From last week:

**Differential Amplification**

- This diagram shows a low frequency signal from the patient that differs between the two inputs and is therefore amplified, with an interfering high frequency signal picked up by the leads that is the same for both inputs and is therefore blocked.

- Note that the electrode leads must be kept together otherwise the interfering signals they pick up will differ and will not be blocked!

---

**Basic Electrophysiology, the Electrotetinogram (ERG) and the Electrooculogram (EOG)**

- Signal origins, recording methods and clinical applications

---

**The body is a complex electrical machine**

Central  Peripheral

---

**Peripheral nervous system is divided into sensory and motor fibres**

Skin with nerve endings  Sensory nerve fibre  Posterior root ganglion  Motor end plate  Motor nerve fibre  Mixed nerve  Connector neurone  Spinal cord  Anterior

Fibres are bundled together into nerve trunks (‘nerves’) which can have up to ~20,000 fibres in a structure ~3mm in diameter

---

**Myelinated and unmyelinated fibres**

- Nerve fibres are long and thin (~10µm diameter x 1m long)
- Myelin on some fibres insulates them except at small gaps, decreasing the area of membrane that needs to be ‘depolarised’

---

**Resistence of axon = R**

- Membrane capacitance is proportional to exposed area
- Time taken to depolarise next section of nerve is proportional to RC
- Therefore decreasing C and/or R (fatter fibres) increases conduction velocity
- Myelination increases conduction velocity by ~ x 10 up to ~70m/s max, i.e. 241kph (150 mph)
All nerve signals are transmitted digitally

- Digital transmission avoids crosstalk and external interference
- Impulses either occur or do not occur—“all or nothing”
- Impulses last about 1 ms
- Body uses up to ~100 ips (impulses per second)

Information is frequency modulated

- More intense sensation, or greater force required, both result in more impulses per second

Electrical nerve stimulation

- Current applied via surface or needle electrodes
- Pulses of ~100 µsec used
- 20mA needed to stimulate through the skin
- 250 volts (because dry skin has high electrical resistance - Ohm’s law!)

Non-invasive nerve conduction velocity measurement

- In practice, surface electrodes are used to stimulate and record from superficial nerves – needle electrodes required for deeper nerves

Measurement of nerve conduction velocity - electrodes

- Total time from stimulation to muscle ‘twitch’ is termed ‘latency’
- Includes transit time across neuromuscular junction
- Hence, it is necessary to stimulate at two positions & measure at one position to get true motor nerve conduction velocity
- Signal size: approximately 300 µV with fibre

Motor nerve signals

Sensory nerve signals
Typically conduction velocity for myelinated fibres ~50m/s (180 kph)

Changes with age:

Conduction velocity (95% limits) m/sec

Ophthalmic electrophysiology - the ERG and EOG

- The Electroretinogram (ERG) - the electrical response of the retina to flashes of light or patterns
- The Electrooculogram (EOG) - the electrical response of the retina to changes in steady-state illumination

Source of the ERG

- The Electroretinogram (ERG) - the electrical response of the retina to flashes of light or patterns
- The Electrooculogram (EOG) - the electrical response of the retina to changes in steady-state illumination

Light-dependent decrease in rod and cone dark current gives ‘a’ wave plus release of K+ (potassium)

Müller cells absorb extracellular K+, resulting in part of the ‘b’ wave; rest of ‘b’ wave comes from bipolar cells

Idealised ERG response

- a-wave from rods and cones
- b-wave from bipolar cells and Müller cells
- oscillatory potentials from amacrine cells

Electrodes: contact lens or fibre electrodes (infra-orbital skin for children), with Ag/AgCl ground electrode on forehead and reference electrode on ipsilateral temple

Comfort: local anaesthetic necessary for contact lens, not for fibre

Dilation: ensures pupils are same diameter for all stimuli

Signal size: approximately 300 µV with fibre

Averaging: typically 10 responses (or more if signal is small / noisy)

Bandwidth: 0.3 Hz – 300 Hz for full response

100 Hz – 300 Hz for oscillatory potentials alone
**JET Corneal Electrode**

- Used for ERGs under GA in theatre at SCH
- Would need topical anaesthetic otherwise
- Disposable
- £9 each

**DTL Fibre Electrode**

- Dawson, Trick and Litzkow 1978
- Used in clinic @ RHH
- No anaesthetic required
- Can be worn all day
- No effect on VA
- Suitable for all diffuse and structured stimuli
- Disposable
- £3.50 each
- Often easier to get in than the drops!
- Patients don’t remember them

**Light stimuli used for the ERG (I)**

- Stimuli delivered via Ganzfeld stimulator
- Standard flash luminance defined as
  - $3 \text{ cd} \cdot \text{s} \cdot \text{m}^{-2}$
  - which is quite bright, especially if you have dilated pupils!

