

Unit II : Biopotential Recording (ECG · EEG · EMG)

1. Electrocardiography (ECG)

1.1 Basic Principles

The Electrocardiogram (ECG) is the recording of the electrical activity associated with the functioning of the heart. It is a quasi-periodic, rhythmically repeating signal synchronized with the heart's mechanical cycle.

- Waveforms are standardized in amplitude and phase; any deviation from the standard pattern indicates a possible cardiac abnormality.
- The heart generates and conducts action potentials through a change in ionic concentration across the cell membrane.
- The body acts as a purely resistive (volume conductor) medium, so the potential field generated by the heart can be picked up on the body surface.

1.2 Cardiac Conduction System

The sequence of electrical activation of the heart is the basis of the ECG waveform:

1. **SA Node (Sino-atrial node):** 25–30 mm long, 2–5 mm thick; located in the right atrium. It is the primary (natural) pacemaker of the heart, firing at ~72 beats/min at rest and initiating the impulse.
2. **Atrial spread:** The impulse spreads through the atrial wall at ~1 m/s, completing atrial excitation in ~0.1 s and reaching the AV node in ~0.04 s.
3. **AV Node (Atrio-ventricular node):** Located in the lower inter-atrial wall; delays the impulse by ~0.12 s due to a fibrous barrier of non-excitabile cells — this delay allows the atria to finish contracting before the ventricles begin.
4. **Bundle of His:** Carries the impulse from the AV node to the ventricles.
5. **Purkinje fibres:** Branch from the Bundle of His; conduct at 1.5–2.5 m/s and trigger simultaneous contraction of both ventricles, starting at the apex and moving upward — producing the squeezing action that ejects blood into the arteries.

1.3 ECG Waveform & Signal Characteristics

The standard ECG cycle consists of the following deflections:

- **P wave** — atrial depolarisation
- **QRS complex** — ventricular depolarisation; typical amplitude ≈ 1 mV in Lead I for a normal heart
- **T wave** — repolarisation of both ventricles
- **U wave** — small wave sometimes seen after the T wave
- **QT interval** — period of one complete ventricular contraction (systole)
- **Ventricular diastole** — from the end of the T wave to the beginning of the next Q wave

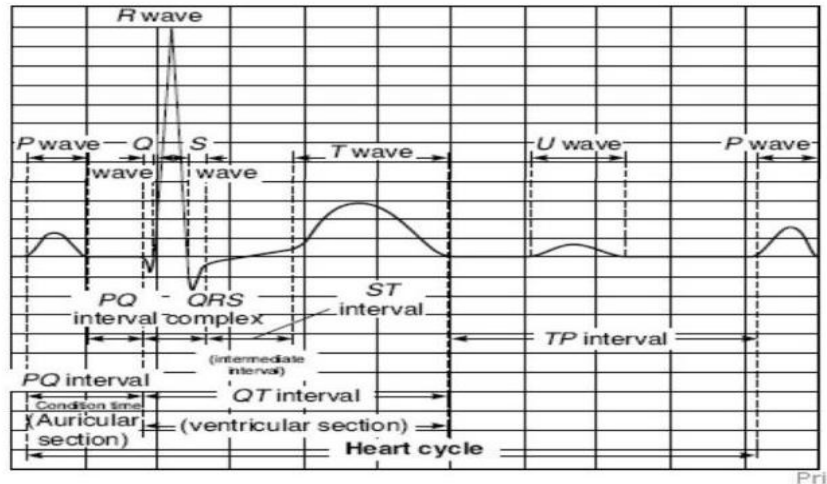


Fig 1.2 — Standard ECG waveform: P-QRS-T-U with PQ, ST, QT and TP intervals

1.4 ECG Electrodes

Five main electrode types are used to pick up the cardiac signal from the body surface:

Electrode Type	Key Features
Limb electrode	Rectangular/circular metal (German silver, nickel-silver, or nickel-plated steel), 3×5 cm; high contact impedance (rim contact only)
Floating electrode	Metal does not directly touch skin; connection via silver-plated copper wire in conducting gel/adhesive; contact impedance $\approx 50 \text{ k}\Omega$
Pre-gelled disposable electrode	0.3–1.5 g electrolyte gel forms the conducting bridge; strict limits on DC offset ($<100 \text{ mV}$), noise ($<150 \text{ mV}$), impedance ($<2 \text{ k}\Omega$ pair) and defibrillation-recovery voltage
Pasteless (dry) electrode	Metal plate applied after skin cleaning; uses a thin coupling paste/jelly rather than wet gel
Fabric-based electrode	Flexible Ni/Cu-polyester fabric tape (e.g., 3M CN-3190); concentric 'L'-shaped strip array ensures a good signal vector regardless of patient size/orientation

1.5 ECG Lead Systems

A 'lead' is the tracing of the voltage difference between any two recording sites due to the heart's electrical activity. If one electrode senses 1 mV and another senses 0.2 mV at the same instant, the lead records the difference (0.8 mV).

