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Neuromonitoring for Prognostication under ECMO

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Hôpital Bichat Claude-Bernard AP-HP

iame UMR 1137 Infection • Antimicrobials • Modelling • Evolution

Conflicts of interest

Grants:

- French Ministry of Health.
- LFB

Neuromonitoring in ICU

Q: What is neuromonitoring ?

A: Neuromonitoring refers to the (continuous or intermittent) **assessment of the neurological status of critically ill patients**.

Main aims :

- to **detect** and **prevent secondary brain injury**
- to guide **therapeutic intervention**
- to **provide prognostic information**

Framework

- VV-ECMO is associated with neurologic complications
- Pathophysiology and risk factors
- Brain monitoring tools
- Conclusion

VV-ECMO & Neurologic Complications

Neurologic Injury in Adults Supported With Veno-Venous Extracorporeal Membrane Oxygenation for Respiratory Failure: Findings From the Extracorporeal Life Support Organization Database

Roberto Lorusso, MD, PhD[1]; Sandro Gelsomino, MD, PhD[1]; Orlando Parise, MSc[1]; Michele Di Mauro, MD[2]; Fabio Barili, MD, PhD[3]; Gijs Geskes, MD[1]; Enrico Vizzardi, MD[4]; Peter T. Rycus, MPH[5]; Raf Muellenbach, MD, PhD[6]; Thomas Mueller, MD[7]; Antonio Pesenti, MD[8]; Alain Combes, MD, PhD[9]; Giles Peek, MD[10]; Bjorn Frenckner, MD, PhD[11]; Matteo Di Nardo, MD[12]; Justyna Swol, MD[13]; Jos Maessen, MD, PhD[1]; Ravi R. Thiagarajan, MD, PhD[14]

4988 adult patients under VV-ECMO
1992-2015

7% of them developed neurologic injury.

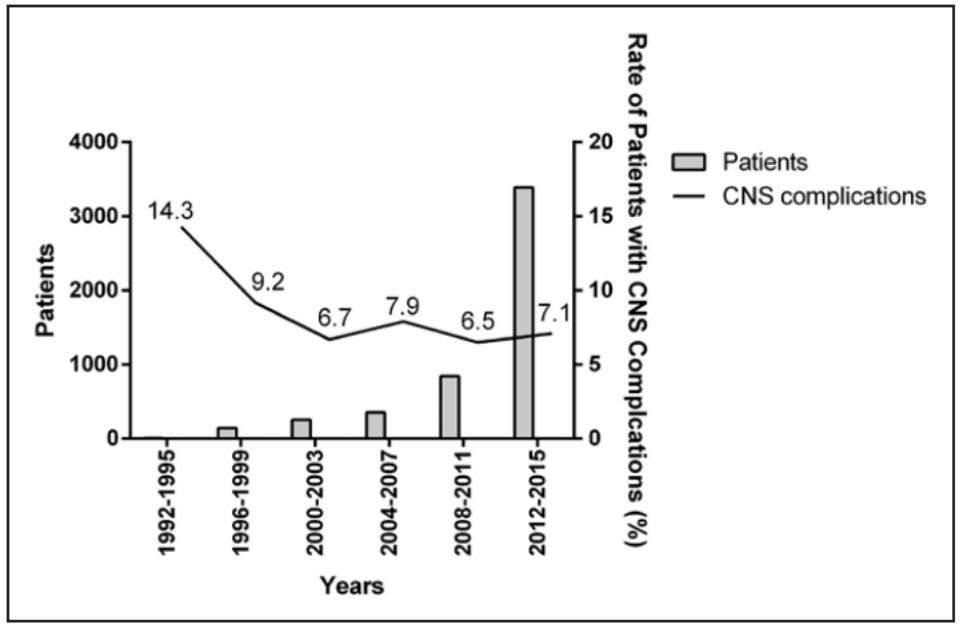

Figure 1. Trends and survival rate in veno-venous extracorporeal membrane oxygenation use and neurologic complications during 1992–2015 period according to the Extracorporeal Life Support Organization Database.

R Lorusso, Crit Care Med 2017

VV-ECMO & Neurologic Complications

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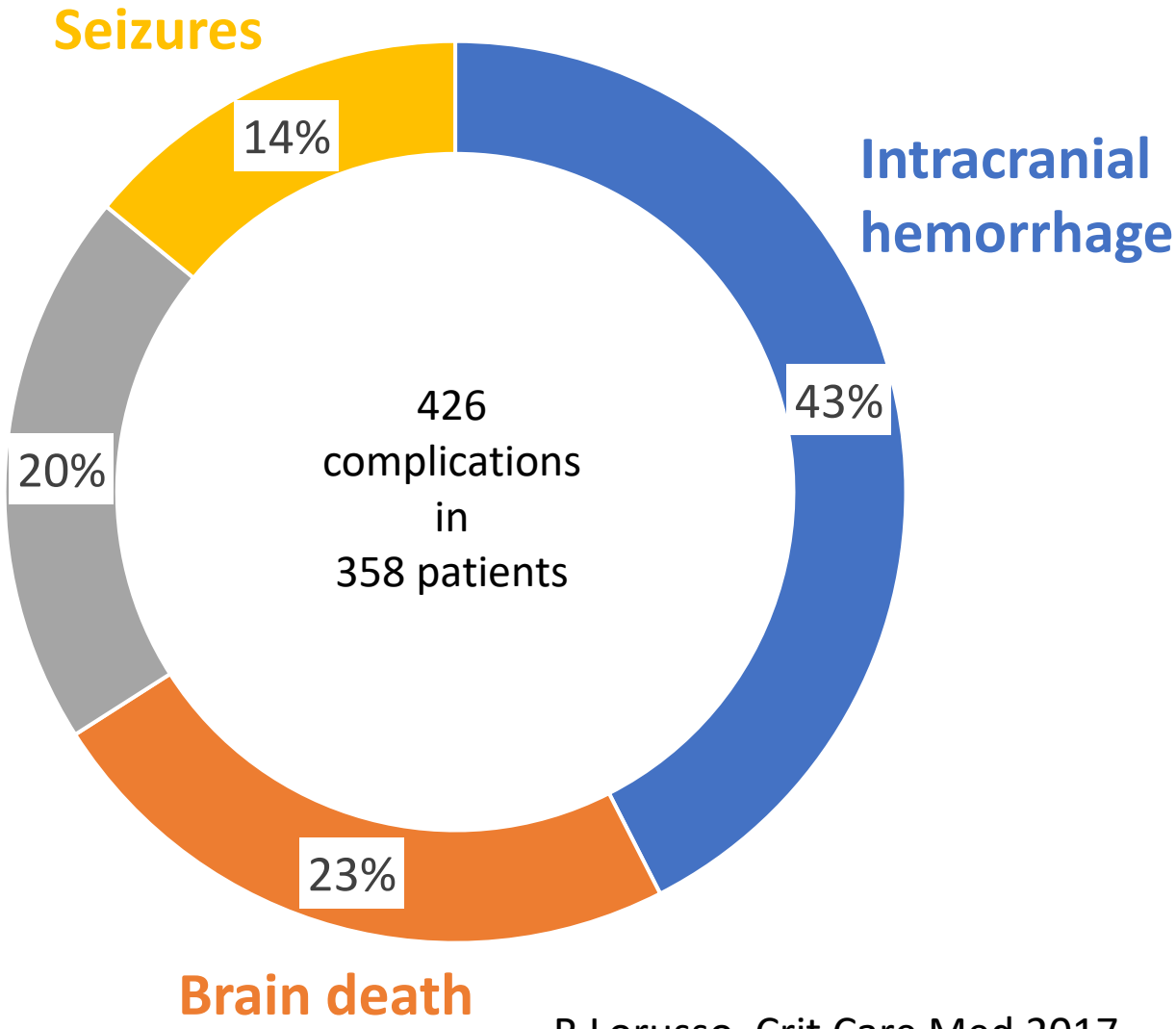

R Lorusso, Crit Care Med 2017

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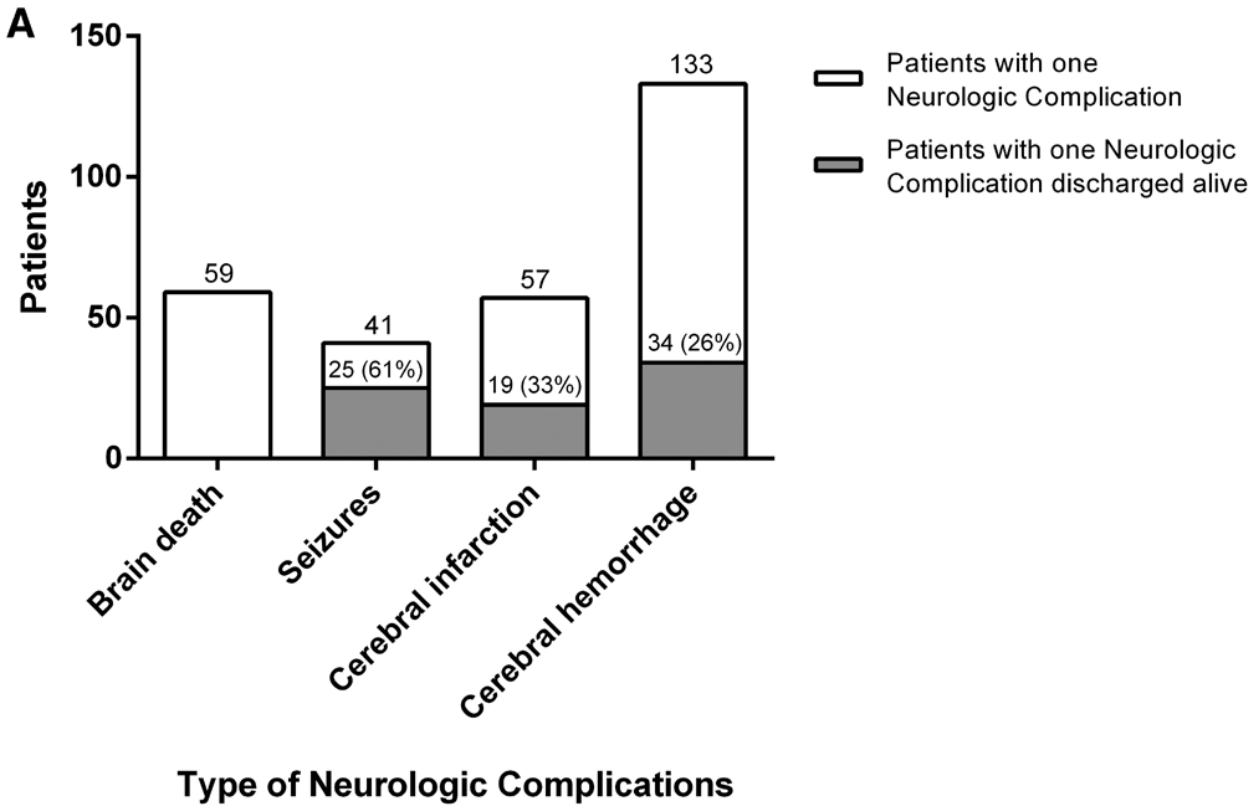
4988 adult patients under VV-ECMO
1992-2015

7% of them developed neurologic injury.

Intracranial hemorrhage was the most frequent type.

Survival for patients with neurologic injury was poor.

