持続脳波モニタリング
2014/6/10
松井宏樹
目次

・前回までの話。
  2013/7/9、慈恵ICU勉強会、井澤先生による非痙攣性癲癇重積と持続脳波モニタリングについてもう一度。

・脳波のおさらい。

・どのようにすればcEEGを実施しやすくできるか。
  ・誘導を減らす
  ・トレンドを見る
  ・異常波形を非専門家が認識する、CSAを使う
Continuous Electroencephalographic Monitoring in Critically Ill Patients: Indications, Limitations, and Strategies*

Raoul Sutter, MD; Robert D. Stevens, MD; Peter W. Kaplan, MBBS, FRCP

- 「なぜ脳波の話か」→持続的脳波モニタリング（cEEG）のレビューがCCMに出た。

- 意識障害患者、脳梗塞、頭蓋内出血、頭部外傷などでは、かなりの頻度でてんかん波が記録される。

- その中には痙攣を伴わないてんかん（NCS）が含まれ、これは脳波でのみ診断が可能である。
前回までの話

cEEGとは？

・Continuous electroencephalography
  持続脳波モニタリング
・文字通り、通常30分間で終了する脳波検査を、より長時間（24時間）モニタリングすること

用いる電極は通常の脳波と何ら変わりない

BIS (Bispectral index) とは全く異なる
to achieve seizure suppression or to manage elevated intracranial pressure via electroencephalographic burst suppression. While these are common practices in the ICU, the optimal electroencephalographic endpoint and the duration of such suppression have not been determined.

The need to identify electroencephalographic patterns warranting treatment is based on the assumption that certain types of sustained ictal activity damage the brain. Animal models demonstrating ictal damage (11) are flawed because the models imperfectly represent human brain function, and the lesions inducing seizures and SE may themselves produce deficits. The main challenge is distinguishing the effects of initial brain insult from possible consequences of subsequent ictal activity (12). In patients with brain trauma or with intracerebral hemorrhage (ICH), NCSE or seizures increase the risk of death. In other settings, the effect of seizures or SE is less well established (Fig. 2).

One study found a 3% mortality after NCSE in epilepsy patients who had subtherapeutic antiepileptic drug (AED) levels, while those patients in NCSE from secondary causes had a much higher mortality (27%), suggesting that it is the underlying disorder rather than the seizures which drive mortality (13). The problem is similar when nonconvulsive seizures (NCSz) follow convulsive seizures (subtle SE). Studies of convulsive status epilepticus (CSE) indicate that early treatment improves outcome (14–17), but there is limited evidence supporting extrapolation to NCSE.

Studies of NCSE in comatose ICU patients after cardiorespiratory arrest (CRA) consistently indicate that outcomes depend primarily on the severity of anoxic brain damage, far more than any effect attributable to superimposed seizure activity (Fig. 2).

ELECTROENCEPHALOGRAPHIC PATTERNS AND THE CHALLENGES THEY PRESENT IN ICU MANAGEMENT

Artifacts
Acquisition and interpretation of the ICU electroencephalography are compromised (18, 19) by a number of factors including wounds or bandages that limit electroencephalography electrode placement, as well as sweating, muscle activity, and movements commonly seen in delirious or agitated patients. Electrical interference may occur from mechanical ventilators, machines for renal replacement therapy, neuromonitoring apparatus, pumps, and electronic beds. Routine 20- to 30-min electroencephalography should be reviewed for artifacts before considering cEEG, and efforts should be made to produce artifact-free recordings.

Periodic Discharges and Triphasic Waves
Periodic discharges (PDs) including (pseudo)periodic lateralized epileptiform discharges (PLEDs) (20), bilateral independent pseudoperiodic lateralized discharges (21), general periodic epileptiform discharges (Fig. 3 B) (22), and triphasic waves (TWs) (23–25) are patterns often encountered in ICU electroencephalography. Definitions and clinical associations are given in Table 2.

<table>
<thead>
<tr>
<th>Critical Illness</th>
<th>Seizures</th>
<th>References</th>
<th>Status Epileptic</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonneurologic ICU patients</td>
<td>4%–15%</td>
<td>5, 117</td>
<td>0.4%</td>
<td>117</td>
</tr>
<tr>
<td>Ischemic stroke</td>
<td>5%</td>
<td>50</td>
<td>1%–10%</td>
<td>58, 112</td>
</tr>
<tr>
<td>Subarachnoidal hemorrhage</td>
<td>4%–16%</td>
<td>65–69</td>
<td>10%–14%</td>
<td>64, 114</td>
</tr>
<tr>
<td>Intracerebral hemorrhage</td>
<td>10%–30%</td>
<td>52, 72–75</td>
<td>1%–21%</td>
<td>74–76</td>
</tr>
<tr>
<td>Hypoxic-ischemic encephalopathy</td>
<td>5%–40%</td>
<td>98–101</td>
<td>30%</td>
<td>41</td>
</tr>
<tr>
<td>Traumatic brain injury</td>
<td>12%–50%</td>
<td>84</td>
<td>8%–35%</td>
<td>90, 113, 114</td>
</tr>
</tbody>
</table>

Crit Care Med 2013;41:1124-1132

TABLE 1. Occurrence Rates of Seizures and Status Epilepticus

てんかんの発作
程度にばらつきはあるが、いずれの疾患においてもかなりの頻度でてんかん波が記録される。
Crit Care Med 2013;41:1124-1132

Figure 1. Time elapsed between start of continuous electroencephalography (cEEG) monitoring and detection of the first seizure in critically ill patients (n = 110). *Three of these nine patients had nonconvulsive seizures as well. Reproduced with permission from Claassen et al (2).