(a) Limb Leads — Einthoven's Triangle (Bipolar)

- Electrodes: Right Arm (RA), Left Arm (LA), Left Leg (LL); Right Leg (RL) is the ground/reference.
- **Lead I** = $LA - RA$ (travels horizontally; LA positive, RA negative)
- **Lead II** = $LL - RA$ (points diagonally downward; LL positive, RA negative)
- **Lead III** = $LL - LA$ (points diagonally downward; LL positive, LA negative)

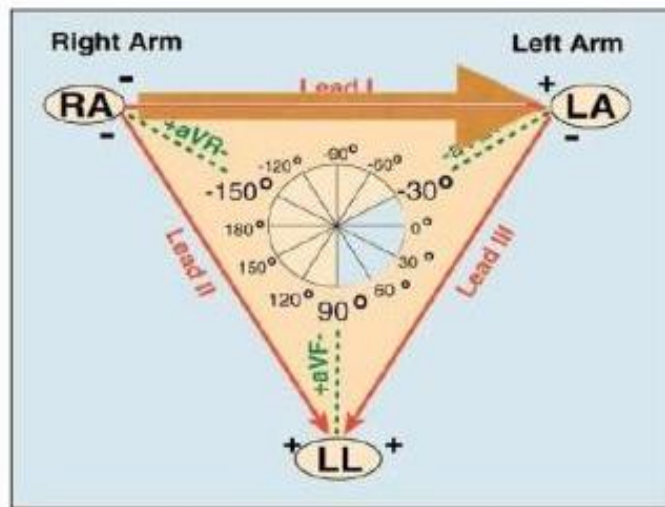


Fig 1.3 — Lead I formation: LA (positive pole) minus RA (negative pole)

(b) Augmented / Unipolar Limb Leads

- aVR, aVL, aVF record the electrical potential at one limb relative to the average of the other two (rather than relative to a second single electrode).
- Key relationship: $aVR + aVL + aVF = 0$

(c) Chest (Precordial) Leads — V1 to V6 (Unipolar, Horizontal Plane)

Lead	Placement
V1	4th intercostal space, right of sternum
V2	4th intercostal space, left of sternum
V3	Midway between V2 and V4

Lead	Placement
V4	5th intercostal space, mid-clavicular line
V5	Level with V4, left anterior axillary line
V6	Level with V5, left mid-axillary line

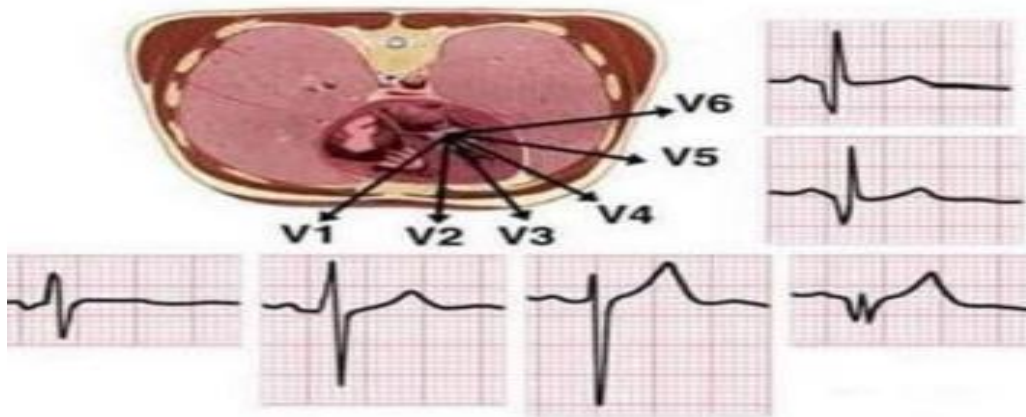


Fig 1.4 — Chest (precordial) leads V1–V6 in the horizontal plane

(d) 12 / 15 / 18-Lead Systems

- **12-Lead ECG** = 6 limb leads (I, II, III bipolar + aVR, aVL, aVF unipolar) + 6 chest leads (V1–V6) — the clinical standard.
- **15-Lead ECG** = 12-lead + 3 extra chest leads across the right precordium → early diagnosis of right-ventricular and posterior left-ventricular infarction.
- **18-Lead ECG** = 15-lead + 3 more chest leads → early detection of myocardial ischaemia and injury.

