Acıbadem Univ. Sağlık Bilim. Derg. 2022; 13 (4): 462-469
https://doi.org/10.31067/acusaglik.1130277

ORIGINAL ARTICLE / ARAŞTIRMA YAZISI

Neurology / Nöroloji

Electroencephalography and Neuroimaging Markers of Poor Prognosis in Hypoxic-Ischemic Brain Injury

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ABSTRACT

Purpose: Hypoxic-ischemic brain injury (HIBI) can cause coma.Several factors may affect the outcome after HIBI and prediction of the prognosis is challenging in clinical practice.Magnetic Resonance Imaging (MRI) and Electroencephalography (EEG) are two reliable tools to predict the possible outcome after brain damage.We aimed to test the utility of MRI and EEG in predicting the outcome by exploring specific lesion and electrophysiological patterns.

Method: Patients admitted to the intensive care unit (ICU) due to hypoxic-ischemic brain injury between January 2017 and March 2020 were retrospectively reviewed.Patients over 18 years of age with a history of cardiac arrest or respiratory problems leading to hypoxic-ischemic brain injury were included in the study. Glasgow Coma Score (GCS) was used as a clinical measure for the level of consciousness.All patients had a Glasgow Coma Score (GCS) of <8 and had both MRI and EEG investigations.Patients were classified as having Poor Outcome (PO) and Good Outcome (GO).Poor outcome defines either death or lack of recovery in consciousness (GCS<8).MRI findings that could lead to a coma state were classified as "MRI-positive", otherwise were classified as "MRI-negative". Modified Hockaday Scale was used for grading of EEG.

Results: Nineteen patients with HIBI were included. In the MRI-positive group, 87.5% of the patients had poor outcome whereas the remaining 12.5% had good outcome. In the MRI-negative group, 45.5% of the patients had poor outcome whereas the remaining 54.5% had good outcome. According to the Modified Hockaday EEG Grading System, 91% of the patients with a score of Grade 4 and above had poor outcome whereas only the remaining 9% had good outcome.

Conclusion: Although MRI is a valuable clinical marker, EEG seems to be more reliable for predicting prognosis in HIBI.The modified Hockaday scale can be useful for determining the cut-off points for the prediction of poor prognosis.

Keywords: Hypoxia-Ischemia, Brain, coma, magnetic resonance imaging, electroencephalography, prognostic factors

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Hipoksik-İskemik Beyin Hasarında Kötü Prognozun Elektroenseflaogram ve Nöro-görüntüleme Belirteçleri

ÖZET

Amaç: Hipoksik-iskemik beyin hasarı komaya neden olabilir. Çeşitli faktörler bu hasar sonrası prognozu etkilemekte olup; prognozu tahmin etmek klinisyeni zorlayan bir süreçtir. Manyetik Rezonans Görüntüleme (MRG) ve Elektroensefalogram (EEG), beyin hasarı sonrasında olası prognozu tahmin etmede kullanılan iki güvenilir yöntemdir. Çalışmamızda MRG ve EEG yöntemlerinde spesifik lezyon ve elektrofizyolojik paternleri araştırarak prognoz tahminlerini test etmeyi amaçladık.

Yöntem: Ocak 2017 ile Mart 2020 tarihleri arasında hipoksik beyin hasarı sebebi ile yoğun bakım ünitesinde (YBÜ) izlenmiş olan hastalar retrospektif olarak taranmıştır. 18 yaş üzeri, kardiak arrest veya solunumsal problemler sebebi ile hipoksik iskemik beyin hasarı gelişen hastalar çalışmaya dahil edilmiştir. Glasgow Koma Skalası (GKS) bilinç durumu için kullanılmış olup, çalışmaya dahil edilen tüm hastalarda GKS<8'dir ve her hastanın MRG ve EEG'ları mevcuttur. Hastalar kötü ve iyi prognozlu olarak iki gruba ayrılmıştır. Kötü prognoz ölüm veya şuurun toparlamamasını (GKS<8) tanımlamaktadır. Koma tablosunu açıklayacak MRG bulguları olanlar "MR-pozitif", olmayanlar "MR-negatif" olarak sınıflandırılmışlardır. EEG sınıflaması modifiye Hockaday ölçeğine göre yapılmıştır.

