Basic Electrophysiology, the Electoretinogram (ERG) and the Electrooculogram (EOG) - Signal origins, recording methods and clinical applications

The body is a complex machine consisting of the central and peripheral nervous systems. The peripheral nervous system is divided up into sensory and motor fibres:

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

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’
Membrane capacitance is proportional to exposed area. The 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 $\sim x 10$ up to $\sim 70 \text{m/s}$ max, i.e. $241 \text{kmph}$ (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”, and they last for about 1 ms. The body uses up to $\sim 100 \text{ ips}$ (impulses per second).
More intense sensation, or greater force required, both result in more impulses per second.

**Motor nerve signals**

**Electrical Nerve Stimulation**

Current is applied via surface or needle electrodes. Pulses of ~ 100 µsec are used. A current of 20mA is needed to stimulate through the skin. This requires up to 250 volts because dry skin has high electrical resistance – Ohm’s law!
In practice, surface electrodes are used to stimulate and record from superficial nerves – needle electrodes required for deeper nerves.

Peripheral nerve anatomy

Electrodes
Non-invasive nerve conduction velocity measurement

Total time from stimulation to muscle ‘twitch’ is termed ‘latency’ and includes the transit time across neuromuscular junction; hence, it is necessary to stimulate at two positions & measure at one position in order to get true motor nerve conduction velocity. Signal size: approximately 300 µV with fibre.
Typically conduction velocity for myelinated fibres ~50m/s (180 kph). Velocity changes with age:

**Ophthalmic electrophysiology - the ERG and EOG**

The Electroretinogram (ERG) – a recording of 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:**

- Light-dependant 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
Sources of the a- and b-waves:

- a-wave from rods and cones
- b-wave from bipolar cells and Müller cells
- oscillatory potentials from amacrine cells
The ERG - recording methods

Recorded using fibre electrodes for adult out-patients, infra-orbital skin electrodes for infants and contact lens electrodes for patients in theatre. An Ag/AgCl ground electrode is placed on the forehead and another as a ‘reference' electrode on the ipsilateral temple. Local anaesthetic is necessary for comfort with contact lens electrodes, not for fibre. Dilating drops (typically Tropicamide 1% & Phenylephrine 2.5%) ensure pupils are same diameter for all stimuli regardless of stimulus brightness. This is not to get more light in, although it does allow up to 84 times as much, but for consistent and repeatable stimulation. Signals are smallest with infra-orbital skin electrodes, largest with contact lens electrodes - approximately 300 µV with fibre electrodes.

Typically 10 responses need to be averaged for a clear recording, more if the signal is small or noisy. Bandwidth is 0.3 Hz - 300 Hz for full response, or 100 Hz - 300 Hz for the oscillatory potentials alone.

JET Corneal Electrode

Used for ERGs under GA in theatre at SCH - would need a topical anaesthetic if the patient was awake. These are disposable and cost about £9 each.
**DTL Fibre Electrode**

Lovely electrodes invented by Dawson, Trick and Litzkow 1978. Used in clinic @ RHH. No anaesthetic required. They can be worn all day, do not interfere with vision and hence, are 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**

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

A light-adapted (photopic) response is recorded with the rods suppressed by 30 cd/m² for 10 mins beforehand and during recording. Then a standard flash used to elicit a '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 $1/316$ of, standard flash luminance)
  - Then standard flash used to produce a mixed response from both rods and cones
- 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 IT.

ERG Clinical Uses

- 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
- Normal a-wave, reduced b-wave:
  - Congenital stationary night-blindness
  - 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

The Electrooculogram (EOG)

Source of the EOG:

- Standing trans-epithelial potential of ~ 10mV
- Quite a large potential
- Varies slowly with illumination
- ? c-wave of ERG

Recording Methods
- 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
Recording electrodes are placed on the nasion and lateral canthus, with a reference electrode on the ear lobe.

- Signal size approx. 1 mV (about 30 µV/°).
- Bandwidth of signal approx. 0.01 Hz - 30 Hz.

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.

Decreased Arden ratio:
- Best vitelliform macular dystrophy.
- pretty much essential for the diagnosis
- Retinal pigment epithelium disease
- Central retinal artery occlusion
- Quinine toxicity
- Retinitis Pigmentosa
  - but results parallel the ERG

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