1.6 ECG Graph Paper & Heart-Rate Calculation

- Horizontal axis = time; 1 small square (1 mm) = 0.04 s → 1 large square (5 mm) = 0.2 s.
- Vertical axis = voltage; 1 small square = 0.1 mV.

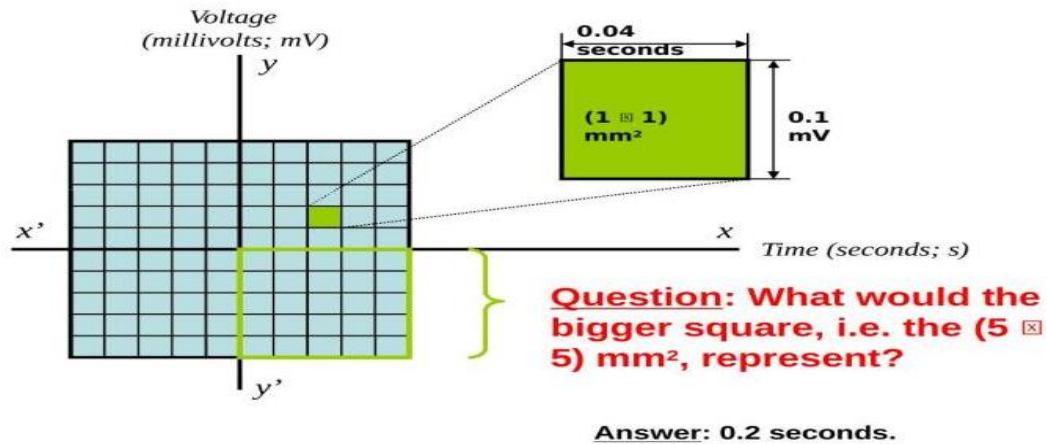


Fig 1.6 — ECG graph paper: 1 small square = 0.04 s (time) × 0.1 mV (voltage)

2. Electroencephalography (EEG)

2.1 Introduction

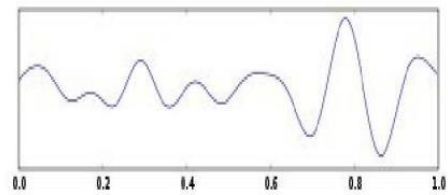
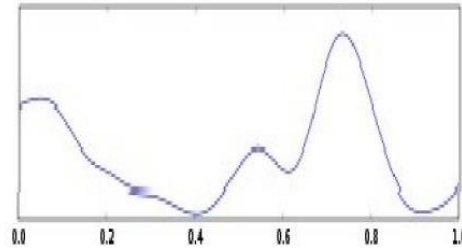
- EEG is the recording of electrical activity along the scalp, reflecting voltage fluctuations from ionic current flow within brain neurons.
- First measured in humans by Hans Berger in 1929.
- Amplitude: $\approx 100 \mu\text{V}$ at the scalp; 1–2 mV when measured directly on the brain surface.
- Used to diagnose epilepsy, sleep disorders, coma, and brain death.
- Single-neuron activity can be studied using microelectrodes that impale individual cells.

2.2 EEG Frequency Bands

Band	Frequency	Associated State
Delta (Δ)	0.5 – 4 Hz	Deep sleep
Theta (θ)	4 – 8 Hz	Drowsiness / tiredness (common in children & young adults)
Alpha (α)	8 – 12 Hz	Relaxed but alert; present with eyes closed, disappears on eye-opening/concentration
Beta (β)	12 – 30 Hz	Highly alert & focused; associated with anxiety, depression, sedative use
Gamma (γ)	30 – 100 Hz	High-level cognitive processing