- cEEGによるモニタリングを開始し、初回のseizureを発見するまでの頻度（n=110）。

- seizuresのほとんどがnonconvulsiveである。

- 最初の24時間で、88％のseizureが発見できる。
前回までの話

脳波電極とりつけの国際規格

- 10-20 (電極) 法
ten-twenty system
- 19か所が決められているが、その全てに取り付ける必要はない
- 奇数: 左
- 偶数: 右

β波（14〜30Hz）
α波（10Hz）
θ波（4〜7Hz）

Pentfield and Jasper, 1954

・cEEGを判読 or スクリーニングするためには、基本パターンを知っているといけない

電極がたくさん必要
脳波自体難しいイメージ
前回までの話

・→cEEGは必要であるが施行が困難である。
目次

・ 前回までの話。

・ 脳波のおさらい。

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  ・ トレンードを見る
  ・ 異常波形を非専門家が認識する、CSAを使う
脳波のおさらい—脳波は何を計測しているか

A. 表層への入力

A1. 興奮入力

B. 深層への入力

B1. 興奮入力

・ 頭皮において電極の直下にある大脳皮質神経細胞の電気活動。

A2. 抑制入力

B2. 抑制入力

・ 上向きがマイナスの電位。

・ 同じ興奮入力でも深さで向きが変わる。
脳波のおさらい—基礎律動の周波数

脳活性が低下すると同期して興奮し（高振幅徐化）、逆に脳活性が亢進すると脱同期すると考えられている（周波数増加）。

周波数は脳波の判読で最も注意すべき指標である。
脳波のおさらい—電極配置

- 頭全体を10%、20%、20%、20%、20%、10%で分割
- 頭の大きさに関係なくほぼ一定部位に電極配置ができる。
- 各電極間の距離をほぼ等しくできる。
- 電極に対応する大脳の解剖学的部位が確認されている。
脳波のおさらい—健常脳波

- 閉眼安静覚醒時の健常脳波。
- アーチファクトを鑑別するため
  に眼電図（EOG）と心電図（ECG）を同時に記録する。
- 3cmで1秒。定規を当てて3cm
  分の波のピークを数えれば基礎
  律動の周波数がわかる。

- 後頭部優位のアルファ律動
  （10Hz）
脳波のおさらい—突発波

・脳神経細胞の過剰興奮を反映して、突発波が記録される。

・てんかんの診断価値の高い突発波は棘波（spike）と銣波（sharp wave）。

・棘徐波複合、銣徐波複合は過剰興奮とその後に誘発される脱分極を表している。
脳波のおさらい—基礎律動の徐化

- burst-suppression: 高振幅鋭波（a,b）とその間の低電位脳波（＊）を周期的に反復する。
- 蘇生後脳症などで意識障害が重症化するとみられる。
- 深麻酔にした時にも認められる。（BISで30以下程度）

- 平坦脳波（flat）
- 矢印は心電図。
- 脳死あるいは深麻酔（BIS 0）
目次

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  ・ 誘導を減らす
  ・ トレンドを見る
  ・ 異常波形を非専門家が認識する、CSAを使う
Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

G. Bryan Young · Michael D. Sharpe · Martin Savard · Eyad Al Thenayan · Loretta Norton · Corrine Davies-Schinkel

INTRODUCTION

In comatose patients, the clinical examination is often an unreliable monitor of cerebral cortical function, yet the cerebral cortex is subject to further damage from seizures and/or ischemia, particularly in patients with acute brain injury [1]. The advent of digital EEG has provided an opportunity to assess cerebral cortical function in real time at the bedside. More than 90% of seizures in comatose ICU patients are nonconvulsive and therefore, cannot be diagnosed reliably without an EEG. Since the majority of these seizures also occur within the first 48 h of brain injury, early application of continuous electroencephalography (cEEG) is necessary in order to detect and treat nonconvulsive seizures [2]. Early detection of seizures is also important since mortality also increases exponentially with seizure duration [3–5].

However, the ability to perform EEG monitoring is not present in many hospitals, or it is delayed in its application, as it requires trained technicians and equipment, which are often not immediately available. With the introduction of digital, bedside EEG modular technology, and the application of a subhairline montage utilizing stick-on surface electrodes, which can be easily applied by the bedside ICU nurse, prompt, cEEG monitoring for high risk patients is...
Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

· Introduction

ICUで使用できる持続脳波モニタリングの機器は非常に限られている。その中でも比較的よく使われる4チャンネルのモニターを、国際10-20法を用いたスタンダードなモニターと比較した。

· Methods

対象は内科系ICU・外科系ICU・てんかん病棟のいずれかに入室した、てんかん患者と急性頭部外傷患者70人。患者には番号が割り付けられ4チャンネルの脳波モニターと19チャンネルの一般的な脳波モニターがどちらも装着された。解析は別々に行われ、もう一方の解析結果を見ることができないようにした。

· Analysis

脳波は以前より定義されている分類を用いて解析された。それぞれの脳波につき2人の解析者が判読し、別の分類をした時には結論が得られるまで2人でレビューした。
Now feasible. We sought to determine the accuracy of this new technology, by comparing it to standard 16-channel EEG monitoring, for detection of seizures, spikes, and periodic lateralizing epileptiform discharges (PLEDs), in patients at high risk of seizures.

