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Reliability of high-sensitivity electroencephalograms in critically brain injured patients who undergo decompressive craniectomy

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Abstract

Objectives: Demonstration of flat electroencephalogram (EEG) both at low- and high-sensitivity is required to legally determine brain death. Critically brain-injured patients frequently undergo decompressive craniectomy (DC) to relieve the raised intracranial pressure before being considered as candidates for legal brain death determination. The main objective of this study was to evaluate influence of DC on the interpretation of EEG at high-sensitivity.

Methods: A retrospective study was conducted in 23 critically brain-injured patients with flat EEGs at low-sensitivity. An experienced EEG technician determined whether each high-sensitivity EEG was interpretable as flat in a blinded manner. DC had been performed in 13 patients (57%).

Results: There was no significant difference in the demographics between the DC and non-DC group. The frequency of flat EEG at high-sensitivity was 62% in DC and 100% in the non-DC group, and the difference was statistically significant ($p = 0.045$). Determination of flat EEG at high-sensitivity was unable to be made in five DC patients (38%). All five patients died within 4 days of the initial EEG.

Conclusions: In DC patients, EEG amplitudes at high-sensitivity may be exaggerated on the side of DC due to the absence of the skull. The findings of this study are: (1) 38% of DC patients showed some electrical activity at high-sensitivity on the side of DC; and (2) the electrical activity disappeared within several days and did not predict resuscitability. These findings may be useful to physicians who treat critically brain injured patients.

Keywords: Brain death, Decompressive craniectomy, Electrocerebral inactivity, Flat EEG, High-sensitivity

Introduction

Electroencephalogram (EEG) is an ancillary test that must be performed for the legal determination of brain death in Japan.[1,2] Demonstration of electrocerebral inactivity (ECI) by both low-sensitivity (10 μV/mm) and high-sensitivity EEG (2-2.5 μV/mm) is required.[1,2] However, high-sensitivity EEG may be susceptible to various artifacts, and its interpretation in emergency settings can be challenging. Most critically brain-injured patients have raised intracranial pressure as a consequence of severe stroke or brain trauma, and have undergone decompressive craniectomy (DC) to relieve this pressure. DC temporarily removes part of the skull, leaving the scalp in direct contact with the dura mater and underlying brain.[3,4] Due to the absence of the skull, high-sensitivity EEG waveforms recorded over the craniectomy area may be amplified and different to waveforms obtained from the contralateral side. That is, determination of flat EEG at high-sensitivity may not be made with certainty in some DC patients whose EEG is determined as flat at low-sensitivity. Few studies have investigated how often determination of flat EEG at high-sensitivity is found to be difficult by specialists. Similarly, it remains unclear whether DC patients with some electrical activity on high-sensitivity EEG are resuscitable or not. The main objectives of this study are to clarify these two questions.

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Patients and Methods

Patients

This retrospective observational study was conducted at the Fujita Health University Hospital, Toyoake, Japan, which is a tertiary referral center for emergency patients. It is our institutional policy to obtain EEGs from critically brain injured patients within 48 h of loss of cortical/brainstem function. Twenty-nine adult critically brain-injured patients (16 men/13 women), with bilaterally fixed pupils and loss of all brainstem reflexes, underwent low- and high-sensitivity EEGs to determine possible ECI between April 2009 and March 2012. The EEGs were reviewed by an experienced technician (AK), who determined whether each EEG was interpretable as flat or not, in a blinded manner. Six patients whose low-sensitivity EEG revealed some electrical activity were excluded. The remaining 23 patients whose low-sensitivity EEGs were determined to be flat were divided into two groups (DC vs. non-DC) based on whether they had undergone DC. All 23 patients had undergone auditory brainstem response (ABR) audiometry on the same day as the EEG, and all of them had shown loss of ABRs. The frequency of the technician's inability to determine ECI was compared between the DC and non-DC groups. Three of the 23 patients (13%) underwent a legal determination of brain death and repeat EEGs. In the remaining 20 patients, EEG was obtained only once during admission, with no apnea tests conducted. Pediatric patients (<18 years of age) were excluded from analysis. The study design was in accordance with the Declaration of Helsinki 1964 and was given our institutional Ethics Committee identification number 13-266.

