l	32.2	16.2 to 50.7

CI confidence interval; *VA* Venoarterial; *VV* venovenous; *CPR* cardiopulmonary resuscitation; *LVEF* left ventricular ejection fraction

Extracorporeal Membrane Oxygenation for Septic Shock

Lars Falk, MD[1,2]; Jan Hultman, MD, PhD[1,2]; Lars Mikael Broman, MD, PhD[1,2]

- Retrospective observational studies
- N = 37 patients
- 27 patients VV – ECMO and 10 patients VA – ECMO
- Septic shock with left ventricular failure n = 20
- Septic shock n = 17
- Primary outcome : survival to discharge from ECMO unit, hospital survival, and survival at follow-up of at least 6 months
- Secondary outcomes : days on ECMO and ECMO-associated complications

Critical Care Medicine. 2019 Aug 1;47(8):1097-105

TABLE 1. Infection and Sepsis-Related Variables

No.	Days Sepsis Before ECMO	Primary Site Infection	Primary Agent	Positive Blood Culture	Antibiotics Before ECMO	Secondary Infection (Agent)	Antibiotics on ECMO
1	2	Lung	*Staphylococcus aureus* (blood)	Yes	PipTaz, tobramycin, moxifloxacin	–	Meropenem, vancomycin, clindamycin, cefotaxime
2	0.5	Gut	*Klebsiella pneumoniae*, *Candida albicans* (BAL)		PipTaz, gentamicin	*Candida krusei*	Meropenem, vancomycin, caspofungin
3	1	Lung	Pneumococci (blood, BAL)	Yes	Meropenem, vancomycin, erythromycin, cefotaxime, oseltamivir	–	Meropenem, vancomycin, erythromycin, cefotaxime
4	1.5	Lung	Pneumococci (blood)	Yes	Cefotaxime, clindamycin	–	Cefotaxime, clindamycin
5	1	Fasciitis	*Escherichia coli*, *E. faecalis* (urine)	Yes	Meropenem, clindamycin		Meropenem, vancomycin, clindamycin, Amph
6	1	Lung	InflA, *Streptococcus pyogenes* (blood)	Yes	Meropenem, moxifloxacin, linezolid		Meropenem, clindamycin, moxifloxacin, linezolid
7	1	Fasciitis	*S. pyogenes*	Yes	Meropenem, moxifloxacin	*K. pneumoniae* (BAL)	Meropenem, vancomycin, clindamycin

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8	1	Fasciitis	StrepA (blood)	Yes	Meropenem, clindamycin		Meropenem, vancomycin, clindamycin
9	0.5	Lung	StrepA (BAL, blood)	Yes	Cefotaxime, gentamicin	*Saccharomyces cerevisiae*, *Enterococcus faecium*	Meropenem, moxifloxacin, vancomycin, zanamivir
10	1.5	Lung	InflA, *S. aureus*, Panton-Valentine Leukocidin producing *S. aureus* strain (BAL)		Meropenem, azithromycin, oseltamivir	*C. albicans* (BAL)	Meropenem, vancomycin, clindamycin, azithromycin, oseltamivir
11	1	Lung	StrepA	Yes	Cefotaxime, erythromycin	*C. albicans, Candida glabrata (BAL), Staphylococcus epidermidis* (blood)	Meropenem, cefotaxime, erythromycin, tobramycin
12	1	Lung	Influenza B, StrepA	Yes	Meropenem, clindamycin, vancomycin, moxifloxacin, zanamivir		Meropenem, clindamycin, moxifloxacin, oseltamivir
13	2	Lung	*Candida kefyr, C. krusei, C. albicans*, rhinovirus, *Pseudomonas aeruginosa* (BAL)		Meropenem		Meropenem, levofloxacin, vancomycin, Amph

Critical Care Medicine. 2019 Aug 1;47(8):1097-105

TABLE 1. (*Continued*). Infection and Sepsis-Related Variables

No.	Days Sepsis Before ECMO	Primary Site Infection	Primary Agent	Positive Blood Culture	Antibiotics Before ECMO	Secondary Infection (Agent)	Antibiotics on ECMO
14	1	Lung		Yes	Cefotaxime, erythromycin, tobramycin	*C. albicans* (blood, BAL), Epstein-Barr virus (blood)	Meropenem, vancomycin, erythromycin, micafungin
15	1	Lung	Legionella		Cefotaxime, clindamycin, erythromycin, tobramycin	Aspergillus niger (BAL)	Meropenem, vancomycin, levofloxacin
16	0.5	Pyelonephritis	*E. coli* (blood, urine)	Yes	Meropenem	*C. albicans* (BAL)	Meropenem, vancomycin
17	2	Gut	*Acinetobacter baumanii* (BAL), *E. faecium* (blood, BAL)	Yes	Meropenem, rifampicin, colistin, caspofungin, vancomycin		Meropenem, vancomycin, rifampicin, colistin, caspofungin
18	1	Myocarditis			Meropenem, vancomycin		Meropenem, vancomycin, levofloxacin
19	0.5	Lung	*A. baumanii* (blood), *S. cerevisiae* (BAL)	Yes	Meropenem, levofloxacin	*Stenotrophomonas maltophilia* (BAL), *S. epidermidis* (BAL)	Meropenem, levofloxacin, clindamycin
20	1	Blood	*S. aureus*, *E. coli*, Enterococci (blood)	Yes	Cefotaxime, gentamicin	*C. albicans* (BAL)	Meropenem, vancomycin, clindamycin, tobramycin, caspofungin
21	0.5	Lung	Pneumococci (blood, BAL)	Yes	Cefotaxime, gentamicin	*S. maltophilia*, *C. albicans*	Meropenem, vancomycin