**Methods**

With approval from our institutional Research Ethics Board for Health Sciences Research Involving Human Subjects and signed consent, we studied 70 patients admitted to our medical-surgical intensive care unit or epilepsy unit either with seizures or with acute brain injury. cEEGs were simultaneously recorded for 24 h with a standard 16-channel EEG monitor (XLTEK EEG, Canada) using the International 10-20 system and tin disk scalp electrodes attached with collodion, and a 4-channel bipolar EEG monitor (Datex-Ohmeda S/5 M-EEG Module; model #898683-00 plugged in Datex-Ohmeda Critical Care monitor, GE Healthcare, Helsinki, Finland) using skin surface electrodes (Zipprep #186-0023, Aspect Medical Systems, Inc., Norwood, MA) and a subhairline montage (Fig. 1). The recordings were coded by number (without patient identification) and archived onto CD ROM disks. The XLTEK and Datex-Ohmeda recordings were interpreted by GBY or MS and were interpreted usually more than a month after they were archived, with the interpreters blinded to the identity of the patients. The two EEG recordings from each patient were reviewed independently of one another and the reader was unaware of the results of the other simultaneous EEG recording. The XLTEK recordings were considered the "gold standard" for comparing the Datex-Ohmeda recordings.

**Analysis**

The EEG recordings were classified according to standard nomenclature previously described and, whether or not, focal or generalized seizures, spikes, or PLEDs were identified. When a discrepancy in classification occurred between the two observers for any single recording, the EEG was reviewed by both readers together to arrive at a consensus. Calculation of sensitivity and specificity were performed for seizure activity and epileptiform spike/PLED activity by constructing 2x2 tables as depicted in Table 1.

**Results**

The diagnostic categories and EEG results are detailed in Table 2. The study group consisted of 70 patients (26 females) with an average age of 53 ± 18 (range 20–85) years. The most common ICU admission diagnosis was metabolic disorder (e.g., organ failure/sepsis). Nineteen (27%) patients were admitted to the ICU (14 patients) or epilepsy unit (5 patients) with a primary diagnosis of seizures. Seizures were detected in 31% (n = 22) of patients using standard 16-channel XLTEK cEEG and only 15/22 of these seizures were detected using the Datex-Ohmeda, modular, bedside technology (sensitivity = 68%; 95% confidence interval [95% CI] 45–86%). One of the Datex-Ohmeda recordings was interpreted as showing a seizure when the XLTEK recording of the same patient did not (specificity = 98%; 95% CI 89–100%). The positive predictive value (PPV) of the Datex-Ohmeda system was 94%.

**Fig. 1 Placement sites of adhesive electrodes for SHM**

**Table 1 Calculation of sensitivity and specificity**

<table>
<thead>
<tr>
<th>XLTEK seizure</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datex-Ohmeda</td>
<td>Yes</td>
<td>ab</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>cd</td>
</tr>
</tbody>
</table>

Sensitivity = a / (a + c)  
Specificity = d / (b + d)
Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

### Result

**Table 2** Diagnostic categories and seizure detection

<table>
<thead>
<tr>
<th>Diagnosis (number of cases)</th>
<th>XLTEK-recorded seizures</th>
<th>Datex-recorded seizures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seizure disorder (Epilepsy—19)</td>
<td>8</td>
<td>6 (1 false positive)</td>
</tr>
<tr>
<td>Metabolic (organ failure/sepsis—21)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Neurosurgical post-op for tumor (8)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Trauma (4)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Cardiac arrest (4)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ischemic stroke (5)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>CNS infection (3)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Intracerebral hemorrhage (2)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Drug intoxication (2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CNS vasculitis (1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hypertensive encephalopathy (1)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 3** Seizure detection

<table>
<thead>
<tr>
<th></th>
<th>Standard EEG positive</th>
<th>Standard EEG negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datex positive</td>
<td>15</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Datex negative</td>
<td>7</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>48</td>
<td>70</td>
</tr>
</tbody>
</table>

*Datex bedside module with SHM; Standard EEG 18-channel recordings with XLTEK digital EEG machine*

結果をTable 2, Table 3にしめます。
26人の女性を含む70人の患者。最も多い入室理由は敗血症を含む代謝性疾患の21人、次がてんかんの19人。

XLTEK(standard EEG)では22人の患者がてんかんと診断された。Datex (4-channel)ではそのうち15人の患者しかてんかんと診断できなかった。（感度68%）
XLTEKではてんかんなしとされた1人の患者が、Datexではてんかんありと診断されてしまった。（特異度98%）
Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

Table 4 Spike or PLEDs detection

<table>
<thead>
<tr>
<th></th>
<th>Standard EEG positive</th>
<th>Standard EEG negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datex positive</td>
<td>12</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Datex negative</td>
<td>19</td>
<td>36</td>
<td>55</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>39</td>
<td>70</td>
</tr>
</tbody>
</table>

- 棘波(spike)と周期性一側性てんかん形発射（PLEDs）は31例中12例しか検出できなかった。（感度39％）
- 3例は偽陽性であった。（特異度92％）
Fig. 2 a Sequential frames of a seizure maximally expressed in the left posterior head (the odd numbered channels, e.g., involving electrodes C3, P3, F7, T3, T5, and O1, are from the left hemisphere). The first frame is on the left, the next the upper right and the third is on the lower right. Note the evolutionary changes in morphology, amplitude, and frequency that characterize the seizure.

b The same seizure recorded with SHM, using the same arrangement of sequential frames as in a. The first and third channels are from the left hemisphere. Note that the evolutionary changes of the seizure are recognizable, but there is abundant EKG artifact.
Multiple Independent Spikes
(sp = epileptiform spikes; X = EKG)

Fig. 3 SHM tracing showing epileptiform spikes and EKG contamination. It was often difficult to differentiate between them, especially with ectopic or irregular cardiac rhythms.

