Prognostic Value of Early Intermittent Electroencephalography in Patients After Extracorporeal Cardiopulmonary Resuscitation

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Research

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Abstract

Background

The aim of this study was to investigate whether intermittent electroencephalography (EEG) could be used to predict neurological prognosis of patients who underwent extracorporeal cardiopulmonary resuscitation (ECPR).

Methods

This was a retrospective, single center, and observational study of adult patients who were evaluated by EEG scan within 96 hours after ECPR between February 2012 and December 2018. The primary endpoint was neurological status upon discharge from the hospital assessed with Cerebral Performance Categories (CPC) scale.

Results

Among 69 adult cardiac arrest patients who underwent ECPR, 32 (46.4%) patients survived until discharge from the hospital. Of these 32 survivors, 17 (24.6%) patients had favorable neurological outcomes (CPC score: 1 or 2). Sedatives or analgesics were used in 41 (59.4%) patients. Malignant EEG patterns were more common in patients with poor neurological outcome than in patients with favorable neurological outcome (73.1% vs. 5.9%, $p < 0.001$). All patients with highly malignant EEG patterns (43.5%) had poor neurological outcome. Moderately malignant EEG patterns were reported in 8 (11.6%) patients with poor neurological outcome and one (1.4%) patient with favorable neurological outcome. Benign EEG patterns were more common in patients with favorable neurological outcome than in patients with poor neurological outcome (94.1% vs. 26.9%, $p < 0.001$). In multivariable analysis, malignant EEG patterns (adjusted odd ratio [OR]: 53.26, 95% confidence interval [CI]: 5.956 – 476.249) and duration of cardiopulmonary resuscitation (adjusted OR: 1.07, 95% CI: 1.011 – 1.130) were significantly associated with poor neurological outcomes in patients who underwent ECPR (Hosmer-Lemeshow Chi-squared = 7.84, df = 7, p = 0.347).

Conclusions

In this study, malignant EEG patterns within 96 hr after cardiac arrest were significantly associated with poor neurological outcomes in patients who underwent ECPR. Therefore, early intermittent EEG scan could be helpful for predicting neurological prognosis of post-cardiac arrest patients after ECPR.

Background

Neurological prognosis is one of the most important issues in patients who survive a cardiac arrest [1, 2]. It is important to estimate the reversibility of cerebral function in patients after return of spontaneous circulation. It may prevent inappropriate continuation of intensive treatment in patients who are predicted to have poor neurological outcome [2, 3]. Recently, extracorporeal membrane oxygenation (ECMO) has been increasingly used as adjuvant therapy of conventional cardiopulmonary resuscitation (CPR), providing oxygenated blood and hemodynamic support in the absence of spontaneous cardiac circulation [4, 5].

Autoregulation of cerebral blood flow may be changed in patients resuscitated from cardiac arrest [6]. It is difficult to predict how highly oxygenated continuous flow by ECMO affects cerebral autoregulation and neurological recovery in the setting of ECPR [2]. In previous studies of extracorporeal conventional cardiopulmonary resuscitation (ECPR), several predictors of mortality have been reported. However, limited data are available on neurological prognosis after ECPR [7].

Among electrophysiologic studies, electroencephalography (EEG) has been most widely used as one of assessment tools for survivors after cardiac arrest [8]. In the setting of ECPR, whether early intermittent EEG scan may be helpful for systemically estimating neurological outcomes of survivors has not been reported yet. Therefore, the objective of this study was to investigate whether early intermittent EEG scan could be used to predict neurological outcomes of patients who underwent ECPR.

Methods

Study Population

This was a retrospective, single-center, observational study of adult patients who underwent ECPR during hospitalization between February 2012 and December 2018. This study was approved by the Institutional Review Board of Samsung Medical Center (IRB no. SMC 2019-05-002). The requirement for informed consent was waived due to its retrospective nature. Clinical and laboratory data were collected by a trained study coordinator using a standardized case report form. Inclusion criteria were: (1) those who underwent ECPR during the study period, (2) those who had decreased mentalities (a score of < 13 on the Glasgow Coma Scale) on EEG scan after cardiac arrest, and (3) those whose EEG scans were performed within 96 hours after ECPR. Exclusion criteria were: (1) those who were under 18 years of age, (2) those with malignancy whose life expectancy was less than 1 year, (3) those with insufficient medical records, (4) those with causes of death verified to be other than brain death, and (5) those with a history of head trauma or a chronic neurological abnormality upon admission to the intensive care unit (ICU). Ultimately, a total of 69 patients with EEG scan who were resuscitated by veno-arterial ECMO were analyzed in this study (Fig. 1).

