EEG monitoring in critical care

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History: EEG

EEG recording: technique

History:
EEG System for recording EEG (1926)
Hans Berger (1873 - 1941) – The discoverer of human EEG.

Role of EEG in common clinical practice

Clinical role of EEG in epilepsy
• Diagnosis and management of the epilepsies
• Differentiate generation of focal epilepsy
• Define specific epileptic syndromes
• Pre-surgical localisation
• Monitor brain function in patient with alteration of consciousness

Clinical role of EEG in common clinical practice

EEG 32 channel

Neurophysiologic basis of EEG

• Repetitive waves generated by pyramidal cells in the cerebral cortex.
• Synaptic potentials: response of cortical cells EPSP and IPSP
• Frequencies and sizes of the thalamic D/C are determined by the arrangement of excitatory and inhibition interconnection and the neuron of thalamic cells

• Repe,,ve waves generated by pyramidal cells in the cerebral cortex.
• Synap,c poten,als:- response of cortical cells EPSP and IPSP
• Freq,encies and sizes of the thalamic D/C are determined by
  • the arrangement of excitatory and inhibition interconnection
  • and the neuron of thalamic cells
Cerebral cortex: Nissel Stain

EEG: Synchronization of post-synaptic potential (PSPs)
Geometry of pyramidal cell and its thalamo-cortical input result in it behaving as dipole with electrical field perpendicular to the surface
PSPs = EPSP and IPSP
Record different potential

Principles of dipole layer
Physical relationships of cortical dipole layers and scalp potentials.

Equivalent Current Dipole (ECD)

Radial dipole in the crown Tangential dipole in the sulcus

Interictal spikes (Right occipital lobe epilepsy)
EEG waveform

- Delta rhythm <4 Hz
- Theta rhythm 4-7 Hz
- Alpha rhythm 8-13 Hz
- Beta rhythm >13 Hz
- Gamma rhythm >30 Hz
- > 1 200 Hz

Types of EEG recording

- Routine Recording
  - analog, digital
  - with computerized analysis & brain electrical activity mapping
- Long-term monitoring
At present

- Analysis and interpretation of the EEG is both science and an art.

EEG 8 channel

EEG 32 channel

EEG 64-128 channel (video)

EEG 64-128 channel
EEG in critical care monitoring

Continuous EEG (cEEG) in critical care

- Patient with alteration of consciousness in ICU
- Epilepsy e.g. status epilepticus
- Nonconvulsive status epilepticus (NCSE) 20-40% in neuro ICU, patient with comorbidity, post anoxic encephalopathy

Ictal EEG

Ictal EEG
Why do cEEG in ICU

• To detect seizures
• Defining nature of spell, including autonomic
• Quantifying seizures
• Detecting hypoxia / ischemia
• Prognostication
• Other

How common are nonconvulsive seizures

• Neuro ICU
  - 24% of 124 patients had non-convulsive seizure, 76% of those with had NCSE (Jordan 1992)
  - 18% of 105 patients had NCSE (Pandian 2004)
• Overall
  - 37% of 168 patients undergoing urgent EEG for altered mental status (Pihlanto 1994)
  - 16% of 56 patients with severe head trauma (Vesa 1997)
  - 8% of 236 comatose patient ICU patient with no evidence of seizure (Tawee 2000)
  - 18% of consecutive patients undergoing CEEG monitoring - 10% NCSE (Claassen 2004)

Which ICU patients should be monitored?

• Any patient with impaired consciousness either in the setting of acute brain injury or without clear explanation is appropriate for cEEG monitoring to detect nonconvulsive seizures.

How long should patient be monitored?

• 24 hrs if not comatose
• 48 hrs or more if comatose
• Longer if periodic discharges, withdrawing sedation or AEDs
• Routine EEG is not adequate in critically ill patients

Digital video-EEG monitoring in the Neurological-Neurosurg ICU

• 105 patients
• All patients had routine EEG for at least 30 minutes at start of study
• Mean duration of DVEEG 2.9 days

Pandian AJD et al. Arch Neurol July 2004
Digital video-EEG monitoring in the Neurological-Neurosurg ICU

<table>
<thead>
<tr>
<th>Clinical events</th>
<th>EEG seizure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine EEG</td>
<td>21%</td>
</tr>
<tr>
<td>cDVEEG</td>
<td>40%</td>
</tr>
<tr>
<td>P value</td>
<td>0.01</td>
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</tbody>
</table>

Criteria for non-convulsive seizure

- Any pattern lasting at least 10 s satisfying any one of the following three primary criteria
- **Primary criteria**
  - Repetitive generalized or focal spikes, sharp-waves, spike-and-wave complexes at ≥3/s
  - Repetitive generalized or focal spikes, sharp-waves, spike-and-wave or sharp-and-slow wave complexes at <3/s and the secondary criterion
  - Sequential rhythmic, periodic, or quasi-periodic waves at 1/s and unequivocal evolution in frequency (gradually increasing or decreasing by at least 1/s, e.g. 2–3/s), morphology, or location (gradual spread into or out of a region involving at least two electrodes).