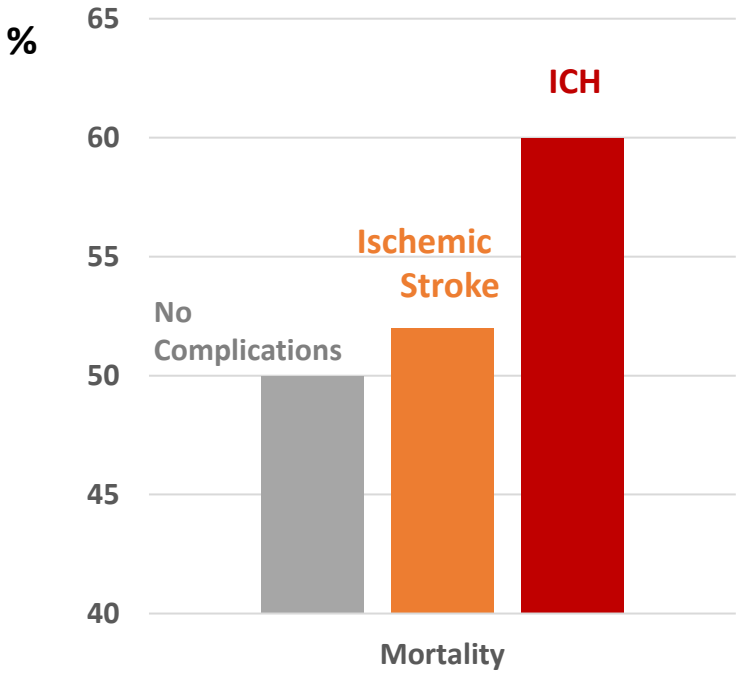


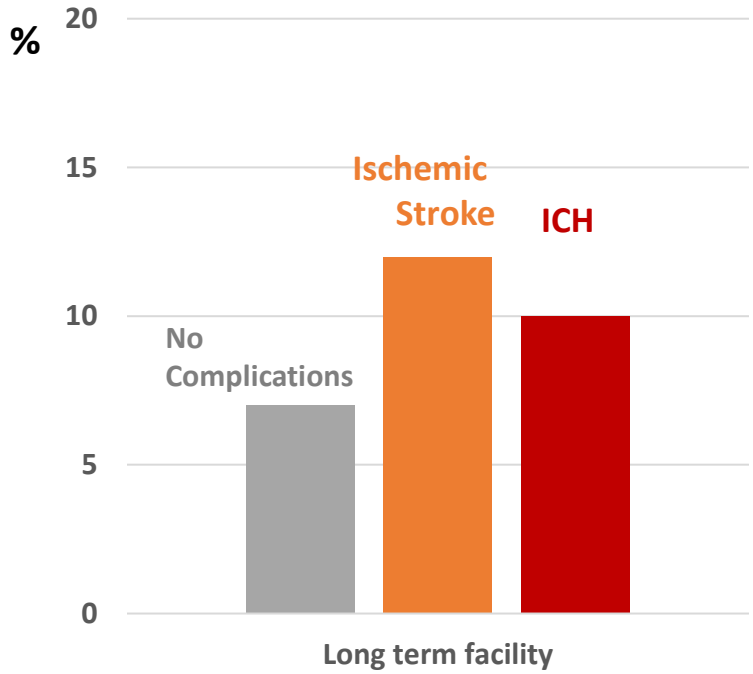
R Lorusso, Crit Care Med 2017

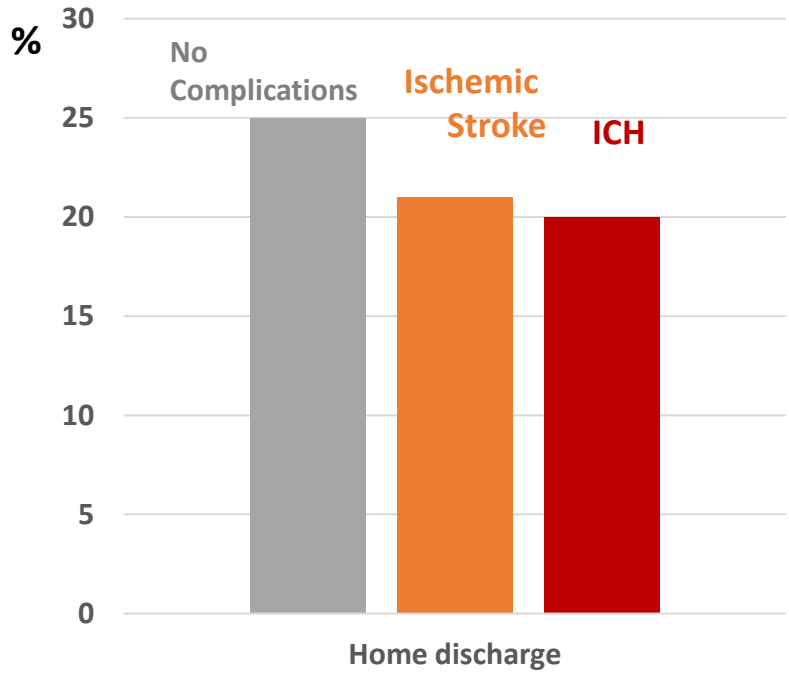
VV-ECMO & Neurologic Complications

Neurologic Complications of Extracorporeal Membrane Oxygenation

2001-2011, n=23951 patients on ECMO (all ages, all types of ECMO)







ICH is a strong **independent predictor of mortality**, aOR 2.31 (95%CI, 1.89-2.84)

DM Nasr, AA Rabinstein, J Clin Neurol 2015

Framework

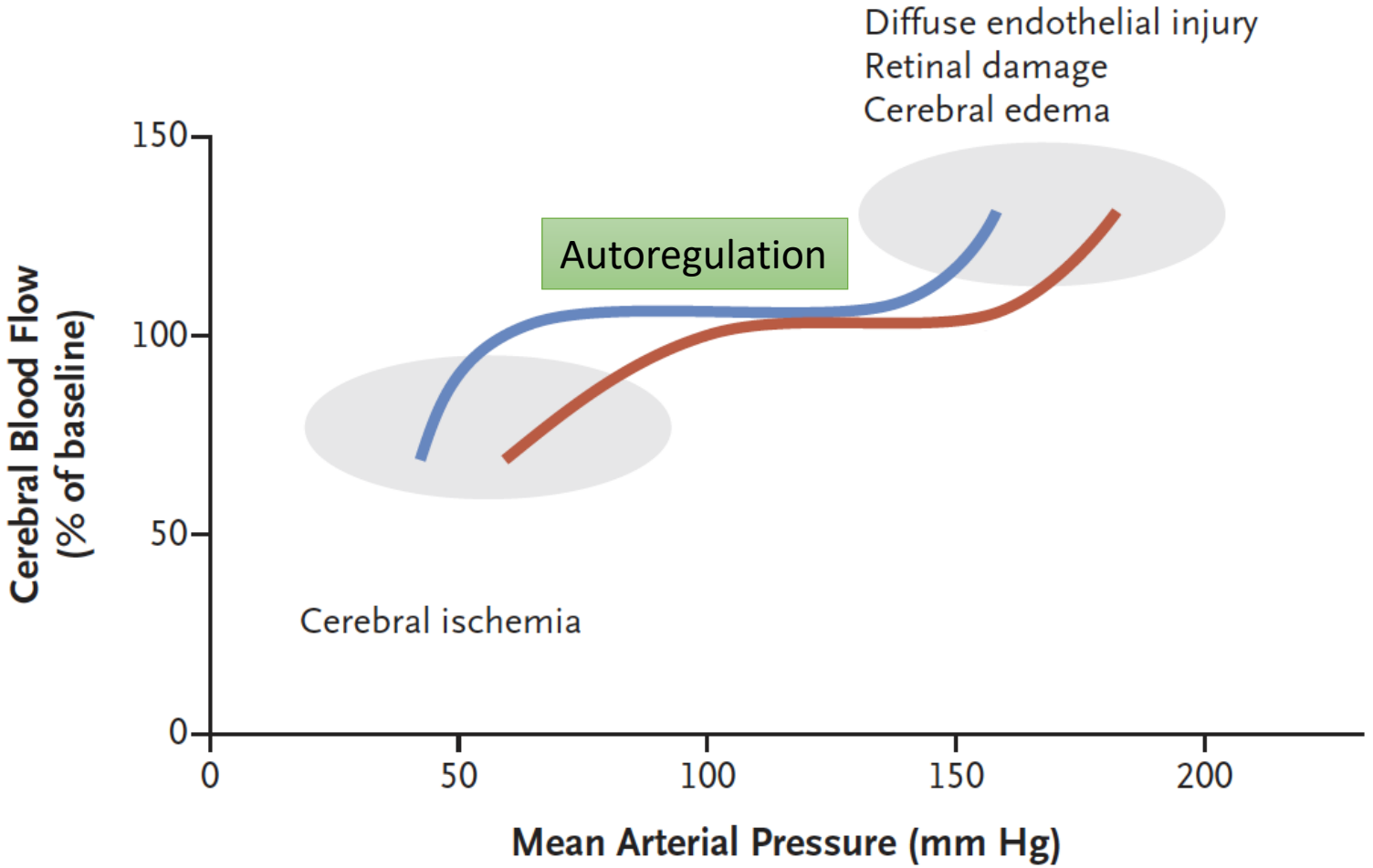
- VV-ECMO is associated with neurologic complications
- Pathophysiology and risk factors
- Brain monitoring tools
- Conclusion

Determinants of Cerebral Blood Flow (CBF) : MAP

CBF is preserved under physiological conditions

Both acute **hypotension** and **hypertension** -> deleterious neurologic consequences

Brain perfusion !

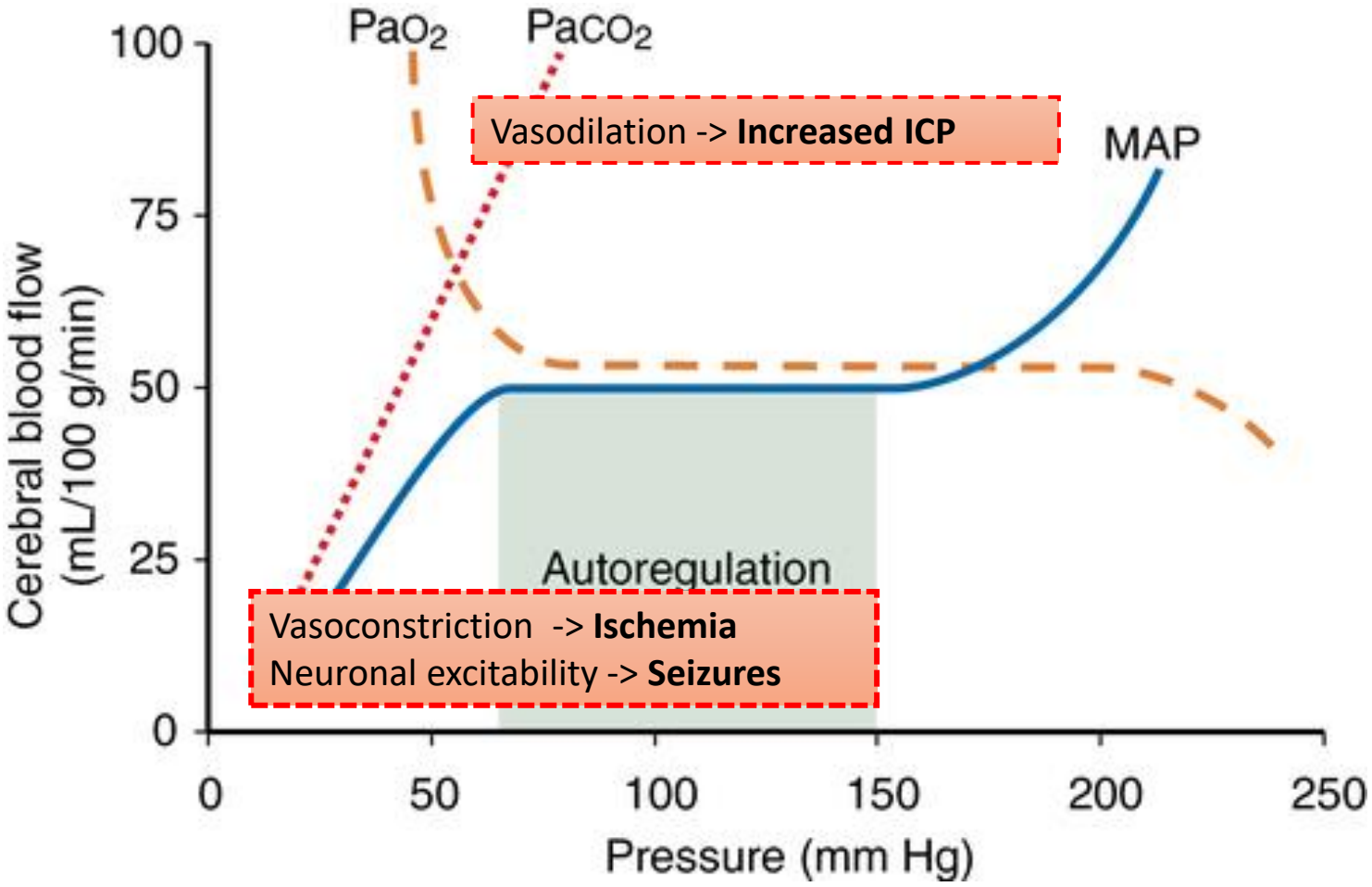


AJ Peixoto, New Eng J Med 2018

Determinants of CBF : $PaCO_2$ and PaO_2

CBF is preserved under physiological conditions

Both **acute hypo** and **hypercapnia -> deleterious neurologic consequences**



ECMO and ICH

ORIGINAL

Brain injury during venovenous extracorporeal membrane oxygenation

Charles-Edouard Luyt[1,2*], Nicolas Bréchot[1,2], Pierre Demondion[3], Tamara Jovanovic[1], Guillaume Hékimian[1,2], Guillaume Lebreton[3], Ania Nieszkowska[1,2], Matthieu Schmidt[1,2], Jean-Louis Trouillet[1,2], Pascal Leprince[3], Jean Chastre[1,2] and Alain Combes[1,2]