Definitions and endpoints

In this study, ECPR was defined as successful veno-arterial ECMO implantation and pump-on with chest compression for external cardiac massage during index procedure in patients with cardiac arrest. When a return of spontaneous circulation occurs during ECMO cannulation, practitioners typically do not remove the cannula or stop the ECMO pump-on process [7]. Surface cooling and the degree of targeted temperature were determined by each intensivist in the ICU according to the targeted temperature management protocol [9]. The primary endpoint was neurological status on discharge from the hospital. It was assessed with the Glasgow-Pittsburgh Cerebral Performance Categories (CPC) scale (scores range from 1 to 5) [10]. CPC scores of 1 and 2 were classified as favorable neurological outcomes while CPC scores of 3, 4, and 5 were considered as poor neurological outcomes [11, 12]. Medical records were thoroughly reviewed. Patients were graded on the CPC scale by two independent neurologists. If CPC did not match between the two neurologists, they discussed and reached an agreement. After successful ECPR, EEG scan was not performed for patients who had a rapid recovery of mentality and neurological deficits. If not, EEG scan was performed to identify causes of decreased consciousness or predict neurological outcome in ECPR patients. EEG scan was also performed when patients had accompanied seizures or abnormal movements. If sedatives, analgesics, or antiepileptic drug were administrated to patients after ECPR, these drugs were not stopped during EEG scan. EEG was performed using a 64-channel digital video-EEG system (Nicolet Biomedical, Inc., Madison, WI, USA). Surface electrodes were placed according to the international 10–20 system. Additional electrodes were placed whenever needed [13]. EEG patterns of ECPR patients were defined using the EEG terminology of the American Clinical Neurophysiology Society [14, 15]. Malignant EEG patterns were defined as highly malignant EEG patterns and moderate malignant EEG patterns. Highly malignant EEG patterns were defined as suppressed background (amplitude < 10 μV, 100% of the recording) without discharges, suppressed background with superimposed continuous periodic discharges, or burst-suppression (periods of suppression with amplitude < 10 μV constituting > 50% of the recording) with superimposed discharges or without discharges [15]. Moderate malignant EEG patterns were defined as malignant periodic or rhythmic patterns (abundant periodic discharges; abundant rhythmic spikes, polyspikes, sharp waves, spike-and-wave or sharp-and-slow wave; unequivocal electrographic seizure), malignant background (discontinuous background; low voltage background; reversed anterior-posterior gradient), or unreactive EEG (absence of background reactivity or only stimulus-induced discharges) [15]. Benign EEG patterns were defined as absence of all malignant features stated above. EEG findings were confirmed by three EEG specialists.

Procedure

CPR was led by the CPR team of the hospital. All facts related to the CPR scene were recorded by bedside nurses according to Utstein-style guidelines [16]. When CPR was performed for more than 10 minutes or in the event of unstable vital signs or recurrent cardiac arrest, the institutional rapid response team contacted the on-call ECMO team leader, who along with the CPR leader assessed the patient and made a decision about whether to institute ECPR. ECPR was performed when a witnessed arrest was confirmed, when the arrest persisted despite conventional CPR lasting for more than 10 minutes, and when the event that caused the arrest was considered reversible [4]. Cases in which ECPR was deferred included those with a short life expectancy (< 6 months), terminal malignancy, an unwitnessed collapse, limited physical activity, or CPR undertaken for more than 60 minutes at the time of initial contact. Age alone did not constitute a contraindication to ECPR [4].

The ECMO team consisted of cardiologists, cardiovascular surgeons, intensivists, special nurses, and perfusionists. Either a Capiox Emergency Bypass System (Terumo, Tokyo, Japan) or a Prolonged Life

Support System (Maquet Cardiopulmonary, Hirrlingen, Germany) was used in all cases. A crystalloid solution such as normal saline or balanced solution was used for priming. No patient had blood-primed ECMO. A percutaneous vascular approach was tried initially in all cases using the Seldinger technique. When percutaneous cannulation failed, surgical cutdown exposure was performed [4]. Femoral vessels were the most common sites of vascular access using 14 to 17 French arterial cannulas and 20 to 24 French venous cannulas [7]. Cardiac compression was stopped once ECMO pump-on was successful during CPR. Anticoagulation was accomplished by a bolus injection of unfractionated heparin, followed by continuous intravenous heparin infusion to maintain an activated clotting time between 150 and 180 seconds. The initial number of revolutions per minute of the ECMO device was adjusted to achieve an ideal cardiac index greater than 2.2 $L/min/m^2$ of body surface area, central mixed venous oxygen saturation above 70%, and a mean arterial pressure above 65 mm Hg [7]. Blood pressure was monitored continuously through an arterial catheter. An artery in the right arm was used for arterial blood gas analysis to estimate cerebral oxygenation. After ECMO, necessary steps were taken to treat the cause of the arrest, such as percutaneous coronary intervention, coronary artery bypass grafting, heart transplantation, non-coronary cardiopulmonary surgery, or non-cardiopulmonary surgery [7].