Semiological spectrum of nonconvulsive seizures and nonconvulsive status epilepticus

<table>
<thead>
<tr>
<th>Negative symptoms</th>
<th>Positive symptoms</th>
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</thead>
<tbody>
<tr>
<td>Anorexia</td>
<td>Agitation/irritation</td>
</tr>
<tr>
<td>Confusion</td>
<td>Somnolence</td>
</tr>
<tr>
<td>Anosmia</td>
<td>Blinking</td>
</tr>
<tr>
<td>Antisocial behavior</td>
<td>Nystagmus/eye deviation</td>
</tr>
<tr>
<td>Convulsion</td>
<td>Delirium</td>
</tr>
<tr>
<td>Coma</td>
<td>Perseveration</td>
</tr>
<tr>
<td>Convulsive</td>
<td>Delusions</td>
</tr>
<tr>
<td>Lethargy</td>
<td>Psychosis</td>
</tr>
<tr>
<td>Staring</td>
<td>Tremor/ataxia</td>
</tr>
</tbody>
</table>

EEG pattern frequently in coma and unresponsiveness

- Electrographic seizures
- Potential epileptiform patterns: Periodic lateralized epileptiform discharges (PLEDs)
  - PLEDs
  - GPLEDs
  - Bi-PLEDS, PLEDs Plus
  - Suppression-burst

EEG pattern frequently in coma and unresponsiveness

- Likely not epileptiform patterns
- Frontal intermittent rhythmic delta activity (FIRDA)
- Uncertain if epileptiform or not
  - Stimulus-induced rhythmic, periodic or ictal discharges (SIRPDs)
  - Triphasic waves
NCSE with generalized epileptic discharges. This 55-year-old man with AIDS presented with fluctuating mental status change and was later found to have cryptococcal meningitis.

NCSE with focal ictal activity. This 39-year-old woman with primary CNS lymphoma presented with a cluster of generalized convulsions, but several hours later was poorly responsive. A right parieto-temporal hemorrhage was demonstrated.

**Electrographic seizures**

- Rhythmic discharges or spike and wave pattern with definite evolution in:
  - Frequency
  - Location
  - Morphology
  - Evolution in amplitude alone did not qualify

**Electrographic seizure:** left centro-parietal rhythmic ictal discharges

**Periodic lateralized epileptiform discharges (PLEDs)**

- Repetitive sharp wave, spikes or sharply contoured wave at regular or nearly regular intervals

- Without clear evolution in frequency or location

- PLEDs
  - GPLEDs
  - Bi-PLEDs
PLEDs Proper

- Repetitive sharp wave, spikes or sharply contoured wave at regular or nearly regular intervals
- Lateralized PLEDs
- Five classes:
  - Class I: Metronomic periodicity
  - Class II: Intermittently
  - Class III: Continuously
  - Class IV: PLEDs Plus with brief rhythmic discharges
  - Class V: PLEDs Plus with prolonged rhythmic discharges

Class I
Class II
Class III
Class IV
Class V

Classical PLEDs lateraled right cerebral hemisphere

Right central periodic lateralizing epileptiform discharges (PLEDs) in a 42-year-old man with intraparenchymal and intraventricular hemorrhage.

PLEDs proper involving the right hemisphere in a 74-year-old woman, 11 days following cardiac arrest.
GPLEDs

- Repetitive sharp wave, spikes or sharply contoured wave
- PLEDs occurring bilaterally and synchronous
- No consistent lateralization

Bi-PLEDs

- Repetitive sharp wave, spikes or sharply contoured wave
- PLEDs occurring bilaterally
- But independently and asynchronously

Bi-PLEDs Plus

- PLEDs-plus were distinguished morphologically from PLEDs by having
  - Low-voltage rhythmic discharges associated in time and spatial distribution with the epileptiform discharges
LEDs-plus in an 84-year-old woman following an acute left occipital stroke. Left hemisphere periodic discharges of variable periodicity and associated with low-amplitude rhythmic faster activity.

PLUDs Plus

Generalized triphasic waves in a 79-year-old man with renal failure. Note the prominent second positive phase and the anterior–posterior lag.

Triphasic waves

Ambiguous, asymmetric triphasic waves in a patient with subarachnoid hemorrhage.

