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Short paper

EEG in a four-electrode frontotemporal montage reliably predicts outcome after cardiac arrest

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Abstract

Aim: To increase efficiency of continuous EEG monitoring for prognostication of neurological outcome in patients after cardiac arrest, we investigated the reliability of EEG in a four-electrode frontotemporal (4-FT) montage, compared to our standard nine-electrode (9-EL) montage.

Methods: EEG recorded with Ag/AgCl cup-electrodes at 12 and/or 24 h after cardiac arrest of 153 patients was available from a previous study. 220 EEG epochs of 5 minutes were reexamined in a 4-FT montage according to the ACNS criteria. Background classification was compared to the available 9-EL classification using Cohens kappa. Reliability for prognostication was assessed in 151 EEG epochs at 24 h after CA using sensitivity and specificity for prediction of poor (cerebral performance categories (CPC) 3–5) and good (CPC 1–2) neurological outcome.

Results: Agreement for EEG background classification between the two montages was substantial with a kappa of 0.85 (95%-CI 0.81–0.90). Specificity for prediction of poor outcome was 100% (95%-CI 95–100) for both montages, sensitivity was 31% (95%-CI 21–43) for the 4-FT montage and 35% (95%-CI 24–47) for the 9-EL montage.

Good outcome was predicted with 65% specificity (95%-CI 53–76) and 81% sensitivity (95%-CI 71–89) for the 4-FT montage, similar to the 9-EL montage.

Conclusion: In this cohort, EEG background patterns determined in a four-electrode frontotemporal montage predict both poor and good outcome after CA with similar reliability. Our results may contribute to decreasing the workload of EEG monitoring in patients after CA without compromising reliability of outcome prediction. However, validation in a larger cohort is necessary, as is a multimodal approach.

Keywords: Cardiac arrest, EEG, Prognostication

Introduction

Accumulating evidence supports the value of early electroencephalography (EEG) for prognostication in patients after cardiac arrest (CA). Based on studies by Ruijter et al, results of early EEG at 12 and 24 hours after CA are incorporated in the Dutch guideline for prognostication after CA, updated in 2019.[1–3] The European guideline, updated in 2021, includes the EEG after 24 hours after CA.[4]

Applying electrodes for EEG recording remains time consuming and requires skilled technicians. Several studies investigated effects of a reduction of the number of EEG electrodes on outcome prediction in CA patients.[5–9] In our hospital, recording with nine electrodes, evenly distributed across the scalp, is the standard for post CA monitoring. To improve efficacy, we aim to further reduce the number of electrodes. Ultimately, this could enable ICU nurses to start the EEG recording as soon as the patient is admitted to the ICU, ideally with self-adhesive sub hairline electrodes.

In this study we investigated the reliability of EEG in a four-electrode frontotemporal (FT) montage for outcome prediction after CA compared to our standard nine-electrode montage, which is routinely used at our institution. We hypothesized that EEG in a four-electrode FT montage is equally reliable for outcome prediction as our standard nine-electrode montage.

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Methods

Subjects

A previously described prospective cohort was available for this post hoc analysis.[10] In short, between april 2015 and februari 2018, in two academic and one large teaching hospital, 160 patients after CA were enrolled. Continuous EEG (cEEG) was initiated within 24 h after cardiac arrest. Patients were treated according to the local targeted temperature management protocol for 24 hours, that generally followed European guidelines.[4] Decisions for withdrawal of life sustaining treatment in patients remaining comatose were based on the Dutch recommendations for prognostication after cardiac arrest at that time.[11] The EEG before 72 h after CA was not part of the prognostication protocol and the cEEG results were not disclosed to the treating physicians.

Neurologic outcome was classified as the best score on the Cerebral Performance Category (CPC) scale within the first 6 months after CA (assessed at ICU discharge, 3 months and 6 months post CA).[12–13] This was dichotomized as "good" (CPC 1–2: no or moderate cerebral impairment) or "poor" (CPC 3–5: severe cerebral impairment, vegetative state, or death).