- 4チャンネルのものでは、棘波とアーチファクトの区別が難しい。
- sp＝棘波、X＝心電図アーチファクト
誘導を減らす

Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

まとめ

・KollsとHusainの研究でもほぼ同様の感度・特異度であった（Kolls BJ, Husain AM. Assessment of hairline EEG as a screening tool for nonconvulsive status epilepticus. Epilepsia. 2007;48: 959–65）。彼らはstandard EEGのほうが持続脳波モニタリングには適しているとしている。

・しかし、てんかんの検査前確率が高い病態のとき、あるいは脳波検査がすぐできないときには4チャンネルの簡易脳波検査も有用だと考えられる。

・4チャンネルのものでも特異度は高いため、異常波が捕まえられればてんかんである可能性が高い。

・その他にもてんかんの治療に際し、鎮静が深すぎないか、浅すぎないかの判断にも用いることができる。

・クリームを使った脳波用電極は6時間程度で剥がれ始めるが、心電図用電極などを用いれば48時間以上適切な記録がとれた。
Clinical review: Continuous and simplified electroencephalography to monitor brain recovery after cardiac arrest

Hans Friberg*1,2, Erik Westhall2,3, Ingmar Rosén2,3, Malin Rundgren1,2, Niklas Nielsen2,4 and Tobias Cronberg2,5

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Friberg et al. Critical Care 2013, 17:233
http://ccforum.com/content/17/4/233

心肺蘇生後の持続脳波モニタリング
Continuous and simplified electroencephalography to monitor brain recovery after cardiac arrest

Introduction

- Low temperature therapy has also been developed, and neurologic recovery after cardiac arrest has become a growing concern.

- Despite this, transient or non-convulsive status epilepticus (NCS) can occur, often due to a lack of resources or complexity, making EEG monitoring difficult.

- To simplify monitoring, we focus on amplitude-integrated EEG (aEEG) to observe trends.
Continuous and simplified electroencephalography to monitor brain recovery after cardiac arrest

Introduction

・ 日の単位で脳波をモニターする場合、何らかの方法で脳波を定量化し（qEEG）、時間軸を圧縮してトレンドを作る必要がある。

・ トレンドを見ることで、てんかんや基礎律動の変化を見つけやすくなる。

・ 脳波を定量化する方法として、aEEGやCSAがあり、最近の脳波計にはこれらのソフトが搭載されている。

・ 今回は異常波も検出でき基礎律動の変化がわかりやすいaEEGについてレビューする。
トレンドをみる

aEEGとは
トレンドをみる

aEEGとは

非対称フィルター

・非対称フィルターがEEGの2Hz以下、25Hz以上の波形を除く。

・2Hz以下は呼吸の影響、25Hz以上は筋電図と考える。
トレンドをみる

aEEGとは

半対数でスケール変更

- 臨床と関連深い低振幅域の感度を上げ、スケールを変更する。
aEEGとは
整流 + 平滑化

- マイナス方向のピークをプラス方向に変換する。
- トレースを滑らかにし、ピークをなくす。
トレンドをみる

aEEGとは

最後に、時間の圧縮を行い、aEEGが生成します。

・1画面に4時間から6時間が表示できるように圧縮する。

・同時に元の脳波波形も表示し、比較できるようにする。
Monitoring procedure for assessment of brain maturity and asphyxia in newborns. aEEG recordings within 6 hours after birth have been shown to correctly predict outcome after perinatal asphyxia in term infants [31]. Early normalization of aEEG and early onset of sleep-wake cycling predict a good outcome [45]. Interestingly, hypothermia treatment changes the predictive value of early aEEG since normalization of an infant’s aEEG pattern is delayed by hypothermia. Moreover, time to recover a normal aEEG is a better predictor than time to recover a sleep-wake cycling pattern in hypothermia-treated infants [46].

Seizures, myoclonus, and electrographic status epilepticus after cardiac arrest

An epileptic seizure is the manifestation of an abnormal and excessive synchronized discharge of cerebral neurons. Each seizure can be classified as a clinical seizure, which is what is observed, or an electrographic seizure, which is what is monitored with an EEG device.

Clinical seizures are reported in approximately one fourth of all patients after cardiac arrest [7], but seizure mimics are common in the intensive care setting and may be difficult to differentiate from true epileptic seizures without the aid of EEG [47]. Correspondingly, electrographic seizures may or may not have clinical correlates [48].

Figure 1. Trend monitor displays original electroencephalography (EEG) and amplitude-integrated EEG (aEEG) from two channels. The channels correspond to the left and right sides of the scalp. The aEEG timescale is compressed, showing 4 to 6 hours per screen. The aEEG trend is scanned by the interpreter for changes in background pattern or seizures, and details are explored in the corresponding original EEG. Clinical notes can be used to mark clinical events (for example, convulsions) to facilitate interpretation. In this display, a burst suppression pattern is shown.

