Electrocardiogram Physiology, Waves, Intervals, Axis and Segments

An electrocardiogram (ECG or EKG) is a non-invasive, rapid, and cost-effective diagnostic tool used to assess the electrical activity of the heart. It reflects the summation of cardiac action potentials as they propagate through the myocardium, captured by electrodes placed on the skin.

The ECG is essential in evaluating heart rhythm, detecting ischemia or infarction, diagnosing conduction abnormalities, and monitoring electrolyte imbalances or drug effects (e.g., digoxin, antiarrhythmics).

Principles of ECG Recording

Electrical Activity of the Heart

Cardiac myocytes generate action potentials that propagate through the conduction system:

- **SA Node** ? **Atria** ? **AV Node** ? **Bundle of His** ? **Bundle Branches** ? **Purkinje fibers** ? **Ventricular myocardium**

The propagation of depolarization and repolarization generates electric fields, which are transmitted through the body's tissues and recorded at the skin's surface using electrodes.

Deflection Principles

- A wave of depolarization moving **toward** a positive electrode = **positive (upward) deflection**
- A wave moving **away** = **negative (downward) deflection**
- A wave **perpendicular** to the electrode axis = **isoelectric (flat) line**

How to Obtain a 12-Lead ECG

A standard 12-lead ECG requires:

- **4 limb electrodes** : Right Arm (RA), Left Arm (LA), Right Leg (RL - ground), Left Leg (LL)
- **6 chest (precordial) electrodes** : V1–V6

Lead Types

- **Limb leads (frontal plane)** : I, II, III (bipolar); aVR, aVL, aVF (augmented unipolar)
- **Chest leads (transverse plane)** : V1–V6

Each lead provides a unique "view" of the heart's electrical activity.

Understanding ECG Leads

Einthoven’s Triangle and Bipolar Limb Leads

Bipolar leads record voltage between two electrodes:

- **Lead I** : LA (+) ? RA (?) ? 0°
- **Lead II** : LL (+) ? RA (?) ? +60°
- **Lead III** : LL (+) ? LA (?) ? +120°

These form an equilateral triangle around the heart called **Einthoven’s Triangle** .

Augmented Limb Leads (Unipolar)

These compare a single positive electrode to a central reference (Wilson’s Central Terminal):

- **aVR** : RA (+) ? ?150°
- **aVL** : LA (+) ? ?30°
- **aVF** : LL (+) ? +90°

Precordial (Chest) Leads

Placed on the anterior chest wall and view the heart in the horizontal plane:

Lead	Placement
V1	4th ICS, right sternal border
V2	4th ICS, left sternal border
V3	Between V2 and V4
V4	5th ICS, midclavicular line
V5	Level with V4, anterior axillary line
V6	Level with V4, midaxillary line

ICS : Intercostal Space

ECG Paper and Calibration

ECG is usually recorded at:

- **Speed** : 25 mm/sec
- **Voltage calibration** : 10 mm = 1 mV

Grid Interpretation

- **1 small box (horizontal)** = 0.04 sec
- **1 large box (5 small boxes)** = 0.20 sec
- **1 large box (vertical)** = 0.5 mV

ECG Waveform and Intervals

1. P Wave

- **Represents** : Atrial depolarization
- **Normal duration** : 0.08–0.12 sec (2–3 small boxes)
- **Usually upright** in leads I, II, aVF
- **Biphasic** in V1 (RA = first part; LA = second part)

2. PR Interval

- **Represents** : Conduction from atria to ventricles (SA ? AV node)
- **Normal** : 0.12–0.20 sec (3–5 small boxes)
- **Prolonged PR** ? 1° AV block
- **Short PR** ? pre-excitation (e.g., WPW syndrome)

3. QRS Complex

- **Represents** : Ventricular depolarization
- **Normal** : < 0.12 sec (< 3 small boxes)
- **Q wave** : Initial negative deflection (can indicate old MI if >1 small box deep)
- **R wave** : First positive deflection
- **S wave** : Negative deflection after R

High-Yield:

- Wide QRS (>0.12 sec) ? bundle branch block or ventricular origin
- Tall R in V5/V6 or deep S in V1 ? LVH

4. ST Segment

- **Represents** : Early ventricular repolarization
- **Normally isoelectric** (flat)
- **Elevation** : STEMI
- **Depression** : Ischemia, reciprocal changes

5. T Wave

- **Represents** : Ventricular repolarization
- Usually upright in I, II, V3–V6
- **Inverted** ? ischemia, hypokalemia
- **Tall, peaked** ? hyperkalemia

6. QT Interval

- **Represents** : Total ventricular depolarization + repolarization
- **Corrected QT (QTc)** = QT / ?RR
- **Normal QTc** : <440 ms (men), <460 ms (women)
- **Prolonged QTc** ? risk of Torsades de Pointes (drug-induced, congenital)

High-Yield Notes

Feature	Clinical Insight
ST elevation in ?2 contiguous leads	STEMI (emergency!)
Peaked T waves	Hyperkalemia
U wave	Hypokalemia
Prolonged PR	1° AV Block
Wide QRS	Bundle Branch Block
Delta wave + short PR	Wolff-Parkinson-White (WPW) Syndrome
Irregularly irregular rhythm	Atrial Fibrillation
Sawtooth P waves	Atrial Flutter
Wide QRS tachycardia	VTach (assume VT in unstable patients)