EEG recordings

EEG was recorded using at least eleven Ag/AgCl cup-electrodes placed according to the 10–20 system (Fp1, Fp2, T3, C3, Cz, C4, T4, O1, O2, ground, and reference) using a Viasys Nicolet (CareFusion, Middleton, WI), a BrainQuick ICU (Micromed, Mogliano Veneto, Italy), or a Nihon Kohden system (VCM Medical, Leusden, the Netherlands) with a sampling frequency of at least 256 Hz.

Five minute EEG epochs containing the least amount of artifact were extracted from the cEEG in a window of 30 minutes around 12 and 24 h after CA. For this study, EEGs were re-examined in a four-electrode FT montage (T3-Fp1, Fp1-Fp2, Fp2-T4, T3-T4). EEG background patterns were classified according to the ACNS criteria, irrespective of rhythmic or periodic discharges, in one of the following categories: continuous normal voltage (>20μ), discontinuous normal voltage (>20 μV), burst-suppression, burst-suppression with identical bursts, low voltage (<20 μV), or suppressed (<10 μV). Visual EEG interpretation of both the four-electrode FT montage and our standard nine-electrode montages were done by three experienced raters (MMA, JH, AFvR, 8–25 years' experience). Raters scored the EEGs independently and were blinded for patient characteristics and outcome. Final pattern classification was based on majority vote and remaining inconsistencies were resolved in a consensus meeting.

For outcome prediction, the EEG background patterns at 24 h after CA were clustered as follows, based on current literature: Suppressed, and burst-suppression with identical bursts were clustered for prediction of poor outcome and a continuous EEG background pattern was used to predict good outcome.[1–2,14–18] The same clustering was used for outcome prediction at 12 h. Other patterns were considered indiscriminate.

Statistical analyses

EEG background pattern classification agreement between the two montages, using all available epochs and based on majority vote scores, was analyzed using Cohens kappa. For each montage, the agreement between the three raters (inter-rater agreement), for all epochs, was assessed using the intraclass correlation coefficient.

Reliability for prediction of poor and good neurological outcome was determined by calculating sensitivity and specificity, including Clopper-Pearson exact 95%-confidence intervals, for both montages at 12 h and 24 h after CA.

Results

Out of 160 patients, 153 had EEG available at 12 h (69 epochs) and/or 24 h (151 epochs) after CA (total 220 epochs). Seventy-four patients (48%) had poor outcome. Three patients were lost to follow-up after ICU discharge (all CPC 2 at discharge), and twelve patients were lost to follow-up after 3 months after CA (three CPC 2 at 3 months and nine CPC 1 at 3 months after CA). Baseline characteristics of these patients are shown in Table 1.

EEG background classification agreement

EEG background pattern classification agreement was determined in all 220 available EEG epochs, based on majority vote scores. Results are shown in Fig. 1. The corresponding kappa was 0.85 (95%-CI 0.81–0.90), indicating substantial agreement between the two montages.

Three patients showed burst suppression with identical bursts in the four-electrode FT montage, while a non-identical burst suppression pattern was seen in our standard nine-electrode montage. All patients showing burst suppression with identical bursts in any of the two montages had poor outcome.

Interrater agreement

Agreement between raters, as assessed by the intraclass correlation coefficient for EEG background pattern classification was 0.94 (95%-CI 0.93–0.95) for the 4-electrode FT montage and 0.94 (95%-CI 0.93–0.95) for our standard nine-electrode montage.

Outcome prediction

Sensitivity and specificity for prediction of poor and good outcome at 12 h and 24 h after CA were essentially similar between the four-electrode FT montage and our standard nine-electrode montage (Table 2).

Poor outcome, based on a burst-suppression with identical bursts, or suppressed EEG background pattern at 24 h after CA, was predicted with 100% specificity (95%-CI 95–100) in both the four-electrode FT montage and our standard nine-electrode montage at essentially similar sensitivity.