EEG analysis

According to the American Neurophysiology Society, ECI is defined by having no EEG activity over 2 μV when recording from scalp electrode pairs 10 cm or more apart with interelectrode impedances under 10,000 ohms.[5] EEG recording procedures were performed in strict compliance with the manual authorized by the Health, Labour and Welfare Ministry.[1,2] Scalp electrodes were placed manually, and needle-type electrodes were used for all patients.[1,2] For digital EEG recording, a Synafit EE2514 (NEC Medical Systems, Ltd., Tokyo, Japan) was used. All EEGs were obtained by the same well-trained technicians in the same room, in which the influence of electromagnetic waves from the environment was considered minimal. According to the inclusion criteria, all 23 patients were determined to have flat EEGs at low-sensitivity.

Statistical analysis

For inter-group comparisons of the demographics, categorical variables were analyzed using Fisher's exact test and numerical variables were analyzed using Student's *t*-test. The variables compared included age, male: female ratio, and side of the affected hemisphere (left vs. right). SPSS 10.0 software (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. Numerical data are expressed as means ± SD, and $p < 0.05$ was considered statistically significant.

Results

Of the 23 patients whose low-sensitivity EEGs were determined to be flat, DC for supratentorial lesions had been performed in 13 (57%). In both the DC and non-DC groups, subarachnoid hemorrhage (SAH) was the most common cause of admission (Table 1). There were no significant differences in the demographic variables between the two groups. In the DC group, the technician was unable to determine a flat EEG at high-sensitivity in five patients (38%). In the non-DC group, however, there were no patients for whom the interpreter was unable to make determination of flat EEG at high-sensitivity (0%). This difference was statistically significant ($p = 0.045$).

The details of the five patients in the DC group for which the technician was unable to make determination of flat EEG at high-sensitivity, are summarized in Table 2. In all of these patients, sporadic slow-waves with amplitudes exceeding 2 μV were present in the hemisphere ipsilateral to the DC in monopolar leads. Four of them were not legally determined brain dead, and repeat EEGs were not performed. All four patients of these patients died within 4 days of the EEG recordings. A repeat high-sensitivity EEG was performed in the fifth patient, a 54-year-old woman (Case 1), who underwent the legal procedure to determine brain death. She had sustained a Hunt-Hess grade V SAH resulting from a ruptured anterior communicating aneurysm. After right frontal craniotomy, an attempt to clip the aneurysm via interhemispheric approach was abandoned due to severe brain swelling, and a bone flap was left unreturned to attenuate the swelling. A brain computed tomography scan shortly after surgery showed diffuse darkening of the brain (Figure 1). The initial high-sensitivity EEG obtained shortly after loss of brainstem reflexes showed the presence of sporadic low-frequency waveforms in the monopolar leads corresponding to the right frontal lobe (Figure 2A). However, follow-up high-sensitivity EEG obtained 24 h after the initial EEG under the same technical conditions, demonstrated disappearance of the sporadic slow waves and ECI was determined (Figure 2B).