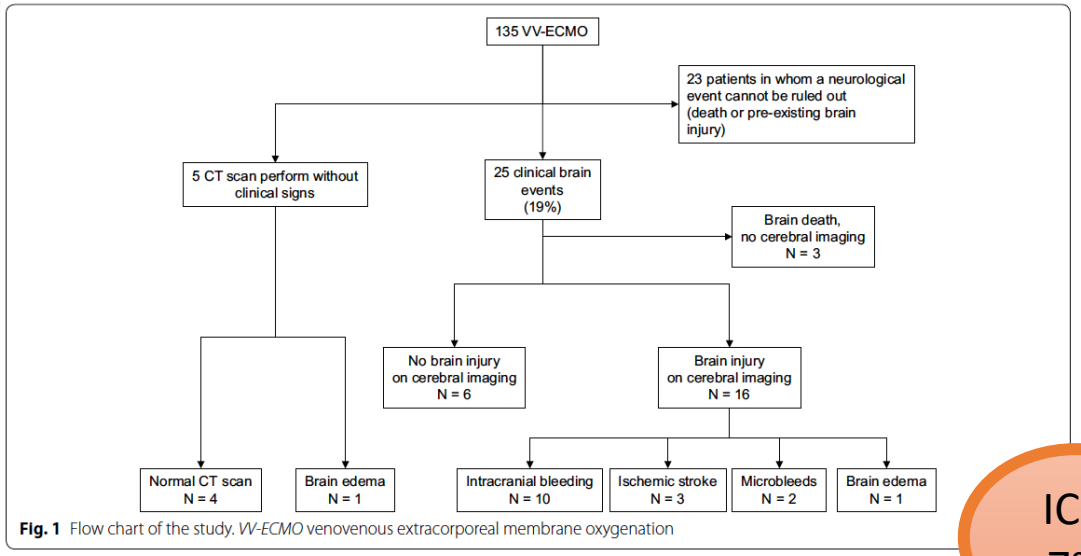
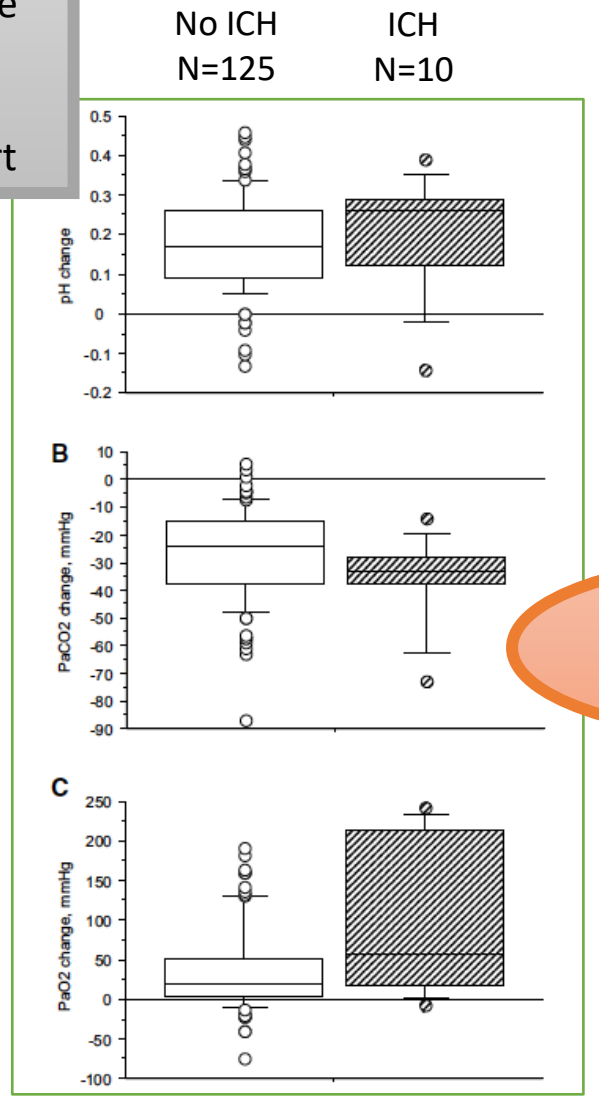


Fig. 1 Flow chart of the study. *VV-ECMO* venovenous extracorporeal membrane oxygenation

ICH 7%

Gas exchange parameters changes @ECMO start



$PaCO_2$ drop >27 mm Hg

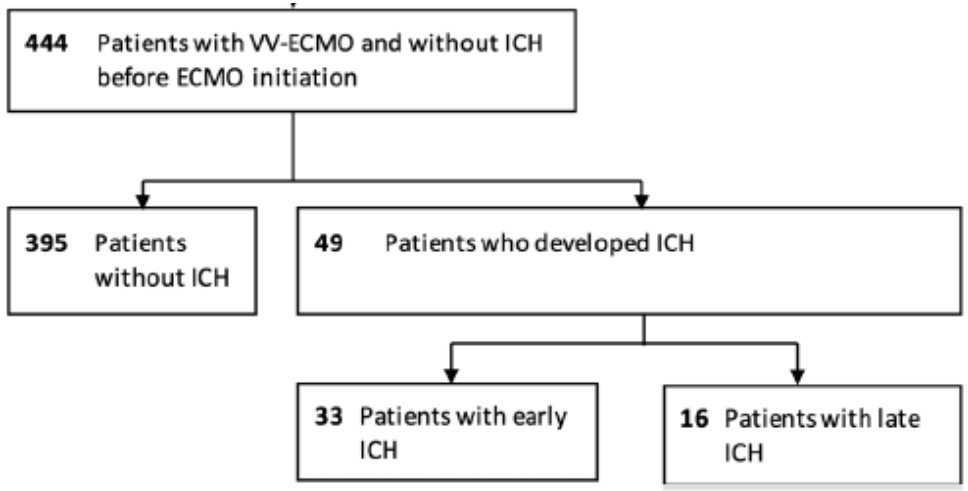
Risk Factors for ICH, multivariable analysis

Variable	Odds Ratio	95%CI
Renal failure	1.22	1.05-1.44
PaCO2 drops > 27 mmHg	1.28	1.11-1.52

Intensive Care Medicine 2016

ECMO and ICH

Timing, Outcome, and Risk Factors of Intracranial Hemorrhage in Acute Respiratory Distress Syndrome Patients During Venovenous Extracorporeal Membrane Oxygenation



49/444 (11%) patients developed ICH after a median time of 4 (2-7) days

Risk Factors for ICH, multivariable analysis

Variable	Odds Ratio	95%CI
$PaCO_2$ decrease at ECMO initiation, mmHg	1.22	1.05-1.44
PEEP, cm H2O	1.28	1.11-1.52
Platelets, per 10/nl	0.83	0.71-0.94

O Hunsiker, Crit Care Med 2021

Risk Factors for Neurologic Complications

Patient-related ?

Age ?

High BMI

Cardiovascular risk factors ?

Arythmia ?

...

Critical illness

Pre-ECMO cardiac arrest

CV failure

Renal failure* / CVVHD

Hyperbilirubinemia

ECMO-related

$PaCO_2$ drops*

Hyperoxia

Low platelet count*

Brain injury

***Specific risk factors for ICH**

CE Luyt, Intensive Care Med 2016
R Lorusso, Crit Care Med 2017
O Hunsiker, Crit Care Med 2021
AM Zaaqoq, Crit Care Med 2023

Framework

- VV-ECMO is associated with neurologic complications
- Pathophysiology and risk factors
- Brain monitoring tools
- Conclusion

Clinical examination

Validation of a New Coma Scale: The FOUR Score

A 4-component score

Greater neurological detail than the GCS, including :

- **brainstem reflexes**
- **(breathing patterns)**
- the ability to recognize **different stages of herniation.**

A strong predictor of outcome

FOUR Score

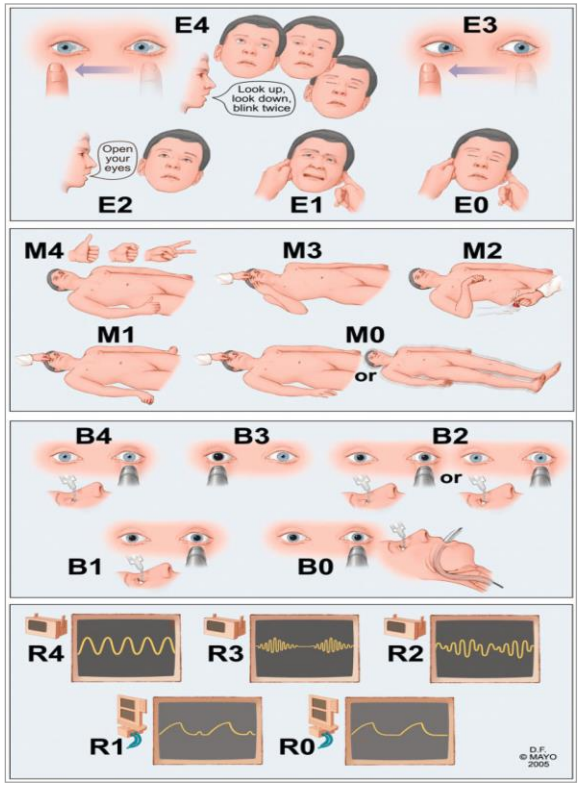
Eye response
- 4 = eyelids open or opened, tracking, or blinking to command
- 3 = eyelids open but not tracking
- 2 = eyelids closed but open to loud voice
- 1 = eyelids closed but open to pain
- 0 = eyelids remain closed with pain

Motor response
- 4 = thumbs-up, fist, or peace sign
- 3 = localizing to pain
- 2 = flexion response to pain
- 1 = extension response to pain
- 0 = no response to pain or generalized myoclonus status

Brainstem reflexes
- 4 = pupil and corneal reflexes present
- 3 = one pupil wide and fixed
- 2 = pupil or corneal reflexes absent
- 1 = pupil and corneal reflexes absent
- 0 = absent pupil, corneal, and cough reflex

Respiration
- 4 = not intubated, regular breathing pattern
- 3 = not intubated, Cheyne–Stokes breathing pattern
- 2 = not intubated, irregular breathing
- 1 = breathes above ventilator rate
- 0 = breathes at ventilator rate or apnea