**Light stimuli used for the ERG (II)**

- Light-adapted (photopic) response:
  - Rods suppressed by 30 cd/m² for 10 mins
  - then standard flash used to produce ‘cone response’
- Dark-adapted (scotopic) responses
  - Eyes are dark adapted for approx. 20 mins
  - Dim flash (0.01 cd·s·m⁻²) used to produce ‘rod response’ (~2.5 log units below, or $1/\sqrt{316}$ of, standard flash luminance)
  - Then standard flash used to produce a mixed response from both rods and cones

**Light stimuli used for the ERG (III)**

- Can also use alternating patterns like chequerboards as stimuli for zonal stimulation
- more on these later...

**Examples of normal flash ERGs**
Measurements made from the ERG

- Most clinical information comes from the amplitudes of the responses
- ‘a’ wave amplitude normally measured from baseline to first -ve peak
- ‘b’ wave amplitude normally measured from ‘a’ wave -ve peak to next +ve peak
- However, timing is an important factor

Time from light stimulus being applied to response peak occurring gives information about the response time and is known as the ‘implicit time’ (or ‘peak latency’)

ERG Clinical uses (I)

- **No ERG response:**
  - Retinitis Pigmentosa (severe retinal degeneration)
  - Ophthalmic artery occlusion
  - Total retinal detachment
- **Reduced a- and b-wave amplitudes (both photopic and scotopic):**
  - Rod / cone dystrophy
  - Drug toxicity
  - Retinal degeneration

ERG Clinical uses (II)

- **Normal a-wave, reduced b-wave:**
  - Congenital stationary nightblindness
  - Juvenile retinoschisis (splitting of retinal layers)
  - Central retinal artery occlusion
- **Normal scotopic response, abnormal photopic responses:**
  - Cone dysfunction
- **Normal photopic responses, abnormal scotopic responses:**
  - Rod dysfunction
- **Diminished oscillatory potentials:**
  - Early retinal dysfunction in diabetes - ischaemia

EOG

- **The Electrooculogram**

Source of the EOG

- Standing potentials difficult to measure because of uncertainty concerning baseline position – e.g. electrode offset potentials
- Therefore signal of interest made to vary with time by voluntary eye movements
- Two LEDs in Ganzfeld, subtending an arc of 30°, illuminated alternately for 1 second and subject asked to track them

The EOG - recording methods (I)
The EOG - recording methods (II)

- Recording electrodes are placed on the nasion and lateral canthus, with a reference electrode on the ear lobe.
- Signal size approx. 1 mV (~30 µV/°).
- Bandwidth of signal approx. 0.01 Hz - 30 Hz.

The EOG - stimuli and responses (I)

- Record response for 10 secs every 1 min (to avoid fatigue) for 15 mins during dark adaptation.
- Amplitude 'dark trough' occurs after typically 12 mins.

The EOG - stimuli and responses (II)

- 500 cd/m² steady illumination switched on.
- Recording continued until 'light peak' amplitude occurs, typically after ~10 mins.

The EOG - stimuli and responses (III)

- Arden ratio = 'light peak' / 'dark trough', a value of greater than 1.85 is regarded as normal.

The EOG - clinical uses

- Decreased Arden ratio:
  - Best vitelliform macular dystrophy – v. subnormal.
    - pretty much essential for the diagnosis.
  - Adult vitelliform macular dystrophy
    - Can be normal, but tends to be low-normal to slightly subnormal.
  - Central retinal artery occlusion
    - but ERG much more informative.
  - Quinine toxicity
  - Retinitis Pigmentosa (rod/cone dystrophy)
    - but results parallel the ERG.
The EOG - clinical uses

- Electronystagmography (ENG)
  - Saccadic velocity
  - Horizontal angle of gaze
    - with electrodes either side of the eye
  - Vertical angle of gaze
    - with electrodes above and below the eye
  - Position of gaze
    - a vector derived from vertical and horizontal angles

Summary

- Nerves conduct digital electrical impulses around the body
- They can be electrically stimulated and the responses recorded for diagnostic purposes
- Conduction velocity is increased by the presence of myelin
- Information is coded by pulse frequency modulation
- The ERG records responses to brief visual stimuli
- Adaptation and stimulus luminance can be used to select rod and cone responses
- The EOG records slow changes in the retinal trans-epithelial potential in response to general illumination levels