

Electromyography (EMG)

1. Definition

Electromyography (EMG) is a biomedical technique used to measure and record the electrical activity produced by skeletal muscles during contraction and relaxation. It helps evaluate muscle function and the nerves that control the muscles.

2. Physiological Basis

A motor unit is a single motor neuron together with all the muscle fibres it supplies. When the neuron fires, every fibre in its motor unit is activated almost together, and the summed electrical response is called the Motor Unit Action Potential (MUAP). The EMG recorded at an electrode is the combined (superimposed) effect of the MUAPs from many active motor units.

3. Principle of Operation

1. The brain sends electrical impulses through motor neurons.
2. These impulses activate the muscle fibres.
3. The resulting electrical signals (MUAPs) are detected by electrodes.
4. The EMG system amplifies, filters and displays the signals for analysis.

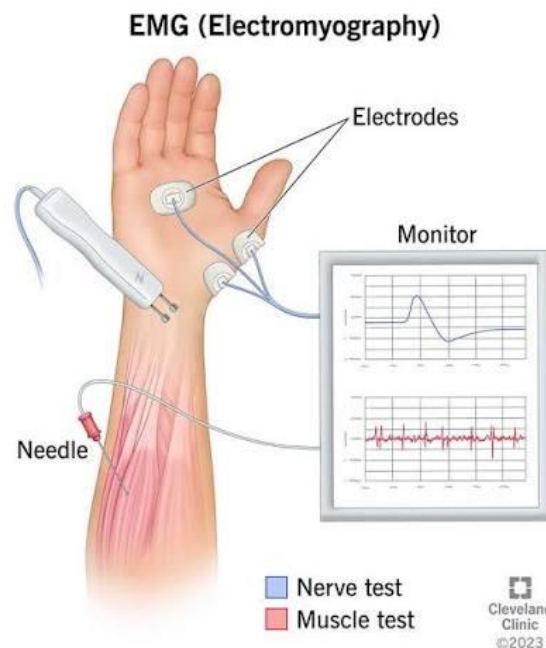


Figure 1: EMG recording – electrodes on the forearm connected to a monitor (nerve test and muscle test traces)

4. Electrodes Used

- **Surface electrodes (sEMG)** – placed on the skin over the muscle; non-invasive and used for general monitoring, rehabilitation and control applications.
- **Needle / fine-wire electrodes** – inserted into the muscle; used in clinical diagnosis to record individual motor units (see the Bioelectrodes notes).

5. Signal Characteristics

Parameter	Value
Frequency range	10 – 500 Hz
Major signal energy	50 – 150 Hz
Most useful clinical information (surface EMG)	20 – 450 Hz
Typical amplitude (textbook value)	about 0.1 – 5 mV
Recommended band-pass for recording	10 – 500 Hz

6. Applications

- Diagnosis of neuromuscular disorders
- Prosthetic and robotic control
- Sports and rehabilitation monitoring
- Human–Machine Interfaces (HMI)
- Biomedical research

Electrocardiography (ECG)

1. Definition

Electrocardiography (ECG) is a biomedical technique used to measure and record the electrical activity of the heart. It helps evaluate heart rhythm and heart rate, and detect abnormalities in cardiac function.

2. Principle of Operation

1. The sinoatrial (SA) node generates an electrical impulse.
2. The impulse travels through the atria → AV node → Bundle of His → Purkinje fibres.
3. This electrical activity causes the heart muscle to contract and relax.
4. Electrodes placed on the skin detect these electrical signals.
5. The ECG machine amplifies, filters and displays the signal as an ECG waveform.

3. The ECG Waveform

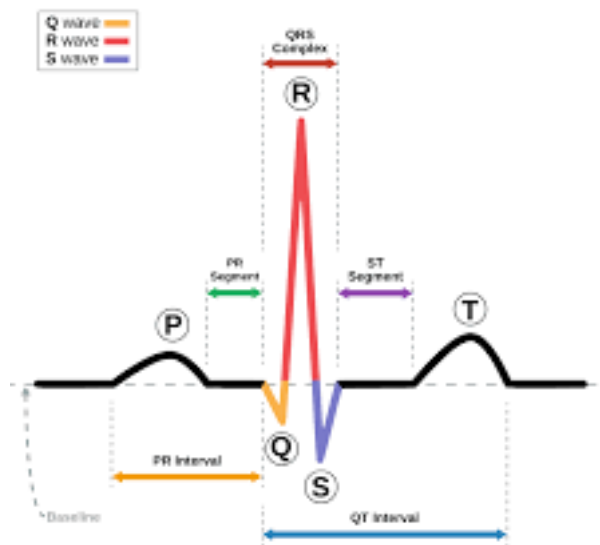


Figure 1: Standard ECG waveform showing P wave, QRS complex, T wave and the PR / ST / QT intervals