Sonuç: Toplamda on dokuz hasta çalışmaya dahil edilmiş olup; MR-pozitif grupta hastaların %87.5'i kötü prognoz gösterirken sadece %12.5'i iyi prognoz göstermiştir. MR-negatif grupta ise hastaların %45.5'i kötü prognoz gösterirken %54.5'i iyi prognoz göstermiştir. EEG sınıflaması Modifiye Hockaday ölçeğine göre 4 ve üzeri olan hastaların %91'i kötü prognoz gösterirken sadece %9 hastada iyi prognoz gözlenmiştir.

Yorum: Pozitif MRG bulguları EEG kadar hassasiyete sahip olmayıp; EEG daha kesin prognoz tahmin etmede yardımcı olmaktadır. Hockaday ölçeği, kötü prognoz tahmininde eşik değerleri belirlemede yararlı gözükmektedir.

Anahtar Kelimeler: Hipoksik-iskemi, Beyin, koma, manyetik rezonans görüntüleme, elektroensefalografi, prognostic faktörler

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Received: 14 June 2022
Accepted: 24 July 2022

Severe brain damage caused by lesions to the brainstem reticular formation, large hemispheric areas, or widespread bilateral hemispheric areas may cause coma. Coma is a state of consciousness characterized by continuous absence of eye-opening (unawakefullnes), and any spontaneous or stimulus-induced arousal or voluntary behavioral responses (unresponsiveness) (1).

Hypoxic-ischemic brain injury (HIBI) is one of the most common causes of coma. Hypoxia may lead to brain damage due to a reduction of oxygen supply or utilization. Low oxygen pressure and low hemoglobin levels are frequent causes of hypoxia. On the other hand, ischemia is caused by a reduction of blood flow which may lead to both decreased oxygen delivery and tissue damage (2,3). Cardiac arrest and respiratory failure may lead to HIBI (4). Patients with a prolonged stay at the intensive care unit (ICU) may require additional interventional and surgical procedures such as central venous catheterization and tracheostomy. Both procedures are essential for the continuation of hemodynamic, metabolic, and respiratory support. However, these procedures may lead to significant complications including emphysema, infection, bleeding, hematoma, tracheal injury, trachea esophageal fistula, pneumothorax, arrhythmias, cardiac arrest, arterio-venous fistula, embolism, etc (5,6).

Several factors may affect the outcome after HIBI including the duration and the severity of hypoxemia, accompanying small vessel diseases, and cerebral vascular diseases (2). Nevertheless, predicting the prognosis of coma caused by hypoxic-ischemic brain injury (HIBI) is extremely challenging in neurological intensive care practice. Predicting the prognosis of comatose patients is vital for the clinician before critical decisions are made in the management of HIBI. Magnetic Resonance Imaging (MRI) and Electroencephalography (EEG) are two reliable tools for investigating the magnitude of brain damage and predicting the probable prognosis. Recent studies showed promising results for the utility of MRI and EEG in predicting the prognosis of patients with HIBI (7-10).

MRI provides information about the localization (i.e. focal or diffuse) and the nature (i.e. hypoxic, ischemic, or hemorrhagic) of the brain lesions. Diffusion-Weighted Imaging (DWI) and apparent diffusion coefficient (ADC) are two MRI modalities that provide information about the hemodynamic changes and neuronal damage even in the early stages of HIBI. T2 weighted and fluid-attenuated inversion recovery (FLAIR) sequences are expected to be normal in the early stages of acute ischemia (2). DWI is used to get a more accurate result in the detection of acute ischemic lesions, which are seen in stroke and HIBI patients within 6 hours. Moreover, it is superior to computerized tomography and conventional MRI (11). ADC increases the precision in the estimation of disease severity (12,13). However the sensitivity and specificity of DWI in post-cardiac arrest patients are inconsistent between studies (14-17).

EEG detects the natural electrical activity of the brain and it is widely used to assess the level of consciousness and to predict the prognosis after HIBI (18,19). In the early period after hypoxic damage, EEG may show electrical silence while the patient is in a deep coma which may be followed by a gradual evolution of spesific rhythms reflecting neuronal functionality. It should be kept in mind that confounders such as sepsis, medications, and metabolic derangements may have influence on EEG (2). Continuous patterns of EEG such as normal or diffusely slowed rhythms were found to be predictors of good outcome; whereas suppression and burst-suppression patterns were found to be highly specific for poor prognosis. On the other hand, the sensitivity of these EEG parameters was low (20-22). Therefore, using EEG may increase the specificity in predicting outcomes in HIBI-related comatose patients, however additional modalities such as ADC and DWI imaging are necessary to increase the sensitivity.