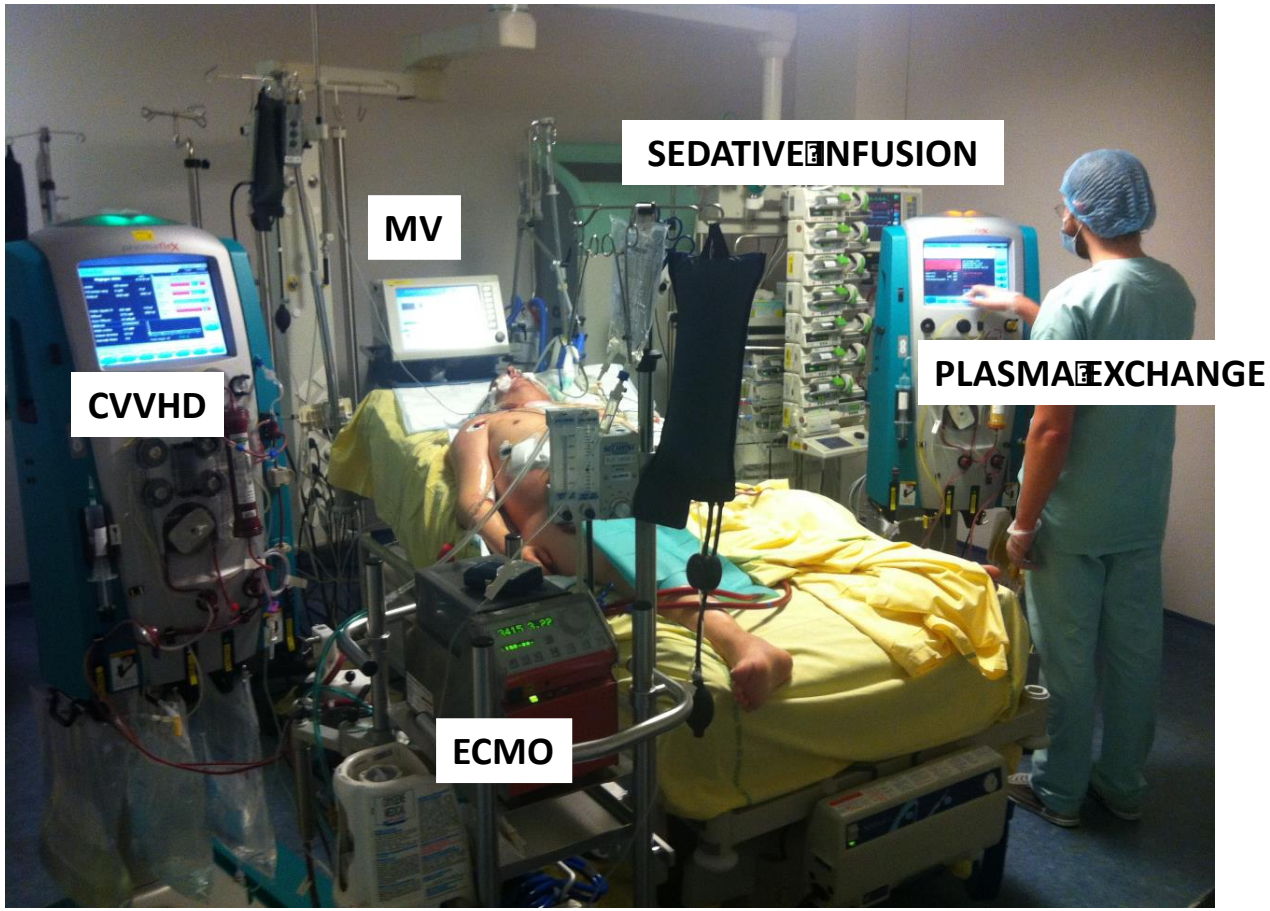
FOUR = Full Outline of UnResponsiveness.



EF Wijdicks, Annals of Neurology 2005

Clinical examination …

Confounders …
- Sedation
- Paralyzing agents



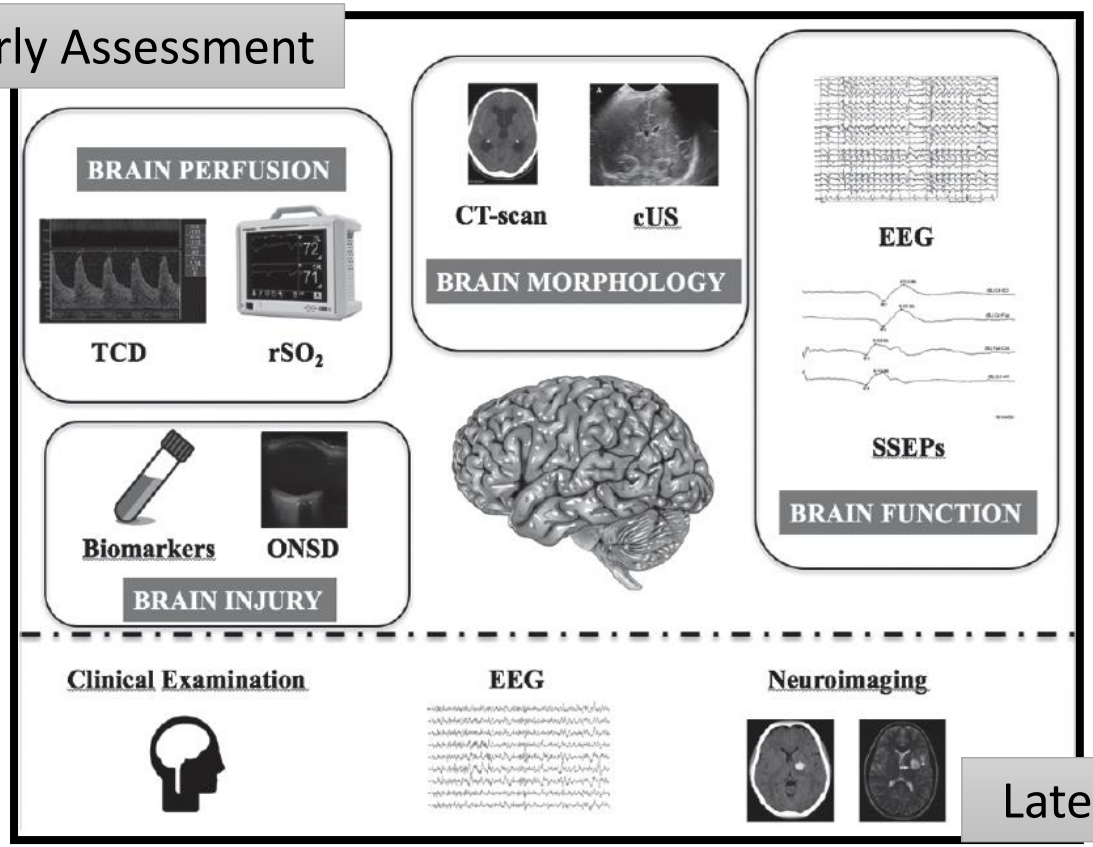
Guidelines ?

Brain monitoring in adult and pediatric ECMO patients: the importance of early and late assessments

Roberto LORUSSO [1 *], Fabio S. TACCONE [2], Mirko BELLIATO [3], Thijs DELNOIJ [4], Paolo ZANATTA [5], Mirjana CVETKOVIC [6], Mark DAVIDSON [7], Jan BELOHLAVEK [8], Nashwa MATTA [9], Carl DAVIS [10], Hanneke IJSSELSTIJN [11], Thomas MUELLER [12], Ralf MUELLENBACH [13], Dirk DONKER [14], Piero DAVID [15], Matteo DI NARDO [16], Dirk VLASSELAERS [17], Dinis dos REIS MIRANDA [18], Aparna HOSKOTE [19], on behalf of the Euro-ELSO Working Group on Neurologic Monitoring and Outcome

Multimodal Monitoring ?

Early Assessment



Late Assessment

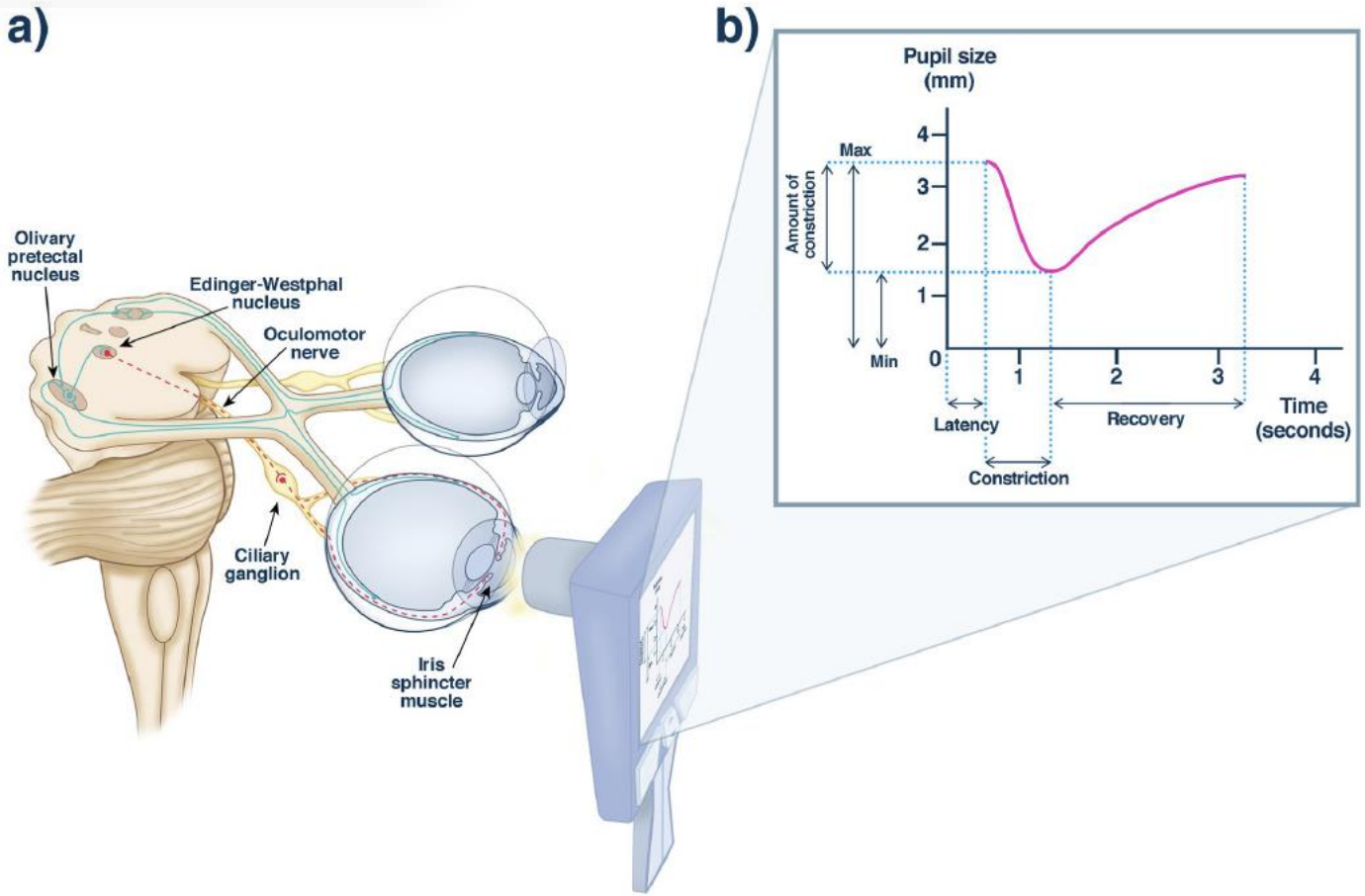
Minerva Anestesiologica 2017

Automated Pupillometry

SPECIAL ISSUE INSIGHT

Automated pupillometry in intensive care

Claudio Sandroni[1*], Giuseppe Citerio[2,4] and Fabio S. Taccone[3]