Wave	Cardiac event
P wave	Atrial depolarisation
QRS complex	Ventricular depolarisation (largest deflection; atrial repolarisation is hidden within it)
T wave	Ventricular repolarisation

Intervals and segments marked on the figure

Interval / segment	Meaning	Typical normal value*
PR interval	Start of P wave to start of QRS – conduction time through atria and AV node	0.12 – 0.20 s
QRS duration	Ventricular depolarisation time	0.06 – 0.10 s
ST segment	End of QRS to start of T wave – ventricles fully depolarised	Isoelectric (flat)
QT interval	Start of QRS to end of T wave – total ventricular activity	up to about 0.44 s

*Typical textbook values added for reference; they are not stated on the slides.

4. Signal Characteristics

Parameter	Value
Frequency range of ECG	0.05 – 150 Hz

Parameter	Value
Typical amplitude (textbook value)	about 0.5 – 4 mV (R wave)
Recommended band-pass for recording	0.05 – 100 Hz
Common interference	50/60 Hz mains, baseline wander (respiration), EMG, motion

5. Applications

- Diagnosis of cardiac arrhythmias
- Detection of myocardial infarction (heart attack)
- Heart rate and rhythm monitoring
- ICU monitoring
- Wearable health-monitoring devices

Electroencephalography (EEG)

1. Definition

Electroencephalography (EEG) is a biomedical technique used to measure and record the electrical activity of the brain. It helps evaluate brain function by detecting electrical signals generated by neurons in the cerebral cortex.

2. Principle of Operation

1. Billions of neurons in the brain communicate through electrical impulses.
2. This activity produces small voltage fluctuations.
3. Scalp electrodes detect these signals.
4. The EEG system amplifies, filters, digitises and displays the brain waves for analysis.

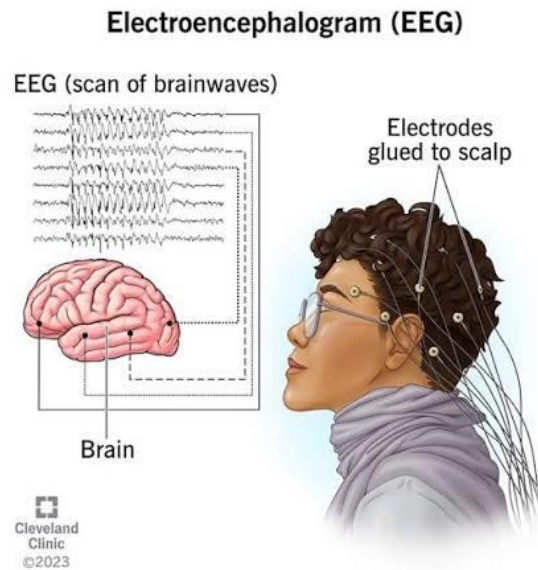


Figure 1: EEG recording – electrodes attached to the scalp and the multichannel brain-wave trace