In this study, we aimed to test the utility of MRI and EEG in predicting the outcome of patients with HIBI. Therefore, we will explore specific lesion and electrophysiological patterns that may guide clinicians in the prediction of prognosis in HIBI.

METHOD

In this study, medical reports of the patients admitted to the intensive care unit (ICU) and referred to the neurology clinic because of suspected hypoxic-ischemic brain injury between January 2017 and March 2020 were reviewed, retrospectively. Patients over 18 years of age with a history of cardiac arrest or respiratory problems leading to hypoxic-ischemic brain injury were included in the study. Glasgow Coma Score (GCS) was used as a practical measure for the level of consciousness which ranges between 3 (deep coma) and 15 (full consciousness). Patients receive scores for an eye-opening response as an indicator of wakefulness (1-4), for a verbal response as an indicator of language comprehension and orientation (1-5), and for motor response to a verbal command or painful stimuli

(1-6) (23). All patients included in our study were with a Glasgow Coma Score (GCS) of <8.

All patients had both MRI and EEG investigations completed and consulted by a neurology specialist during their admission to the ICU and were classified into two groups; Poor Outcome (PO) and Good Outcome (GO). Poor outcome defines either death or lack of recovery in consciousness. A cut-off value of 8 or above for GCS was used as an indicator of recovery of consciousness as those patients are more likely to be extubated and discharged from ICU. Two patients were transferred to other ICU units without reaching a Glasgow Coma Score of 8, and they were accepted as having a poor outcome.

MRI sequences were obtained using a Siemens 3T (Skyra, head coil 32 channel) scanner. Diffusion-weighted imaging (DWI), apparent diffusion coefficient (ADC) maps, and perfusion-weighted imaging were used to detect signal changes associated with acute ischemic changes and/or hypoxia. High-intensity signals on DWI and low-intensity signals on ADC sequences in the acute phase have been described as signal changes associated with hypoxic brain damage (24). Changes due to hypoperfusion were detected by arterial spin labeling (ASL) MR perfusion sequence. Ascending reticular activating system (ARAS) connects thalamic and subthalamic nuclei to the reticular intermediary grey substance of the spinal cord. Bilateral damage of ARAS leads to alteration of consciousness, even with very small lesions. Damage to the brainstem also can lead to coma (25). Patients having MRI findings in these sequences that could lead to a coma state by disturbing ARAS were classified as "MRI-positive", otherwise were classified as "MRI-negative". Please see Figure 1 for representative MRI findings in the MRI-positive group.

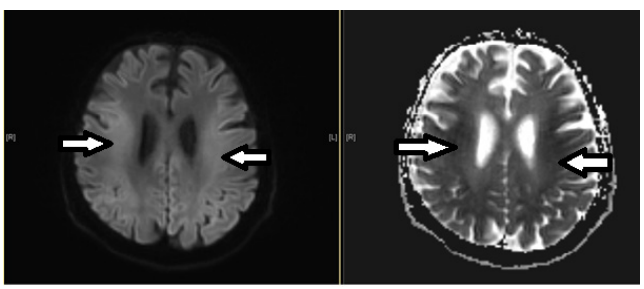

Figure 1: MRI IMAGES
a) Diffuse hypoxia, hyperintense in the DWI (left) and hypointense in the ADC (right) sequence (white arrows)

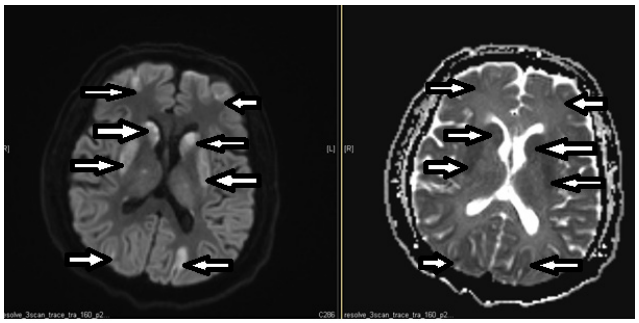

Figure 1: MRI IMAGES
b) Ischemic findings at anterior and posterior watershed zones and basal ganglia; hyperintense in the DWI (left) and hypointense in the ADC (right) sequence (White arrows)

EEG was recorded using a Neurosoft Neuron-Spectrum-4/P® 21 channel EEG System. All EEG recordings were obtained at least 24 hours after cessation of any sedation. Silver and silver chloride (Ag/AgCl) electrodes were used and placed according to the international 10-20 system (26). The duration of EEG recordings ranged between 20 to 30 minutes. The EEGs were analysed in Double banana montage with a high frequency filter setting of 35 Hz and low frequency filter setting of 0.5 Hz and sweep speed set at 30 mm/s.

