BRIEF REPORT

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Neurosurgical Procedures in Patients Requiring Extracorporeal Membrane Oxygenation

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OBJECTIVES: Extracorporeal membrane oxygenation (ECMO) is often withheld in patients with significant neurologic injury or recent neurosurgical intervention due to perceived futility. Studies of neurosurgical interventions before or during ECMO are limited to case reports or single-center series, limiting generalizability, and outcomes in this population are unknown. We therefore sought to report the outcomes of ECMO patients with acute neurosurgical interventions at four high-volume ECMO and comprehensive stroke centers.

DESIGN: Retrospective case series.

SETTING: Four academic tertiary referral hospitals in the United States.

PATIENTS: Adults ($n = 24$) having undergone neurosurgical procedures before or during ECMO.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: We retrospectively reviewed adults at four institutions who had undergone neurosurgical procedures immediately before or during ECMO from 2015 to 2023. The primary outcome was survival to hospital discharge. Secondary outcomes included favorable neurologic outcome (Cerebral Performance Category 1 or 2) and neurosurgical complications. Twenty-four of 2957 ECMO patients (0.8%) were included. Primary indications for neurosurgical intervention included traumatic brain ($n = 8$) or spinal ($n = 3$) injury, spontaneous intracranial hemorrhage ($n = 6$), and acute ischemic stroke ($n = 5$). Procedures included extraventricular drain (EVD) and/or intracranial pressure monitor placement ($n = 10$), craniectomy/craniotomy ($n = 5$), endovascular thrombectomy ($n = 4$), and spinal surgery ($n = 3$). Fifteen patients (63%) survived to hospital discharge, of whom 12 (80%) were discharged with favorable neurologic outcomes. Survival to discharge was similar for venoarterial and venovenous ECMO patients (8/12 vs. 7/12; $p = 0.67$) and those who had neurosurgery before vs. during ECMO (8/13 vs. 7/11; $p = 0.92$). One patient (4%) experienced a neurosurgical complication, a nonlethal tract hemorrhage from EVD placement. Survival to discharge was similar for neurosurgical and nonneurosurgical ECMO patients at participating institutions (63% vs. 57%; $p = 0.58$).

CONCLUSIONS: Patients with acute neurologic injury can feasibly undergo neurosurgery during ECMO or can undergo ECMO after recent neurosurgery. Larger studies are needed to fully understand risks for bleeding and other procedure-related complications.

KEYWORDS: acute brain injury; extracorporeal membrane oxygenation; mechanical circulatory support; neurology; neurosurgery

Extracorporeal membrane oxygenation (ECMO) is a lifesaving intervention for refractory cardiopulmonary failure. One of the chief concerns among ECMO specialists is the risk of intracranial hemorrhage (ICH) (1, 2). Patients with recent neurosurgical procedures may be at particularly

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KEY POINTS

Question: How do survival and neurologic outcomes of extracorporeal membrane oxygenation (ECMO) patients who underwent neurosurgical procedures compare to those of ECMO patients overall?

Findings: In a retrospective case series of 24 adults who underwent neurosurgical interventions immediately before or during ECMO, survival to discharge was not statistically different when compared with nonneurosurgical patients at the participating study sites (63% vs. 57%).

Meaning: Patients with acute neurologic injury requiring surgical intervention may feasibly undergo ECMO therapy and should not altogether be refused this lifesaving intervention.

high risk of ICH on ECMO, and due to this perception, ECMO may not be offered to patients after recent neurosurgical procedures or neurosurgical procedures may not be offered to patients on ECMO.

ECMO-related outcomes in patients with significant neurologic injury that require neurosurgical procedures are largely limited to case reports or single-center case series focused on traumatic brain injury (TBI) (3). A recent retrospective study of TBI patients who received ECMO reported an in-hospital mortality of 34%, consistent with a similarly sized international cohort's mortality of 38% (4, 5). However, few patients in this cohort received neurosurgical intervention. Whether ECMO is feasible after a recent neurosurgical procedure or if neurosurgical procedures are safe while patients are on ECMO is uncertain. To address these knowledge gaps, we evaluate outcomes for patients who underwent various acute neurosurgical interventions either before or during ECMO across four institutions.