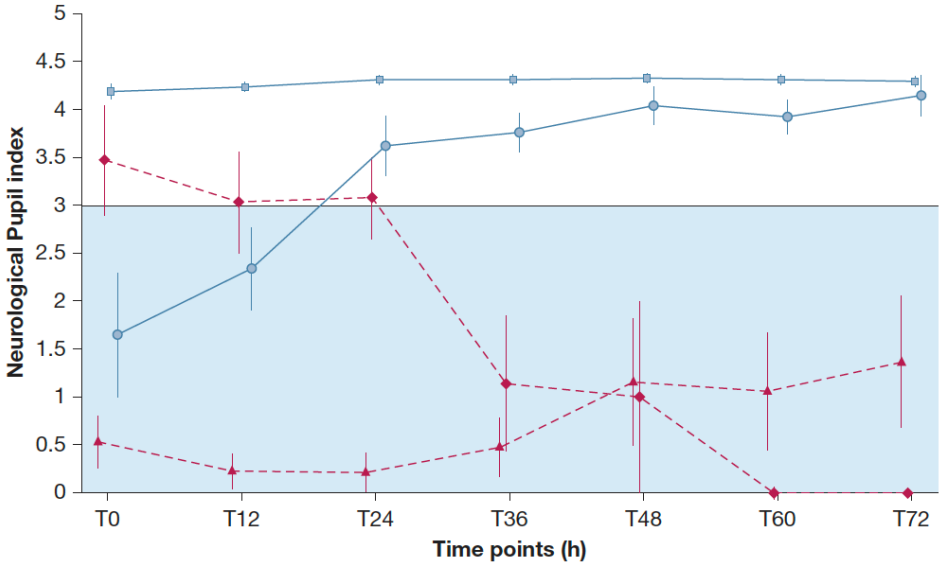
Intensive Care Medicine 2022

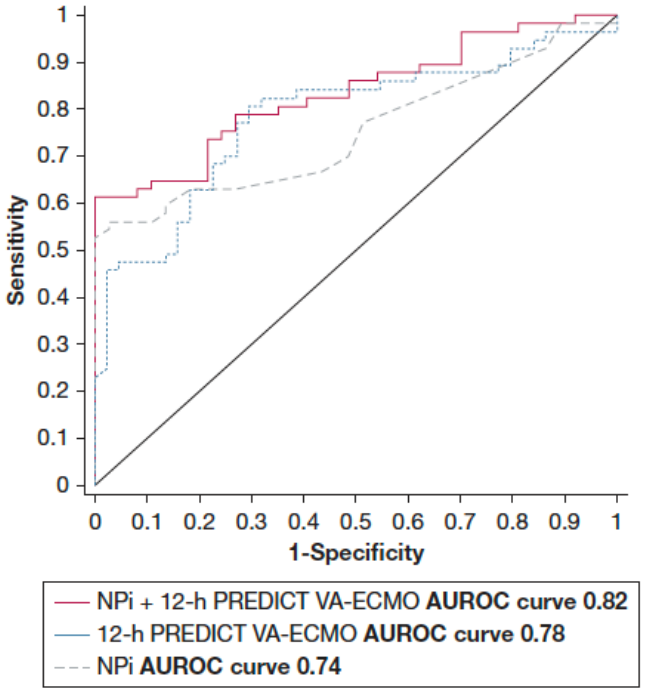
Automated Pupillometry

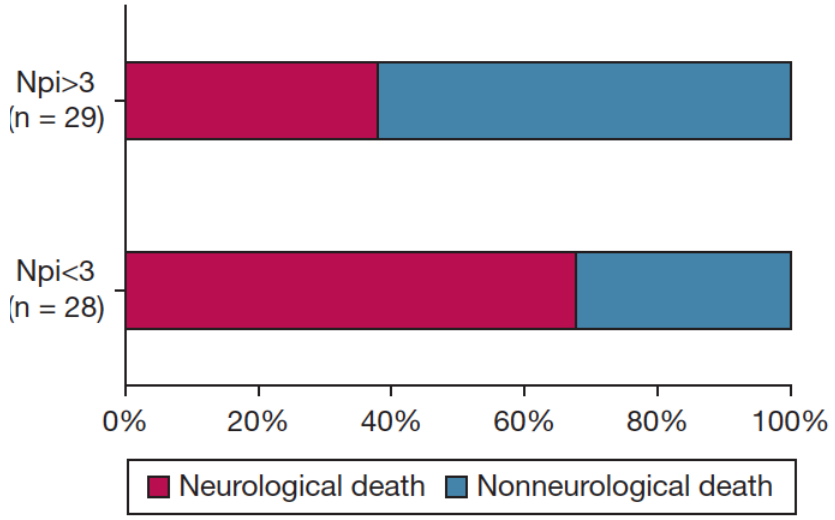
Neurological Pupil index for Early Prognostication After Venoarterial Extracorporeal Membrane Oxygenation

John-Paul Miroz, RN; Nawfel Ben-Hamouda, MD; Adriano Bernini, MSc; Federico Romagnosi, MD; Filippo Bongiovanni, MD; Aurélien Roumy, MD; Matthias Kirsch, MD; Lucas Liaudet, MD; Philippe Eckert, MD; and Mauro Oddo, MD

Single-center study, n=100 patients under VA-ECMO







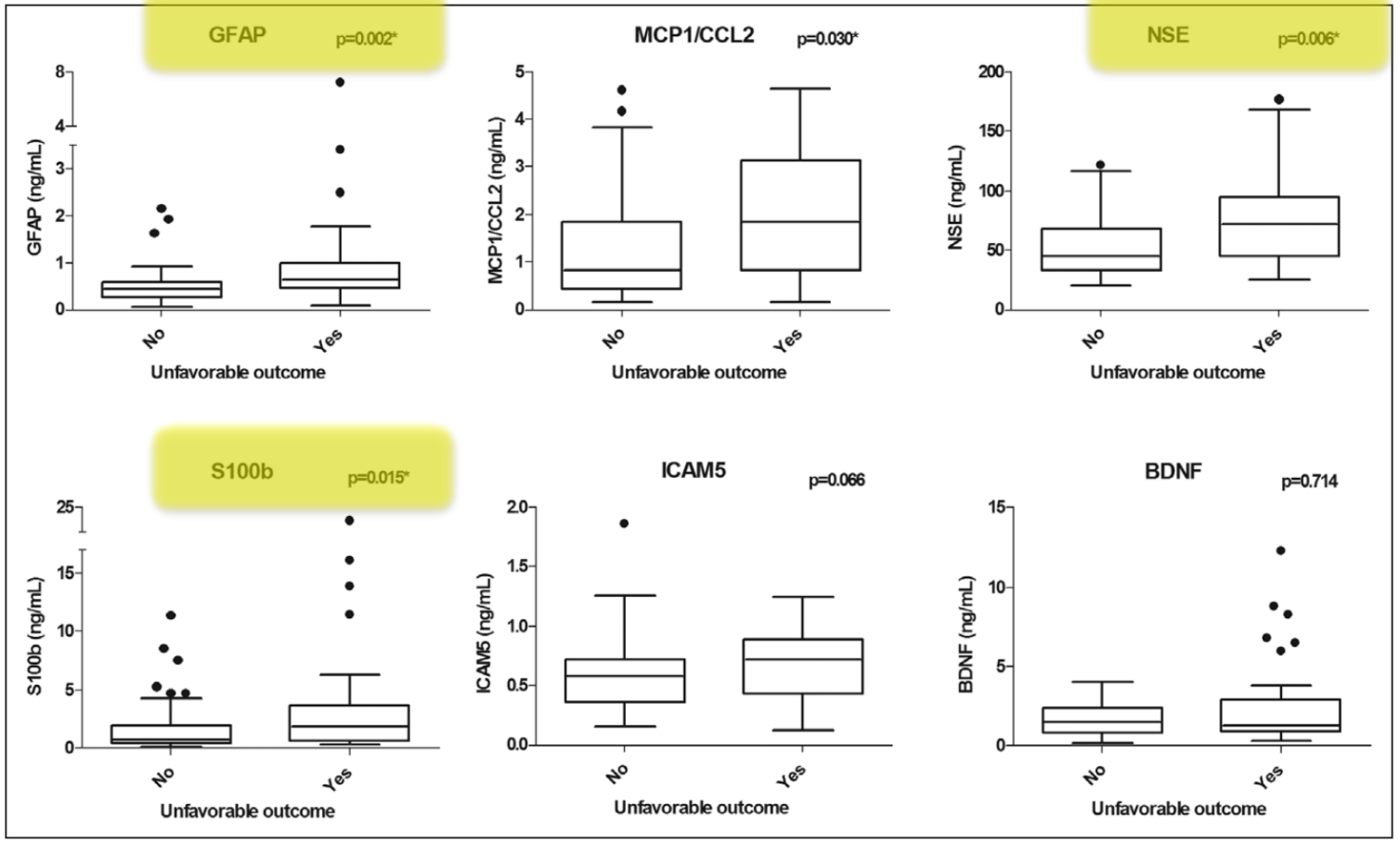
Quantitative NPi alone had **excellent ability to predict a poor outcome from day 1** after VA-ECMO insertion, with no false positives.

Chest 2020

Blood Biomarkers

Plasma Biomarkers of Brain Injury as Diagnostic Tools and Outcome Predictors After Extracorporeal Membrane Oxygenation*

80 children on ECMO
Prospective study
Tertiary care center



MM Bembea, Crit care med 2015

Blood Biomarkers

Plasma Biomarkers of Brain Injury as Diagnostic Tools and Outcome Predictors After Extracorporeal Membrane Oxygenation*

TABLE 4. Area Under the Receiver Operating Characteristic Curve for Plasma Brain Injury Biomarkers to Classify Outcomes

Biomarker	Cutoff (ng/mL)	Area Under the Receiver Operating Characteristic Curve	SE	95% CI	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
Unfavorable outcome								
GFAP	0.46	0.707	0.059	0.60–0.81[a]	76	57	56	77
MCP-1/CCL-2	0.63	0.643	0.063	0.52–0.74[a]	85	45	52	81
NSE	68.1	0.682	0.062	0.57–0.79[a]	61	75	63	73
S100b	0.52	0.660	0.061	0.55–0.76[a]	94	36	51	90
ICAM-5	0.70	0.621	0.065	0.51–0.73	55	75	60	70
BDNF	3.82	0.524	0.068	0.41–0.64	21	98	88	64
GFAP + NSE	NA	0.730	0.058	0.61–0.82[a]	67	77	67	77

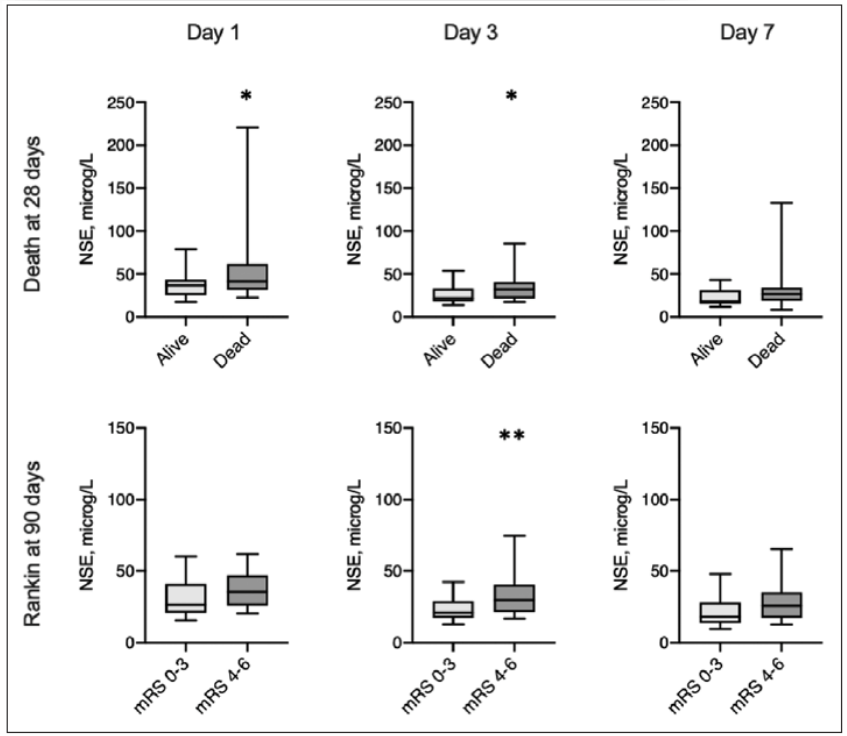
MM Bembea, Crit care med 2015

NSE

Neuron-Specific Enolase Levels in Adults Under Venoarterial Extracorporeal Membrane Oxygenation

Jean Reuter, MD[1,2]; Katell Peoc'h, PharmD, PhD[3,4]; Lila Bouadma, MD, PhD[2]; Stéphane Ruckly, BSc[1]; Valérie Chicha-Cattoir, PharmD[3]; Dorothée Faille, PharmD, PhD[1,5]; Marie-Charlotte Bourrienne, PharmD[1,5]; Claire Dupuis, MD, PhD[2]; Eric Magalhaes, MD[2]; Sébastien Tanaka, MD[6,7]; Camille Vinclair, MD[2]; Etienne de Montmollin, MD[2]; Mikael Mazighi, MD, PhD[1,8]; Marylou Para, MD[9]; Wael Braham, MD[9]; Angelo Pisani, MD[9]; Nadine Ajzenberg, MD, PhD[1,5]; Jean-François Timsit, MD, PhD[2,10]; Romain Sonneville, MD, PhD[1,2]

N=103 VA-ECMO patients
(Pre-ECMO CPR n=26, 25%) patients



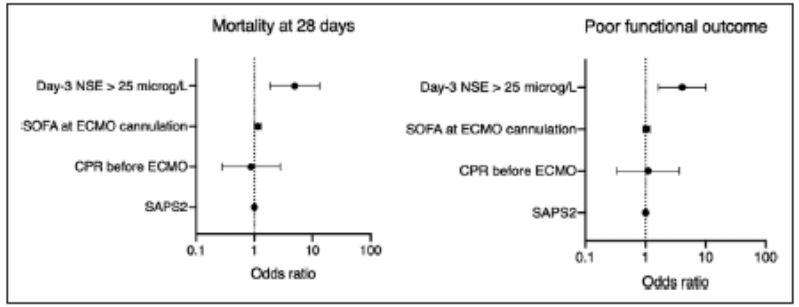


Figure 2. Predictors of outcomes, multivariable logistic regression analysis. The analysis was conducted on 99 patients (Three patients died before day 3, and one patient was weaned from extracorporeal membrane oxygenation [ECMO] before day 3). Area under the curve (AUC) = 0.739 for mortality; AUC = 0.714 for poor functional outcome. A poor functional outcome was defined as a score of 4 to 6 on the modifed Rankin scale at 90 d. CPR = cardiopulmonary resuscitation, NSE = neuron-specific enolase, SAPS = Simplified Acute Physiology Score, SOFA = Sepsis-related Organ Failure Assessment.