Statistical Analyses

All data are presented as medians and interquartile ranges (IQRs, Q1 ~ Q3) for continuous variables and as numbers (percentages) for categorical variables. Data were compared using the Mann-Whitney U test for continuous variables and the Chi-square test or Fisher's exact test for categorical variables. Variables with p values less than 0.05 in univariate analyses and clinically relevant variables were subjected to a stepwise multiple logistic regression model to obtain statistically meaningful predictor variables. They were EEG groupings by its pattern, age, target temperature management, first monitored rhythm, CPR duration, Glasgow Coma Scale on EEG scan, and use of sedative or analgesic. Due to small event rates, we take the caution of the general rule of 10 events per variable before any routine application of statistical methods. Adequacy of the prediction model was determined using the Hosmer-Lemeshow test, along with C-index. The predictive performance of malignant EEG patterns assessed using the areas under the curve (AUCs) of the receiver operating characteristic (ROC) curves for sensitivity vs. 1-specificity. The AUCs compared using the nonparametric approach published by DeLong et al. [17] for two correlated AUCs. All tests were two-sided and $p < 0.05$ was considered statistically significant. All data were analyzed using IBM SPSS version 20 (IBM, Armonk, NY, USA).

Results

Baseline Characteristics and Clinical Outcomes

The median patient age was 56 (IQR: 47–70) years. Of 69 patients included in this study, 52 (75.4%) were males. Hypertension (42.0%) and diabetes mellitus (33.3%) were the most common comorbidities among patients who underwent ECPR. Hypertension was more common in patients with poor neurological outcome than in patients with favorable neurological outcome (50.0% vs. 17.6%, $p = 0.005$). A cardiac cause of arrest was verified in 59 (85.5%) patients. Acute coronary syndrome was the main cause of cardiac arrest in 26 (44.1%) patients. Fourteen (20.3%) patients had a history of ischemic heart disease. Forty-seven (68.1%) patients experienced cardiac arrest in the hospital while 22 (31.9%) patients suffered cardiac arrest in an out-of-hospital setting. Compared with the group with favorable neurological outcome, the group with poor neurological outcome had a longer CPR duration ($p = 0.005$). Baseline characteristics of ECPR patients are presented in Table 1.

Table 1

Baseline characteristics

	Favorable neurological outcome (n = 17)	**Poor neurological outcome (n = 52)**	**p value**
Age (yr) — median (IQR) Gender, male — no. of patients (%) Body mass index (kg/m^2) — median (IQR)	51.0 (36.0–73.0) 15 (88.2) 23.5 (21.3–27.7)	57.5 (50.0–69.5) 37 (71.2) 25.2 (22.2–28.7)	0.460 0.206 0.354
Medical history — no. of patients (%) Hypertension Diabetes mellitus Current smoker Previous myocardial infarction Malignancy Dyslipidemia	3 (17.6) 3 (17.6) 6 (35.3) 2 (11.8) 1 (5.9) 2 (11.8)	26 (50.0) 20 (38.5) 11 (21.2) 12 (23.1) 11 (21.2) 10 (19.2)	0.039 0.199 0.331 0.491 0.269 0.716
Target temperature management — no. of patients (%)	9 (52.9)	21 (40.4)	0.532
Type of cardiac arrest — no. of patients (%) Out of hospital cardiac arrest In hospital cardiac arrest Bystander witnessed cardiac arrest — no. of patients (%) Bystander performed CPR — no. of patients (%) First monitored rhythm — no. of patients (%) Asystole Pulseless electrical activity Shockable rhythm (VT or VF) Defibrillation — no. of patients (%) CPR duration — median (IQR)	4 (23.5) 13 (76.5) 17 (100) 16 (94.1) 1 (5.9) 6 (35.3) 10 (58.8) 12 (70.6) 19.0 (8.0–28.0)	18 (34.6) 34 (65.4) 50 (96.2) 48 (92.3) 11 (21.2) 23 (44.2) 18 (34.6) 30 (57.7) 31.0 (21.0–40.5)	0.581 0.999 0.999 0.167 0.510 0.005
Location of ECMO insertion — no. of patients (%) Emergency room Intensive care unit Cath room Operation room	9 (52.9) 4 (23.5) 4 (23.5) 0 (0)	24 (46.2) 23 (44.2) 4 (7.7) 1 (1.9)	0.177
Cardiac cause of arrest — no. of patients (%) Ischemic Non-ischemic	7 (41.2) 10 (58.8)	19 (45.2) 23 (54.8)	0.999

IQR, interquartile range; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation.

Among the 69 adult cardiac arrest patients who underwent ECPR, 32 (46.4%) survived until discharge from the hospital. Of these 32 survivors, 17 (24.6%) had favorable neurological outcomes (CPC score of 1 or 2). The entire distribution of CPC scores is shown in Fig. 1.

Relationship between EEG and Neurologic Outcomes

Sedatives or analgesics were used in 41 (59.4%) patients who underwent ECPR. These drugs were used more in patients with favorable neurological outcome than in patients with poor neurological outcome (88.2% vs. 50.0%, p = 0.012). There was no significant difference in the use of antiepileptic drugs between the two groups of patients (p = 0.999). Characteristics on EEG scan are presented in Table 2.