METHODS

We performed a multicenter retrospective chart review of patients admitted from April 15, 2015, to April 19, 2023, who underwent venovenous or venoarterial ECMO. Inclusion criteria were adults 18 years old or older and patients with any neurosurgical procedure before or during ECMO within the same hospitalization. The four study sites (University of Maryland Medical Center, University of Rochester Medical Center, Johns Hopkins Hospital, and the University of Virginia Medical Center) are high-volume ECMO centers and Joint Commission-certified Comprehensive Stroke Centers. This study was approved by institutional review boards at all participating sites—for more information, please see **Supplemental Digital Content** (http://links.lww.com/CCX/B422). All procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975.

Data extracted from electronic medical records were entered into a centralized database (Research Electronic Data Capture). Laboratory values closest to the time point of the intervention (ECMO cannulation, surgical procedure, etc.) were used. Neurologic outcomes were measured by the Cerebral Performance Category score dichotomized to favorable (1–2) or unfavorable (3–5). Criteria for hemorrhagic complications were defined by the presence of new bleeding on any subsequent CT or MRI imaging during the index hospitalization.

Descriptive statistical analysis of the data sample was performed and reported as mean ± SD (parametric) or median and interquartile range (1st–3rd quartiles) (nonparametric). Comparisons between groups were performed using Student *t* test, Wilcoxon rank-sum test, or chi-square tests, with statistical significance defined at p value of less than 0.05.

RESULTS

A total of 2957 patients underwent ECMO therapy and were screened for inclusion, of which 24 patients met inclusion criteria (88% male, mean age 41 yr, mean ECMO duration 251 hr) (**Supplementary Table 1**, http://links.lww.com/CCX/B422). The median Glasgow Coma Score at admission was 9 (5–15). Venovenous and venoarterial ECMO were performed in 12 patients each. Compared with venovenous ECMO patients, venoarterial ECMO patients were older (48 vs. 34 yr old; $p = 0.04$), had higher Sequential Organ Failure Assessment (SOFA) scores on cannulation day (12 vs. 8; $p = 0.005$), higher serum creatinine (1.6 vs. 0.9 mg/dL; $p = 0.02$), higher lactate (11 vs. 3

TABLE 1.
Neurosurgical Procedures, Indications, and Complications for Extracorporeal Membrane Oxygenation Patients

Patient	NSGY Procedure	Age	ECMO Type	Indications	Days Between NSGY and ECMO	Anticoagulation Used?	Complications on ECMO
1	Craniectomy	21	VA	TBI, contusions, SAH, SDH	8	X	H, A
2	Craniectomy[a]	54	VV	AIS	2		A, TCP
3	Craniectomy	19	VV	TBI, contusions, SDH	4		H
4	Craniotomy	17	VA	TBI, contusions	29	X	
5	Craniotomy	68	VV	Brain tumor	1		H, A, TCP
6	EVD	25	VA	SAH, IVH, hydro	5		H, TCP
7	EVD	48	Veno-arterial-venous	SAH	7		
8	EVD[a]	21	VV	AIS, IVH, hydro	5	X	H, tract hemorrhage
9	EVD[a]	45	VV	ICH	30	X	H, ICH
10	EVD[a]	61	VV	SAH, IVH, hydro	7	X	H, ICH
11	EVD[a]	50	VV	SAH, IVH, hydro	1	X	
12	ICP bolt	22	VA	TBI, contusions	1		
13	ICP bolt	23	VA	TBI, contusions	8	X	
14	ICP bolt	52	VV	TBI, contusions, SDH	8	X	H
15	ICP bolt	24	VV	TBI, contusions, IVH	3	X	A, TCP
16	EVT	39	VA	AIS	0	X	
17	EVT[a]	48	VA	AIS	2	X	S
18	EVT[a]	57	VA	AIS	4	X	S
19	EVT[a]	56	VA	AIS	4	X	S
20	Transverse venous stent[a]	60	VV	Cerebral venous thrombus	36	X	H
21	Middle meningeal artery embolization[a]	60	VA	TBI, SDH	2	X	A, TCP
22	Spine surgery (thoracic)	36	VV	TSI	12		
23	Spine surgery (thoracic)	33	VA	TSI	33	X	H, A, TCP, ICH, SAH
24	Spine surgery (cervical)[a]	43	VV	TSI	2	X	H, A, TCP