3. Brain Regions

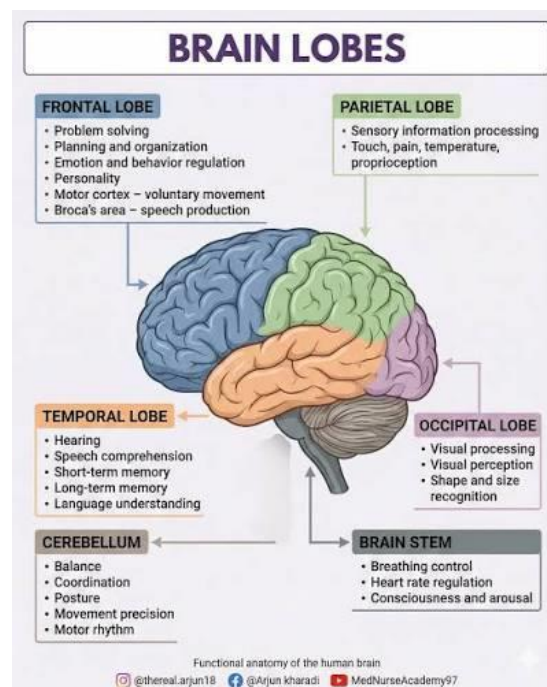


Figure 2: Lobes of the brain and their functions

Region	Main functions
Frontal lobe	Planning, decision making, personality, voluntary movement, speech production
Parietal lobe	Sensory processing, spatial awareness
Temporal lobe	Hearing, memory, language understanding
Occipital lobe	Vision
Cerebellum	Balance and coordination

4. Major Brain Waves

Wave	Frequency	Associated state
Delta (δ)	0.5 – 4 Hz	Deep sleep
Theta (θ)	4 – 8 Hz	Drowsiness, meditation, light sleep
Alpha (α)	8 – 13 Hz	Relaxed and awake (eyes closed)
Beta (β)	13 – 30 Hz	Alertness, concentration, active thinking
Gamma (γ)	30 – 100 Hz	Memory, learning, higher cognitive functions

5. Signal Characteristics

Parameter	Value
Frequency range	about 0.5 – 100 Hz (brain-wave bands above)
Recommended band-pass for recording	0.5 – 50 Hz
Typical amplitude (textbook value)	about 10 – 100 μ V (microvolt level)
Common artifacts	Eye blinks (EOG), muscle activity (EMG), ECG, power-line, electrode movement

6. Applications

- Diagnosis of epilepsy and seizures
- Sleep disorder analysis
- Brain–Computer Interface (BCI)
- Cognitive and neurological research
- Monitoring brain activity during surgery

Electrooculography (EOG)

1. Definition

Electrooculography (EOG) is a biomedical technique used to measure and record the electrical activity generated by eye movements. It detects changes in the electrical potential between the cornea (positive) and the retina (negative) as the eyes move.

2. Principle of Operation

The eye behaves like an electrical dipole:

- Cornea (front of the eye): positively charged (+)

- Retina (back of the eye): negatively charged (–)
1. When the eyeball moves, the position of this dipole changes.
 2. Electrodes placed around the eyes detect the resulting voltage changes.
 3. The EOG system amplifies, filters, digitises and displays the signals for analysis.

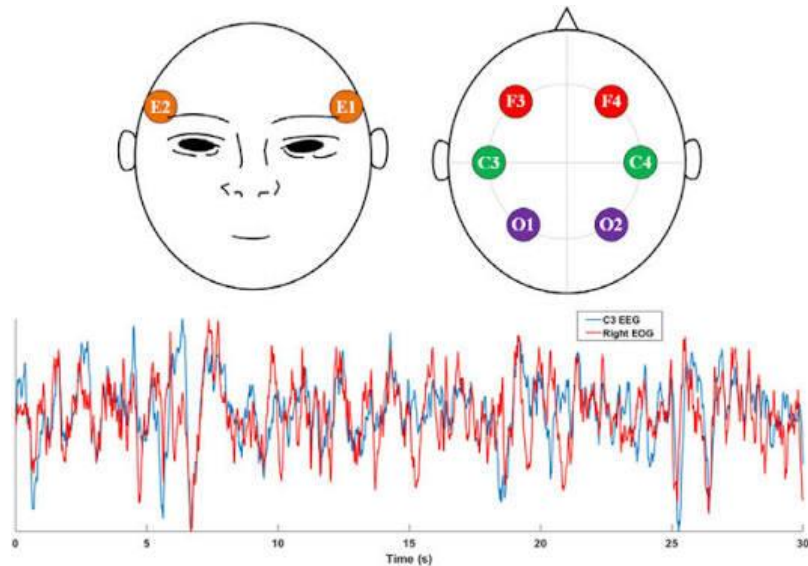


Figure 1: Electrode positions around the eyes and the recorded trace (from the lecture slide)

Electrode placement (standard practice)

- **Horizontal movement:** one electrode at the outer corner of each eye; moving the gaze left or right makes one electrode more positive than the other.
- **Vertical movement and blinks:** electrodes above and below one eye.
- A reference/ground electrode is placed on the forehead or mastoid.

