Role of EEG in diagnosis & management of status epilepticus

Outline:

• ILAE-classification of SE: semio & EEG
• Role of EEG in diagnosing SE
  – EEG patterns in SE
  – EEG criteria for SE
  – Diagnostic accuracy of EEG in NCSE
• Role of EEG in management of SE
  – Monitoring therapeutic effect
  – Monitoring brain function during withdrawal
• Cases

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A definition and classification of status epilepticus – Report of the ILAE Task Force on Classification of Status Epilepticus

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SPECIAL REPORT

Summary

This defines a classification of and terminology for the initial diagnosis and treatment of status epilepticus. The treatment of status epilepticus is dependent on the location of the seizure focus. Status epilepticus is characterized by ictal symptoms. Ictal symptoms can be identified using patient reports or indirect observation. Ictal symptoms can be continuously monitored using EEG. EEG is needed for diagnosis.

Can be diagnosed without EEG

EEG is needed for diagnosis

KEYWORDS: Status epilalepticus, Seizure, Definition, Classification, Duration.
- Wide variety of ictal EEG-patterns
- Wide variety of SE EEG-patterns

Several attempts to develop EEG-criteria for NCSE:

An assessment of nonconvulsive seizures in the intensive care unit using continuous EEG monitoring:

An investigation of variables associated with mortality

Table 1 Criteria for seizure

Guideline: To qualify at least one primary criteria 1-3 and one or more of secondary criteria, with discharges >10 seconds

G. Bryan Young, MD; Kenneth G. Jordan, MD; and Gordon S. Doig, MSc, DVM

NEUROLOGY 1996;47:83–89

Which EEG patterns warrant treatment in the critically ill? Reviewing the evidence for treatment of periodic epileptiform discharges and related patterns.

Chung D.J., Hirsch J.L.

EEG criteria for nonconvulsive status epilepticus

Peter W. Kaplan

Epilepsia, 48(Suppl. 8):39–41, 2007
Unified EEG terminology and criteria for nonconvulsive status epilepticus

*Sándor Beniczky, ‡Lawrence J. Hirsch, §Peter W. Kaplan, ¶Ronit Pressler, **Gerhard Bauer, †††Harald Aurlien, ††‡Jan C. Brøgger, and §§Eugen Trinka

Table 1. Working clinical criteria for nonconvulsive status epilepticus

<table>
<thead>
<tr>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients without known epileptic encephalopathy</td>
</tr>
<tr>
<td>EDS &gt; 2.5 Hz, or</td>
</tr>
<tr>
<td>EDS ≤ 2.5 Hz or rhythmic delta/theta activity (~0.5 Hz) AND one of the following:</td>
</tr>
<tr>
<td>EEG and clinical improvement after IV AED*, or</td>
</tr>
<tr>
<td>Subtle clinical ictal phenomena during the EEG patterns mentioned above, or</td>
</tr>
<tr>
<td>Typical spatiotemporal evolution?</td>
</tr>
<tr>
<td>Patients with known epileptic encephalopathy</td>
</tr>
<tr>
<td>Increase in prominence or frequency of the features mentioned above, when compared to baseline with observable change in clinical state</td>
</tr>
<tr>
<td>Improvement of clinical and EEG features with IV AEDs</td>
</tr>
</tbody>
</table>

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Epileptiform discharges

Frequency > 2.5 c/s

Clinical suspicion of NCSE

NCSE

C3 – P3
P3 – O1
Fp2 – F8
F8 – T4
T4 – T6
T6 – O2
C3 – P3
P3 – O1
Fp2 – F8
F8 – T4
T4 – T6
T6 – O2
C3 – P3
P3 – O1
Fp2 – F8
F8 – T4
T4 – T6
T6 – O2

wave length
per second
per 10 seconds
Brief Communication

Salzburg Consensus Criteria for Non-Convulsive Status Epilepticus – approach to clinical application

M. Leitinger ad, S. Beniczky bc, A. Rohracher ad, E. Gardella b, G. Kalas ad, E. Qerama c, J. Höfler ad, A. Hess Lindberg-Larsen d, G. Kachukhidze ad, J. Dobesberger ad, P.B. Langthaler ad, E. Trinka ad,a

a Department of Neurology, Christian Doppler Klinik, Paracelsus Medical University, Salzburg, Austria
b Department of Clinical Neurophysiology, Danish Epilepsy Centre, Danmarkland, Denmark
c Department of Clinical Neurophysiology, Aarhus University Hospital, Denmark
d Centre for Cognitive Neuroscience, Salzburg, Austria

