THE ELECTROENCEPHALOGRAM (EEG) IN ANAESTHESIA

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Learning Outcomes

To be able to describe:

• The basic physiology and waves of the EEG

• How the EEG changes under general anaesthesia

• Factors that influence the EEG (other than anaesthetic agent concentration)

• Use and limitations of processed EEG Indices
**EEG: Definition**

“Electrical activity of the brain plotted over time”

- Voltmeter for the cerebral cortex
- Measured in microvolt range (typically scale of 5-10 µV)
- Extracellular potentials or Local field potentials
- $1 \, V = 10^6 \, \mu V = 1000000 \, \mu V$
  $= 10^3 \, mV = 1000 \, mV$
EEG Electrodes

Bipolar
- Voltage measured between 2 electrodes
- Most commonly type used in clinical EEG monitors

Referential Montage
- Multiple electrodes all with reference to a single common electrode
Fourier Analysis:
The complex wave (upper) can be decomposed into the sum of the three simple sine waves (lower).
Main Characteristics of EEG Waves

Amplitude

Frequency

Power = amplitude squared
# Frequency Changes under GA

<table>
<thead>
<tr>
<th>Wave</th>
<th>Frequency Range (Hz)</th>
<th>Depth of GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>100 - 30</td>
<td>Awake</td>
</tr>
<tr>
<td><strong>Beta</strong></td>
<td>30 - 12</td>
<td>‘Deep’ GA</td>
</tr>
<tr>
<td><strong>Alpha</strong></td>
<td>12 - 8</td>
<td></td>
</tr>
<tr>
<td><strong>Theta</strong></td>
<td>8 - 4</td>
<td></td>
</tr>
<tr>
<td><strong>Delta</strong></td>
<td>4 - 1</td>
<td></td>
</tr>
<tr>
<td>Burst Suppression</td>
<td>“Brain asystole”</td>
<td></td>
</tr>
</tbody>
</table>
Power (amplitude) changes under GA

- **Beta**
  [12-30 Hz]

- **Alpha**
  [8-12 Hz]

- **Theta**
  [4-8 Hz]

- **Delta**
  [1-4 Hz]
Beta waves Predominate

“alpha riding on delta”

Burst Suppression
Burst Suppression

- Seen in deep anaesthesia and pathological brain states
  - Hypoxia
  - Brain trauma
  - Hypothermia
  - Severe developmental conditions

- Associated with post op delirium
- ??? Harmful
Spectrograms
Numerical Methods to describe the EEG

- **Spectral Edge Frequency (SEF95)**
  - Frequency below which 95% of the total power lies

- **Burst Suppression Ratio 0 -100**
  - Percentage of each minute spent in burst suppression

- **Proprietary Indices (typically 0 to 100)**
  - BIS / E Entropy / Narcotrend
What else affects the EEG?

• Agent used
  • Volatiles and Propofol similar
  • Different patterns with nitrous, ketamine, xenon and alpha 2 agonists

• Age (or more accurately how elderly the brain is)

• Artefacts

• (EMG)
Changes with different agents

Propofol

Sevoflurane

Ketamine

Dexmedetomidine
Changes with Age

Propofol general anaesthesia age spectrogram

Frequency (Hz)

Age (yrs)

Power (dB)
Advantages of EEG Monitoring

Related to Awareness:

- Decreased incidence of awareness
- Decreased severity of awareness when it does occur
- Ability to monitor continuously from induction to emergence (cf. end tidal gas monitoring)

Recommended by:
- AAGBI guidelines* for TIVA + NMB.
- NICE: recommended as an ‘option’ for ‘higher risk’ patients and TIVA
Decision Tree

General Anaesthesia

- YES: Neuromuscular blocking drug?
  - YES: TIVA as primary anaesthetic?
    - YES: Set BIS alarm
    - NO: Potent volatile as primary anaesthetic?
      - YES: Set ETAC alarm
  - NO: Movement might be best indicator of awareness

- NO: Set ETAC alarm
Advantages of EEG Monitoring (2)

Non-Awareness Advantages:

• Reduced rates of post op delirium
• Shorter recovery times (time to extubation and time in PACU)
• Decreased PONV

• Identifying at-risk patients
  • ‘Vulnerable’ brains: elderly phenotype, not just old
  • But is this risk modifiable?
EEG Indices: Limitations

Numbers may not reflect actual hypnotic state

• Interference: EMG / ECG / electrical / diathermy

• Often combined with EMG activity, therefore affected by neuromuscular blocking agents

