From Spikes to Ripples: The Evolving and Expanding Role of Electroencephalography in the Diagnosis and Treatment of Epilepsy

December 3, 2011

Gregory K. Bergey, M.D.
Johns Hopkins University School of Medicine

American Epilepsy Society | Annual Meeting
# Disclosures

*(Last 12 months)*

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Learning Objectives

• At the conclusion of this presentation attendees will understand the early development and applications of EEG.

• At the conclusion of the presentation attendees will appreciate the current utility of EEG and potential future uses.
Before Hans Berger: Precursors to the Human EEG

• Caton (1842-1926) recorded electrical activity from brain cortex of living animals using galvanometer (“electrical current of grey matter”)

• Pravdic-Neminsky (1879-1952) “electrocerebrogram,” recorded electrical activity from the animal brain (1912).

• Kauffman – recorded experimentally induced seizures in dogs (1912).
Hans Berger: The Father of the Human EEG

• Professor of Psychiatry and later rector of the University of Jena
• Interested in the physical basis of psychic phenomena
• First succeeded in recording the electrical activity of the brain through the skull – by adding a vacuum tube as an amplifier to the string galvanometer in 1924 - “Elektrenkephalogramm”.
• Recorded from normal controls and brain injured.
Über das Elektrenkephalogramm des Menschen.

Von

Professor Dr. Hans Berger, Jena.

(Mit 17 Textabbildungen.)

(Eingegangen am 22. April 1929.)


Catton hat bereits 1874 Versuche an Kaninchen- und Affenhirnen veröffentlicht, bei denen unpolarisierbare Elektroden entweder an der Oberfläche beider Hemisphären oder an eine Elektrode an der Hirnrinde, die andere an der Schädeloberfläche angelegt worden waren. Die Ströme wurden zu einem empfindlichen Galvanometer abgeleitet. Es fanden sich deutliche Stromschwankungen, die namentlich beim Erwachen aus dem Schlaf und beim Eintritt des Todes sich verstärkten, nach dem Tode schwächer wurden und dann vollständig schwanden. Schon Catton konnte nachweisen, daß starke Stromschwankungen bei Belichtung des Auges sich an der Hirnrinde einstellten, und er sprach bereits die Vermutung aus, daß unter Umständen diese Rindenströme zur Lokalisation innerhalb der Hirnrinde verwendet werden könnten.

Fleisch von Marrow hat im Jahre 1883 zuerst beobachtet, daß bei verschiedenen Tieren bei Ableitung von zwei symmetrisch gelegenen...
Hans Berger: The Father of the EEG

- Described two rhythms – *alpha* and *beta*
  - Demonstrated that wave characteristics could be used as index of brain disease
  - Described reactivity of alpha rhythm
- First described the electroencephalogram of an epileptic patient
- At first ignored and even ridiculed, his discovery was lauded in 1937 at a symposium with Adrian in Paris.

*Berger’s First EEG – single channel with time code*
Early Applications of the EEG

- Determination of normal background rhythms
- Detection of generalized and focal (e.g. slowing) abnormal activity
- Detection of epileptiform activity (spikes, spike-wave discharges)
- Used widely in neurologic evaluations for headaches, tumors, stroke, in the absence of modern imaging techniques
Epilepsy Surgery: Increased Need for Seizure Localization

• Earliest surgery (Horsley, Penfield) did not rely much on EEG seizure localization
Early Use of EEG for Seizure Localization

3 channel EEG – a major advance by Albert Grass in 1935
Early Use of EEG for Seizure Localization

Berger has demonstrated the value of certain electrical signs of brain function which can be obtained from electrodes placed across the head—from forehead to occiput. The electro-encephalogram taken in this manner has been considered for the brain as analogous to the electrocardiogram for the heart. Abnormal brain potentials were found to accompany various pathologic processes which caused gross disturbances in the function of the entire cortex or of regions so located between the electrodes that they made their activity apparent in the composite picture thus obtained. Berger reported a case in which slow waves could be picked up with one electrode directly over a tumor in the central part of the head, even though the electro-encephalogram from the forehead-occiput leads appeared normal. In a case of dementia paralytica in which there were periodic spasms of clonic twitches of the right arm and hand he obtained large seizure waves from bipolar leads over the left precentral region. Fairly normal activity was observed from the right precentral region. Andrews and one of us

1938
Later Applications of the EEG

- Increased numbers of scalp electrodes
- Delineation of partial vs generalized epileptiform activity
- Identification of epileptic syndromes which incorporate EEG patterns (e.g. petit mal, Lennox-Gastaut)
Early Use of EEG for Seizure Classification