Table 2
Characteristics on electroencephalography scan

	Favorable neurological outcome (n = 17)	**Poor neurological outcome (n = 52)**	**p value**
Interval between ECPR and EEG scan — no. of patients (%) 0–12 hr 12–24 hr 24–48 hr 48–96 hr	2 (11.8) 4 (23.5) 5 (29.4) 6 (35.3)	10 (19.2) 10 (19.2) 20 (38.5) 13 (23.1)	0.671
Reasons of EEG scan — no. of patients (%) For neurological outcome prediction or decreased mentality Seizure or abnormal movement	7 (41.2) 10 (58.8)	26 (50.0) 26 (50.0)	0.724
Pupil reflex — no. of patients (%) Both prompt One or both sluggish One or both fix	13 (76.5) 2 (11.8) 2 (11.8)	27 (51.9) 8 (15.4) 17 (32.7)	0.199
Glasgow Coma Scale on EEG scan	7.0 (3.0–9.0)	3.0 (3.0–7.0)	0.012
Use of sedative or analgesic — no. of patients (%) Bolus infusion Continuous infusion Remifentanil Midazolam Fentanyl Propofol Use of antiepileptic drug	15 (88.2) 4 (23.5) 15 (88.2) 8 (47.1) 7 (41.2) 6 (35.3) 4 (23.5) 4 (23.5)	26 (50.0) 10 (19.2) 24 (46.2) 13 (25.0) 9 (17.3) 5 (9.6) 2 (3.8) 13 (25.0)	0.012 0.734 0.006 0.999

ECPR, extracorporeal cardiopulmonary resuscitation; EEG, electroencephalography.

Malignant EEG patterns were more common in patients with poor neurological outcome than in patients with favorable neurological outcome (73.1% vs. 5.9%, p < 0.001, Table 3). All patients with highly malignant EEG patterns (43.5%) had poor neurological outcome. Moderately malignant EEG patterns were reported in 8 (11.6%) patients with poor neurological outcome and in only one (1.4%) patient with favorable neurological outcome. Regardless of the interval between ECPR and EEG scan, most patients with malignant EEG patterns had poor neurological outcome in this study. In addition, all patients with myoclonic status epilepticus had poor neurological outcome. Benign EEG patterns were more common in patients with favorable neurological outcome than in patients with poor neurological outcome (94.1% vs. 26.9%, $p < 0.001$, Table 3).

Table 3. Findings of electroencephalography

	Favorable neurological outcome (n = 17)	Poor neurological outcome (n = 52)	*p* value
EEG findings — no. of patients (%)			<0.001
Benign EEG	16 (94.1)	14 (26.9)	
Malignant EEG	1 (5.9)	38 (73.1)	
Highly malignant EEG			
Suppressed background without discharges	0 (0)	18 (34.6)	
	0 (0)	2 (3.8)	
Suppressed background with continuous periodic discharges	0 (0)	10 (19.2)	
Burst-suppression background with or without discharges			
	0 (0)	6 (11.5)	
Moderately malignant EEG			
	0 (0)	2 (3.8)	
Malignant periodic or rhythmic patterns	1 (5.9)	0 (0)	
Malignant background			
Unreactive EEG			
EEG patterns according to time interval — no. of patients (%)			
			0.001
EEG performed within 24hr after ECPR	6 (35.3)	4 (7.7)	
Benign EEG patterns	0 (0)	16 (30.8)	
Malignant EEG patterns			0.001
EEG performed over 24hr after ECPR	10 (58.8)	10 (19.2)	
Benign EEG patterns	1 (5.9)	22 (42.3)	
Malignant EEG patterns			
Accompanied clinical seizure — no. of patients (%)			0.138
	7 (41.2)	35 (50.7)	
Absence of clinical seizure			
	10 (58.8)	28 (40.6)	
Sporadic seizure or myoclonus			
	0 (0)	6 (8.7)	
Myoclonic status epilepticus			

ECPR, extracorporeal cardiopulmonary resuscitation; EEG, electroencephalography.

In multivariable analysis, the only significant indicators were EEG grouping by its pattern and CPR duration. That is, malignant EEG patterns (adjusted odd ratio [OR]: 53.26, 95% confidence interval [CI]: 5.956–476.249) and CPR duration (adjusted OR: 1.07, 95% CI: 1.011–1.130) were significantly associated with poor neurological outcomes in patients who underwent ECPR (Hosmer-Lemeshow Chi-squared = 7.84, df = 7, p = 0.347) with a C-index of 0.908 (95% CI 0.813–0.964). Although there were no differences between the AUCs of malignant EEG patterns and CPR duration, the performance of a composite of these marker was strongly associated with poor neurological outcomes compared with the use of either marker alone (P = 0.008 and P = 0.006, respectively) (Fig. 3).