3. Signal Characteristics

Parameter	Value
Frequency range	0 – 30 Hz (very low frequency, near DC)
Typical amplitude (textbook value)	about 50 – 3500 μV
Relationship to gaze	Output is roughly proportional to the angle of eye rotation over a limited range

4. Applications

- Diagnosis of eye-movement disorders
- Sleep studies (REM sleep detection)
- Human–Computer Interface (HCI)
- Eye-controlled wheelchairs and prosthetics
- Fatigue and drowsiness monitoring
- Virtual reality (VR) and gaming

Bioelectrodes and Electrode–Tissue Interface

1. Role of Biopotential Electrodes

Electrodes make the transfer from ionic conduction in the tissue to electronic conduction in the wires and instrument, which is necessary for making measurements. Inside the body, current is carried by ions; in the measuring circuit it is carried by electrons.

2. Classification of Electrodes

Two types of electrodes are used in practice:

- Surface electrodes – pick up the potential difference from the tissue surface when placed over it, without damaging live tissue.
- Deep-seated electrodes – indicate the electric potential difference arising inside the live tissue or cell.

Surface electrodes	Deep-seated electrodes
Metal plate electrodes	Micro electrodes – metal electrode
Suction cup electrodes	Micro electrodes – glass electrode
Adhesive tape electrodes	Depth or needle electrodes
Multi-point electrodes	
Floating electrodes	

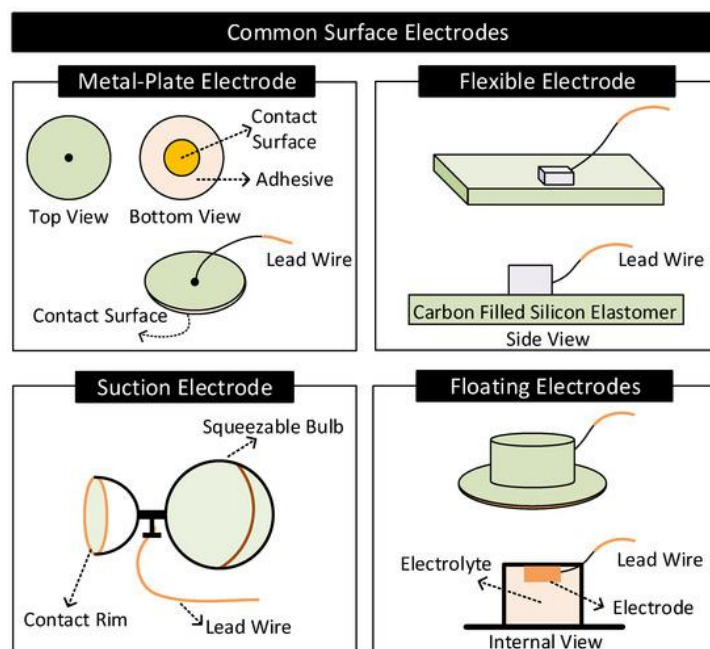


Figure 1: Common surface electrodes – metal plate, flexible, suction and floating types

3. Surface Electrodes

- Used for recording ECG, EEG and respiratory activity by impedance pneumography.

- An electrolyte or electrode paste is placed between electrode and skin to avoid movement artefacts and to obtain a clearly established contact with low contact impedance.

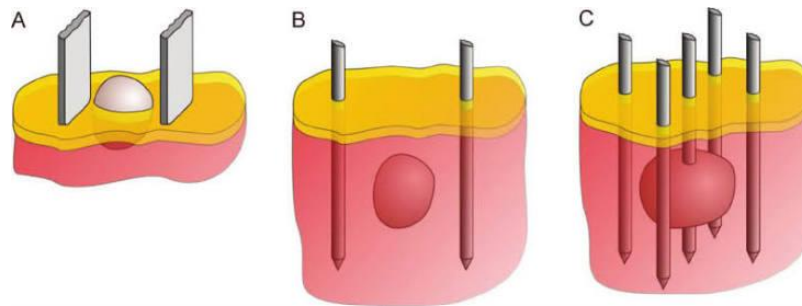


Figure 2: Electrode–tissue arrangement – surface contact versus penetrating electrodes

4. Electrode–Electrolyte (Metal–Electrolyte) Interface

At the metal–electrolyte transition there is a tendency for the metal to discharge ions into the solution, and for ions in the electrolyte to combine with the electrode. This sets up a charge separation.