EEG waves

• Theta

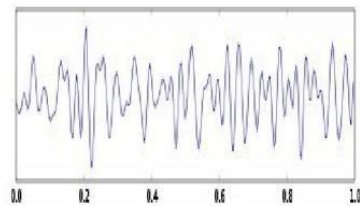
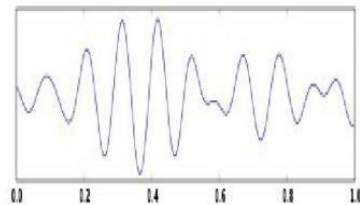


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Fig 2.2 — Representative delta and theta wave morphology

EEG waves

• Beta



1
0

Fig 2.3 — Representative alpha and beta wave morphology

2.3 Sleep & Clinical Correlation

- Eyes closed → alpha waves dominate.
- Falling asleep → dominant EEG frequency decreases.
- REM (Rapid Eye Movement) sleep → dreaming, active eye movement, characteristic EEG pattern.
- Deep sleep → large, slow delta waves.
- Complete cerebral death → no detectable cerebral activity.

2.4 Evoked Potentials

- **Evoked Potentials (EP):** components of the EEG elicited by a stimulus (visual, somatosensory, or auditory), extracted by averaging.
- **Sensory Evoked Potentials (SEP):** recorded from the CNS following stimulation of a sense organ.
- **Event-Related Potentials (ERP):** averaged EEG responses time-locked to complex stimulus processing (e.g., N170 – faces, N400 – word/meaning, P300 – surprise, P600 – memory recall).

2.5 EEG Recorder

An EEG machine consists of four main blocks:

1. Electrodes
2. Amplifiers
3. Filters
4. Recording unit

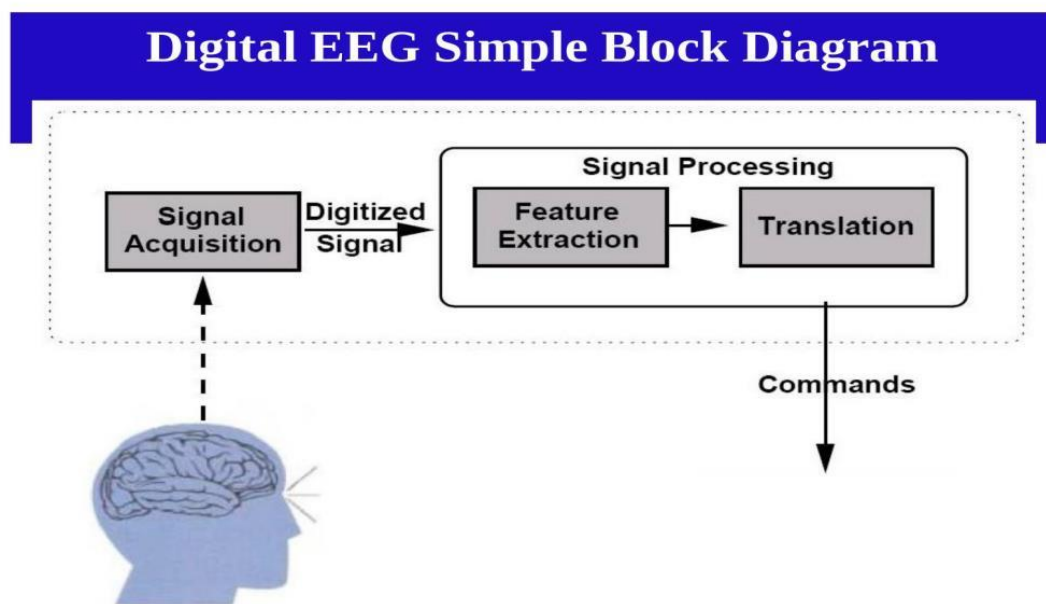


Fig 2.4 — Digital EEG system block diagram (Signal Acquisition → Digitized Signal → Feature Extraction → Translation → Commands)

- **Analog EEG:** direct pen/ink chart recording of amplified signals.
- **Digital EEG:** signal is amplified, filtered, digitized (ADC), processed and displayed/stored digitally — enables computer-based analysis, montage re-referencing, and storage.

2.6 Electrode Montage & Placement

- A montage = the pattern of electrode pairs whose signals are subtracted to form each output channel.
- The montage selector (analog machines) is a switch panel allowing selection of which electrode pairs are combined.
- Reference electrode is usually placed on a non-active site (forehead or earlobe).
- Electrodes are small, disposable, self-adhesive, and pre-gelled; recording is typically done with the subject resting, awake, eyes closed.