Table 1. Demographics of 23 patients with flat EEG at low-sensitivity

	DC+ (n=13)	DC- (n=10)	p-value
Age (y)	63.2 ± 11.0	56.2 ± 11.0	0.16
Male: Female	4:9	4:6	0.69
Side of lesion (Left: right)	7:6	4:4:2 (midline)	1.00
Underlying diseases	SAH9, ICH2, TBI 1, CI1	SAH7, ICH2, CI1	N/A
EEG obtained within 48h of loss of brainstem reflexes	13 (100%)	10 (100%)	1.00
Difficulty in determining flat EEG at high-sensitivity	5 (38%)	0 (0%)	0.045*

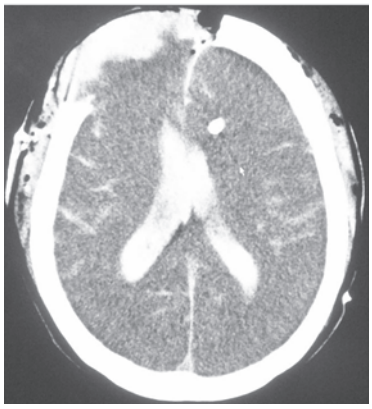
CI, cerebral infarction; DC, decompressive craniectomy; EEG, electroencephalography; ICH, intracerebral hemorrhage; SAH, subarachnoid hemorrhage; TBI, traumatic brain injury
*: statistically significant ($p < 0.05$)

Table 2. Characteristics of five patients with difficulty determining flat EEG at high-sensitivity

	Age, sex	Underlying disease	Side of DC	Survival after EEG	Repeat EEG
Case 1*	54F	SAH	Right	3 days*	Yes
Case 2	66F	SAH	Right	1 day	No
Case 3	66M	SAH	Left	3 days	No
Case 4	69F	SAH	Right	3 days	No
Case 5	74F	SAH	Left	4 days	No

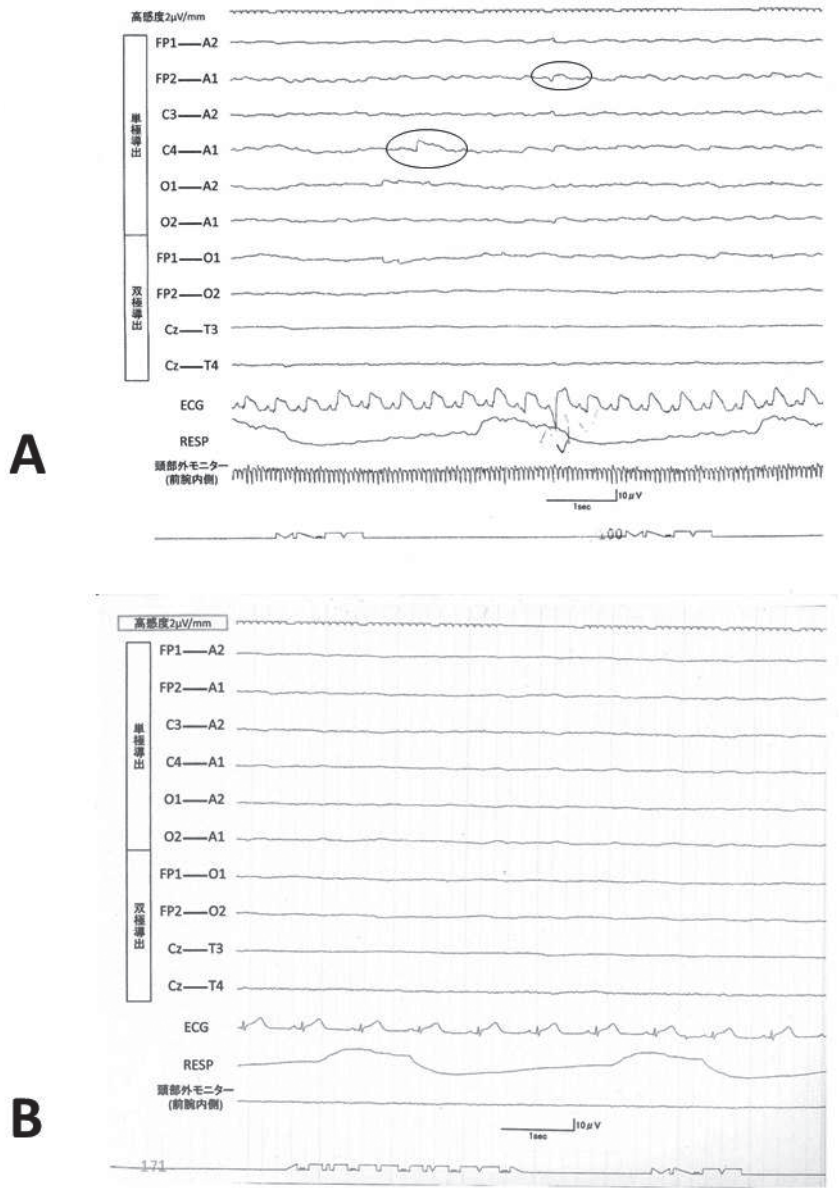
DC, decompressive craniectomy; EEG, electroencephalography; SAH, subarachnoid hemorrhage.
*: patient who underwent legal determination of brain death