Discussion

In this study, we investigated whether intermittent EEG could be used to predict neurological outcomes of patients who underwent ECPR. Major findings of this study were as follows. First, regardless of sedation, malignant EEG patterns were more common in patients with poor neurological outcome than in patients with favorable neurological outcome. Especially, all patients with highly malignant EEG patterns had poor neurological outcome. In addition, patients with moderate malignant EEG patterns had poor neurological outcome except for one patient. Second, benign EEG patterns alone did not necessarily imply a favorable neurological outcome. Third, in multivariable analysis, malignant EEG patterns and CPR duration were significantly associated with poor neurological outcomes in patients who underwent ECPR. Therefore, early intermittent EEG scan and CPR duration could be helpful for predicting neurological outcomes of post-cardiac arrest patients after ECPR.

EEG signals mainly reflect cerebral cortical function and some subcortical function [8]. EEG is very sensitive to ischemia because cortical neurons of the brain need consistent blood supply to maintain signaling and integrity [8]. Therefore, EEG scan is a standard and useful tool to predict neurological outcomes after cardiac arrest [3, 15]. Especially, malignant EEG patterns such as suppressed background, status epilepticus, burst suppression, periodic patterns, and unreactive EEG are associated with poor neurological prognosis after cardiac arrest [8, 15, 18]. In addition, early continuous wave with normal voltage could be a predictor of favorable neurological outcome after cardiac arrest [19].

Cerebral autoregulation may be changed in survivors after cardiac arrest [6]. Highly oxygenated continuous ECMO flow could affect cerebral autoregulation after ECPR [2]. In addition, neurological outcomes may be affected by functional recovery of native heart and lung, the amount of ECMO support, and changed cerebral autoregulation [2]. Altered cerebral hemodynamics by ECMO support may influence neurological outcome after ECPR. Therefore, it is difficult to predict neurological prognosis by these changed situations after ECPR [2]. Ultimately, the interaction between cerebral autoregulation and ECMO flow may affect neurological recovery and prognosis in ECPR patients through mechanisms of primary ischemic damage and secondary additive injury [2]. Thus, EEG change by this interaction should be studied for neurological prediction after ECPR. However, there has been no report of EEG according to neurological outcomes after ECPR.

Sedation may confuse outcome prediction in survivors of cardiac arrest [1, 8, 20]. Sedatives are commonly used in survivors after cardiac arrest for 72 hours as important confounders [1, 20]. A motor response to noxious stimuli, corneal reflex, caloric testing, and some electrophysiologic studies may also be confounded by sedation [20, 21]. Although mild to moderate hypothermia does not significantly affect EEG in patients with induced hypothermia [8, 22], a confounder accompanied by induced hypothermia such as analgesics, sedatives, or artifacts from shivering, mechanical ventilator, or electrical devices may affect the reliability of EEG interpretation [8]. However, a recent study has reported that the predictive performance of EEG after cardiac arrest is similar between patients with ongoing sedation and those without ongoing sedation [8, 15]. In this study, sedation or targeted temperature management did not significantly affect the prediction of poor neurological outcome after ECPR. Regardless of sedation or targeted temperature management, patients with malignant EEG patterns had poor neurological outcome in this study.

Benign EEG patterns may be associated with a favorable neurological outcome in survivor after cardiac arrest [19]. Especially, early continuous wave with normal voltage could be a predictor of favorable neurological outcome after cardiac arrest [8, 15, 19]. However, in previous studies, benign EEG patterns are not always associated with good neurological outcome [15, 18]. Additive secondary injury is characterized by an imbalance in post-resuscitation cerebral oxygen delivery and use [23]. This injury is associated with reperfusion injury, impaired autoregulation, fluctuations in oxygen support and arterial carbon dioxide, hyperthermia, and concomitant anemia [23]. Early EEG findings may not be shown to be malignant EEG patterns in patients with poor neurological outcome if the secondary cerebral injury is more serious than the primary cerebral injury. In this study, benign EEG patterns were not always associated with a favorable neurological outcome. In addition, intermittent EEG scan may be less sensitive for predicting favorable neurological outcome than continuous EEG monitoring in this study.

This study has several limitations. First, this was a retrospective review. Thus, CPC score was determined based on medical records. By using two independent specialists' agreement on the score, any bias may be mitigated to some extent. In addition, although the cause of death had to be accurately verified, its identification was insufficient due to the retrospective nature of this study. Second, the nonrandomized nature of registry data might have resulted in selection bias. Particularly, during the study period, EEG scans were not performed in all patients. They were only performed in patients with abnormal consciousness, seizure, abnormal movements, or other symptoms. Although EEG scans were performed within 96 hours following ECPR, a major limitation of the study might be that EEG scans were performed in different time settings. Lastly, our study was conducted in a small cohort at a single institution. Therefore, future studies with larger cohorts are needed to confirm our findings.