All the EEGs were reviewed by two experienced neurologists M.S and M.E.T. using a Neurosoft Neuron-Spectrum-4/P® software. Modified Hockaday Scale was used for grading of EEG (27,28). According to this grading system Grade 1 defines dominant alpha activity, with or without theta or delta activity; Grade 2 defines dominant theta or delta rhythm, with detectable alpha activity; Grade 3 defines dominant theta or delta rhythm without any detectable alpha activity; Grade 4a defines low voltage delta activity with the possibility of short interval isoelectric intervals; Grade 4b defines monomorphic and nonreactant alpha activity; Grade 4c defines periodic generalized activity with a very low background voltage; and Grade 5 defines flat to isoelectric voltage (Table 1). Any epileptiform activity was also noted. Finally, EEG readers were blind to the clinical outcome. Please see Figure 2 for representative EEG findings used for Modified Hockaday Grading system.

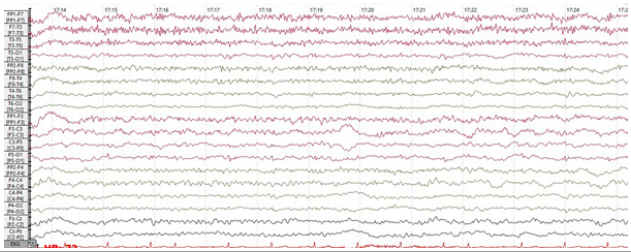

Figure 2: EEG images
a) Grade 1: Dominant alpha activity, with or without theta or delta activity

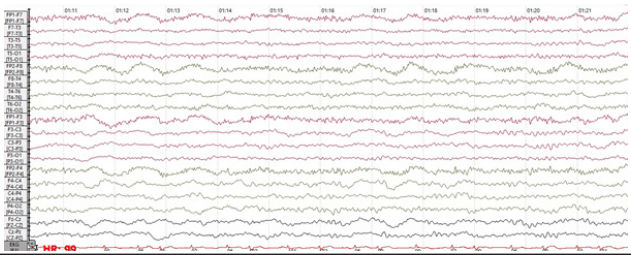

Figure 2: EEG images
b) Grade 2: Dominant theta or delta rhythm, with detectable alpha activity

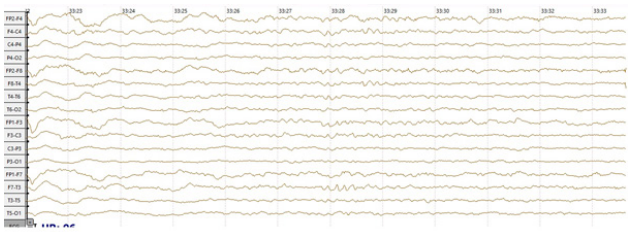

Figure 2: EEG images
c) Grade 3: Dominant theta or delta rhythm without any detectable alpha activity

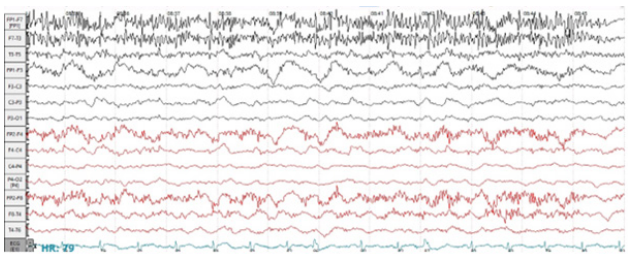

Figure 2: EEG images
d) Grade 4(a): Low voltage delta activity

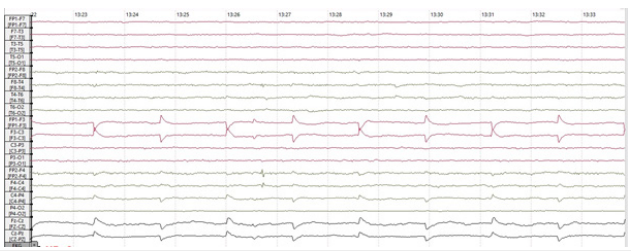

Figure 2: EEG images
e) Grade 5: Flat to isoelectric voltage

Table 1: Modified Hockaday Grading Scale	
Grade	**Description**
1	Dominant rhythm is alpha with or without theta or delta rhythm activity
2	Dominant rhythm is theta and/or delta with detectable alpha rhythm
3	Dominant rhythm is theta and/or delta without detectable alpha rhythm
4a	Low voltage delta rhythm activity. There may be short periods of isoelectric activity
4b	Dominant rhythm is monomorphic and non- reactive alpha activity
4c	Periodic generalized activity on low voltage background rhythm.
5	Isoelectric activity