A = anemia (hemoglobin < 7 g/dL), AIS = acute ischemic stroke, ECMO = extracorporeal membrane oxygenation, EVD = extraventricular drain, EVT = endovascular thrombectomy, H = systemic hemorrhage, hydro = obstructive hydrocephalus, ICH = intracerebral hemorrhage, ICP = intracranial pressure, IVH = intraventricular hemorrhage, NSGY = neurosurgery, S = ischemic stroke, SAH = subarachnoid hemorrhage, SDH = subdural hematoma, TBI = traumatic brain injury, TCP = thrombocytopenia (platelets < 100,000), TSI = traumatic spinal injury, VA = venoarterial, VV = venovenous, X = yes.

[a]Indicates neurosurgical procedure occurred while on ECMO.

mmol/L; $p = 0.001$), and higher international normalized ratio (1.6 vs. 1.2; $p = 0.05$) (**Supplementary Table 2**, http://links.lww.com/CCX/B422). Thirteen patients underwent neurosurgical interventions a median of 7 days (range, 0–33 d) before ECMO initiation, while 11 patients underwent neurosurgery a median of 4 days (range, 1–36 d) after ECMO start.

Venoarterial ECMO patients were mostly cannulated femoro-femorally ($n = 11$, 92%), while one patient (8%) was cannulated femoro-jugularly. One femoro-femoral venoarterial ECMO patient (subject 7) received an additional jugular venous ECMO cannula for refractory hypoxemia. Indications for venoarterial ECMO were cardiogenic shock ($n = 6$), cardiac arrest ($n = 5$), and traumatic acute respiratory distress syndrome (ARDS) ($n = 1$). Venoarterial ECMO patients underwent craniectomy ($n = 1$) or craniotomy ($n = 1$) for TBI, extraventricular drain (EVD) for subarachnoid hemorrhage (SAH) ($n = 2$), intracranial pressure (ICP) monitor placement for TBI ($n = 2$), endovascular thrombectomy (EVT) for acute ischemic stroke (AIS) ($n = 4$), endovascular middle meningeal artery embolization (MMAE) for traumatic subdural hematoma ($n = 1$), and spinal fixation for traumatic spinal injury (TSI, $n = 1$). Three EVT and the MMAE occurred during ECMO, all while patients received systemic anticoagulation and none of whom were thrombocytopenic (platelets < 100,000) or anemic (hemoglobin < 7 g/dL). No complications were reported from any procedures. Eight patients (67%) survived to discharge, including three of four EVT patients (75%). Three patients (25%) who died underwent withdrawal of life-sustaining therapies (WLST), all for poor neurologic prognosis; one decedent was declared brain dead.

Venovenous ECMO patients were cannulated femoro-femorally ($n = 8$) or femoro-jugularly ($n = 4$) using single-lumen catheters. The indication for 11 patients (92%) was ARDS; one patient (8%) experienced cardiac arrest with refractory hypoxia. Venovenous ECMO patients underwent craniectomy for AIS ($n = 1$) or TBI ($n = 1$); craniotomy for brain tumor ($n = 1$); EVD for SAH, ICH, and/or intraventricular hemorrhage (IVH) ($n = 4$); ICP monitor placement for TBI ($n = 2$); transverse venous sinus stent placement for cerebral venous thrombosis ($n = 1$); and spinal fixation for TSI ($n = 2$) (**Table 1**). Seven patients underwent procedures during venovenous ECMO: one craniectomy, four EVD, one spinal fixation, and the transverse venous stenting. Six (86%) of these patients received systemic anticoagulation during ECMO. Three of four (75%) venovenous ECMO patients who received EVD experienced systemic hemorrhage and ICH or IVH, all of whom were anticoagulated. One patient (subject 8) experienced an EVD-tract hemorrhage, the only neurosurgical complication in our cohort (1/24, 4%). This patient did not exhibit coagulopathy at the time of EVD placement during venovenous ECMO and required multiple insertion attempts before successful placement. Seven (58%) venovenous ECMO patients survived to discharge, three (25%) underwent WLST for poor neurologic prognosis, and two (17%) were declared brain dead.