Discussion

EEG background pattern assessed in a four-electrode FT montage has substantial agreement with a nine-electrode montage, which is routinely used in CA patients at our institution. Sensitivity and specificity of prediction of poor and good outcome is not significantly different between the four-electrode FT montage and our standard nine-electrode montage. These EEGs were not used for outcome prediction at the time of recording, limiting effects of self-fulfilling prophecy.

We found no major discrepancies between the four-electrode FT and our standard nine-electrode montage. The only discrepancy was detection of burst-suppression (poor outcome likely, but not 100% certain) in the standard nine-electrode montage and burst-suppression with identical bursts (highly specific for poor outcome)

Table 1 – Baseline characteristics.

	Poor outcome (n = 74)	Good outcome (n = 79)	p-value
Age	65 (52–72)	62 (51–70)	0.5
Male	52 (70%)	66 (84%)	0.06
OHCA	65 (85%)	73 (92%)	0.2
Witnessed arrest	49/71 (69%)	63/77 (82%)	0.09
Time to ROSC in minutes	22 [15–32][b]	13 [10–17][a]	0.00
Initial rhythm shockable	36/71 (51%)	70/75 (93%)	0.00
Cardiac etiology	35/64 (55%)	63/72 (88%)	0.00

a: n = 76, b: n = 67, OHCA out of hospital cardiac arrest, ROSC return of spontaneous circulation.

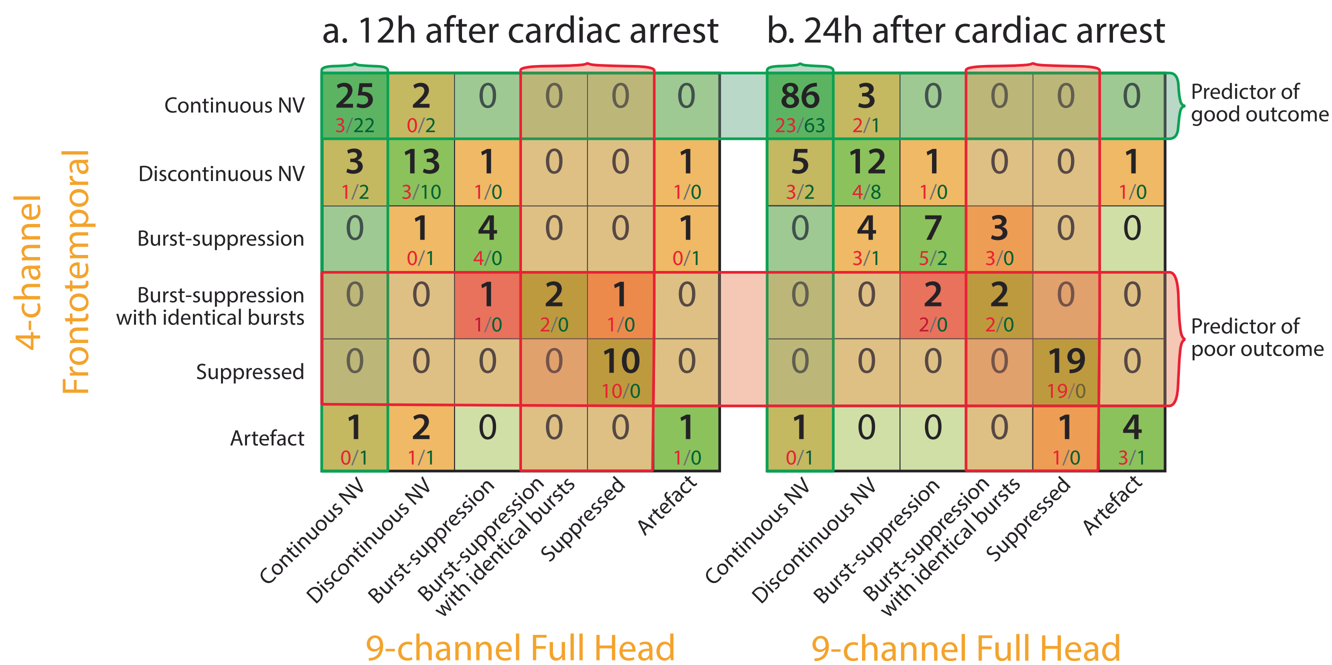

Fig. 1 – EEG background pattern classification agreement at a. 12 h and b. 24 h after cardiac arrest. The total number of patients are given, and below, the number of patients with poor outcome (in red) and the number of patients with good outcome (in green). NV normal voltage.