RESULTS

Nineteen patients (8 female and 11 male) were evaluated with a mean age of 72±10 years (56-90 years). The mean ages of female and male groups were equivalent (71.37±8.6 years for the female group and 72.81±10.7 years for the male group) (p=0.75). Cardiac arrest was the reason for admission to ICU in 4 patients and the remaining patients were admitted due to respiratory distress caused by several etiologies such as pneumonia, exacerbation of bronchitis, and sepsis. Sixteen patients were intubated on the admission day, two of them were intubated on the 4th and one of the patients was intubated on the 6th day of admission. The mean intubation-extubation period of the patients who recovered was 14,6±13,41 days (5-44 days). MRI scans were obtained between 1st to the 27th days of admission (Mean 6,89±6,31 days).

The MRI-negative group consisted of 11 patients who had no detectable perfusion abnormalities or hypoxic damage. The admission-to-brain scan period in the MRI-negative group ranged from 1 to 13 days (Mean 6,25±4,89 days).

On the other hand, 8 patients were grouped as MRI-positive. Two patients had a hypoxic brain injury, watershed hypoperfusion was detected in five patients, and one patient had both hypoxic brain injury and watershed hypoperfusion. Admission-to-brain scan period in the MRI-positive group ranged from 1 to 27 days (Mean 7,36±7,37 days). Admission-to-brain scan period did not differ between MRI-negative and MRI-positive groups (p=0,93).

In the poor-outcome (PO) group, the admission-to-brain scan period ranged between 1 to 12 days (Mean 5,28±9,4 days) in patients with positive MRI, whereas the admission-to-brain scan period ranged between 1 to 27 days (Mean 9,4 ± 10,73 days) in patients with negative MRI. MRI-positive and MRI-negative subgroups of the PO group did not differ significantly in the admission-to-brain scan period (p=0,68). Table 2 shows the demographic and clinical characteristics of each patient.

The admission-to-EEG period ranged from 1 to 28 days of admission (Mean 7,21±6,85). EEGs were graded according to the modified Hockaday scale and more than 50% of the patients had a grade of at least 4 (Table 3).

Only 36.8% of the patients with a Glasgow score of ≥8 showed good prognosis and were discharged from ICU. In the MRI-positive group (with hypoxia or hypoperfusion), 87.5% of the patients had poor outcome whereas the remaining 12.5% had good outcome. In the MRI-negative group, 45.5% of the patients had poor outcome whereas the remaining 54.5% had good outcome. Table 4 shows the sensitivity and specificity of positive MRI and EEG findings.

Table 3: EEG grades and clinical outcome

Grade	N of patients	Outcome
1	1	Good (1)
2	3	Good (2) Poor (1)
3	4	Good (3) Poor (1)
4a	3	Poor (3)
4b	0	N/A
4c	1	Poor (1)
5	7	Good (1) Poor (6)

Table 4: The sensitivity and specificity of the MRI and EEG findings.

Diagnostic Procedure	Poor Outcome (%)	Good Outcome (%)	Sensitivity (CI 95%)	Specificity (CI 95%)
MRI- Positive(regardless of EEG)	87.5	12.5	58,3 (0.28-0.83)	85,71 (0.42-0.99)
EEG grade 3,4 or 5 (regardless of MRI)	73.3	26.6	91,66 (0.59-0.99)	42.85 (0.11-0.79)
EEG grade 4 or 5 (regardless of MRI)	91	9	83,3 (0.50-0.97)	85,71 (0.42-0.99)
MRI-positive with EEG grade 3,4 or 5	100	0	50 (0.22-0.77)	100 (0.56-1)
MRI-positive with EEG grade 4 or 5	100	0	50 (0.22-0.77)	100 (0.56-1)

Table 2:Demographic and clinical characteristics of HIBI patients.