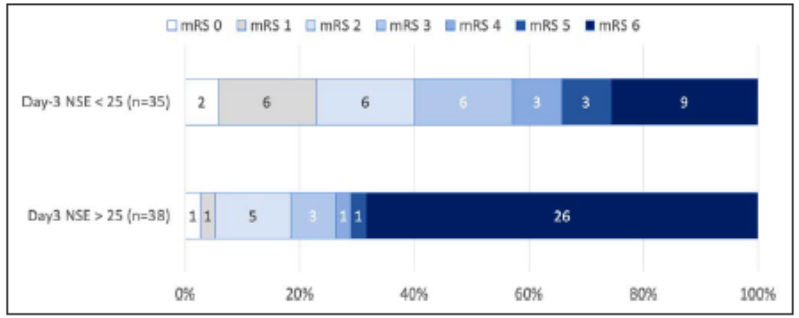


Figure 3. Distribution of the modified Rankin Scale (mRS) scores at 90 d. Scores range from mRS 0 to mRS 6, with mRS 0 indicating no neurologic deficit; mRS 1, no clinically significant disability (return to usual activities); mRS 2, slight disability; mRS 3, moderate disability requiring some help; mRS 4, moderately severe disability; mRS 5, severe disability; and mRS 6, death. NSE = neuron-specific enolase.

TABLE 2. Measures of Diagnostic Accuracy of Different Neuron-Specific Enolase Concentration Thresholds at Day 3 for Prediction of Mortality at 28 Days and Poor Functional Outcome at 90 Days

Variable	Sensitivity % (95% CI)	Specificity % (95% CI)
Mortality at day 28, µg/L		
NSE > 25	71 (53–85)	62 (48–75)
NSE > 50	14 (6–31)	89 (77–95)
NSE > 75	11 (4–27)	98 (88–100)
NSE > 80	10 (4–27)	100 (92–100)
Modified Rankin scale ≥ 4 at 90 d, µg/L		
NSE > 25	65 (51–79)	67 (50–84)
NSE > 50	19 (10–33)	93 (79–99)
NSE > 75	9 (4–22)	100 (89–100)
NSE > 80	7 (2–19)	100 (89–100)

Crit Care Explor 2020

EEG

EEG monitoring

- Background
- Reactivity
- Seizure detection

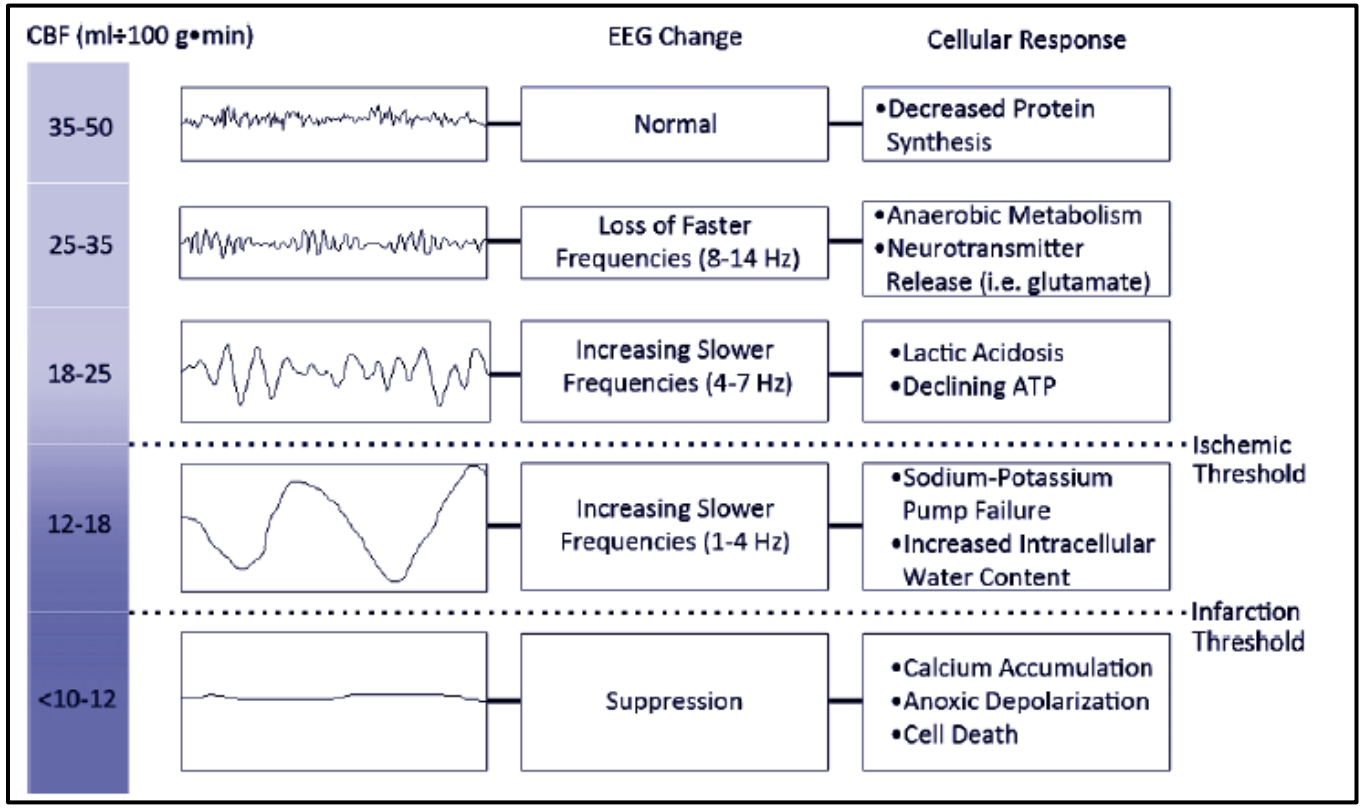
Background frequency

β

α

θ

δ



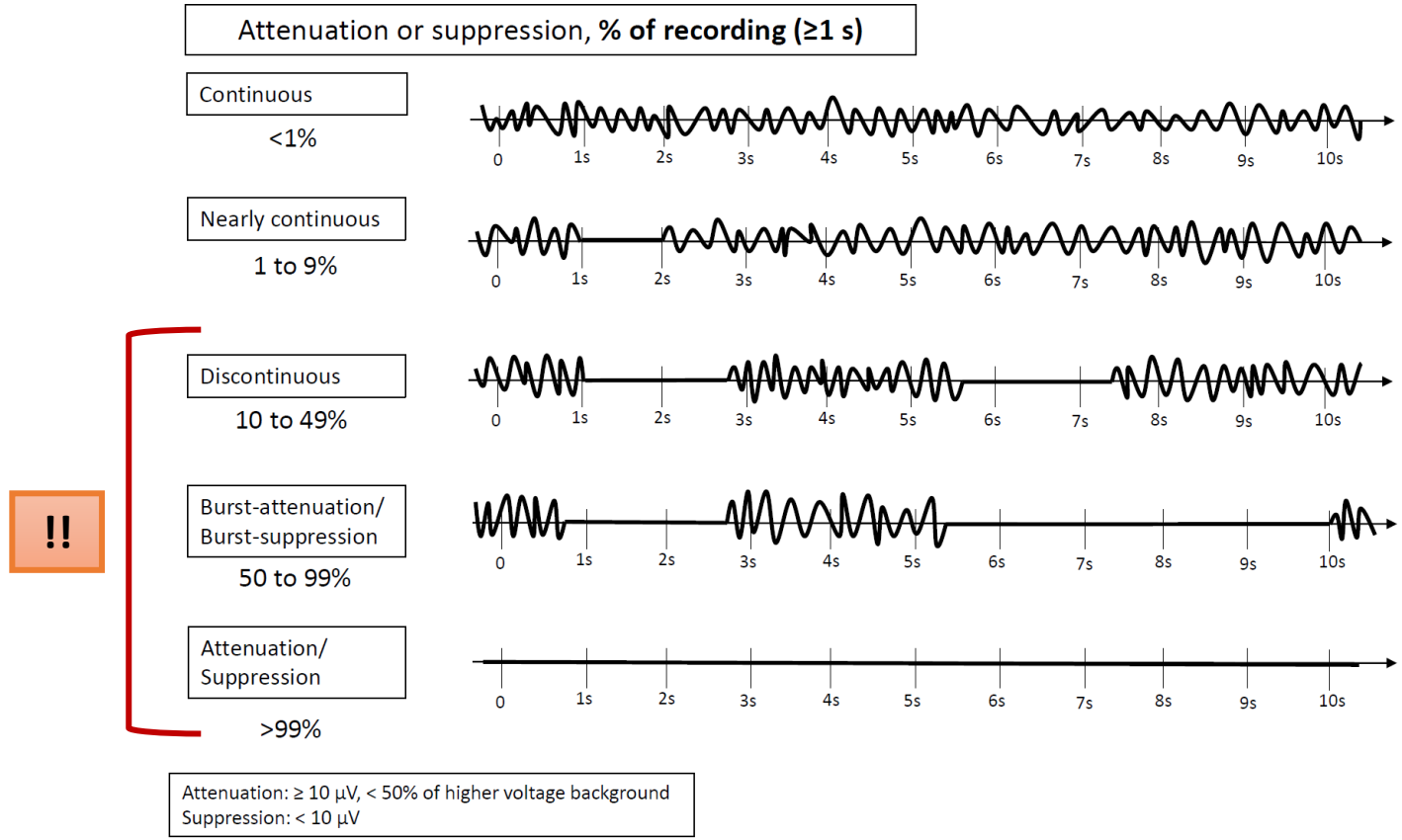
Foreman and Claassen, Crit Care 2018

EEG

EEG monitoring

- Background
- Reactivity
- Seizure detection

Suppression ?