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22	1	Pyelonephritis	*E. coli* (blood)	Yes	PipTaz, amikacin	*C. albicans* (BAL)	Meropenem, vancomycin, micafungin
23	0.5	Blood	Pneumococci (blood, BAL)	Yes	PipTaz, moxifloxacin, gentamicin	Candida species	Meropenem, vancomycin, moxifloxacin, fluconazole
24	1	Fasciitis	*S. pyogenes*		Cefotaxime, clindamycin, gentamicin, metronidazole	*S. epidermidis*, *E. coli* (urine)	Meropenem, vancomycin, clindamycin, levofloxacin, metronidazole
25	1				Meropenem, moxifloxacin, cotrimoxazole	*C. albicans* (lung)	
26	1	Lung	Pneumococci and CNS (blood)	Yes	PipTaz, gentamicin	Candida species (lung)	Meropenem, vancomycin, ciprofloxacin, amikacin, metronidazole, caspofungin
27	1	Blood	*E. coli* (extended spectrum beta-lactamses)	Yes	Meropenem, levofloxacin	CNS	Meropenem, vancomycin, levofloxacin, caspofungin
28	1.5	Blood	Pneumococci and *E. coli* (blood)	Yes	PipTaz, azithromycin	*C. glabrata*	Meropenem, vancomycin, moxifloxacin
29	1	Urine	*K. pneumoniae*	Yes	Meropenem		Meropenem, vancomycin, ciprofloxacin
30	0.5	Lung	Pneumococci, *Haemofilus pneumonaie*		Meropenem, erythromycin	*C. albicans* (BAL)	Meropenem, vancomycin, erythromycin

Critical Care Medicine. 2019 Aug 1;47(8):1097-105

TABLE 1. (*Continued*). Infection and Sepsis-Related Variables

No.	Days Sepsis Before ECMO	Primary Site Infection	Primary Agent	Positive Blood Culture	Antibiotics Before ECMO	Secondary Infection (Agent)	Antibiotics on ECMO
31	1	Lung	Aspergillus		Meropenem, linezolid, clindamycin, gentamicin, AmB, voriconazole		Meropenem, vancomycin, clindamycin, linezolid, gentamycin, AmB, voriconazole
32	1	Pyelonephritis	Influenza A, Beta streptococci	Yes	Cefotaxime, oseltamivir	*C. albicans, S. epidermidis,* herpes simplex virus	Meropenem, vancomycin, zanamivir
33	0.5	Lung	Influenza A, *S. pyogenes* (blood)	Yes	Meropenem, erythromycin	*C. albican, S. maltophilia*	Meropenem, vancomycin, clindamycin, micafungin, zanamivir
34	0.5	Lung	Beta streptococci		Meropenem, clindamycin		
35	0.5	Lung	*K. pneumoniae*	Yes	Meropenem, moxifloxacin, vancomycin	*C. glabrata, C. albicans*	Meropenem, vancomycin, tobramycin
36	0.5	Pyelonephritis	*E. coli*	Yes	Ciprofloxacin, clindamycin		Meropenem, vancomycin
37	2	Lung	*S. aureus*	Yes	PipTaz, piperacillin, clindamycin	*C. albicans*	Meropenem, vancomycin, linezolid, clindamycin, fluconazole

Critical Care Medicine. 2019 Aug 1;47(8):1097-105

Outcome	Survival (%)			Risk Score Relations			
	ECMO	Hospital	Long Term	SAPS-3	Estimated Mortality Rate Based on SAPS-3	Standardized Mortality Ratio	Number Needed to Treat for One Extra Survivor Compared With Reference Cohort
All ($n = 37$)	81.1	78.4	59.5	86	81	0.27	1.68
LVF ($n = 20$)	90.0	90.0	75.0	85.5	79.9	0.13	1.43
Venovenous ECMO ($n = 2$)	50.0	50.0	50.0	90.0	85	0.59	2.86
Venoarterial ECMO ($n = 18$)	94.4	94.4	83.3	85.5	79.9	0.07	1.36
non-LVF ($n = 17$)	70.6	64.7	47.1	87	82	0.43	2.14
Venovenous ECMO ($n = 8$)	62.5	62.5	37.5	86	81	0.46	2.30
Venoarterial ECMO ($n = 9$)	66.7	66.7	55.6	87	82	0.41	2.05
LVF vs non-LVF	NS	0.044	0.081	NS	–	–	–

ECMO = extracorporeal membrane oxygenation, LVF = left ventricular failure, NS, not significant, SAPS-3 = Simplified Acute Physiology Score, Third Revision.

Critical Care Medicine. 2019 Aug 1;47(8):1097-105

Venoarterial extracorporeal membrane oxygenation to rescue sepsis-induced cardiogenic shock: a retrospective, multicentre, international cohort study

Nicolas Bréchot, David Hajage, Antoine Kimmoun, Julien Demiselle, Cara Agerstrand, Santiago Montero, Matthieu Schmidt, Charles-Edouard Luyt, Guillaume Lebreton, Guillaume Hékimian, Erwan Flecher, Elie Zogheib, Bruno Levy, Arthur S Slutsky, Daniel Brodie, Pierre Asfar, Alain Combes*, for the International ECMO Network*

- Retrospective muticentre cohort study
- 82 patients (aged ≥18 years) with septic shock received VA-ECMO at five academic ECMO centres, with 130 controls (not receiving ECMO)
- Inclusion criteria : severe cardiovascular dysfunction leading to VA-ECMO initiation, left ventricular ejection fraction (LVEF) 35% or less or cardiac index 3 L/min per m^2 or less; lactate of 4 mmol/L; and inotrope score at least 75 µg/kg per min
- Primary endpoint : survival at 90 days

The Lancet. 2020 Aug 22;396(10250):545-52

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- **Secondary outcomes :**
- Decrease in inotrope score
- Rate of lactate clearance in the 5 days after inclusion
- 1-year outcomes of patients treated with ECMO.
- Health-related quality of life, anxiety, depression, and post-traumatic stress disorder were prospectively evaluated by phone interviews at 1 year after hospital discharge