Fifteen of 24 patients (63%) survived to discharge and most survivors (12/15, 80%) had favorable outcomes (**Table 2**; and Supplemental Table 1, http://links.lww.com/CCX/B422). Survival to discharge was similar between those who had neurosurgical procedures performed before or during ECMO (8/13, 62% vs. 7/11, 63%; $p = 0.92$). Survival to discharge was also similar to that of all patients treated with ECMO at the four study sites over the same time period (15/24, 63% vs. 1681/2957, 57%; $p = 0.58$).

DISCUSSION

We found most patients who underwent neurosurgical procedures before or during ECMO survived, and survivors had generally favorable neurologic outcomes. These patients experienced similar survival rates to the general ECMO population over the same period in the participating institutions. This suggests that recent neurosurgical procedures should not be viewed as an absolute contraindication to ECMO and vice versa.

Few studies have reported outcomes in brain-injured ECMO patients. One study in patients with venovenous ECMO for traumatic ARDS found similar survival rates in patients with and without TBI (28/39, 72% vs. 23/36, 64%; $p = 0.45$), of whom 28% required neurosurgical intervention (4). Our study describes a wider variety of brain injuries. Our cohort's survival outcomes were similar or higher than other reported ECMO populations including ARDS (61%), severe trauma (70%), and cardiogenic shock (45%) (1, 6).

We compared venoarterial and venovenous ECMO patients to examine differences in underlying risk factors associated with neurosurgical complications. While

TABLE 2.

Survival, Mortality, and Discharge Outcomes for Patients With Neurosurgical Procedures Before or During Extracorporeal Membrane Oxygenation

Patient	Neurosurgery Procedure	Age	ECMO Type	Survive ECMO	Survival to Discharge	Discharge Cerebral Performance Category	Outcome/Reason for Withdrawal of Life-Sustaining Therapy
1	Craniectomy	21	VA	Yes	Yes	2	ARF
2	Craniectomy	54	VV	No	No	5	Poor neuro prognosis[a]
3	Craniectomy	19	VV	Yes	Yes	2	ARF
4	Craniotomy	17	VA	Yes	Yes	2	ARF
5	Craniotomy	68	VV	Yes	Yes	2	Home with PT/OT
6	EVD	25	VA	No	No	4	Poor neuro prognosis[a]
7	EVD	48	Veno-arterial-venous	Yes	Yes	3	ARF
8	EVD	21	VV	Yes	Yes	2	ARF
9	EVD	45	VV	No	No	5	Brain death
10	EVD	61	VV	No	No	5	Poor neuro prognosis[a]
11	EVD	50	VV	Yes	Yes	3	ARF
12	ICP bolt	22	VA	No	No	5	Poor neuro prognosis[a]
13	ICP bolt	23	VA	Yes	Yes	2	ARF
14	ICP bolt	52	VV	No	No	5	Poor neuro prognosis[a]
15	ICP bolt	24	VV	No	No	5	Brain death
16	EVT	39	VA	Yes	Yes	3	ARF
17	EVT	48	VA	Yes	Yes	1	Home with PT/OT
18	EVT	57	VA	Yes	Yes	1	Home
19	EVT	56	VA	No	No	5	Poor neuro prognosis[a]
20	Transverse venous stent	60	VV	Yes	Yes	1	Home with PT/OT
21	Middle meningeal artery embolization	60	VA	Yes	Yes	1	ARF
22	Spine surgery (thoracic)	36	VV	Yes	Yes	1	ARF
23	Spine surgery (thoracic)	33	VA	Yes	No	5	Brain death[b]
24	Spine surgery (cervical)	43	VV	Yes	Yes	1	ARF

ARF = acute rehabilitation facility, ECMO = extracorporeal membrane oxygenation, EVD = extraventricular drain, EVT = endovascular thrombectomy, ICP = intracranial pressure, OT = occupational therapy, PT = physical therapy, VA = venoarterial, VV = venovenous.

[a]Indicates withdrawal of life-sustaining treatment.