Figure 1.



Case 1, a 54-year-old woman who sustained a Hunt-Hess grade V SAH resulting from a ruptured anterior communicating aneurysm. After right frontal craniotomy, an attempt to clip the aneurysm was abandoned due to severe brain swelling, and a bone flap was left unreturned to attenuate the swelling. A brain CT scan shortly after surgery showed diffuse swelling and darkening of the brain.

Figure 2



A: In Case 1, the initial high-frequency EEG showed the presence of sporadic low-frequency waveforms in the monopolar leads corresponding to the right frontal lobe (arrows). B: Follow-up high-sensitivity EEG obtained 24 h after the initial EEG showed disappearance of the sporadic slow waves.

Discussion

To legally determine brain death in Japan, flat EEGs need to be confirmed at both low- and high-sensitivity.[1,2] Many patients who eventually succumb to brain death have sustained either severe stroke or traumatic brain injury, and it is not uncommon that they have undergone DC prior to EEG. Vincenzini et al. reported false positive transcranial Doppler findings in critically brain injured patients who underwent DC.[6] However, the influence of DC in determining ECI has rarely been investigated.

In this study, sporadic slow waves were present in high-sensitivity EEGs in approximately 40% of patients whose EEGs were flat at low-sensitivity. In those patients, the accurate legal determination of brain death was difficult. Due to the absence of the skull, it is probable that EEG amplitudes are exaggerated on the side of DC. In Case 1, a repeat EEG showed disappearance of the slow-waves, implying that agonal EEG activity of the dying brain, which might otherwise be unnoticed in patients with an intact skull, might have been detected in the first high-sensitivity EEG. What the sporadic slow-waves represent is unclear, but this could be either agonal electrical activity, pulsatile movement of the cerebrospinal fluid, or simply a technical artifact. The four patients with the sporadic slow waves did not undergo the legal determination of brain death. In all of them, repeat EEGs were not performed and therefore, chronological changes in the waveforms were unevaluable (Table 2). All died within 4 days of their EEG, implying that the presence of sporadic slow-waves in high-sensitivity EEGs may have little prognostic significance in terms of resuscitability. When legally determining brain death in DC patients, we should be aware of potential difficulty in determining ECI. As the findings of this study show: (1) as many as 38% of DC patients had some electrical activity with high-sensitivity EEG on the side of DC; and (2) the presence of electrical activity disappeared within a few days and did not predict resuscitability. This may be useful to physicians who treat critically brain-injured patients and/or determine brain death.

This study is limited by the small number of patients and a lack of assessment of inter-reader variability. It should also be stressed that only 13% of the patients underwent legal determination of brain death.

We conclude that in patients with DC, EEG amplitudes at high-sensitivity

may be exaggerated on the side of DC due to the absence of the skull. The agonal EEG activity of the dying brain, which might otherwise be unnoticed, may be detected in patients with DC. Physicians should be aware of potential difficulties in determining ECI in patients who undergo DC.

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Conflict of Interest

None of the authors have any financial relationships with other people or organizations that could inappropriately influence their work.

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