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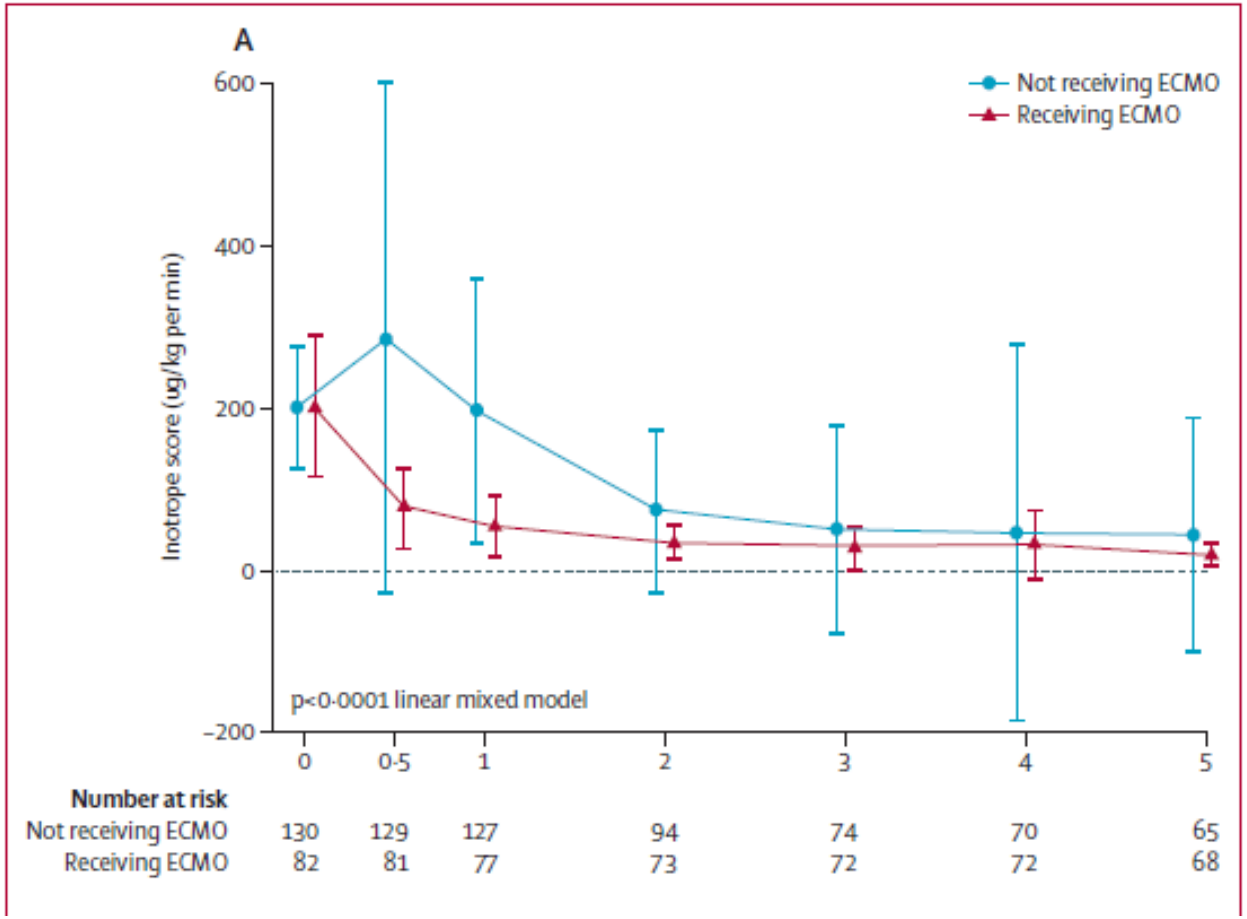
- Survival at 90 days for patients treated with VA-ECMO was significantly higher than for controls (60% *vs* 25%, risk ratio [RR] for mortality 0·54, 95% CI [0·40–0·70]; p<0·0001)
- After propensity score weighting, ECMO remained associated with improved survival (51% *vs* 14%, adjusted RR for mortality 0·57, 95% CI [0·35–0·93]; p=0·0029)

The Lancet. 2020 Aug 22;396(10250):545-52



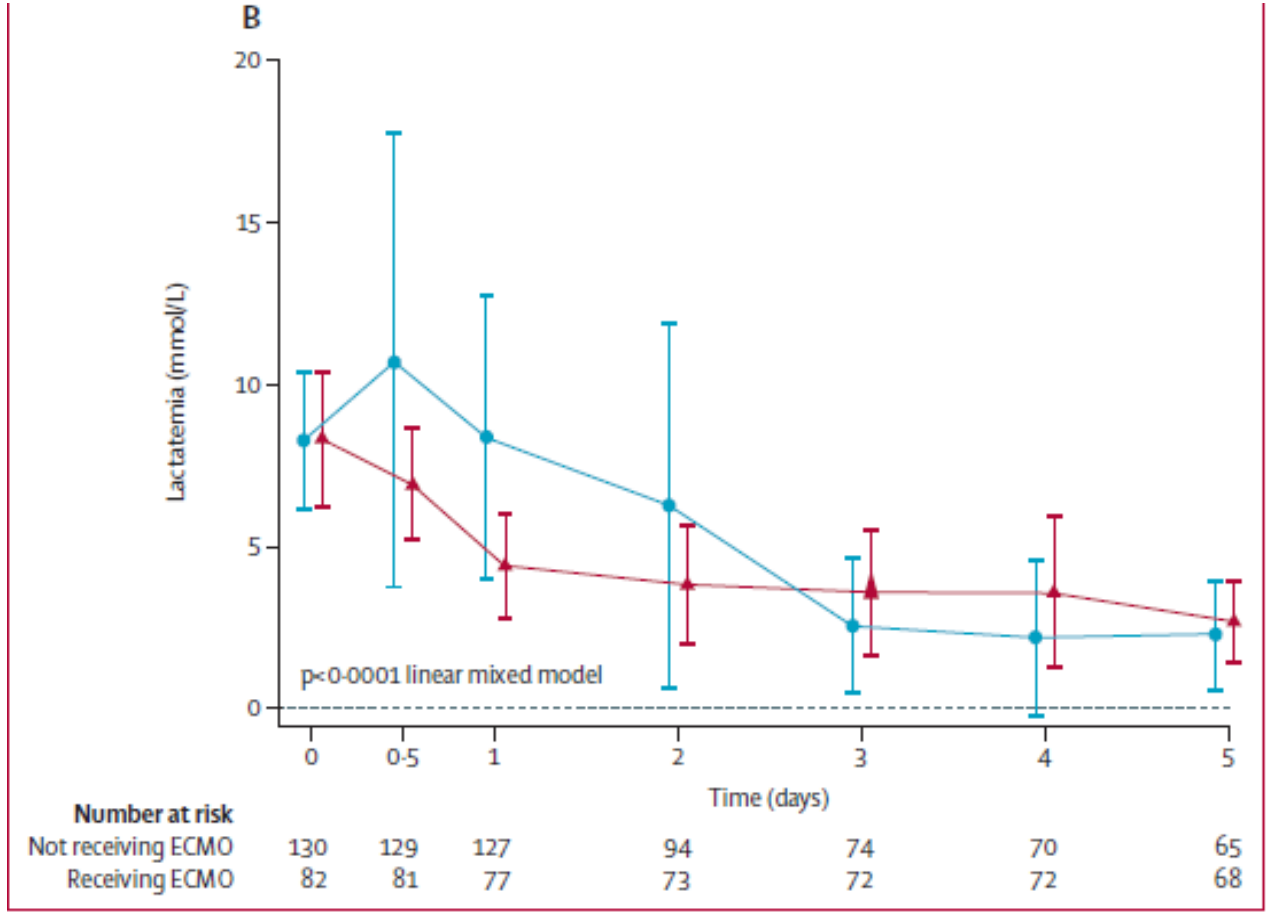


***Figure 3*: Evolution of (A) inotrope score and (B) lactataemia between patients receiving ECMO and not receiving ECMO**