Conclusions

In this study, malignant EEG patterns within 96 hr after cardiac arrest were significantly associated with poor neurological outcomes in patients who underwent ECPR. Therefore, early intermittent EEG scan could be helpful for predicting neurological outcomes of post-cardiac arrest patients after ECPR.

Key messages

- Regardless of sedation, malignant EEG patterns were more common in patients with poor neurological outcome than in patients with favorable neurological outcome in this study.
- All patients with highly malignant EEG patterns had poor neurological outcome.
- Benign EEG patterns alone did not necessarily imply a favorable neurological outcome.
- Multivariable logistic regression analysis revealed that malignant EEG patterns and CPR duration were significantly associated with poor neurological outcomes in patients who underwent ECPR.

Abbreviations

CI, confidence interval; CPC, Cerebral Performance Categories; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; EEG, electroencephalography; ICU, intensive care unit; OR, odd ratio.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Samsung Medical Center (IRB no. SMC 2019-05-002). Patients' records were reviewed and published according to the Declaration of Helsinki. Informed consent was waived because of the retrospective nature of this study.

Consent for publication

Not applicable. This study does not contain individual or personal data in any form (including individual details, images, or videos).

Availability of data and materials

Regarding data availability, our data are available on the Harvard Dataverse Network (http://dx.doi.org/10.7910/DVN/KYJNVA) as recommended repositories of critical care.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YOK contributed to the study design, data collection, drafting of the manuscript, and statistical analysis. REK contributed to the study design, data collection, drafting of the manuscript, and statistical analysis. CRC contributed to the study design and coordination and helped draft the manuscript. JHY contributed to the study design, data collection, and study design. TKP contributed to the drafting of the manuscript, and statistical analysis. YHC contributed to the drafting of the manuscript, and statistical analysis. KS contributed to the study design. GYS contributed to the study design. JAR contributed to the study conception and design, data collection, and drafting of the manuscript. All authors read and approved the final manuscript.