Suppression periods with low amplitudes in the original EEG correspond to the lower border of the aEEG trends (aEEG minimum level), and the burst periods correspond to the upper border (aEEG maximum level).

Figure 2. Example of a simplified electroencephalography montage. Four recording electrodes in left frontal (F3), right frontal (F4), left parietal (P3), and right parietal (P4) positions are shown with ground (GND) and reference (REF) electrodes in the midline. The original electroencephalography is displayed as two bipolar channels (F3-P3, F4-P4), one on each side (red = left, blue = right).
Monitoring procedure for assessment of brain maturity and asphyxia in newborns. aEEG recordings within 6 hours after birth have been shown to correctly predict outcome after perinatal asphyxia in term infants [31]. Early normalization of aEEG and early onset of sleep-wake cycling predict a good outcome [45]. Interestingly, hypothermia treatment changes the predictive value of early aEEG since normalization of an infant's aEEG pattern is delayed by hypothermia. Moreover, time to recover a normal aEEG is a better predictor than time to recover a sleep-wake cycling pattern in hypothermia-treated infants [46].

Seizures, myoclonus, and electrographic status epilepticus after cardiac arrest

An epileptic seizure is the manifestation of an abnormal and excessive synchronized discharge of cerebral neurons. Each seizure can be classified as a clinical seizure, which is what is observed, or an electrographic seizure, which is what is monitored with an EEG device. Clinical seizures are reported in approximately one fourth of all patients after cardiac arrest [7], but seizure mimics are common in the intensive care setting and may be difficult to differentiate from true epileptic seizures without the aid of EEG [47]. Correspondingly, electrographic seizures may or may not have clinical correlates [48].

Figure 1. Trend monitor displays original electroencephalography (EEG) and amplitude-integrated EEG (aEEG) from two channels. The channels correspond to the left and right sides of the scalp. The aEEG timescale is compressed, showing 4 to 6 hours per screen. The aEEG trend is scanned by the interpreter for changes in background pattern or seizures, and details are explored in the corresponding original EEG. Clinical notes can be used to mark clinical events (for example, convulsions) to facilitate interpretation. In this display, a burst suppression pattern is shown. Suppression periods with low amplitudes in the original EEG correspond to the lower border of the aEEG trends (aEEG minimum level), and the burst periods correspond to the upper border (aEEG maximum level).

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Myoclonus is a common form of motor manifestation in the comatose survivor of cardiac arrest and consists of brief repetitive jerks, which may be irregular or rhythmic and spontaneous or stimulus-induced. It may occur in isolated muscles (focal) or be generalized in face, limbs, and axial musculature. Myoclonus may be of cortical or subcortical origin and occurs in approximately 20% of patients after cardiac arrest; myoclonus of cortical origin is the more common [30]. Prognosis is generally poor, especially when myoclonus occurs early after arrest of cardiac origin (<24 hours) and when it is generalized and persistent [49,50]. However, several case reports show that even an early and generalized myoclonus may be compatible with good neurologic recovery [51,52]. In a recent retrospective report from The Netherlands, 12% of all patients who had some kind of myoclonus eventually had a good outcome [30], but whether hypothermia treatment affects the incidence and prognosis of myoclonus is not clear. Lance-Adams syndrome denotes a chronic form of action-induced post-hypoxic myoclonus, which is more common after cardiac arrest of a primary hypoxic cause and compatible with a good outcome [53]. ESE occurs in a significant fraction of hypothermia-treated patients who remain unresponsive after rewarming [15] and is a predictor of a poor neurologic prognosis after cardiac arrest [9], although some patients may recover [16,18]. In a recent report, a subgroup of hypothermia-treated cardiac arrest patients with post-anoxic ESE and a good outcome was described, and all had preserved brain stem reflexes and a reactive EEG [29]. This group of patients may be similar or identical to those who develop a late ESE from a cEEG pattern [10] and with a potentially good outcome.

A major question, yet to be answered, is whether post-anoxic ESE is a condition that causes further brain injury, as indicated by a recent study [54], or is simply a sign of the hypoxic-ischemic encephalopathy. No systematic trials regarding treatment of post-anoxic ESE have been performed, and the available observational data do not allow conclusions about whether survival of patients is due to aggressive anti-epileptic treatment or merely to prolonged intensive care [55]. Nevertheless, most clinicians agree that visible seizures should be treated with anti-convulsive drugs, but there is no consensus on treatment strategy or duration.