Patient No	Gender	Age (years)	HIBI Etiology	Admission-to-Intubation (days)	Admission-to-Brain Scan (days)	MRI Finding	Admission-to-EEG (days)	EEG Grade	Outcome
1	Male	70	Respiratory distress	1	6	Negative	7	2	Good
2	Female	56	Cardiac arrest	1	11	Negative	2	3	Good
3	Male	61	Cardiac arrest	1	1	Positive	2	5	Poor
4	Male	71	Cardiac arrest	1	2	Positive	5	5	Poor
5	Female	79	Respiratory distress	6	6	Negative	1	3	Good
6	Male	90	Cardiac arrest	1	2	Positive	1	5	Poor
7	Male	68	Respiratory distress	1	3	Positive	13	5	Poor
8	Female	80	Respiratory distress	1	4	Negative	4	5	Good
9	Male	79	Cardiac arrest	1	12	Negative	17	5	Poor
10	Female	78	Cardiac arrest	1	1	Negative	1	4a	Poor
11	Female	63	Respiratory distress	1	27	Negative	28	4a	Poor
12	Female	73	Cardiac arrest	1	7	Positive	10	4c	Poor
13	Male	61	Respiratory distress	1	2	Negative	4	5	Poor
14	Female	67	Respiratory distress	1	2	Negative	2	3	Good
15	Female	75	Respiratory distress	4	10	Positive	8	4a	Poor
16	Male	63	Respiratory distress	1	5	Negative	5	2	Good
17	Male	84	Cardiac arrest	1	5	Negative	4	3	Poor
18	Male	88	Respiratory distress	4	12	Positive	12	2	Poor
19	Male	66	Respiratory distress	1	13	Positive	11	1	Good

DISCUSSION

In this study, we aimed to test the utility of EEG and MRI in predicting the prognosis of HIBI patients. Since the DWI modality is sensitive to cortical changes after hypoxemia, MRI can provide valuable information about the prognosis in HIBI (29-31). Grey matter in the brain is much more vulnerable to ischemia and hypoxia because it is metabolically more active than white matter. It requires high amounts of oxygen and glucose supply for its large number of synapses. Glutamate excitotoxicity caused by HIBI also gives severe damage to grey matter since it contains most of the dendrites where postsynaptic glutamate receptors are located. Basal ganglia, thalamus, cerebral cortex, cerebellum, and hippocampus are the most frequently affected sites due to hypoxia (2,14,15,32-36).

MRI findings may change as the time passes after the onset of HIBI. The sequence of these changes was characterized as brain swelling, cortical laminar necrosis, hyperintense signal in the basal ganglia, delayed white matter degeneration, and atrophy (37). However it is recently shown that different patterns of MRI findings can be seen at varying intervals. Due to this variability, a uniform sequence of MRI change after HIBI is unlikely (2). Poor prognosis is associated with early abnormal findings in DWI and the use of ADC increases the precision of poor outcome if a severe reduction in the whole brain is evident (2,19,29).

A recent meta-analysis on the prediction of outcome by using MRI scans showed a range of the sensitivity as 59% to 62% (95% CI); and a range of specificity as 94% to 96% (95% CI). This heterogeneity in the sensitivity and specificity was considered to be associated with the timing of the MRI scan after hypoxemia and the inconsistencies in the MRI criteria which were accepted as positive indicators (38).

In the current study, patients were classified as MRI-positive if the DWI and the ADC modalities showed findings of hypoxic injury and/or the perfusion-weighted imaging showed hypoperfusion which could lead to a coma state based on the size and location of lesions. The sensitivity and specificity of positive MRI in our study were 58.3% (95% CI 0.28-0.83) and 85.71% (95% CI 0.42-0.99), respectively. Although the sample size of the present study is small; the sensitivity of MRI was between the ranges reported in the previous studies.

The timing of the MRI scan after the onset of hypoxia may affect the appearance of typical signs. Therefore, we also calculated the admission-to-brain scan period (days) and there was no statistical significance between the timing of the pathological and normal MRI scans. We also calculated the admission-to-brain scan period (days) in patients with poor prognosis with pathological versus normal MRI findings and no significant difference was detected.