31 SW / 10 seconds

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Epileptiform discharges

Clinical suspicion of NCSE

Frequency > 2.5 c/s

Frequency ≤ 2.5 c/s

No epileptiform discharges

Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

Typical spatiotemporal evolution

NCSE

Typical spatiotemporal evolution

Sequential change in voltage and frequency, or evolution in frequency and change in location:

- Change in voltage (increase or decrease) with a minimum factor of two of the voltages measured between the first and last graphoelement.
- Change in frequency more than 1 Hz: frequency of the second with highest rate of graphoelements and the second with lowest rate of graphoelements differed by more than 1 Hz.
- Evolution in frequency is defined as at least two consecutive changes in the same direction by at least 0.5 per s.9
- Change in location sequential spreading into or out of at least two different standard 10–20 electrode locations.9
- To qualify as present, a single frequency or location must persist at least three cycles. The criteria for evolution must be reached without the pattern remaining unchanged in frequency, morphology, or location for 5 min or more.9
(Quasi)Rhythmic activity

Polymorphic activity (delta)

Clinical suspicion of NCSE

Epileptiform discharges
Frequency > 2.5 c/s
Typical spatiotemporal evolution

Frequency ≤ 2.5 c/s
Subtle clinical ictal phenomena during EEG-patterns mentioned above

No epileptiform discharges
Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

NCSE
Semiology of Subtle Seizures

• Discrete phenomena like:
  – twitches of the eyelids, face, jaw, extremities or the trunk
  – head and/or eye deviation
  – peculiar automatisms.

• They occur when the patient experiences such a degree of encephalopathy that an electromechanical dissociation occurs, so that in spite of continuous ictal activity in the brain, only subtle motor phenomena are generated.
<table>
<thead>
<tr>
<th>Subtle seizure phenomena</th>
<th>NCSE (n=14)</th>
<th></th>
<th></th>
<th>Coma without NCSE (n=46)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of patients</td>
<td>Body part</td>
<td>Occurrence</td>
<td>Number of patients</td>
<td>Body part</td>
<td>Occurrence</td>
</tr>
<tr>
<td>Myoclonus</td>
<td>10 (71%)</td>
<td>Tongue: 2</td>
<td>Almost continuous: 3</td>
<td>19 (41%)</td>
<td>Eyelid: 1</td>
<td>Almost continuous: 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perioral: 2</td>
<td>Sporadic: 2</td>
<td></td>
<td>Face: 1</td>
<td>Sporadic: 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Face: 2</td>
<td>In clusters: 5 (4-30; 20)*</td>
<td></td>
<td>UL: 11</td>
<td>In clusters: 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UL: 6</td>
<td></td>
<td></td>
<td>LL: 7</td>
<td>(4-120; 9)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LL: 4</td>
<td></td>
<td></td>
<td>Axial: 3</td>
<td></td>
</tr>
<tr>
<td>Tonic muscle activation</td>
<td>3 (21%)</td>
<td>UL: 1</td>
<td>Duration: 1-10 s (mean: 5 s)</td>
<td>19 (41%)</td>
<td>Face: 1</td>
<td>Duration: 1-30 s (mean: 4 s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LL: 3</td>
<td></td>
<td></td>
<td>UL: 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LL: 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Axial: 1</td>
<td></td>
</tr>
<tr>
<td>Automatisms</td>
<td>2 (14%)</td>
<td>Oro-facial: 1</td>
<td>Almost continuous: 1</td>
<td>8 (17%)</td>
<td>Oro-facial: 4</td>
<td>Almost continuous: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UL: 1</td>
<td>Sporadic: 1</td>
<td></td>
<td>LL: 2</td>
<td>Sporadic: 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye-deviation</td>
<td>2 (14%)</td>
<td>Almost continuous: 1</td>
<td>4 (9%)</td>
<td></td>
<td>Almost continuous: 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Sporadic: 1</td>
<td></td>
<td>1</td>
<td>Sporadic: 3</td>
</tr>
</tbody>
</table>

Epileptiform discharges

Clinical suspicion of NCSE

- Frequency > 2.5 c/s
- Frequency ≤ 2.5 c/s

Continuous (quasi) rhythmic delta/theta-activity, with frequency > 0.5 c/s

Typical spatiotemporal evolution

Subtle clinical ictal phenomena during EEG-patterns mentioned above

IV AED

EEG and clinical improvement after IV AED

NCSE
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Epileptiform discharges