Evolution of electroencephalography patterns after cardiac arrest

Our group recently proposed a simplified system for interpreting EEG rhythms in the post-ischemic brain after cardiac arrest in order to make EEG more comprehensible and more accessible at the bedside [10]. We defined four common EEG patterns after cardiac arrest, which are presented in Figure 3. Using these four patterns to classify the EEG generated valuable prognostic information, positive as well as negative [10]. In a recent study by Friberg et al. [154], Critical Care 2013, 17:233, http://ccforum.com/content/17/4/233, aEEG also makes it possible to read the differences in waveforms.
meticulous study using intermittent EEG, Jørgensen and Holm [56] reported that cortical inactivity and a flat EEG curve are common immediately after cardiac arrest and that cortical activity eventually returns in most patients. Studies using a simplified cEEG montage have shown that initial cortical inactivity or a flat pattern (<10 µV) is common during the early phase of hypothermia treatment after cardiac arrest but that it has no prognostic significance [10,13]. On the other hand, persistence of low-voltage or isoelectric patterns at 24 hours after the arrest was found to be a strong indicator of poor prognosis [5]. Evolution from a non-continuous to a continuous background pattern during hypothermia or at the time of normothermia is strongly associated with awakening and a good outcome [5,10]. A spontaneous and maintained burst suppression (BS) pattern after cardiac arrest indicates that the prognosis is poor in most [10], but not in all [5,23,51], cases. This discrepancy between studies might be related to different definitions of BS since the development of a continuous background activity usually proceeds through a phase of intermittent cortical activity [57]. Our group has identified patients with two types of post-anoxic ESE, evolving from different background patterns; one develops early (typically during hypothermia) and from a BS background pattern (Figure 4). These patients had a uniformly poor outcome. The other type of ESE develops late (typically during or after rewarming) and from a continuous Figure 5, and in this group survivors were reported [10,15]. Patient categorization based on evolution of the electroencephalography

Our experience in the ICU is that comatose patients after cardiac arrest can be categorized into one of three main groups. The three groups have different prognoses, and the use of cEEG is helpful in differentiating between them. In addition to using the simplified cEEG with a trend monitor, we use serial neurologic investigations and biomarker measurements and tailor the use of additional prognostic methods such as SSEP, routine EEG, and magnetic resonance imaging (MRI) on an individual basis.

The first group consists of comatose patients with a mild or limited brain injury characterized by return of a continuous and reactive EEG pattern during hypothermia. In this group, brain stem functions such as pupillary and corneal reflexes usually return early, and patients recover motor response to pain as sedation wears off. Levels of the brain damage biomarker neuron-specific enolase (NSE) are not elevated [15]. These patients are relatively easy to identify, and information to relatives should be cautiously positive.

The second group consists of patients with severe brain injury characterized by a flat or long-lasting BS EEG pattern, which often evolves into an ESE pattern during hypothermia (Figure 4), and still shows a malevolent and unreactive EEG pattern when sedation is stopped at Figure 5. Electrographic status epilepticus (ESE) evolving from a continuous background pattern. (a) Continuous background (45 hours after cardiac arrest). (b) Onset (arrow) of repetitive epileptiform discharges (>1 Hz, >30 minutes), consistent with ESE (46 hours after cardiac arrest). (c) Ongoing ESE (47 hours after cardiac arrest).

\[ \text{Figure 4. Electrographic status epilepticus (ESE) evolving from a burst suppression (BS) pattern. (a) BS pattern (12 hours after cardiac arrest). (b) BS pattern with short periods of repetitive epileptiform discharges (14 hours after cardiac arrest). (c) ESE with repeated electrographic seizures (>1 Hz) for more than 30 minutes (16 hours after cardiac arrest).} \]

\[ \text{Figure 5. Electrographic status epilepticus (ESE) evolving from a continuous background pattern. (a) Continuous background (45 hours after cardiac arrest). (b) Onset (arrow) of repetitive epileptiform discharges (>1 Hz, >30 minutes), consistent with ESE (46 hours after cardiac arrest). (c) Ongoing ESE (47 hours after cardiac arrest).} \]

- Burst-suppression patternから発生したてんかん異常波。
- 予後が良くない。
- 基礎律動から発生したてんかん異常波。
- 予後が良いものが報告されている。
トレンドをみる（aEEG）
Continuous and simplified electroencephalography to monitor brain recovery after cardiac arrest

まとめ

・ 単純化された脳波モニターは、心肺蘇生後においててんかん異常波の検索に有用である。

・ aEEGは電極が少なく簡便であることと、トレンドを見やすいことからマルチチャンネルの一般的な脳波計よりもICUに適していると考えられる。
Sensitivity of Compressed Spectral Arrays for Detecting Seizures in Acutely Ill Adults

Craig A. Williamson · Sarah Wahlster · Mouhsin M. Shafi · M. Brandon Westover

Published online: 20 September 2013
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Sensitivity of Compressed Spectral Arrays for Detecting Seizures in Acutely Ill Adults

- **Background**
  急性期の重症患者へ持続脳波モニタリングが行われることが多くなってきました。プレスクリーニングで用いられるCSA（Compressed Spectral Array：圧縮スペクトル法）について検証してみた。

- **Methods**
  対象はMGHで持続脳波モニタリングが行われた18歳以上の患者113人。国際10-20法に基づき19の電極で記録された。2時間の説明を受けた2人のレジデントがCSA画面のみで判読した。一方で脳波判読の経験がある第三者がすべての元の脳波を解析し、結果を照らし合わせる。

- **Results**
  113人のうち39人にてんかんが認められ、CSAを用いて98.7%のてんかん患者を同定できた。また総数1190のてんかん異常波のうち、CSAで89%を同定できた。
異常波形を非専門家が認識する

**CSA (Compressed Spectral Array)**

まずフーリエ変換

Y軸：パワースペクトル
各周波数成分の出現量の指標

脳波に含まれている周波数がどの程度あるのか解析する
異常波形を非専門家が認識する

CSAとは

周波数スペクトラム

これだけでは時間の情報がなくなってしまう。

↓

Z軸に時間をとり、重ねあわせ鳥瞰図の形にする。

CSA
Spectrograms, or compressed spectral arrays (CSA), are the most widely used compressed data format, consisting of three-dimensional plots with time on the \(x\)-axis, frequency on the \(y\)-axis, and EEG power on the \(z\)-axis (Fig. 1). Whereas standard EEG displays no more than 10–15 s of data per screen and requires simultaneous inspection of numerous channels, CSA displays may show several hours of data on a single page. This enables the electroencephalographer to identify "suspicious" regions of the EEG from their gross features and then selectively "zoom in" on these regions for more detailed review. However, the sensitivity of CSA to detect clinically significant patterns, as compared to standard exhaustive visual review, has never been quantified.