EEG is another tool that can be used to assess the level of consciousness and to help clinicians predict the prognosis in comatose patients. Several EEG patterns have been associated with poor prognosis such as suppression or suppression-burst pattern, unresponsive rhythms, and periodic patterns including periodic lateralized, bilateral, or synchronous epileptiform activities (10). It was reported that periodic patterns and EEG grades 4 and 5 according to the modified Hockaday Scale are significantly associated with poor outcomes (2). In a recent study, the sensitivity of EEG was found to be highest within 24 hours of the event, and data obtained from 5 centers revealed that the average sensitivity and specificity of poor outcomes were 0.47 (CI 95% 0.42-0.51) and 1 (CI 95% 0.99-1) respectively, if the EEG was performed within 12 hours after cardiac arrest.

When the EEG was performed 12 hours after cardiac arrest, the prediction of a good outcome was reported to have a sensitivity of 50% (CI 95% 0.46-0.55) and a specificity of 91% (CI 95% 0.88-0.93). Generalized suppression or synchronous pattern with 50% suppression were accepted as predictors of poor outcome and the presence of a continuous pattern (delta, theta, and alpha) was accepted as a predictor of good outcome (31).

In our study, EEG was not performed on every patient within 24 hours. That is mainly because the patients were under pharmacological sedation and neurology consultation was required when the patients were unable to gain consciousness after the cessation of anesthetic substances. EEG was performed on the patients at a mean time of 7.21±6.85 days. We classified the EEGs according to the modified Hockaday scale and took two separate cut-off points, grade 3 and grade 4, to see the specificity and sensitivity of the prediction of poor prognosis. No detectable alpha rhythm is present in grades 3 and higher. Therefore, we chose grade 3 and grade 4 as cut-off points. We found that if the EEG pattern was grade 3 or above, the sensitivity was 91.66% (CI 95% 0.59-0.99) and the specificity was 42.85% (CI 95% 0.11-0.79). On the other hand, if the EEG pattern was grade 4 or above, the sensitivity was 83.33% (CI 95% 0.50-0.97) and the specificity was 85,71% (CI 95%

0.42-0.99). Although our sample size is relatively small, it may be concluded that EEG patterns compatible with the modified Hockaday grade 3 and above have more sensitivity but less specificity compared to the previous studies. Whereas, if grade 4 or above is accepted as a predictor, the specificity comes closer to the previous studies with higher sensitivity.

One of our patients showed good prognosis despite being classified as Grade 5 on Modified Hockaday Scale. TThat may be because the EEG was performed within 24-48 hours after cessation of sedation, a time frame which may not be sufficient to wash-out the sedative substances from blood circulation that might have confounded the EEG. No control EEG was performed because she had gained consciousness in the following 48 hours. Thus, a follow-up EEG may be necessary if a suppression pattern is present after the cessation of anesthetics, particularly in elderly patients.

The specificity for prediction of poor prognosis increases significantly (100%; CI 95% 0.56-1) when positive MRI findings accompany EEG patterns at or above grade 3. The specificity is also 100% when positive MRI findings are accompanied by EEG patterns at or above grade 4. On the other hand, the sensitivity in both conditions decreases to 50% (CI95% 0.22-0.77). That is mainly because the sensitivity of positive MRI findings is low.

In conclusion, we recommend that positive MRI findings, hypoxia or hypoperfusion, are not as sensitive as EEG findings. EEG must also be performed on the patients, suffering from hypoxia, to make a more precise prediction. EEG grading according to the modified Hockaday scale seems to be useful for determining the cut-off points for the prediction of poor prognosis. If the cut-off point is Grade 3 or above, the sensitivity is higher, but specificity is significantly lower than a cut-off point of Grade 4.

We believe that the present study contributes to the literature by showing the significance and efficiency of EEG to determine the prognosis in HIBI patients, which is still a challenge in neurology practice. This approach will guide neurologists and intensive care specialists in decision making for specific treatments and interventions (i.e. tracheostomy) based on the patients' prognosis.

Our study has several limitations including a small sample size and the lack of a healthy control group. On the other hand, we showed the significance of EEG along with MRI scans in the prediction of poor prognosis. Studies focusing on EEG patterns with larger sample sizes may help develop new methods to increase the accuracy of prediction of the prognosis in comatose patients with HIBI.

DECLARATIONS

Funding

We declare no funding for the present study.

Conflicts of Interests

We declare no conflict of interest.

Ethics Approval

The present study has the approval of the local ethical committee, ATADEK 2021-03/04.

Availability of Data and Material

Not applicable.

Authors' Contributions

Both authors contributed in the design, data collection, data analysis and writing of the present study.

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