- Electrical double layer – two parallel sheets of charge of opposite sign separated by a thin film of dielectric. The potential across it is the half-cell potential.
- Charge transfer takes place as electrons move from the metal phase to an ionic carrier in the electrolyte.
- Equivalent circuit: a voltage source (half-cell potential) in series with a parallel combination of a capacitance and a reaction (charge-transfer) resistance.
- Electrode potentials are measured with respect to a reference electrode, usually hydrogen absorbed on platinum black, or the calomel electrode.

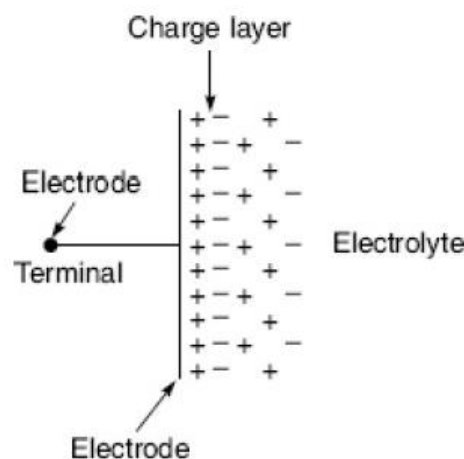


Figure 3: Charge distribution at the electrode–electrolyte interface

Electrode potentials of some metals (with respect to hydrogen)

Metal	Ionic symbol	Electrode potential
Aluminium	Al^{3+}	–1.66 V
Iron	Fe^{2+}	–0.44 V
Lead	Pb^{2+}	–0.12 V
Hydrogen	H^+	0 V

Metal	Ionic symbol	Electrode potential
Copper	Cu^{2+}	+0.34 V
Silver	Ag^{+}	+0.80 V
Platinum	Pt^{+}	+1.2 V
Gold	Au^{+}	+1.69 V

Potential between electrode pairs in electrolytes

Electrode metal	Electrolyte	Potential difference between electrodes
Stainless steel	Saline	10 mV
Silver	Saline	94 mV
Silver–silver chloride	Saline	2.5 mV
Silver–silver chloride (11 mm disc)	ECG paste	0.47 mV
Silver–silver chloride (sponge)	ECG paste	0.2 mV

5. Electrolyte–Skin Interface

- The skin acts like a diaphragm between two solutions (electrolyte and body fluids) of different concentrations containing the same ions, which gives rise to potential differences called contact potentials.
- The signal reaching the instrument therefore has two components: the contact potential and the biological signal.
- The contact potential depends on the type of skin, skin preparation and composition of the electrolyte.
- During recording, the metal–electrolyte and electrolyte–skin potentials appear as interference. They are connected in opposition, so for a truly reversible and uniform electrode pair their difference would be nil.

Equivalent circuit of the electrode pair

Symbol	Meaning
Eb	Bioelectric event (the wanted signal)
E1, E2	Half-cell potentials of the two electrodes (non-physiological)
Z1, Z2	Skin contact impedances of the two electrodes
R	Tissue resistance (resistance of the bioelectric generator)

6. Polarisation

- If a low voltage is applied to two electrodes in a solution, the electrical double layers are disturbed.
- After an initial surge only a very small current flows, indicating a high resistance.
- Such electrodes cannot measure steady or slowly varying potentials in tissue. They are called polarised (non-reversible) electrodes.
- Biopotential recording therefore prefers non-polarisable (reversible) electrodes such as Ag/AgCl.

7. Skin Contact Impedance

- Electrical activity of nerves and muscles reaches the electrode through the body tissues and the skin–electrode transition, then passes by wire to the input of the recorder.
- The impedance at the electrode–skin junction forms part of the overall circuit of the recording machine.
- This contact impedance is much greater than the impedance of the body tissue measured beneath the skin, so it must be reduced by skin preparation and electrolyte jelly.

8. Silver–Silver Chloride (Ag/AgCl) Electrodes

Properties

- Non-polarisable electrode with long-term stability.
- Non-toxic – preferred over zinc–zinc sulphate electrodes, which also give low offset potential but are highly toxic to exposed tissue.

Preparation by electrolysis

1. Two silver discs are suspended in a saline solution.
2. The positive pole of a DC supply is connected to the disc to be chlorided; the negative pole goes to the other disc.
3. A current of about 1 mA per cm² of surface area is passed for several minutes.
4. A layer of silver chloride is deposited on the anode surface.