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Figures

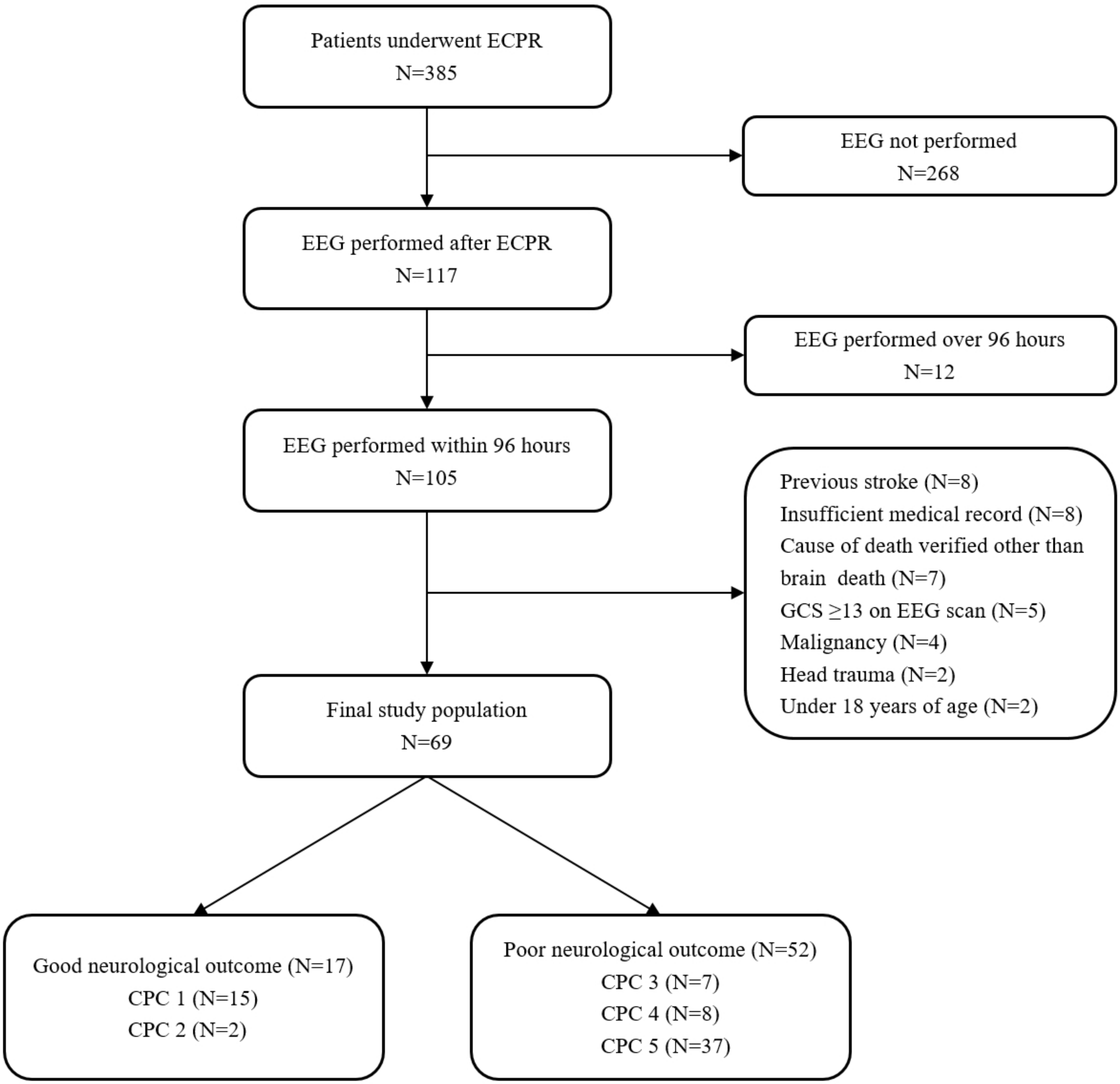

Figure 1

Study flow chart. ECPR, extracorporeal cardiopulmonary resuscitation; EEG, electroencephalography; GCS, Glasgow Coma Scale.

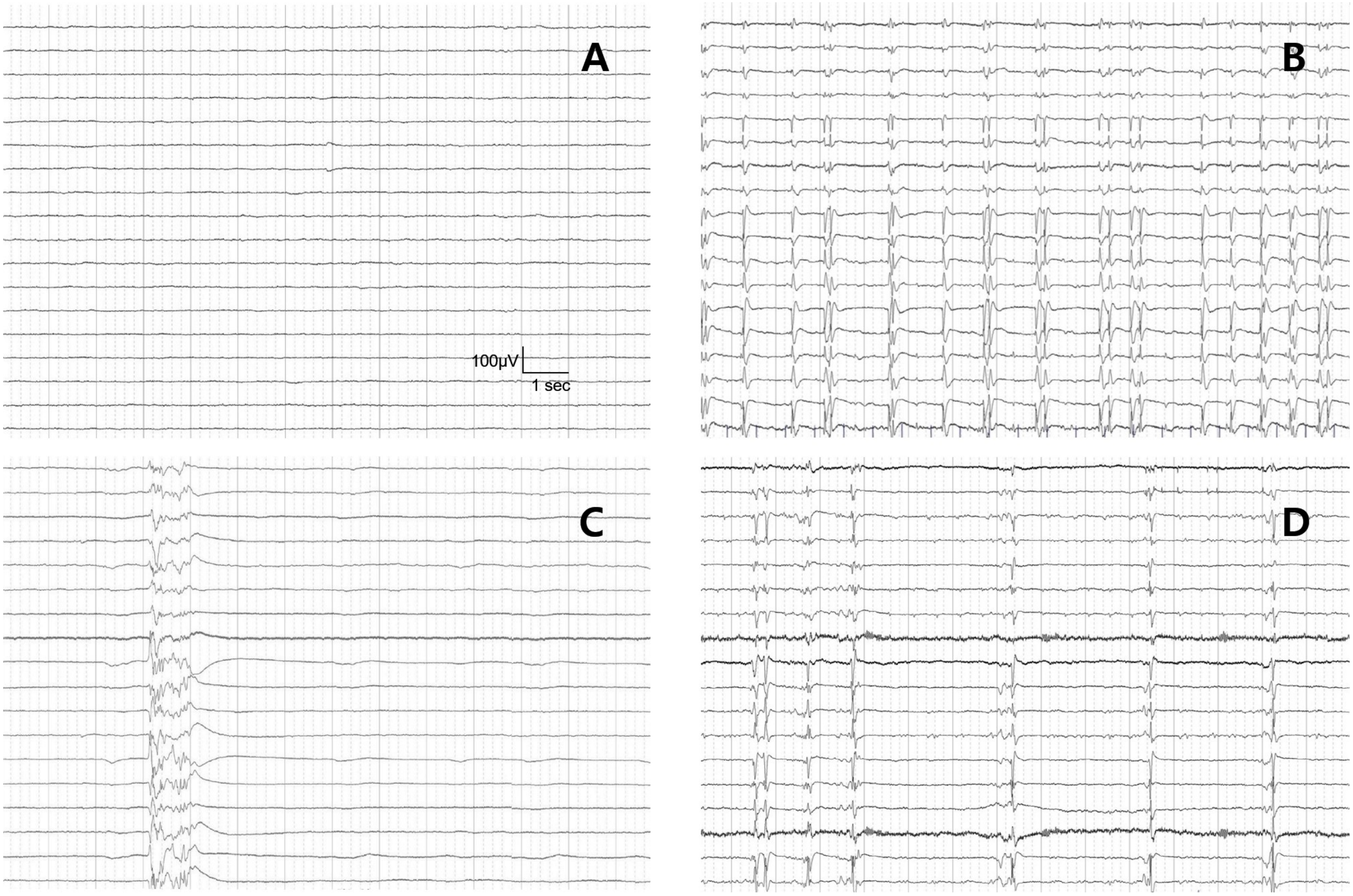

Figure 2

Highly malignant patterns of electroencephalography in patients after extracorporeal cardiopulmonary resuscitation. (A) Suppressed background without discharges, (B) Suppressed background with superimposed continuous periodic discharges, (C) Burst-suppression without discharges, and (D) Burst-suppression with superimposed discharges.