Propensity-weighted for covariables associated with severity of myocardial dysfunction (cardiac index); covariables associated with survival during septic shock (inotrope score, lactatemia, Sequential Organ Failure Assessment (SOFA) score, age, immunocompromised status, and cumulative fluid therapy before inclusion); and delay between shock onset and inclusion. Mean and 95% CI is shown for each timepoint. Inotrope score (µg/kg per min)=dobutamine dose (µg/kg per min) + (epinephrine dose [µg/kg per min] + norepinephrine dose [µg/kg per min]) ×100.[13]
ECMO=extracorporeal membrane oxygenation.

The Lancet. 2020 Aug 22;396(10250):545-52

ECLS as Bridge to Lung Transplantation

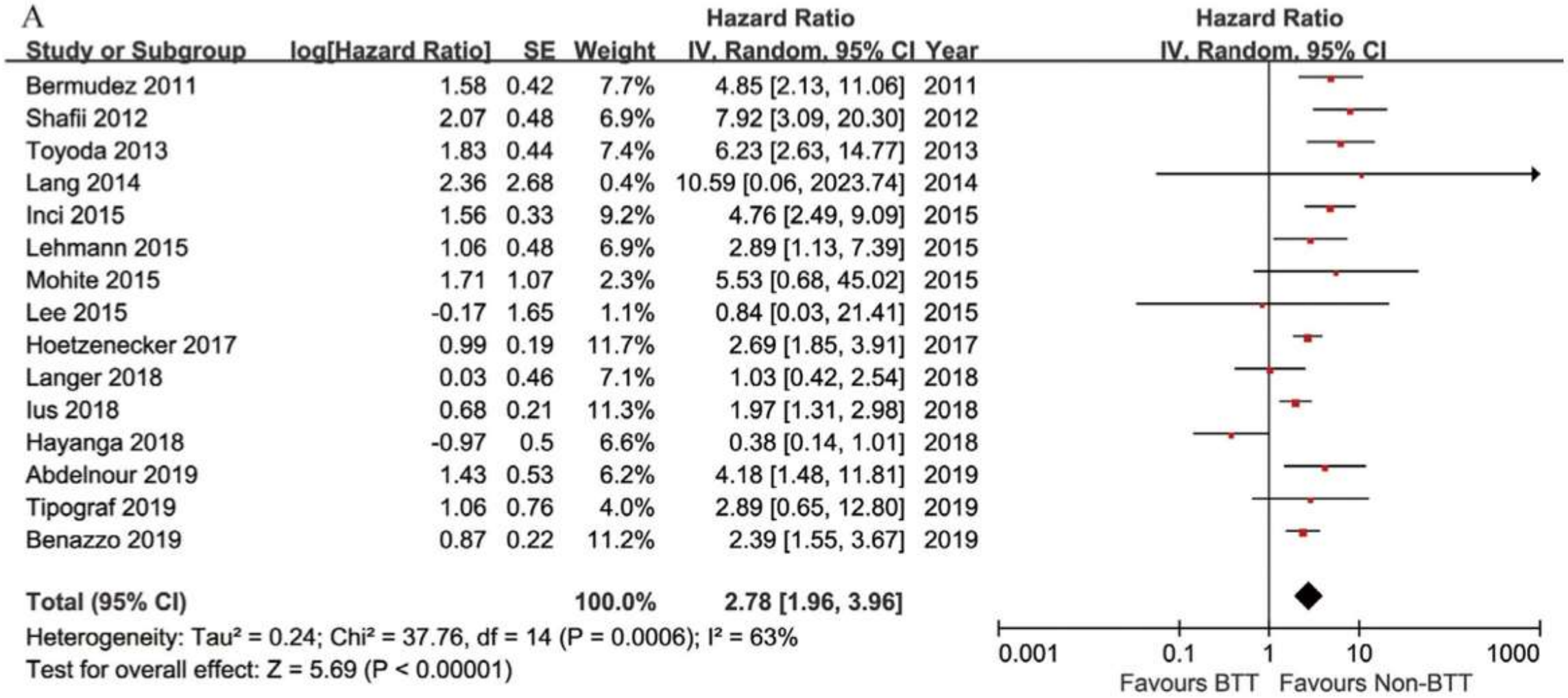
- Patients awaiting lung transplant may deteriorate and require mechanical support for their failing lungs
- Principal goals of these bridging strategies are to restore acceptable physiology, avoid end-organ injury, and maintain or improve functional capacity and physical conditioning while awaiting transplantation

Extracorporeal membrane oxygenation as a bridge vs. non-bridging for lung transplantation: A systematic review and meta-analysis

- 19 studies (cohort studies)
- n = 7061 participants undergoing lung transplantation
- BTT group: 564 participants; non-BTT group: 6497 participants
- Intervention and comparison: ECMO BTT vs. non-BTT for lung transplantation
- Lower overall survival in the BTT group (HR: 2.78, 95% confidence interval [CI]: 1.96–3.96, *P* < .00001
- BTT group showed a higher rate of in-hospital mortality (RR: 2.38, 95% CI: 1.69-3.35, *P* < .00001)