9. Micro Electrodes

- Used to study the electrical activity of individual cells.
- Small enough compared with the cell that penetration does not damage the cell; typical tip dimensions are 0.5 – 5 µm.
- Two forms: metallic and glass micro-capillaries (micropipettes). Glass electrodes are more stable than metal ones.
- Very high impedance, so high-input-impedance amplifiers are required to avoid loading the circuit.

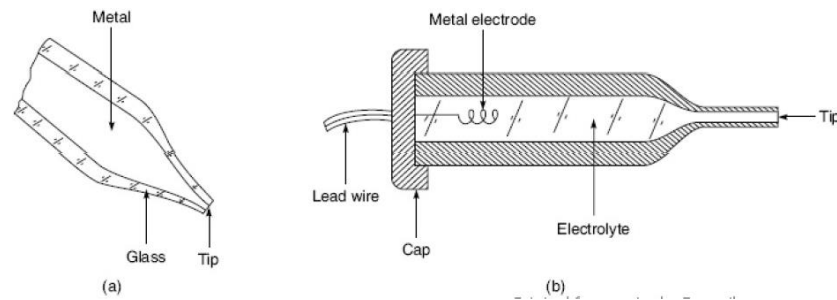


Figure 4: Micro-electrodes – (a) metal microelectrode, (b) micropipette / microcapillary electrode

Type	Why impedance is high	Construction notes
Metal micro-electrode	Very small metal–electrolyte interface area	Fine stainless-steel wire (or tungsten) tip, electro-etched to a very fine point (below 500 Å), insulated with polymethyl methacrylate; a small tip area is then exposed. Tungsten is preferred for its mechanical strength and apparent inertness; its surface oxide layer protects against corrosion.
Glass micro-capillary (micropipette)	Tip is filled with electrolyte, a conductor of tiny cross-section	Glass tube is heated circumferentially under initial tension; when it softens the tension is increased rapidly and the heat is switched off. Controlled heat, tensions, timing and cooling give controlled tip dimensions.

10. Needle (Depth) Electrodes

- Inserted into the tissue just beneath the skin, puncturing the skin at a large oblique angle (nearly parallel to the skin surface).
- Used only for exceptionally poor skin contact, such as anaesthetised patients, and in veterinary work.
- Infection is a concern, so needle electrodes are disposable or are re-sterilised using ethylene oxide gas.
- Variants shown on the slides: insulated needle, coaxial needle, bipolar coaxial, fine-wire electrode with hypodermic needle, and coiled fine-wire electrode.

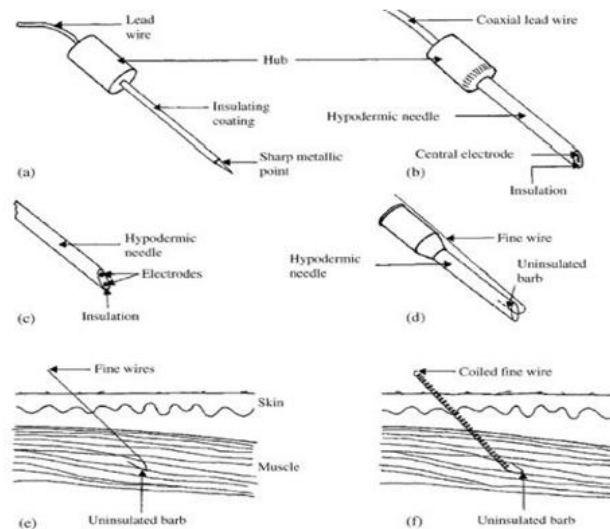


Figure 5: Needle and fine-wire electrodes – (a) insulated needle, (b) coaxial needle, (c) bipolar coaxial, (d)–(f) fine-wire types in skin and muscle

11. Summary Comparison

Electrode	Placed	Typical use	Key point
Surface (Ag/AgCl, plate, suction, floating)	On skin	ECG, EEG, respiration (impedance pneumography)	Needs electrolyte paste for low contact impedance
Needle / fine-wire	Just under skin / in muscle	Poor skin contact, anaesthetised patients, EMG	Disposable or sterilised with ethylene oxide
Metal micro-electrode	Inside a single cell	Cell-level potentials	Very high impedance; tungsten preferred
Glass micropipette	Inside a single cell	Cell-level potentials	More stable than metal; electrolyte-filled tip