Electrocardiography

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February 14, 2025

Contents

1 Introduction

Electrocardiography is the process of producing an electrocardiogram (ECG or EKG), a recording of the heart's electrical activity through repeated cardiac cycles. It is an electrogram of the heart which is a graph of **voltage** *versus* **time** of the electrical activity of the heart using electrodes placed on the skin (also called leads). These electrodes detect the small electrical changes that are a consequence of cardiac muscle depolarization followed by repolarization during each cardiac cycle (heartbeat).

An ECG is a test that records the electrical activity of the heart, including the rate and rhythm. It's usually quick and painless. Changes in the normal ECG pattern occur in numerous cardiac abnormalities, including:

1. Cardiac rhythm disturbances (such as atrial fibrillation and ventricular tachycardia),
2. Ischemic coronary disease: inadequate coronary artery blood flow (such as myocardial ischemia and myocardial infarction),
3. Electrolyte disturbances (such as hypokalemia and hyperkalemia) causing changes in the excitability of myocardial cells.

Traditionally, **ECG** usually means a 12-lead ECG taken while lying down as discussed below. However, ECG signals can be recorded in other contexts with other devices: the electrical activity of the heart can be recorded with a Holter monitor and some models of smartwatchs.

In a conventional 12-lead ECG, ten electrodes are placed on the patient's limbs (4) and on the surface of the chest (6). The overall magnitude of the heart's electrical potential is then measured from twelve different angles (or *leads*) and is recorded over a period of time (usually ten seconds). In this way, the overall magnitude and direction of the heart's electrical depolarization is captured at each moment throughout the cardiac cycle.

During each heartbeat, a healthy heart has an orderly progression of depolarization that starts with pacemaker cells in the sinoatrial node, spreads throughout the atrium, and passes through the atrioventricular node down into the bundle of His and into the

Purkinje fibers, spreading down and to the left throughout the ventricles. This orderly pattern of depolarization gives rise to the characteristic ECG tracing. To the trained clinician, an ECG conveys a large amount of information about the structure of the heart and the function of its electrical conduction system. Among other things, an ECG can be used to measure the rate and rhythm of heartbeats, the size and position of the heart chambers, the presence of any damage to the heart's muscle cells or conduction system, the effects of heart drugs, and the function of implanted pacemakers.

2 Interpretation

Interpretation of the ECG is fundamentally about understanding the electrical conduction system of the heart. Normal conduction starts and propagates in a predictable pattern, and deviation from this pattern can be a normal variation or be pathological. An ECG does not equate with mechanical pumping activity of the heart; for example, pulseless electrical activity produces an ECG that should pump blood but no pulses are felt (and constitutes a medical emergency and CPR should be performed). Ventricular fibrillation produces an ECG but is too dysfunctional to produce a life-sustaining cardiac output. Certain rhythms are known to have good cardiac output and some are known to have bad cardiac output. Ultimately, an echocardiogram or other anatomical imaging modality is useful in assessing the mechanical function of the heart.

Interpretation of the ECG is ultimately that of pattern recognition. In order to understand the patterns found, it is helpful to understand the theory of what ECGs represent. There are three main components to an ECG or a normal rhythm (four, if U wave is taken into account):

1. The P wave represents atrial depolarization, i.e., depolarization of the atria (plural of "atrium").
2. The QRS complex represents ventricular depolarization, i.e., depolarization of the ventricles.
3. The T wave represents ventricular repolarization.
4. The U wave represents papillary muscle repolarization.

Changes in the structure of the heart and its surroundings (including blood composition) change the patterns of these four entities. The U wave is not typically seen and its absence is generally ignored. Atrial repolarization is typically hidden in the much more prominent QRS complex and normally cannot be seen without additional, specialized electrodes.

3 Electrodes and leads

Electrodes are the actual conductive pads attached to the body surface. Any pair of electrodes can measure the electrical potential difference between the two corresponding locations of attachment. Such a pair forms a lead. However, "leads" can also be formed between a physical electrode and a virtual electrode. Commonly, 10 electrodes attached to the body are used to form 12 ECG leads, with each lead measuring a specific electrical potential difference. Leads are broken down into two types: limb and precordial (chest). In medical settings, the term leads is also sometimes used to refer to the electrodes themselves, although this is technically incorrect.