10–20 and 10–10 International Systems

- 10–20 system: 21 electrodes. 10–10 system: 64 electrodes (higher density).
- The numbers '10' and '20' refer to the inter-electrode distance as a percentage (10% or 20%) of the total front-back or left-right skull distance.
- Naming convention: Fp = Frontal Polar; intermediate positions — AF (between Fp & F), FC (between F & C), FT (between F & T), CP (between C & P), TP (between T & P), PO (between P & O).

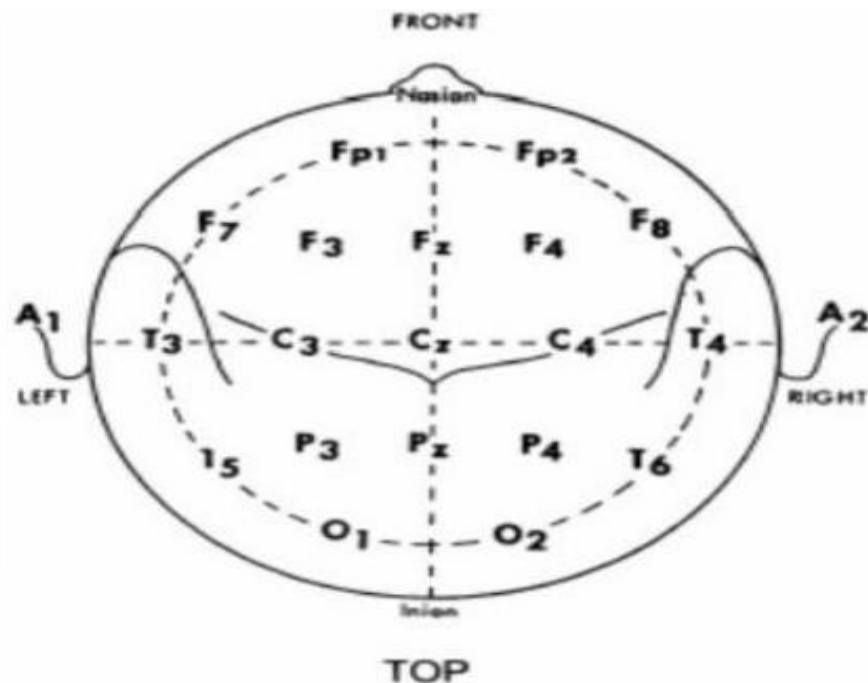


Fig 2.5 — 10–20 international electrode placement system

2.7 Applications of EEG

- **Neuromarketing** — studying brain responses to purchase decisions and store environments.
- **Human Factors** — workplace/interface optimisation, personality-trait and cognitive-state research using wireless EEG headsets.
- **Social Interaction** — 'hyperscanning' records multiple people simultaneously to study synchronisation during conversation/teamwork.
- **Psychology & Neuroscience** — attention, learning and memory studies using Event-Related Potentials (ERPs).
- **Clinical & Psychiatric** — evaluating cognitive state, lesion localisation, treatment effect monitoring (incl. VR-based therapy).
- **Brain-Computer Interfaces (BCI)** — steering wheelchairs/cursors or exoskeletons directly from brain activity.

3. Electromyography (EMG)

3.1 Introduction

Electromyography (EMG) evaluates and records the electrical activity produced by skeletal muscles, at rest and during contraction, using an instrument called an electromyograph.

- Measured EMG potentials range from $<50\ \mu\text{V}$ up to 20–30 mV, depending on the muscle.
- Body temperature can affect test results.
- Nerve Conduction Studies (a related test) measure how well and how fast nerves conduct electrical signals.