Frequency > 2.5 c/s

Epileptiform discharges

Frequency ≤ 2.5 c/s

Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

Clinical suspicion of NCSE

Typical spatiotemporal evolution

Subtle clinical ictal phenomena during EEG-patterns mentioned above

IV AED

EEG and clinical improvement after IV AED

EEG without clinical improvement after IV AED

No other secondary criteria (grey box) is fulfilled

NCSE

Possible NCSE

Fluctuation without definite evolution
Three or more changes, not more than 1 min apart, in frequency (by at least 0.5 per s) or three or more changes in location (by at least one standard interelectrode distance), but not qualifying as evolving.

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• How accurate is this?

• Does it work in all the different types of NCSE patients?

• None of the NCSE-criteria have been clinically validated before.
**Inter-rater agreement for the Salzburg criteria:**

<table>
<thead>
<tr>
<th></th>
<th>All patients</th>
<th>Validation group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salzburg criteria</td>
<td>0.87 (0.81–0.92)</td>
<td>0.81 (0.71–0.89)</td>
<td>0.94 (0.87–0.98)</td>
</tr>
</tbody>
</table>

*Table 2: Inter-rater agreement (κ [95% CI])*

**Diagnostic accuracy of the Salzburg EEG criteria for non-convulsive status epilepticus: a retrospective study**

Markus Leitinger, Eugen Trinka, Elena Gasdolla, Alexandra Rohracher, Godon Kidda, Eriska Qerama, Julia Höffer, Alexander Hess, Georg Zimmermann, Giorgi Kochukhidze, Judith Doderberger, Patrick B Langthaler, Sándor Beniczky

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**Diagnostic accuracy of the Salzburg criteria:**

<table>
<thead>
<tr>
<th>Patients (n)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>97.7</td>
<td>89.6</td>
<td>92.5</td>
</tr>
</tbody>
</table>

- Sliding window: 10 seconds
- Positives = NCSE + Possible NCSE

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The Salzburg criteria for NCSE:
- have high diagnostic accuracy
- excellent inter-rater agreement
- suitable for implementation in clinical practice.
Next (2020?) edition of ACNS terminology for CIPs

- Will include electrographic seizures and non-convulsive status epilepticus
- All-in-one paper 😊

- Largely based on Salzburg criteria- though with some minor modification

Seizures:
1. Electrographic:
   a. EDs ≥ 2.5 Hz (≥ 25 discharges /10s; ≥ 10s) or
   b. Evolving pattern (≥ 10s)
3. Electroclinical:
   a. Time-locked clinical correlate (any duration) OR
   b. EEG and clinical improvement with an IV-AEDs
   (Only EEG improvement = possible NCSz /NCSE)

Status epilepticus
a. > 10 minutes or
b. total duration of >20% (12 min) of any 60-minutes
• **Diagnostic dichotomy: SE = yes / no**

• **Patterns that indicate significantly higher seizure-risk**
  - LPDs: the highest association with seizures
    - regardless of frequency
    - association was greater when the Plus modifier was present
  - LRDA & GPDs were associated with seizures when:
    - Frequency ≥ 1.5 Hz, or
    - Plus modifier was present
  - Increased prevalence / frequency = increased seizure-risk

*CEEGs from 4772 critically ill patients
Rodriguez Ruiz et al, JAMA Neurol 2017*
<table>
<thead>
<tr>
<th>Channel</th>
<th>Signal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fpz-10</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-11</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-20</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-30</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-40</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-50</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-60</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-70</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-80</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-90</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
<tr>
<td>Fpz-00</td>
<td>ECG</td>
<td>ECG Channel</td>
</tr>
</tbody>
</table>

**Contact Information:**

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- Sandor.Beniczky@aarhus.rm.dk
**Brief potentially Ictal Rhythmic Discharges (BIRDs)**

- Focal or generalized, sharply contoured rhythmic activity $> 4$ Hz
  - Brief: 0.5→10s, but at least 6 cycles
  - Not consistent with a known normal pattern or benign variant

- BIRDs – associated with seizures (BIRDs: 75% vs. No-BIRDs: 25%)

Yoo et al., JAMA Neurol 2014

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Monitoring of therapeutic effect: Anesthetics / therapeutic coma

- Increased $\beta$ power
- Increased $\Delta$ power
- Declining $\beta$
- Suppressions with increasing/decreasing duration
- Bursts with decreasing/increasing duration
- Isoelectric EEG

Induction

Withdrawal

Seizure suppression

Burst-suppression?
- Bursts (up to 5s) + suppression (<10 $\mu$V; 8-12 s)
- Suppression (Isoelectric EEG)
Monitoring of brain function during withdrawal of anesthetics / after SE

- Do seizures / SE return?
- Emergence of EEG patterns indicating increased seizure-risk?