[b]Patient 23 experienced cardiac arrest post-decannulation and progressed to brain death.

venoarterial ECMO patients had higher SOFA scores and serum lactate levels, they did not have worse outcomes after neurosurgery. Venovenous ECMO patients are described to have a higher occurrence rate of ICH, while venoarterial ECMO patients have higher occurrence rates of AIS (2). Correspondingly, we found higher rates of ICH or SAH in venovenous ECMO, while AIS occurred exclusively in venoarterial ECMO despite anticoagulation use. Overall, the prevalence of neurosurgical complications did not differ between the groups.

ECMO-induced coagulopathy is associated with thromboembolic and hemorrhagic complications, which require consideration in neurosurgical patients. Most ECMO patients require systemic anticoagulation, raising the risk of additional brain injury. ICH occurs in 2–6% of ECMO patients, while 1–5% experience AIS; associated anticoagulation data are lacking (1). Both patients in our cohort with ICH after ECMO initiation had systemic anticoagulation, which was held indefinitely in both cases after discovery. Furthermore, seven of 24 patients (29.1%) included in our study were managed on ECMO without systemic anticoagulation, an increasingly common approach to patients with contraindications to systemic anticoagulation (7).

Patient selection is paramount to optimizing ECMO outcomes. Our study population represents a heterogeneous group of neurosurgical patients who received ECMO for a variety of indications. Key considerations include comorbidities, destination therapy after ECMO, and the recoverability of the acute brain injury. Advances in interventional techniques and critical care management combined with a shift away from nihilism have contributed to outcome improvements after TBI, AIS, ICH, and SAH (8–10). Our findings suggest that acute brain injury requiring neurosurgery does not warrant indiscriminate exclusion from ECMO consideration. Neurosurgical patients can survive with favorable neurologic outcomes after ECMO. The implementation of multidisciplinary "ECMO teams" has been shown to improve survival (11). Clinicians should be cautious when considering the use of ECMO in patients with devastating CNS injuries and should rely upon the expertise of neurointensivists and neurosurgeons for careful patient selection and management.

Our study has several limitations, inherent to retrospective design, which warrant significant discussion. Given that so few ECMO patients underwent neurosurgical procedures, we included a heterogeneous ECMO population with various neurosurgical indications to present as comprehensive a series of these patients as possible. This heterogeneity imparts variability in outcomes beyond the effect of the brain injury itself and significantly limits applicability of our outcome findings in individual patients. Each neurosurgical procedure carries unique risks that further influence variability in outcomes and procedural complications. The paucity of procedural complications (limited to one in our cohort) precluded making meaningful conclusions about safety profiles for each procedure as they relate to ECMO consideration. Further, there was substantial variability between the date of the neurosurgical procedure and ECMO initiation, which limits the generalizability of our results to detect a risk of adverse effects from neurosurgery or ECMO. Theoretically, longer durations of ECMO therapy can increase coagulopathy, raising the risk of ICH or stroke necessitating surgical intervention or making such interventions riskier. The small number of patients in our cohort coupled with the paucity of adverse events we observed and uneven distribution of time durations between intervention and ECMO initiation limited our ability to control for this phenomenon. It remains to be determined if a safe timeline between neurosurgery and ECMO initiation exists. While the four included centers are considered high-volume centers, each institution had different resources, varying thresholds for utilizing ECMO, and there was no standardized ECMO management. Similarly, because all study sites represent high-volume ECMO and stroke centers, the results may not be applicable to less experienced or lower volume centers. Overall, more ECMO patients with neurosurgical interventions may be identified by including more granular data elements in international ECMO registries, such as the Extracorporeal Life Support Organization International Registry. Finally, we performed statistical exploration as unadjusted analyses; there may be unmeasured confounders.

In conclusion, a carefully selected cohort of patients with neurologic injury requiring neurosurgery and ECMO may have favorable outcomes. Limitations of our study notwithstanding, our retrospective review suggests that neurosurgical procedures should not be viewed as an absolute contraindication to ECMO and vice versa and should be performed based on treatment priorities for each individual case. Further study is warranted to refine the selection of brain-injured patients with cardiopulmonary complications for ECMO candidacy, identify risks

for bad outcomes, and determine which ECMO patients should be considered for neurosurgical procedures.

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