Table 2 – Sensitivity and specificity for outcome prediction at 12 h and 24 h after cardiac arrest.

	Timepoint	Montage	Sensitivity (95%-CI)	Specificity (95%-CI)
Poor outcome	12 h (n = 69)	4-FT	48% (29–67)	100% (91–100)
		9-EL	45% (26–64)	100% (91–100)
	24 h (n = 151)	4-FT	31% (21–43)	100% (95–100)
		9-EL	35% (24–47)	100% (95–100)
Good outcome	12 h (n = 69)	4-FT	62% (46–76)	89% (71–98)
		9-EL	63% (46–77)	86% (68–96)
	24 h (n = 151)	4-FT	81% (71–89)	65% (53–76)
		9-EL	84% (74–91)	64% (52–75)

CI confidence interval, 4-FT four-electrode frontotemporal montage, 9-EL our standard nine-electrode montage.

in the four-electrode FT montage in three epochs. However, all these epochs appeared to show suppressed background patterns with synchronous bursting activity in the montage. Suppressed background with synchronous activity is reliably associated with poor outcome.[1]

Previous studies in CA patients with different reduced montages showed similar results.[5–9] Backman et al.[6] investigated a 6-electrode frontal-parietal-temporal montage and found high performance of assessment of EEG background pattern, as well as rhythmic or periodic patterns in patients after CA. Pati et al.[7] investigated a more frontal montage, similar to our study. They showed in 28 patients that interpretation of background continuity and amplitude in a four-electrode (F7, Fp1, Fp2, F8) was over 80% correct compared to a full montage. Haesen et al.[8] investigated raw EEG from a bispectral index (BIS) monitor, using a self-adhesive six-electrode bilateral BIS sensor. They found a strong correlation between full and simplified EEG. Furthermore, cerebral inactivity reliably predicted poor outcome after 36 h using the simplified raw BIS EEG.[9] Tjepkema-Cloostermans et al.[5] showed similar predictive properties between 21- and 10-electrode montages.

Our study has several limitations. Burst-suppression and burst-suppression with identical bursts were underrepresented in this cohort and low voltage patterns were absent. Theoretically, low voltage patterns could show a discrepancy between the four- and nine-electrode montages as the inter-electrode distances for some of the leads are larger for the four-electrode montage (T3-Fp1 and Fp2-T4). Therefore, amplitudes might be larger in the four-electrode FT montage and EEGs could be categorized as normal voltage instead of low voltage. Furthermore, although previously shown to accurately predict outcome in postanoxic coma,[5] our standard nine-electrode montage is already a reduced montage compared to the standard full 21-electrode 10–20 montage.

Conclusion

In this cohort, prediction of poor and good outcome at 24 h after CA is equally reliable between the four-electrode frontotemporal montage and our standard nine-electrode montage. Our results may contribute to decreasing the workload of EEG monitoring in patients after CA without compromising reliability of outcome prediction, however, they should be validated in a larger cohort. Furthermore, outcome prediction should always be carried out in a multimodal fashion.

CRediT authorship contribution statement

Marjolein M. Admiraal: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Myrthe van Merkerk:** Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Janneke Horn:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. **J.H.T.M. Koelman:** Writing – review & editing, Conceptualization, Supervision. **J. Hofmeijer:** Investigation, Writing – review & editing. **C.W. Hoedemaekers:** Investigation, Writing – review & editing. **Anne-Fleur van Rootselaar:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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