- CAVEAT: Paradoxical effect of drug-withdrawal
  - Anesthetic wean → hyperexcitability
  - Successful wean despite emergence of Ictal–Interictal EEG patterns during the weaning (Alvin et al., Neurocrit Care 2018)

Case 1

- 72-yo male
- Thalamic hemorrhage and right hemiparesis
- Three days after admission: altered consciousness → GCS=10
- CT: no new lesion
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Epileptiform discharges

- Frequency > 2.5 c/s
- Frequency ≤ 2.5 c/s

Clinical suspicion of NCSE

- No epileptiform discharges
- Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

Typical spatiotemporal evolution

- Subtle clinical ictal phenomena during EEG-patterns mentioned above

IV AED

- EEG and clinical improvement after IV AED
- EEG without clinical improvement after IV AED

Fluctuation without definitive evolution

- No other secondary criteria (grey box) is fulfilled

NCSE

Possible NCSE

The whole EEG recording is abnormal. The EEG criteria have to be continuously present for at least 10 s.

Patients with known epileptic encephalopathy: in addition, one of the following should be fulfilled too:

i. Increase in prominence or frequency of the features mentioned above, when compared to baseline, and observable change in clinical state

ii. Improvement of clinical and EEG features with IV AEDs
Case 2

- 78-yo female
- 2 years prior to admission: ischemic stroke (right MCA), palsy on the left side.
- One day prior to admission: agitated → LOC → Periods of 30-90 seconds with discrete jerks in the left upper arm
- CT: no new lesion
Epileptiform discharges

- Frequency > 2.5 c/s
  - Typical spatiotemporal evolution
  - Subtle clinical ictal phenomena during EEG-patterns mentioned above

- Frequency ≤ 2.5 c/s
  - Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s
  - Clinical suspicion of NCSE

- No epileptiform discharges
  - No other secondary criteria (grey box) is fulfilled
  - EEG without clinical improvement after IV AED
  - Fluctuation without definitive evolution

Possible NCSE

NCSE

The whole EEG recording is abnormal. The EEG criteria have to be continuously present for at least 10 s.

Patients with known epileptic encephalopathy: in addition, one of the following should be fulfilled too:

i. Increase in prominence or frequency of the features mentioned above, when compared to baseline, and observable change in clinical state
ii. Improvement of clinical and EEG features with IV AEDs
Case 3

- 67-yo male
- Cardiac arrest
- Three days after return of spontaneous circulation
Epileptiform discharges

- Frequency > 2.5 c/s
- Frequency ≤ 2.5 c/s

Clinical suspicion of NCSE

- Typical spatiotemporal evolution
- Subtle clinical ictal phenomena during EEG-patterns mentioned above

No epileptiform discharges

- Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

IV AED

EEG and clinical improvement after IV AED

Fluctuation without definitive evolution

EEG without clinical improvement after IV AED

No other secondary criteria (grey box) is fulfilled

NCSE

Possible NCSE

The whole EEG recording is abnormal. The EEG criteria have to be continuously present for at least 10 s.

Patients with known epileptic encephalopathy: in addition, one of the following should be fulfilled too:

i. Increase in prominence or frequency of the features mentioned above, when compared to baseline, and observable change in clinical state

ii. Improvement of clinical and EEG features with IV AEDs
Case 4

- 71- yo male
- Cardiac arrest
- Three days after return of spontaneous circulation
- GCS=8; Periods with discrete jerks
Case 5

- 82-yo female
- Cardiac arrest
- Three days after return of spontaneous circulation
- Myoclonic jerks
- Propofol: jerks stopped
Epileptiform discharges

Frequency > 2.5 c/s

Frequency ≤ 2.5 c/s

Continuous (quasi)rhythmic delta/theta-activity, with frequency > 0.5 c/s

Clinical suspicion of NCSE

No epileptiform discharges

Typical spatiotemporal evolution

Subtle clinical ictal phenomena during EEG-patterns mentioned above

IV AED

EEG and clinical improvement after IV AED

EEG without clinical improvement after IV AED

Fluctuation without definitive evolution

NCSE

Possible NCSE

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