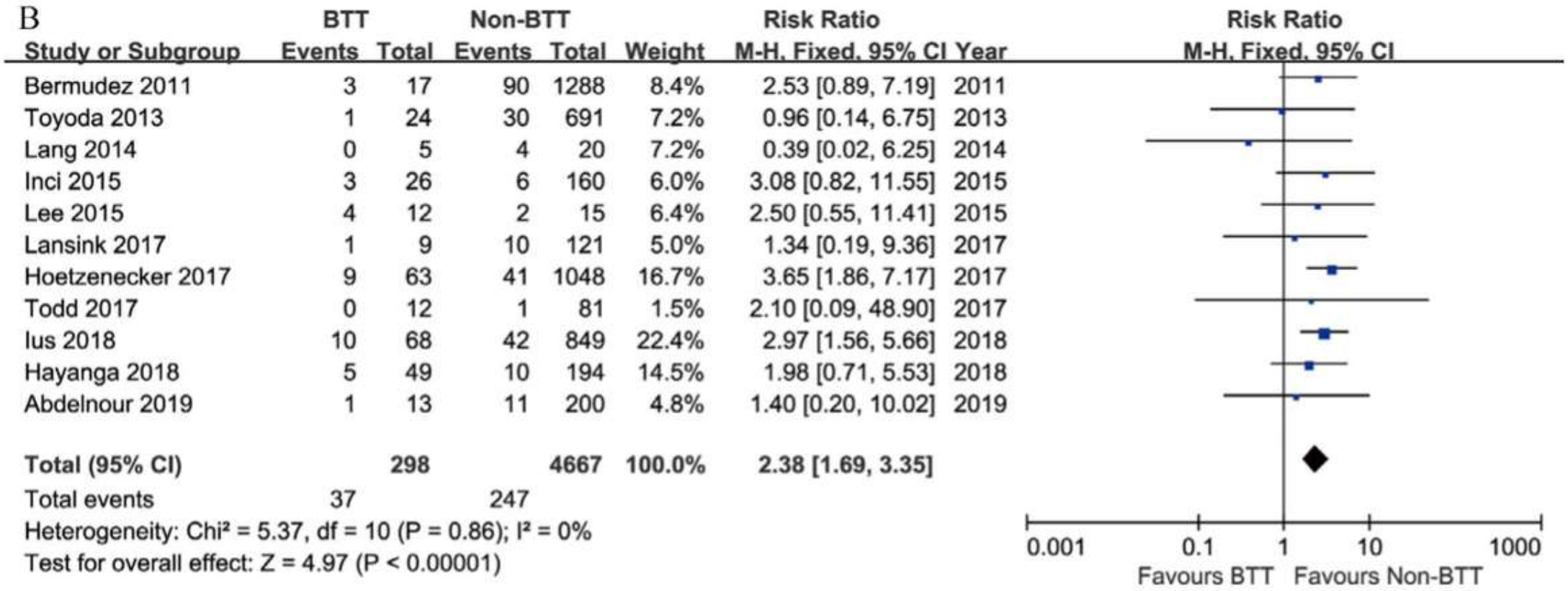
Clinical Transplantation. 2021 Jan;35(1):e14157

Forest plot of over all survival



Clinical Transplantation. 2021 Jan;35(1):e14157

Forest plot of in hospital mortality



Clinical Transplantation. 2021 Jan;35(1):e14157

ECMO IN POISONING

- The use of ECMO in cases of poisoning is associated with good survival at hospital discharge.
- Va ECMO used in majority of cases to treat refractory cardiogenic shock or cardiac arrest
- Acts as a “bridge to elimination” or “bridge to antidote.”

Extracorporeal Membrane Oxygenation in Intoxication and Overdoses: A Systematic Review

Sven Maier[1,2] Lisa Rösner[1,2] Lars Saemann[3] Jonas Sogl[1,2] Friedhelm Beyersdorf[1,2]
Georg Trummer[1,2] Martin Czerny[1,2] Christoph Benk[1,2]

- Study participants (n = 539)
- 64 (11.9%) venovenous ECMO
- 218 (40.4%) venoarterial ECMO
- 257 (47.7%) cases with cardiac arrest and extracorporeal cardiopulmonary resuscitation
- Survival at hospital discharge was 61.0% for all patients, 68.8% for va ECMO, 75% for vv ECMO, and 50.9% for extracorporeal cardiopulmonary resuscitation

The Thoracic and Cardiovascular Surgeon. 2023 Mar 20

Extracorporeal Membrane Oxygenation in Intoxication and Overdoses: A Systematic Review

Sven Maier[1,2] Lisa Rösner[1,2] Lars Saemann[3] Jonas Sogl[1,2] Friedhelm Beyersdorf[1,2]
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	All patients	Neonatal (<28 d)	Pediatric (29 d–< 18 y)	Adult (≥18 y)
Number of patients	539	1	45	493
Number of patients described in case reports or case series (<10 patients)	216	1	45	170
Mode of ECMO (survival [%])				
vaECMO	218 (68.8)	0	11 (63.6)	207 (69)
vvECMO	64 (75)	0	14 (78.5)	50 (74.0)
ECPR	257 (50.9)	1 (100)	20 (80)	236 (48.3)
Age		1 d	9.9 ± 6.1 y	36.5 ± 13.6 y
Duration of ECMO therapy (days)	4.8 ± 4.0	2	5.6 ± 4.2	4.6 ± 4.0
Length of hospital stay (days)	26.8 ± 24.2	9	25.1 ± 16.4	27.5 ± 25.9

The Thoracic and Cardiovascular Surgeon. 2023 Mar 20

Extracorporeal Membrane Oxygenation for Poisonings Reported to U.S. Poison Centers from 2000 to 2018: An Analysis of the National Poison Data System*

- Study participants n = 403
- 332 adults and 75 children
- Overall survival 70%
- Patients with metabolic and hematologic poisonings less likely to survive following

extracorporeal membrane oxygenation than those with other poisonings (49% vs 72%; *p* = 0.004)

Critical care medicine. 2020 May 11;48(8):1111-9

TABLE 1. Demographic Information, Including Reason for Poisoning, Medical Outcomes, and Routes of Exposure For the Entire Cohort and Dichotomized by Age