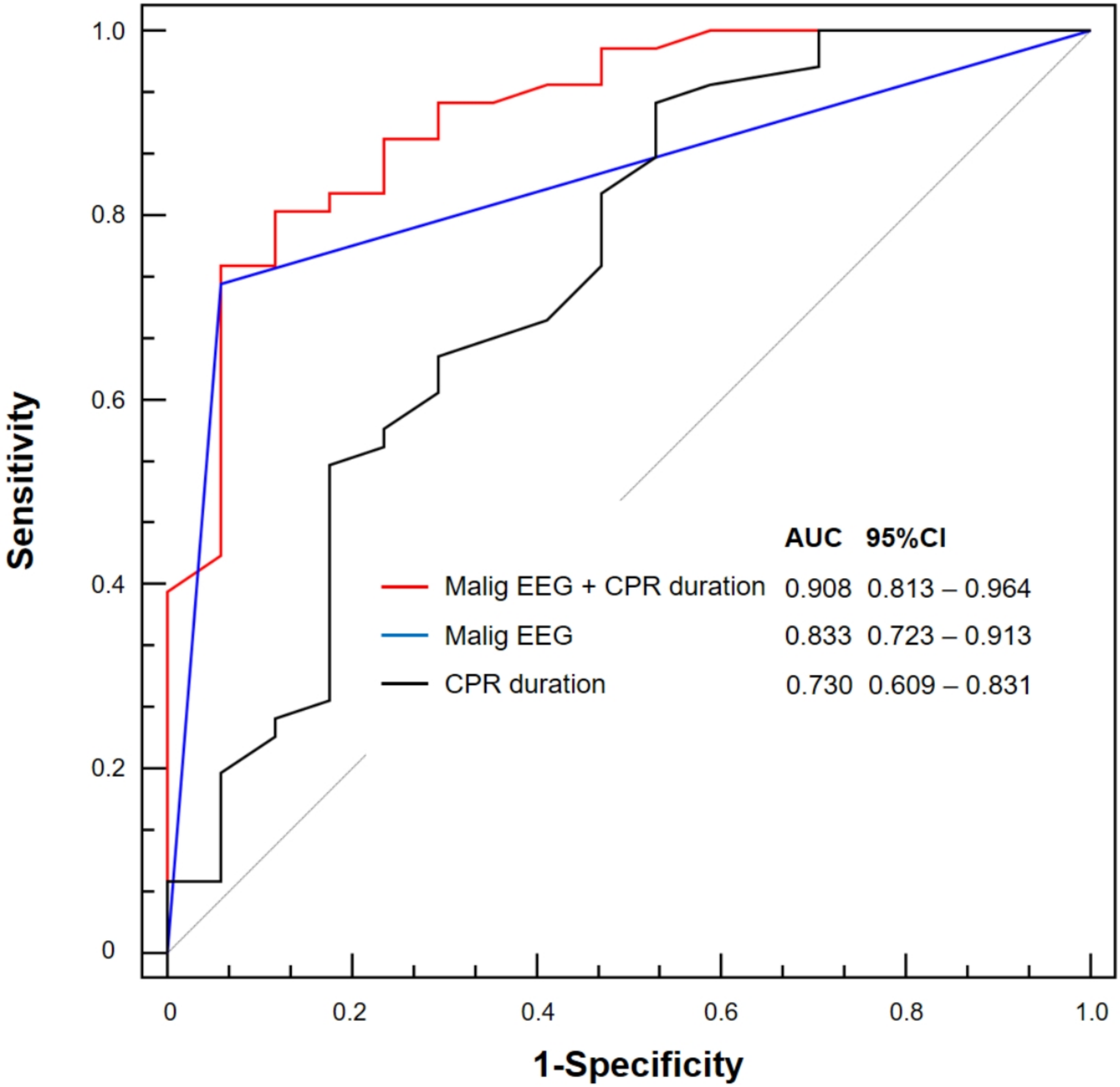

Figure 3

Receiver operating characteristic curves for predicting poor outcomes using malignant patterns of electroencephalography (EEG) and cardiopulmonary resuscitation (CPR) duration. Although there were no differences between the areas under the curve (AUCs) of malignant EEG patterns and CPR duration, the performance of a composite of these marker was strongly associated with poor neurological outcomes compared with the use of either marker alone (P = 0.008 and P = 0.006, respectively). CI, confidence interval; Malig EEG, malignant EEG patterns.