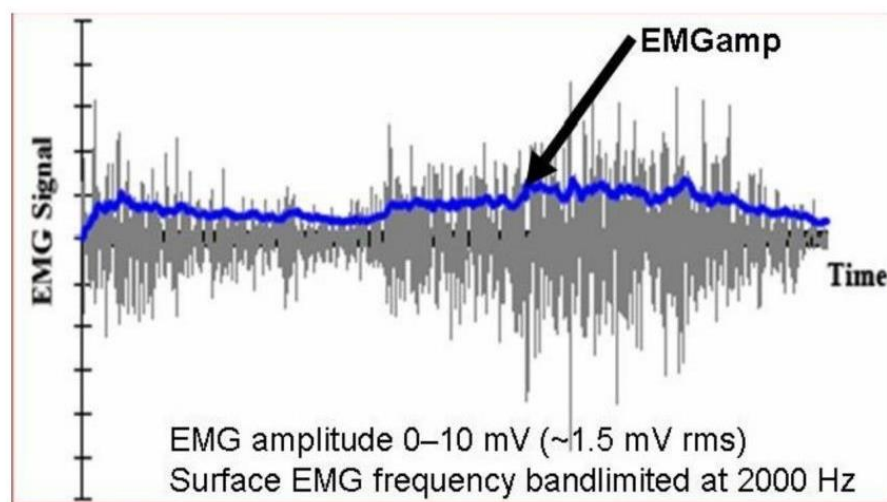


Fig 3.1 — Typical raw EMG signal (envelope amplitude vs time); EMG amplitude 0–10 mV (~1.5 mV rms); surface EMG frequency band-limited at 2000 Hz

3.2 EMG Electrodes

Two types of EMG recording are in clinical use:

- **Surface EMG** — electrode placed on the skin; gives a general picture of overall muscle activation (non-invasive).
- **Intramuscular (needle / fine-wire) EMG** — a needle electrode, or a needle containing two fine wires, is inserted through the skin into the muscle for more localized/detailed recording.

3.3 EMG Recorder

The electromyograph records muscle electrical activity to determine whether a muscle is contracting, and displays action potentials in visual/audible form. It has an important application in myoelectric control of prosthetic limbs — EMG signals from residual nerve endings are used to drive a mechanical arm.

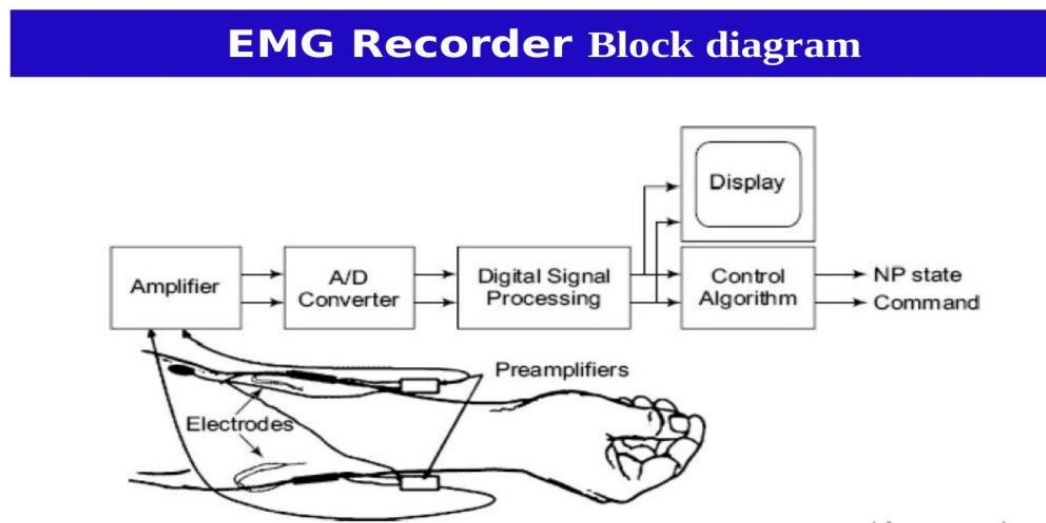


Fig 3.2 — EMG recorder block diagram: Electrodes → Pre-amplifier → Amplifier → A/D Converter → Digital Signal Processing → Control Algorithm → Display

3.4 Clinical Applications of EMG

Condition Category	Description / Example
Muscle disorders (myopathies)	Muscular dystrophy, inflammation — small, brief, rapid potentials during contraction

Condition Category	Description / Example
Nerve compression / entrapment	Carpal tunnel syndrome, sciatica, radiculopathy
Peripheral neuropathy	Nerve damage outside brain/spinal cord, often diabetic in origin
Motor neuron disease	e.g., ALS — abnormal spontaneous activity at rest
Neuromuscular junction disorders	e.g., Myasthenia gravis — disrupted nerve–muscle communication

Reference: R.S. Khandpur, Handbook of Biomedical Instrumentation, 3rd Edition — Bioelectric Signals and Electrodes (McGraw-Hill Professional, 2014). Lecture slide decks 2.1–2.5, Advanced Biomedical Instrumentation, prepared by Threase Sopra A., AP/DoBM.