Demographic	Entire Cohort ($n = 407$)	Patients Age > 12 ($n = 332$)	Patients Age ≤ 12 ($n = 75$)
Age, yr, median (interquartile range)	24 (15–39)	32.6 (19–43)	1.4 (1–3)
Gender, male, *n* (%)	214/407 (52.6)	168/332 (50.6)	46/75 (61.3)
Single-substance mortality, *n* (%)	59/210 (28.1)	39/145 (26.9)	22/65 (33.8)
Multiple-substance mortality, *n* (%)	61/197 (31)	58/186 (31.2)	3/11 (27.3)
Reason, *n* (%)			
Adverse reaction	26 (6.4)	20 (6)	6 (8)
Intentional	248 (60.9)	241 (72.6)	7 (9.3)
Other	3 (0.7)	2 (0.6)	1 (1.3)
Unintentional	93 (22.9)	34 (10.2)	59 (78.7)
Unknown	37 (9.1)	35 (10.5)	2 (2.7)
Medical outcome, *n* (%)			
Death	122 (30)	98 (29.5)	24 (32)
Major effects	256 (62.9)	210 (63.3)	46 (61.3)
Moderate effects	19 (4.7)	16 (4.8)	3 (4)
Unable to follow	10 (2.5)	8 (2.4)	2 (2.7)
Route of exposure, *n* (%)			
Aspiration with ingestion	26 (6.4)	9 (2.7)	17 (22.7)
Bite/sting	2 (0.5)	1 (0.3)	1 (1.3)
Dermal	8 (2)	5 (1.5)	3 (4)
Ingestion	305 (74.9)	243 (73.2)	62 (82.7)
Inhalation/nasal	48 (11.8)	47 (14.2)	1 (1.3)
Ocular	8 (2)	7 (2.1)	1 (1.3)
Other	4 (1)	3 (0.9)	1 (1.3)
Parenteral	29 (7.1)	21 (6.3)	8 (10.7)
Unknown	33 (8.1)	32 (9.6)	1 (1.3)

Critical care medicine. 2020 May 11;48(8):1111-9

TABLE 3. Summary of Responsible Poisons for Single-Substance Cases

Poison	Total Survivors, *n* (%)	Total Fatalities, *n* (%)	Adults Survivors, *n* (%)	Adults Fatalities, *n* (%)	Pediatric Survivors, *n* (%)	Pediatric Fatalities, *n* (%)
Entire cohort (*n* = 210)	151 (72)	59 (28)	106 (73)	39 (27)	43 (66)	22 (34)
Hydrocarbons (*n* = 32)	22 (69)	10 (31)	3 (43)	4 (57)	19 (76)	6 (24)
Calcium channel blocker (*n* = 22)	17 (77)	5 (23)	17 (77)	5 (23)	–	–
Verapamil	8 (88)	1 (12)	8 (88)	1 (12)	–	–
Diltiazem	4 (57)	3 (43)	4 (57)	3 (43)	–	–
Amlodipine	4 (80)	1 (20)	4 (80)	1 (20)	–	–
Unknown (*n* = 20)	15 (75)	5 (25)	14 (78)	4 (22)	1 (50)	1 (50)
Antiarrhythmic and antimalarial (*n* = 19)	13 (68)	6 (32)	7 (70)	3 (30)	6 (67)	3 (33)
Flecainide	9 (82)	2 (12)	3 (60)	2 (40)	6 (100)	–
Hydroxychloroquine	2 (67)	1 (33)	2 (67)	1 (33)	–	–
Cardiac glycoside	1 (33)	2 (66)	1 (100)	–	–	2 (100)
Lidocaine	1 (50)	1 (50)	1 (100)	–	–	1 (100)
Opioids (*n* = 18)	18 (100)	–	17 (100)	–	1 (100)	–
Antidepressant (*n* = 15)	9 (60)	6 (40)	9 (64)	5 (36)	–	1 (100)
Bupropion	7 (58)	5 (42)	7 (64)	4 (36)	–	1 (100)
Tricyclic antidepressants	2 (67)	1 (33)	2 (67)	1 (33)	–	–
Metabolic and hematologic poisons (*n* = 15)	9 (60)	6 (40)	6 (54)	5 (46)	2 (50)	2 (50)
Carbon monoxide	4 (100)	–	3 (100)	–	1 (100)	–
Aluminum phosphide	1 (50)	1 (50)	1 (100)	–	–	1 (100)
Hydrogen sulfide	2 (100)	–	2 (100)	–	–	–
Sodium azide	–	2 (100)	–	2 (100)	–	–
Colchicine	–	1 (100)	–	1 (100)	–	–
Methanol	–	1 (100)	–	1 (100)	–	–
Methylene chloride	1 (100)	–	–	–	1 (100)	–
Metformin	1 (100)	–	–	1 (100)	–	–

Critical care medicine. 2020 May 11;48(8):1111-9

Summary of Responsible Poisons for Single-Substance Cases

Poison	Total Survivors, *n* (%)	Total Fatalities, *n* (%)	Adults Survivors, *n* (%)	Adults Fatalities, *n* (%)	Pediatric Survivors, *n* (%)	Pediatric Fatalities, *n* (%)
Mushroom (*Amanita bisporigera*)	–	1 (100)	–	–	–	1 (100)
Irritant gases and caustics (*n* = 11)	8 (73)	3 (27)	6 (75)	2 (25)	2 (67)	1 (33)
Sedative/hypnotics (*n* = 8)	6 (75)	2 (25)	6 (100)	–	–	2 (100)
Antihistamines (*n* = 7)	6 (86)	1 (14)	4 (100)	–	2 (67)	1 (33)
Diphenhydramine	4 (80)	1 (20)	3 (100)	–	1 (50)	1 (50)
Antihistamine not otherwise specified	2 (100)	–	1 (100)	–	1 (100)	–
Sympathomimetics (*n* = 6)	5 (83)	1 (17)	5 (83)	1 (17)	–	–
Acetaminophen (*n* = 5)	3 (60)	2 (40)	2 (50)	2 (50)	1 (100)	–
Nonsteroidal anti-inflammatory (*n* = 5)	4 (80)	1 (20)	–	–	1 (50)	1 (50)
Ibuprofen	3 (100)	–	3 (100)	–	–	–
Salicylates	1 (50)	1 (50)	–	–	1 (50)	1 (50)
Anticonvulsants (*n* = 3)	3 (100)	–	1 (100)	–	2 (100)	–
Beta-blockers (*n* = 3)	3 (100)	–	3 (100)	–	–	–
Metals (*n* = 3)	–	3 (100)	–	1 (100)	–	2 (100)

Critical care medicine. 2020 May 11;48(8):1111-9

Extracorporeal Membrane Oxygenation in Pregnant and Postpartum Women With H1N1-Related Acute Respiratory Distress Syndrome

A Systematic Review and Meta-analysis

- 5 studies
- Observational studies
- 39 patients
- The pooled estimate of the survival rate among pregnant and postpartum patients who received ECMO for ARDS secondary to H1N1 was 74.6% (95% confidence interval [CI] 60.7–88.6%)