We hypothesized that CSA could be used to screen cEEG recordings for seizures and other clinically relevant pathological patterns. This hypothesis was tested on a collection of 113 cEEG studies, using a CSA review strategy designed to assess the sensitivity with which CSA screening can be used to identify seizures, compared against gold-standard exhaustive visual review.

Fig. 1: Seizures and artifact in CSA displays. Compressed spectral array (CSA) displays, demonstrating a seizure (a) and muscle artifact (c). Each CSA displays 2 h of EEG data. x-axis time, y-axis frequency (0–20 Hz), z-axis power with black representing lowest and white highest power. From top-to-bottom, the individual segments represent: left lateral power (Fp1-F7, F7-T3, T3–T5, T5-O1), left parasagittal power (Fp1-F3, F3-C3, C3-P3, P3-O1), right lateral power (Fp2-F8, F8-T4, T4–T6, T6-O2), right parasagittal power (Fp1-F4, F3-C4, C4-P4, P4-O2) and the relative asymmetry index. For the relative asymmetry index, red represents increased right-sided power and blue increased left-sided power. a Five seizures are present, marked by arrows. b Section of the EEG corresponding to the EEG segment marked by the thick arrow, demonstrating seizure onset. c CSA display with several segments with muscle artifact, each marked by an arrow corresponding to where a CSA reviewer placed a mark. d Section of the EEG corresponding to the CSA segment marked by the thick arrow, displaying muscle artifact (Color figure online).
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\textit{a} Five seizures are present, marked by arrows. \textit{b} Section of the EEG corresponding to the EEG segment marked by the thick arrow, demonstrating seizure onset. \textit{c} CSA display with several segments with muscle artifact, each marked by an arrow corresponding to where a CSA reviewer placed a mark. \textit{d} Section of the EEG corresponding to the CSA segment marked by the thick arrow, displaying muscle artifact (Color figure online)
Results:

Table 1  Patient Demographic Data

<table>
<thead>
<tr>
<th></th>
<th>All patients (n = 113)</th>
<th>Patients without seizures (n = 74)</th>
<th>Seizure patients (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean ± SD (range)</td>
<td>59.6 ± 18.5 (19–95)</td>
<td>59.6 ± 18.6 (19–95)</td>
<td>59.6 ± 18.6 (23–88)</td>
</tr>
<tr>
<td>Male</td>
<td>58 (51.3 %)</td>
<td>38 (51.4 %)</td>
<td>20 (51.3 %)</td>
</tr>
<tr>
<td>ICU</td>
<td>66 (58.4 %)</td>
<td>47 (63.5 %)</td>
<td>19 (48.7 %)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICH</td>
<td>21 (18.6 %)</td>
<td>16 (21.6 %)</td>
<td>5 (12.8 %)</td>
</tr>
<tr>
<td>Ischemic stroke</td>
<td>7 (6.2 %)</td>
<td>6 (8.1 %)</td>
<td>1 (2.6 %)</td>
</tr>
<tr>
<td>TBI</td>
<td>9 (8.0 %)</td>
<td>7 (9.5 %)</td>
<td>2 (5.1 %)</td>
</tr>
<tr>
<td>CNS tumor</td>
<td>11 (9.7 %)</td>
<td>5 (6.8 %)</td>
<td>6 (15.4 %)</td>
</tr>
<tr>
<td>CNS infection/autoimmunity</td>
<td>11 (9.7 %)</td>
<td>7 (9.5 %)</td>
<td>4 (10.3 %)</td>
</tr>
<tr>
<td>Hypoxic–ischemic injury</td>
<td>8 (7.1 %)</td>
<td>4 (5.4 %)</td>
<td>4 (10.3 %)</td>
</tr>
<tr>
<td>Seizure disorder or spells</td>
<td>29 (25.7 %)</td>
<td>20 (27.0 %)</td>
<td>9 (23.1 %)</td>
</tr>
<tr>
<td>General medical disease</td>
<td>17 (15.0 %)</td>
<td>9 (12.2 %)</td>
<td>8 (20.5 %)</td>
</tr>
</tbody>
</table>

ICU intensive care unit; ICH intracranial hemorrhage; TBI traumatic brain injury; CNS central nervous system
Values are n (%) unless otherwise indicated

- 113人中39人にてんかんあり。一人につき1〜151のてんかん異常波が検出された。
- 約半分が男性。58.4%がICUで記録されている。
Sensitivity of Compressed Spectral Arrays for Detecting Seizures in Acutely Ill Adults