Jasper HH and Hawke WA
Arch Neurol Psych 1938; 39:885-901

Gibbs FA, Gibbs EL, Lennox WG. Arch Neurol Psych 1939;41:1111-1116
Frederic A Gibbs (1903-1992)

- Educated at Yale and Johns Hopkins (1929)
- Studied with William G. Lennox
- Married Erna Leonhardt (Lennox’s technician) in 1930
- Published first edition of Atlas of EEG in 1941 (year of Berger’s death)
- Awarded (with William Lennox) Albert Lasker Award in 1951
Eight channel EEG from Albert Einstein during exercise where he is asked to think about the theory of relativity

Life Magazine April 9, 1951
Current State of Scalp EEG

- Use for non-epilepsy diagnoses appropriately diminished by the advances in neuroimaging
- Digital storage
- Ready reformatting
- Remote reading over networks
- Spike and seizure detection software
- Spike and frequency mapping
Continuous Video-EEG Monitoring

• Evolution of the epilepsy monitoring unit (EMU)
  – For diagnosis (e.g. epileptic vs nonepileptic events)
  – For presurgical evaluations

• Outpatient video-EEG

• Ambulatory EEG
Continuous Video-EEG Monitoring

• Earliest arrays used paper and ink recording and unsophisticated video-EEG correlation

• Later digital + VCR technology

• Later digital video with digital EEG
Components of an EMU

• Dedicated unit staffed with technologists and nurses
• Capability for continuous video and EEG monitoring and storage of data
• Various spike and seizure detection software
• Epilepsy fellows
Continuous Video-EEG Monitoring

• Current digital technology for video and EEG
• Excellent synchronization of video and EEG
• Large storage demands
  – Video (5 GB for 24 hr)
  – Directly related to channel number, sampling frequency (e.g. 24 hrs of 124 channels sampled at 2000 Hz requires 20 GB without video)
Continuous Video-EEG Monitoring

• Expansion outside EMU
  – NICU monitoring (seizures, hypothermia)
  – NCCU monitoring
    • Treatment of refractory status epilepticus
    • Detection and treatment of subtle status
Evolution of Intracranial Monitoring

- Need for improved seizure localization in patients with inconclusive scalp ictal recordings
- Need for improved function mapping of eloquent cortex
  - Foerster and Penfield began functional mapping in 1920s

Penfield and Roberts 1959
Evolution of Intracranial Monitoring

- Depth electrode arrays – 1960s
- Subdural grid arrays – 1970s
Evolution of Intracranial Monitoring

• Increased numbers of channels with intracranial arrays
• Increased sampling frequencies for higher frequencies
• Increased storage needs
Recent Applications of the EEG

- High density scalp arrays
- Dipole localization
- Spike mapping
- fMRI
- Functional mapping
Future applications (the future is now)

• High frequency and ultrahigh frequency recording
• Functional mapping without cortical stimulation
• Therapeutic responsive stimulation triggered by EEG activity
• Brain/machine; brain body interface
Future applications (the future is now)

• High frequency and ultrahigh frequency recording

Jouney CC and Bergey GK, unpublished
EEG Terminology

• Old terminology – alpha, beta, delta, theta, spikes

• New terminology
  – Irritative zone (IZ)
  – Seizure onset zone (SOZ)
  – Epileptogenic zone (EZ)
EEG Terminology

- New terminology
  - Gamma (30-80 Hz), high gamma (80-150 Hz)
  - High frequency oscillations (HFO; 40-500 Hz)
  - Ripples (80-250 Hz), fast ripples (250-500 Hz)
Future applications (the future is now)

- Functional mapping without cortical stimulation

Figure 4: (a) Intraoperative image of a high-density 4 mm electrode grid. (b) ERSP analysis of nine electrodes. Responses are locked to hearing phonemes, only significant changes in power are shown ($z$-test, $p<0.05$). (c) Single trial HG power traces of two adjacent electrodes 4 mm apart.

Flinker et al. 2010 J Neurosci

Functional-anatomic and temporal specificity of high gamma augmentation
Future applications (the future is now)

- Responsive stimulation triggered by epileptiform EEG activity

Seizure activity triggers detector early in seizure. Closed-loop therapy delivered and seizure terminated.
Impact on Clinical Care

• The EEG remains important in the evaluation of patients with seizure disorders.

• Development of digital technology has led to dramatic improvements in video-EEG recording technology.

• New recording arrays and high frequency sampling hold promise for improving presurgical evaluations.

• Closed loop systems offer promise for advances in therapeutic neurostimulation.
“The EEG is still useful.”

William Landau, M.D.
September 23, 2010
San Luis Potosi, Mexico