Obstetrics & Gynecology. 2016 Feb 1;127(2):241-7

Study	Country	Year	Sample Population	Sample Size Pregnant or Postpartum (n)	Intervention	Neonatal Outcome	Survival
Hou et al[11]	China	2012	Patients with ARDS secondary to H1N1 on ECMO	4	Venous–venous ECMO	Not stated	2
ANZIC[12]	Australia	2010	Pregnant or postpartum patients with ARDS secondary to H1N1 on ECMO	9	Not stated	Not stated	6
ANZ ECMO[13]	Australia	2011	Pregnant or postpartum patients with ARDS secondary to H1N1 on ECMO	12	Venous–venous ECMO	5/7 live births	8 (5 pregnant, 3 postpartum)
Holzgraefe et al[14]	Sweden	2010	Pregnant patients with ARDS secondary to H1N1 on ECMO	3	Venous–venous ECMO	2/3 live births	3 (pregnant)
Dubar et al[15]	France	2010	Pregnant patients with ARDS secondary to H1N1 on ECMO	11	Not stated	Not stated	9

Obstetrics & Gynecology. 2016 Feb 1;127(2):241-

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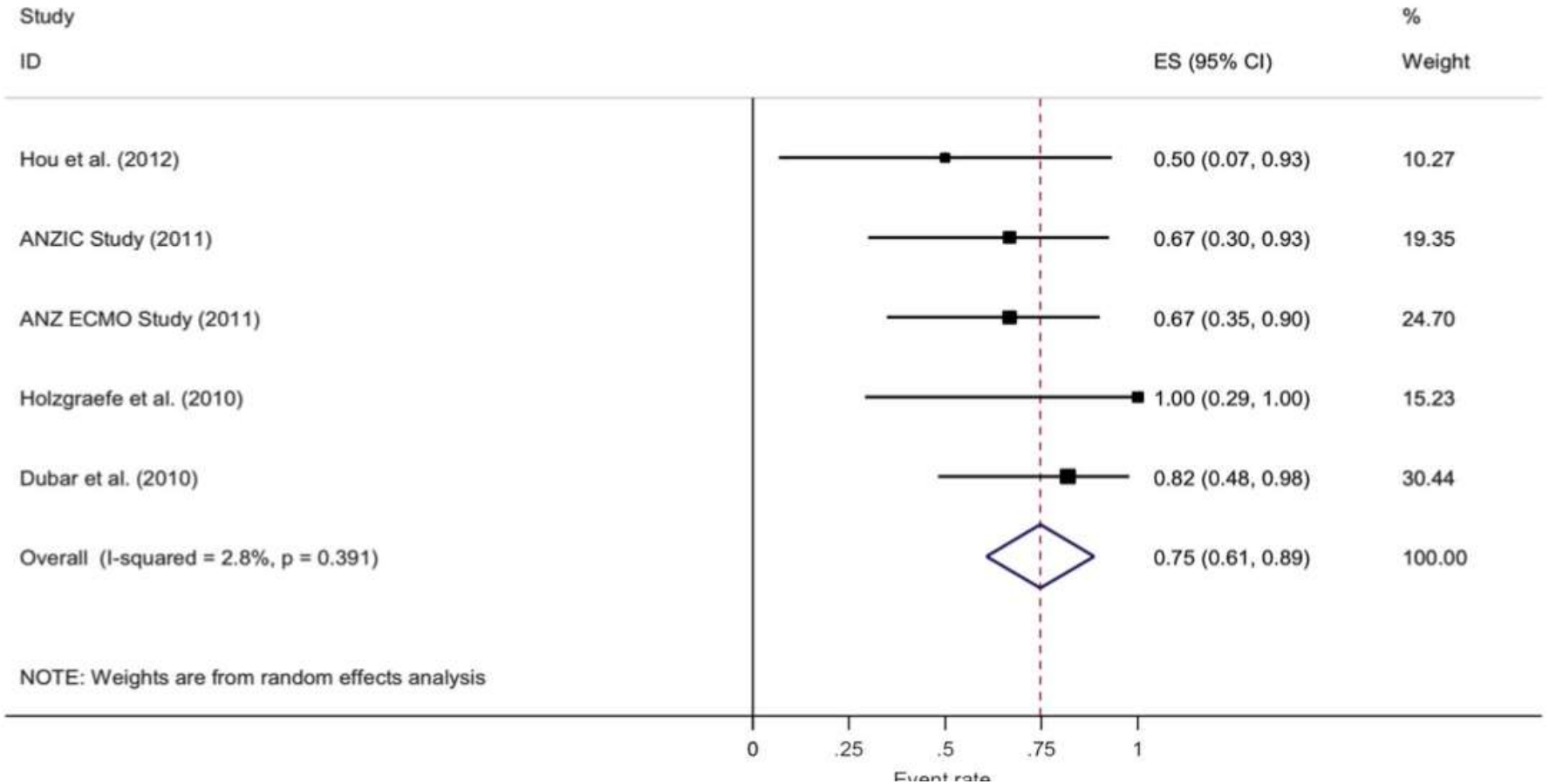