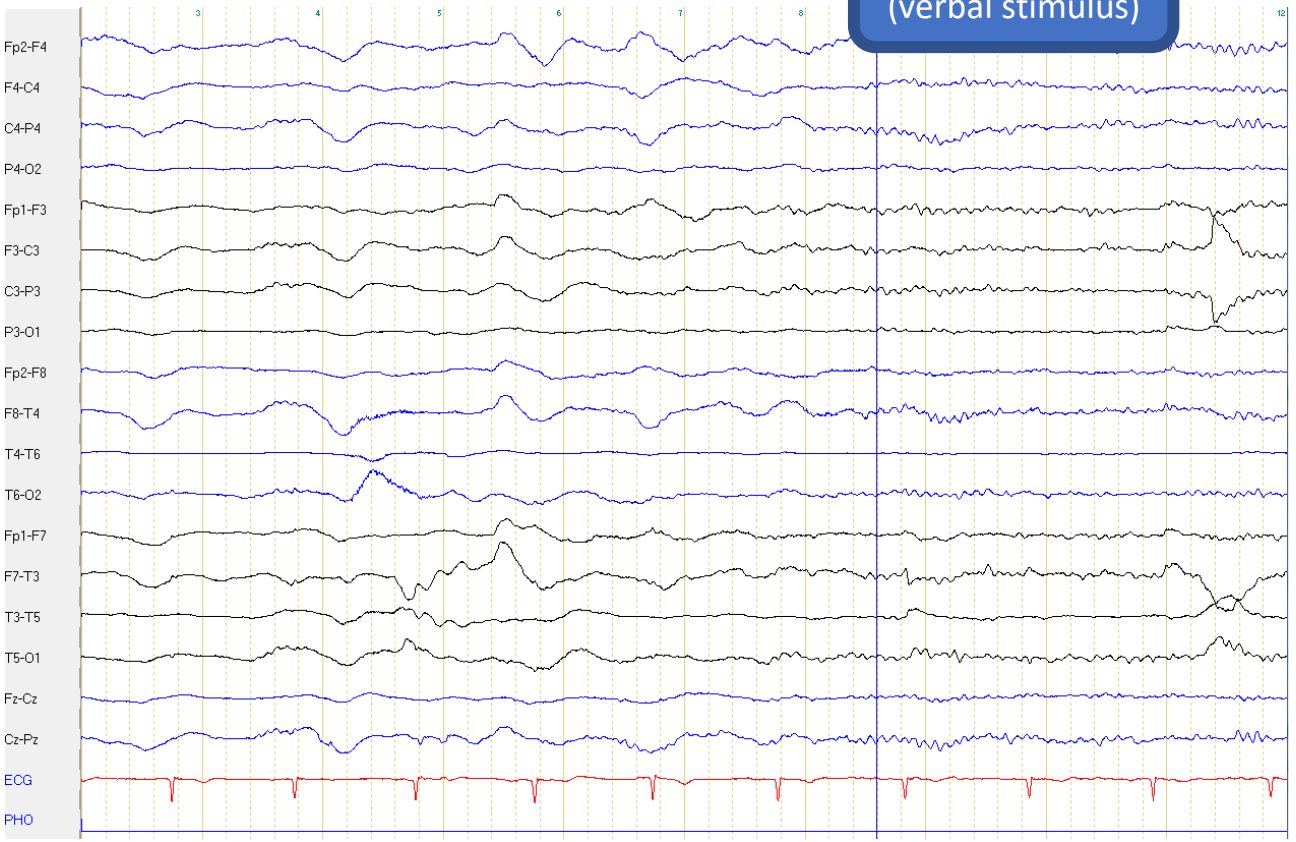


ACNS Critical Care EEG Terminology 2021

EEG

EEG monitoring

- Background
- Reactivity
- Seizure detection

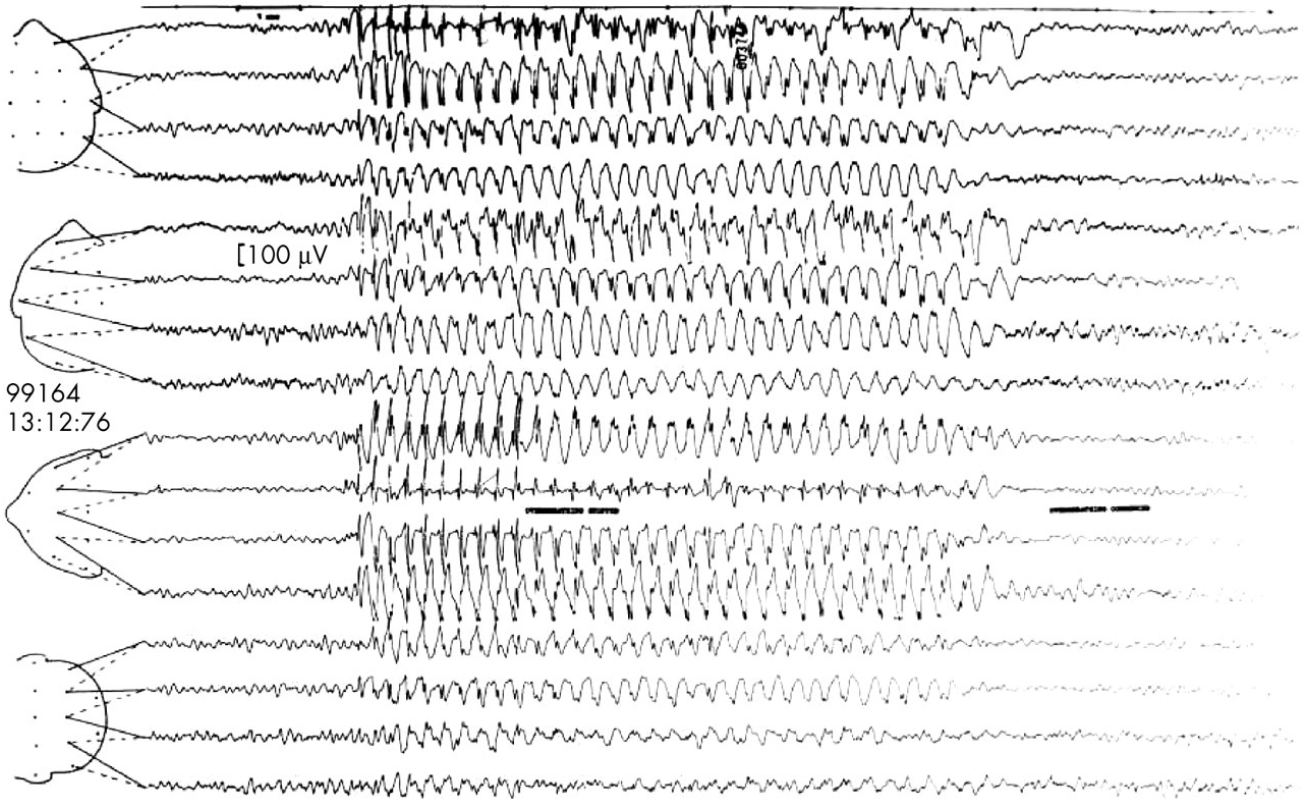


ACNS Critical Care EEG Terminology 2021

EEG

EEG monitoring

- Background
- Reactivity
- Seizure detection



SJM Smith, JNNP 2005

EEG background

RESEARCH Open Access

Electroencephalographic features in patients undergoing extracorporeal membrane oxygenation

Lorenzo Peluso[1*], Serena Rechichi[1,2], Federico Franchi[1,2], Selene Pozzebon[1,2], Sabino Scolletta[2], Alexandre Brasseur[1], Benjamin Legros[3], Jean-Louis Vincent[1], Jacques Creteur[1], Nicolas Gaspard[3,4†] and Fabio Silvio Taccone[1†]

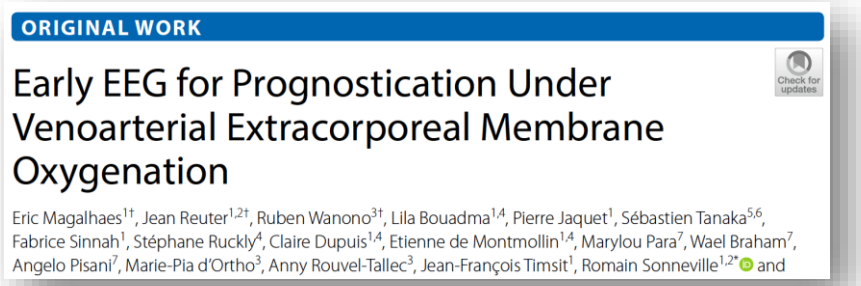
Table 2 Univariate and multivariate analysis to unfavorable neurological outcome at 3 months

	Univariate		Multivariate	
	Unadjusted OR [CI 95%]	*p* value	Adjusted OR [CI 95%]	*p* value
Age	1.02 [0.99–1.04]	0.10	1.02 [1.00–1.05]	0.10
Cardiac arrest	1.44 [0.70–3.00]	0.32	1.20 [0.52–2.73]	0.67
Lactate	1.11 [1.02–1.21]	0.02	1.08 [0.98–1.19]	0.14
Stroke/ICH	3.93 [1.11–13.91]	0.03	4.57 [1.25–16.74]	0.02
Background categories				
Mild/moderate encephalopathy	1		1	
Severe encephalopathy	3.23 [1.13–9.27]	0.03	2.48 [0.82–7.48]	0.11
Burst-suppression	2.69 [0.29–25.10]	0.39	3.94 [0.36–42.75]	0.26
Suppressed background	12.79 [1.64–99.94]	0.02	10.08 [1.24–82.20]	0.03

Hosmer and Lemeshow goodness-of-fit test: $p = 0.04$

Crit Care 2020

EEG Reactivity



ORIGINAL WORK

Early EEG for Prognostication Under Venoarterial Extracorporeal Membrane Oxygenation

Eric Magalhaes[1†], Jean Reuter[1,2†], Ruben Wanono[3†], Lila Bouadma[1,4], Pierre Jaquet[1], Sébastien Tanaka[5,6], Fabrice Sinnah[1], Stéphane Ruckly[4], Claire Dupuis[1,4], Etienne de Montmollin[1,4], Marylou Para[7], Wael Braham[7], Angelo Pisani[7], Marie-Pia d'Ortho[3], Anny Rouvel-Tallec[3], Jean-François Timsit[1], Romain Sonneville[1,2*] and

Variable	Number of events	AUROC	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	FPR % (95% CI)
Clinical characteristics							
Age > 60 years	48/122	0.602	49 (37; 62)	71 (60; 83)	65 (51; 78)	57 (45; 68)	29 (21; 37)
Abnormal pupillary reactivity	10/109	0.528	7 (0; 13)	88 (79; 97)	40 (10; 70)	43 (34; 53)	12 (6; 18)
GCS motor response 1 or 2	89/122	0.550	78 (68; 88)	32 (20; 44)	55 (45; 65)	58 (41; 74)	68 (60; 76)
Electroencephalography							
≤ 4 Hz	27/121	0.582	30 (19; 41)	86 (77; 95)	70 (53; 88)	53 (43; 63)	14 (8; 20)
Background abnormalities	27/120	0.581	30 (19; 41)	86 (77; 95)	70 (53; 88)	53 (43; 63)	14 (8; 20)
Discontinuous	20/121	0.576	24 (13; 34)	91 (84; 99)	75 (56; 94)	52 (43; 62)	9 (4; 14)
Unreactive	12/120	0.545	14 (6; 23)	95 (89; 100)	75 (51; 100)	50 (41; 59)	5 (1; 9)
≤ 4 Hz and unreactive	5/120	0.540	8 (1; 15)	100 (100; 100)	100 (100; 100)	50 (40; 59)	0 (0; 0)

An unfavorable outcome, defined by mortality at 28 days, occurred in 63/122 (52%) patients

AUROC area under the receiver-operating characteristic curve, *FPR* false positive rate, *GCS* Glasgow Coma Scale, *NPV* negative predictive value, *PPV* positive predictive value

Neurocritical care 2020

Frontal EEG

RESEARCH Open Access

Simplified frontal EEG in adults under veno-arterial extracorporeal membrane oxygenation

Cyril Touchard[1], Jérôme Cartailler[1,2], Geoffroy Vellieux[3,4], Etienne de Montmollin[6], Pierre Jaquet[6], Ruben Wanono[3,4], Jean Reuter[6], Marylou Para[7], Lila Bouadma[6], Jean-François Timsit[6], Marie-Pia d'Ortho[4], Nathalie Kubis[5,8], Anny Rouvel Tallec[3,4] and Romain Sonneville[5,6*] The DINAMO Study Group

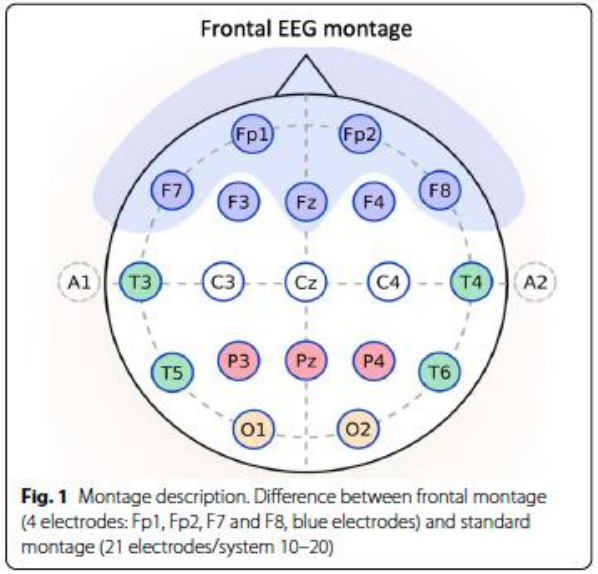


Fig. 1 Montage description. Difference between frontal montage (4 electrodes: Fp1, Fp2, F7 and F8, blue electrodes) and standard montage (21 electrodes/system 10–20)