• Older patients BIS overestimated by ~ 3.5 points

• Ketamine / nitrous oxide give higher numbers
EEG Indices: Limitations (2)

- Slow to respond to changes in patient state (lag of ~25 s)
- No better than using an ET gas alarm of 0.7-1.3 Mac
- BIS is a proprietary algorithm
- Reduce the EEG to a single value
  - Loose valuable Information: “Like summarising to ECG just using heart rate”
Controversies: The ‘Triple Low’

MAP < 75 mmHg, BIS < 45, and MAC < 0.8

Sessler DI, Sigl JC, Kelley SD, et al. Hospital stay and mortality are increased in patients having a “triple low” of blood pressure, low bispectral index, and low minimum alveolar concentration of general anesthesia. Anesthesiology. 2012;116:1195-1203
Controversies: Low BIS and Outcomes

**Malefactor**
- EEG suppression or low BIS reflect direct anaesthetic toxicity
- Worse outcomes for all patients with increasing duration of deep anaesthesia

**Mediator**
- Anaesthetic toxicity with EEG suppression or low BIS is mediated by patient factors
- Adverse outcomes occur when patients have both deep anaesthesia & underlying pathology

**Mirror**
- EEG suppression or low BIS reflect both deep anaesthesia & patient factors
- Those with underlying pathology are prone to EEG suppression, but deep anaesthesia does not cause bad outcomes
Summary

• With increasing anaesthetic dosing the EEG:
  • Shows an overall decrease in frequency
  • The power (amplitude) increases
  • Eventually results in burst suppression

• The EEG is affected differently by:
  • Different anaesthetic agents
  • By increasing age

• Use of the pEEG may help prevent awareness and reduce other negative post-op outcomes (Controversial)
References

Hagihira S. Changes in the electroencephalogram during anaesthesia and their physiological basis. BJA 2015
https://doi.org/10.1093/bja/aev212

Kim et al Role of electroencephalogram oscillations and the spectrogram in monitoring anaesthesia BJA Education 2020
https://doi.org/10.1016/j.bjae.2020.01.004

https://icetap.org/

https://eegforanesthesia.iars.org/
SBA QUESTIONS
Question 1

For a healthy 40 year old patient undergoing GA with propofol and remifentanil TIVA, which of the following EEG parameters is most likely to indicate a profound level of anaesthesia?

A. A BIS value of 40
B. A burst suppression ratio of 2%
C. The presence of slow 4Hz delta waves
D. An isoelectric EEG trace for around 40 seconds of every minute
E. A spectral edge frequency (SEF95) of 20Hz
Question 2

Which of the following clinical scenarios would be most likely to result in an EEG showing clear alpha waves (8-12Hz) on a background of delta waves (1-4Hz)?

A. An ASA1 25 year old patient undergoing day case surgery with TIVA: Propofol Cpt 4mcg/mL and Remifentanil Cpt 4ng/mL

B. A healthy 75 year old undergoing day case surgery with sevoflurane (end tidal 1.8%) in air

C. A 20 year old trauma patient undergoing an emergency laparotomy who was induced with a ketamine and rocuronium RSI

D. A healthy 20 year old patient undergoing day case surgery with sevoflurane (end tidal 2%) in nitrous oxide oxygen 50:50

E. A 70 year patient undergoing urgent burrhole evacuation of subdural haematoma with TIVA: Propofol Cpt 3mcg/mL and Remifentanil Cpt 3ng/mL
Question 3

Which of the following is **not** a typical EEG change seen on induction of general anaesthesia with propofol?

A. A fall in processed EEG indices
B. A decrease in overall frequency
C. An decrease in overall amplitude
D. A loss of high beta waves (20-30Hz)
E. An increase in slow delta waves activity (1-4Hz)
Question 4

In which of the following scenarios would intraoperative EEG monitoring be most beneficial in reducing the risk of accidental awareness under anaesthesia (AAGA)?

A. A 30 year old ASA 1 patient undergoing an ACL reconstruction with sevoflurane maintenance and an LMA

B. A 50 year old patient undergoing a laparotomy with propofol/remifentanil TIVA

C. A 60 year old patient undergoing panendoscopy with inhalational maintenance (desflurane) and a microlaryngoscopy tube

D. A 55 year old patient undergoing middle ear surgery with propofol/remifentanil TIVA

E. A 60 year old patient undergoing carpal tunnel release under GA with propofol/remifentanil TIVA and an LMA