SIRPIDs: Stimulus induced rhythmic periodic or ictal discharges

- Periodic, rhythmic or ictal appearing discharges that were consistently induced by alert stimuli
- 150 consecutive patients undergoing cEEG during a 9-months period
  - 33 patients with SIRPIDs 22%
  - 18 with unequivocal ictal EEG patterns
  - Compared those with and without SIRPIDs

Hirsch 2004
SIRPIDs: and other equivocal EEG patterns in stuporous/comatose patients

- Causing neuronal injury?
- Contributing to impaired mental status
- Need treatment?

Hirsh 2004

The Ictal-Interictal Injury Continuum

Chong & Hirsh 2005

cEEG in neuronal ischemia

<table>
<thead>
<tr>
<th>CBF level (ml/100gm/min)</th>
<th>EEG change</th>
<th>Degree of Neuronal injury</th>
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<tbody>
<tr>
<td>35-70</td>
<td>Normal</td>
<td>No injury</td>
</tr>
<tr>
<td>25-35</td>
<td>Loss of fast beta frequency</td>
<td>Reversible</td>
</tr>
<tr>
<td>18-25</td>
<td>Slow of background to 5-7 Hz theta</td>
<td>Reversible</td>
</tr>
<tr>
<td>12-18</td>
<td>Slowing to 1-4 Hz delta</td>
<td>Reversible</td>
</tr>
<tr>
<td>&lt; 8-10</td>
<td>Suppression of all frequency</td>
<td>Neuronal death</td>
</tr>
</tbody>
</table>

cEEG in Subarachnoid hemorrhage

- Review of 40 consecutive SAH, EEG change preceded other clinical sign when vasospasm was about to occur
- EEG change preceded PE change by as much two days
- Prompt intervention based on EEG may shorten ICU stay and prevent long-term complication
cEEG in Subarachnoid hemorrhage

J. Claassen et al 2004

Increase in delta and decrease in faster activity, more pronounced on the right

Continuous EEG (cEEG) monitoring could benefit stroke patients as it may detect changes in brain function in a possible reversible state, allowing early intervention

• Van Putten and Tavy, Stroke 2004
• 21 cases with acute stroke using cEEG 6 channels
  • Used a mean asymmetry measure
  • 0 = perfect symmetry, 1 max asymmetry

Quantitative EEG

cEEG: Brain symmetry index

BSI from 3 different patients with carotid endarterectomy. Horizontal bars indicate clamping period
New software qualitative cEEG

Automatic Seizure Detection

- Epileptic seizures unpredictable event, may occur only rarely, hence the requirement for long-term video-EEG monitoring in the diagnosis of epilepsy
- A clinical neurophysiologist can periodically review the EEG recordings and analyze the seizures that may have occurred during the monitoring session
- However, reviewing a continuous EEG recording lasting several days can be a very time-consuming process
Automatic Seizure Detection

• In practice, patients can indicate that a seizure occurs using alarm buttons, so that recording sections surrounding the event can be analyzed.

• Unfortunately, many cases are not aware of seizures.

• An automated seizure detection system can thus be of great use in identifying EEG sections that need to be reviewed.

  • Seizure, spikes detection

Spikes detection

Automatic Seizure Detection

• Methods for automatic detection of seizures rely on the identification of various patterns such as an increase in amplitude, sustained rhythmic activity, or EEG flattening.

• Various algorithms have been developed based on spectral or wavelet features, amplitude relative to background activity, and spatial context. These features can then be combined in a decision tree, an artificial neural network, or a Bayesian framework to identify the occurrence of seizures.

• It is crucial for seizure detection systems to have a high sensitivity to seizures.

Automatic Seizure Detection

• In contrast to seizure detection systems applied on long-term recordings, seizure warning systems have been developed to detect seizures in real-time as soon as possible after their onset.

  • A small detection delay could allow patients to take appropriate measures, such as:
    • Sitting down to avoid injuries, even before they themselves are aware that a seizure has begun.
    • It could also be possible to administer treatment such as electrical stimulation or drug injection to stop the evolution of the seizure.

• Many types of seizures for which very few clinical signs are observable, but for better diagnosis could be performed by questioning patient early during seizure.

  • An early detection could also be useful for the purposes of an ictal SPECT scan, which should be performed as close as possible to the onset of the seizure.

  • More important for seizure warning system to have a high specificity rather than a high sensitivity.
In conclusion

- NCSE is common than expected, increasing frequency, both in ambulatory patients with cognitive change, and even more so in the critically ill
- Majority of seizures that occur in the critically ill and can only be diagnosed with EEG monitoring
- cEEG should be used as routinely in patient in critically with unexplained transient loss of consciousness
- Varieties of EEG pattern noted, further study should be done to identify the poor outcome and the specific EEG patterns

In conclusion

- Evidence for and against NCSEs causing neuronal injury, and attempts to develop a rational approach to the diagnosis and management of these seizures, particularly in encephalopathic population
- cEEG will also useful to evaluate neuronal injury in acute stroke, monitoring in SAH to early detection and prevent complication