Results

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Percentage of seizures and other patterns of interest identified and mean and median CSA review times</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reviewer 1</td>
</tr>
<tr>
<td>Sz pts identified (%)</td>
<td>38/39 (97.4)</td>
</tr>
<tr>
<td>Total szs identified (%)</td>
<td>1,039/1,190 (87.3)</td>
</tr>
<tr>
<td>Szs identified per pt, mean % (SD)</td>
<td>85.8 (20.8)</td>
</tr>
<tr>
<td>Szs identified per pt, median %</td>
<td>92.9</td>
</tr>
<tr>
<td>PEDs identified (%)</td>
<td>41/41 (100)</td>
</tr>
<tr>
<td>EDs identified (%)</td>
<td>64/67 (95.5)</td>
</tr>
<tr>
<td>RDA identified (%)</td>
<td>31/32 (96.9)</td>
</tr>
<tr>
<td>FS identified (%)</td>
<td>72/72 (100)</td>
</tr>
<tr>
<td>GS identified (%)</td>
<td>96/96 (100)</td>
</tr>
<tr>
<td>CSA review time, mean min (SD)</td>
<td>10.4 (5.0)</td>
</tr>
<tr>
<td>CSA review time, median min (range)</td>
<td>9.7 (1.5–25.0)</td>
</tr>
</tbody>
</table>

Data are number identified/total number (percent identified) unless otherwise specified

Sz = seizure, pt = patient, % = percent, SD = standard deviation, PEDs = periodic epileptiform discharges, EDs = epileptiform discharges, RDA = rhythmic delta activity, FS = focal slowing, GS = generalized slowing, CSA = compressed spectral array, min = minutes

判読者1は38/39人、判読者2は39/39人のてんかんを同定。
（判読者1が見逃した患者は16秒の短くてんかん波が一度出現したのみであった。）

1190のてんかん波のうち判読者1は1039（87.3％）、判読者2は1080（90.8％）のてんかん波を同定できた。

判読にかかる時間は1患者あたり平均10.3分と短い。
they could subsequently be ignored. This process of adaptation to the individual patient's pattern by a continual suspect-and-verify process of feedback likely affords increased time efficiency.

There are several limitations to the current study which suggest directions for future research. CSA is only one of the several methods that can be used to graphically display compressed EEG data and was used in the current study because of its intuitive nature and ability to represent subtle changes in EEG pattern. However, in future studies, it may be useful to compare its efficacy with other quantitative techniques, such as amplitude-integrated EEG. Additionally, instead of experienced electroencephalographers, CSA review was performed by neurology residents without prior quantitative EEG exposure and limited overall EEG experience. The approach to simply mark visually homogeneous segments is a simple and easily learned technique, which can be taught to novices in EEG interpretation. Therefore, our findings suggest that it may be possible to train bedside nurses or EEG technicians to perform an initial screen to identify areas for closer review, thereby allowing less intermittent seizure screening. However, how best to implement such an approach without placing undue burden on physician responders due to false positives requires further investigation. Finally, by enabling electroencephalographers to review a smaller portion of the raw EEG, it is probable that this method will reduce overall EEG review time. However, further investigation is needed to determine whether CSA indeed results in clinically meaningful time-savings.

Overall, this study suggests that the use of a CSA display as a screening tool is a reasonable alternative to

Fig. 2

Examples of seizures missed by CSA screening. Case 1 (a, b), a very focal right temporal seizure (onset marked by black arrows), lasting 20 s, with no significant change in the CSA background, missed by both reviewers. Case 2 (c, d) A right frontotemporal seizure lasting 83 s. This seizure was marked by reviewer 2 near the seizure onset (thick black arrow), but was 'missed' by reviewer 2 (thin black arrow) whose nearest CSA mark occurred 90 s after the end of the seizure

- A,B: 右側頭葉起源のてんかん波で、持続時間は20秒。CSAではほとんど変化が見られず、2人とも見逃した。
- C,D: 前頭側頭てんかん、持続時間83秒。これは同定されたが、その直後のてんかんが見逃された。
Sensitivity of Compressed Spectral Arrays for Detecting Seizures in Acutely Ill Adults

まとめ

・今回の研究ではスクリーニングを目的としているため、わざと偽陽性を許容した。そのため高いてんかん波検出率（89.0%）となった。

・レビュワーは一時間あたり平均7.3個のマークをしている。そのうち実際にてんかん波であったものは一時間あたり平均0.53個で、ひとつのてんかん波を見つけるために間違ったマークを平均13.8個つけてしまっている。

・今後レビュワーがCSAと元データを照らしあわせ、どれがアーチファクトか認識できるようになれば、偽陽性は減っていくものと思われる。

・視覚的にどこにマークすればいいのかわかりやすくため、初心者にも教えやすく、今後看護師や技師にスクリーニングしてももらうこともできるだろう。

・ただしててんかん患者が一人見逃されているということも心にとどめておかねばならない。
Discussion

- previous studies compared aEEG and CSA.
  aEEG detected 81% and CSA detected 83% of seizures.
  Among 17 patients, aEEG detected all seizures, while CSA only detected 2 cases.

- Further studies are needed.
まとめ

・重症患者が多いICUにおいて、もっと手軽に脳波をみたほうが良いのは間違いなさそう。

・手軽にするためには1. 誘導を減らす 2. 長時間の記録を短時間で読める工夫をする 3. 専門家ではなくても読めるようにする必要がある。

・そのためにはaEEGやCSAなどの方法がある。

・どちらが優れているか結論は出ていないが、まずはCSAが搭載された機器が導入される様子。