Table 2 Association between EEG parameters and outcomes

Outcomes	Day-28 mortality		Day-90 mRS ≥ 4	
Variable	**Adjusted OR[a]**	**95% CI**	**Adjusted OR[a]**	**95% CI**
Synek score, $_{4\text{-front}}$EEG (per 1-point increment)	1.67	[1.25; 2.24]	1.83	[1.25; 2.70]
Synek score, $_{std}$EEG (per 1-point increment)	1.55	[1.16; 2.07]	1.68	[1.13; 2.49]
Background rhythm $_{std}$EEG (per 1-Hz increment)	0.71	[0.52; 0.97]	0.73	[0.52; 1.03]

The Synek score ranges from 1 to 5, with higher scores indicating more severe encephalopathy

mRS: modified Rankin scale; OR: odds ratio; EEG: electroencephalography; $_{4\text{-front}}$EEG: 4-electrode montage; $_{std}$EEG: 21-electrode montage

[a] The association between each EEG variable (background rhythm, and Synek's scores on $_{4\text{-front}}$EEG and $_{std}$EEG) and outcomes (day-28 mortality and day-90 mRS score ≥ 4) were evaluated using logistic regression analyses adjusted for age, pre-ECMO cardiac arrest, and non-neurological SOFA score at time of cannulation

Annals of intensive care 2021

Cerebral Oxymetry

ORIGINAL ARTICLE

Cerebral Near-Infrared Spectroscopy in Adult Patients Undergoing Veno-Arterial Extracorporeal Membrane Oxygenation

Selene Pozzebon[1], Aaron Blandino Ortiz[1], Federico Franchi[2], Stefano Cristallini[1], Mirko Belliato[3], Olivier Lheureux[1], Alexandre Brasseur[1], Jean-Louis Vincent[1], Sabino Scolletta[2], Jacques Creteur[1] and Fabio Silvio Taccone[1*]

Table 3 Multivariable analyses with cerebral desaturation, acute cerebral complication, or hospital mortality as dependent variables

	OR	95% CI	*p* value	AUC (95% CI)
Cerebral desaturation				
SOFA score	1.40	1.06–1.84	0.016	0.80 (0.66–0.94)
Minimum BF (L/min)	3.05	1.01–9.17	0.048	
Acute cerebral complication				
Lowest rSO_2 (%)	1.009	1.005–1.012	0.002	0.88 (0.78–0.98)
$\Delta rSO_2 > 10\%$	24.24	2.77–211.80		
Hospital mortality				
High lactate (mmol/L)	1.22	1.03–1.46	0.025	0.79 (0.66–0.91)
Cerebral desaturation	7.93	1.62–38.74	0.011	

BF, blood flow; rSO_2, regional oxygen saturation; $\Delta rSO_2 > 10\%$, maximal difference between right and left cortical oxygen tissue saturation greater than 10%; SOFA, sequential organ failure assessment score on the day of ECMO initiation

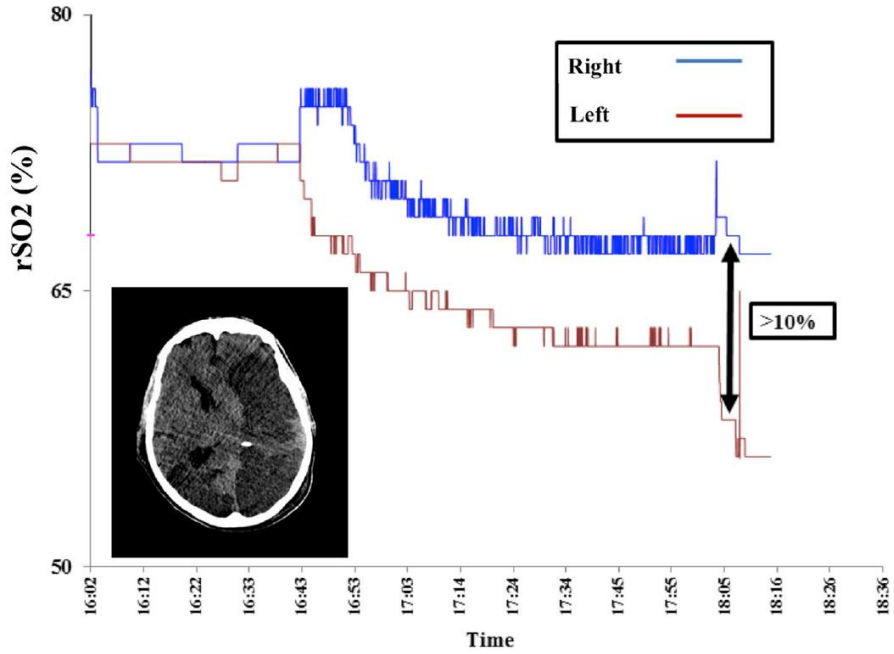


Fig. 3 Time course of rSO_2 values in a patient developing a large left middle cerebral artery ischemic stroke (as shown on the cerebral CT-scan). Left rSO_2 progressively decreases and a left–right difference > 10% is observed

Neurocritical care 2018

Outcome Parameters in ECMO

Tool	Favorable Outcome (All of the following)	Unfavorable Outcome (Any parameter)
Clinical examination (FOUR score)	Preserved motor **AND** brainstem responses	Poor motor response **OR** Altered brainstem responses
Automated Pupillometry	NPi>3 **AND** symmetrical responses	NPi<3 **OR** asymmetrical responses
EEG	Continuous **AND** reactive No severe slowing (delta) No seizure	Suppressed **OR** severe slowing and unreactive
TCD	Preserved velocities	Altered velocities
rSO2	>65% **AND** symmetrical values	Asymmetrical (Delta > 10%)
NSE	Normal values <15 microg/L	High values >50-60 microg/L

Prevention of brain injury during ECMO ?

At ECMO onset: optimize cerebral **perfusion**, avoid **$PaCO_2$** drops ++

Early assessment of **neurological status :**

- **Multimodal, non-invasive, bedside evaluation:** Automated Pupillometry, EEG, TCD
- Repeated **brain imaging (CT)** ?

Use **lower anticoagulation targets** (anti-Xa 0.2-0.3) ?

Higher **transfusion** thresholds ?

platelet count > 100,000 / mm^3

FFP as needed to maintain INR < 1.5

Optimize ECMO weaning process ++

Late assessments after sedation discontinuation and weaning of ECMO

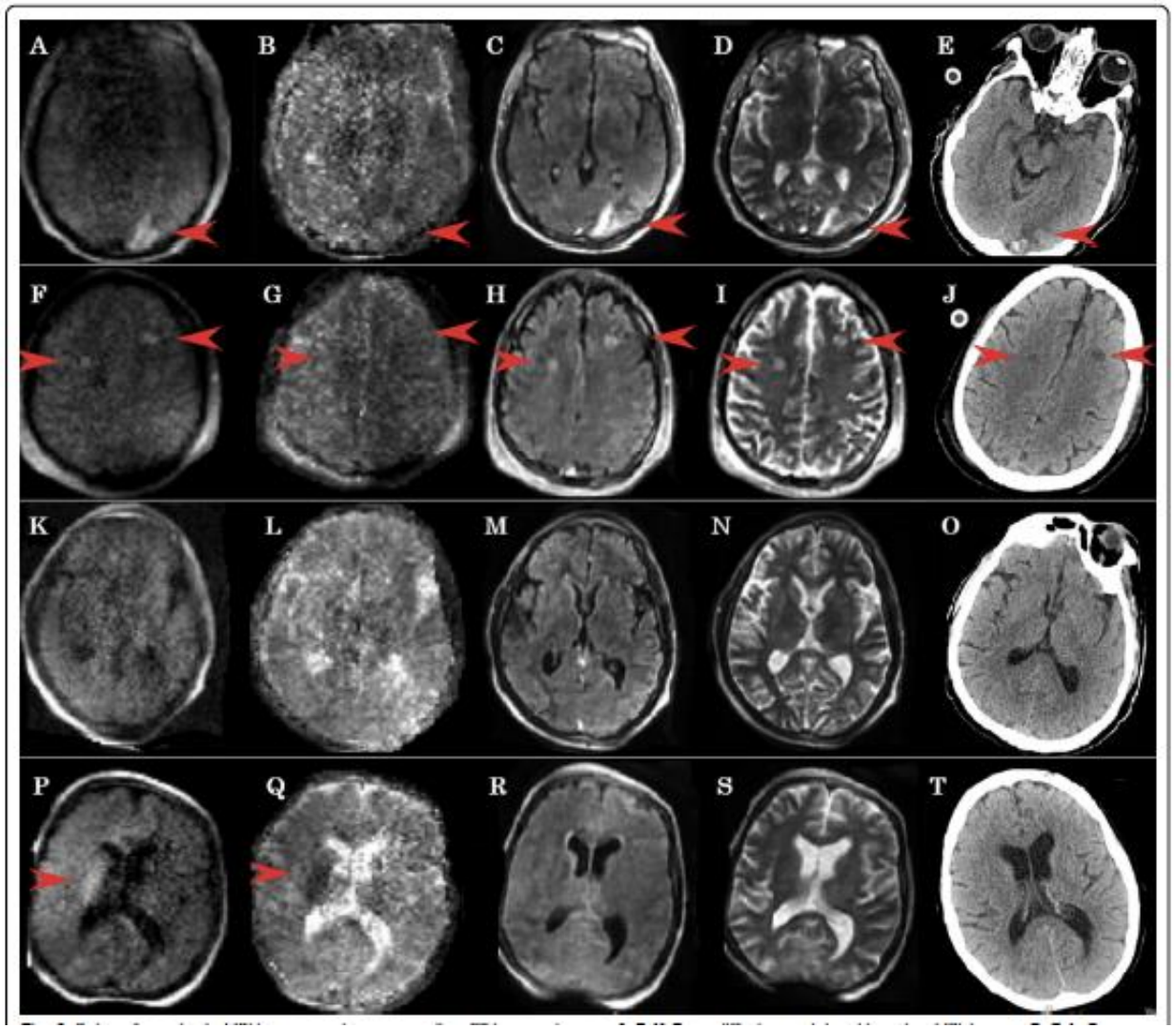
Brain MRI under ECMO … ?

BRIEF REPORT Open Access

Assessing the SAfety and FEasibility of bedside portable low-field brain Magnetic Resonance Imaging in patients on ECMO (SAFE-MRI ECMO study): study protocol and first case series experience

Sung-Min Cho[1,2*], Christopher Wilcox[1], Steven Keller[3,4], Matthew Acton[1], Hannah Rando[1], Eric Etchill[1], Katherine Giuliano[1], Errol L. Bush[5], Haris I. Sair[6], John Pitts[7], Bo Soo Kim[1,4] and Glenn Whitman[1]

POC MRI @bedside of ECMO patients utilizing a 64mT Swoop® MR imaging system



Crit Care 2022

Framework

- VV-ECMO is associated with neurologic complications
- Pathophysiology and risk factors
- Brain monitoring tools
- Conclusion

Conclusion


WHAT'S NEW IN INTENSIVE CARE

Neuromonitoring for prognostication under ECMO

Check for updates

Soojin Park[1,2,3], Chiara Robba[4,5] and Romain Sonneville[6,7*]

- **Neurologic complications** (ICH, ischemic stroke) contribute to **poor outcomes**
- **Early multimodal non-invasive neuromonitoring is mandatory**
  - to **detect** and **prevent brain injury**
  - to guide **therapeutic interventions**
  - to **assist with prognostication**
- Data arise from **single-center (retrospective) studies**
- **Further prospective data needed in VV-ECMO patients**

Intensive Care Medicine 2023

Thank you ! ☺