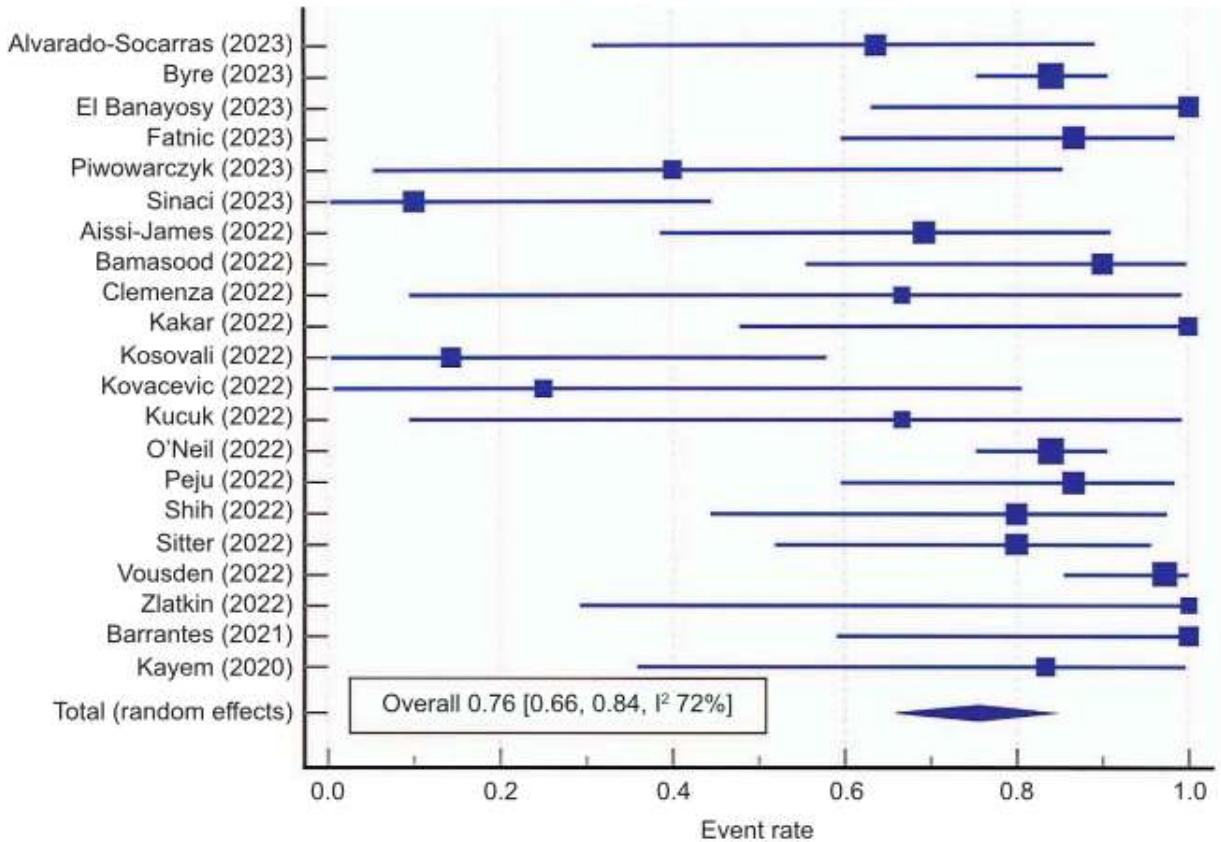
Obstetrics & Gynecology. 2016 Feb 1;127(2):241-7

Extracorporeal Membrane Oxygenation in Pregnant and Postpartum Women With Critical Coronavirus Disease 2019 (COVID-19) Acute Respiratory Distress Syndrome

- Systematic review and meta analysis
- 21 studies (9 retrospective case series and 12 retrospective cohort studies)
- N = 386 pregnant women
- Primary outcomes maternal survival and live-birth rates in pregnant women with ARDS
- The pooled estimate of the maternal survival rate among pregnant patients who were initiated on ECMO was 75.6% (95% CI, 66.0–84.1%)

Obstetrics & Gynecology. 2022 May 5:10-97

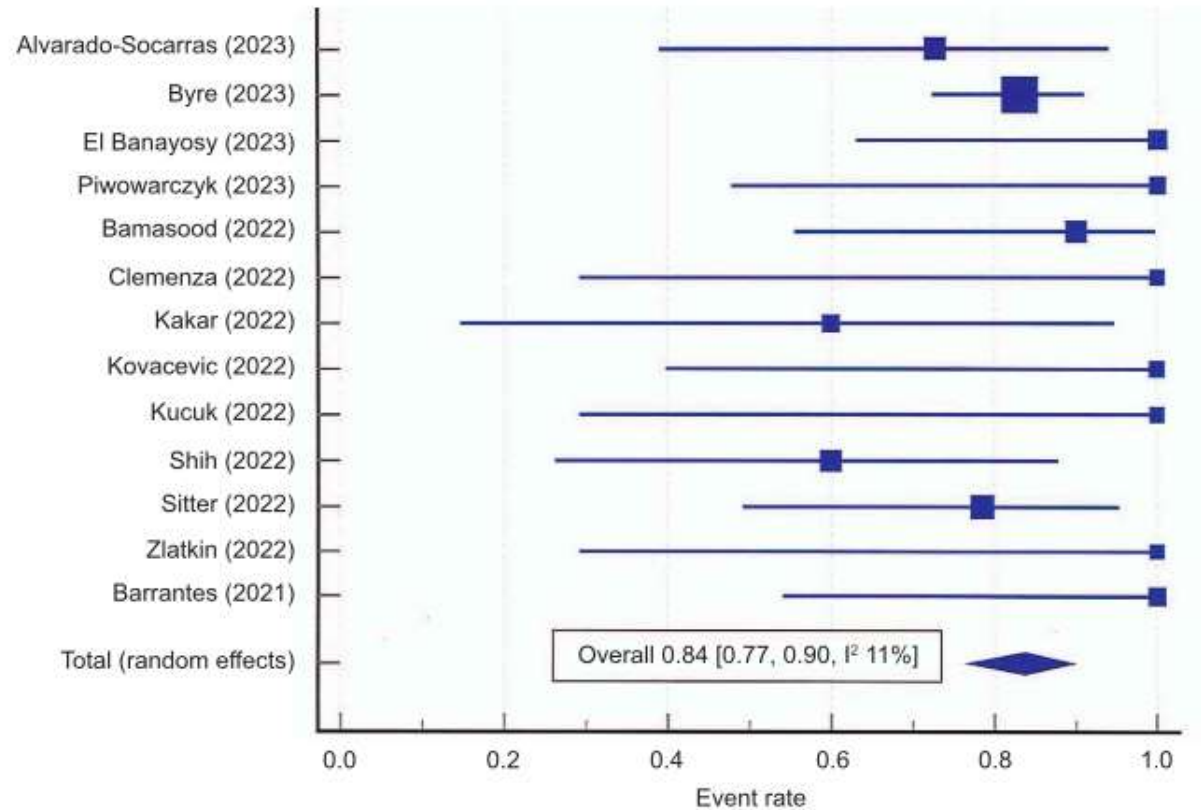
Extracorporeal Membrane Oxygenation in Pregnant and Postpartum Women With Critical Coronavirus Disease 2019 (COVID-19) Acute Respiratory Distress Syndrome



Forest plot of the overall pooled estimate of the maternal survival rate

Obstetrics & Gynecology. 2022 May 5:10-97

Extracorporeal Membrane Oxygenation in Pregnant and Postpartum Women With Critical Coronavirus Disease 2019 (COVID-19) Acute Respiratory Distress Syndrome



Forest plot of the overall pooled estimate of the live-birth rate.

Obstetrics & Gynecology. 2022 May 5:10-97