15 Basic ECG Theory, Recordings, and Interpretation

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CONTENTS

1. THE ELECTROCARDIOGRAM

An electrocardiogram (ECG; in German, the electrokardiogram, EKG) is a measure of how the electrical activity of the heart changes over time as action potentials propagate throughout the heart during each cardiac cycle. However, this is not a direct measure of the cellular depolarization and repolarization with the heart, but rather the relative, cumulative magnitude of populations of cells eliciting changes in their membrane potentials at a given point in time; it shows electrical differences across the heart when depolarization and repolarization of these atrial and ventricular cells occur.

The human body can be considered, for the purposes of an ECG, a large-volume conductor. It is basically filled with tissues surrounded by a conductive ionic fluid. You can imagine that the heart is suspended inside of that conductive medium. During the cardiac cycle, the heart contracts in response to action potentials moving along the chambers of the heart. As it moves, there will be one part of the cardiac tissue that is depolarized and another part that is at rest or polarized. This results in a charge separation, or dipole, which is illustrated in Fig. 1.

The dipole causes current flow in the surrounding body fluids between the ends of the heart, resulting in a fluctuating electric field throughout the body. This is much like the electric field that would result, for example, if a common battery were suspended in a saltwater solution (an electrically conductive medium). The opposite poles of the battery would cause current flow in the surrounding fluid, creating an electric field that could be detected by electrodes placed in the solution. A similar electrical field around the heart can be detected using electrodes attached to the skin. The intensity of the voltage detected depends on the orientation of the electrodes with respect to that of the dipole ends. The amplitude of the signal is proportional to the mass of tissue involved in creating that dipole at any given time. Using electrodes on the surface of the skin to detect the voltage of this electrical field is what provides the electrocardiogram.

It is important to note, as might be expected, that because the ECG is measured on the skin, any potential differences within the body can have an effect on the electrical field detected. This is why it is considered important for diagnostic purposes that, while recording an ECG from an individual, the individual should remain as still as possible. Movements require the use of skeletal muscles, which then contribute to the changes in volt-
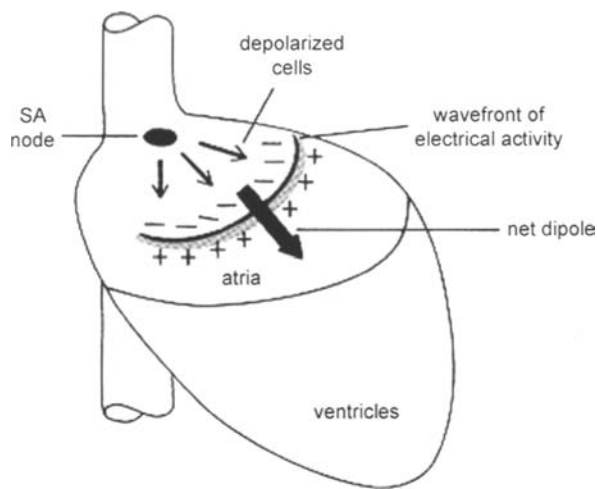
191

Fig. 1. After conduction begins at the sinoatrial (SA) node, cells in the atria begin to depolarize. This creates an electrical wavefront that moves down toward the ventricles, with polarized cells at the front, followed by depolarized cells behind. The separation of charge results in a dipole across the heart (the large black arrow shows its direction). Modified from D.E. Mohrman and L.J. Heller (eds.), *Cardiovascular Physiology*, 5th Ed., 2003. Reproduced with permission of the McGraw-Hill Companies.
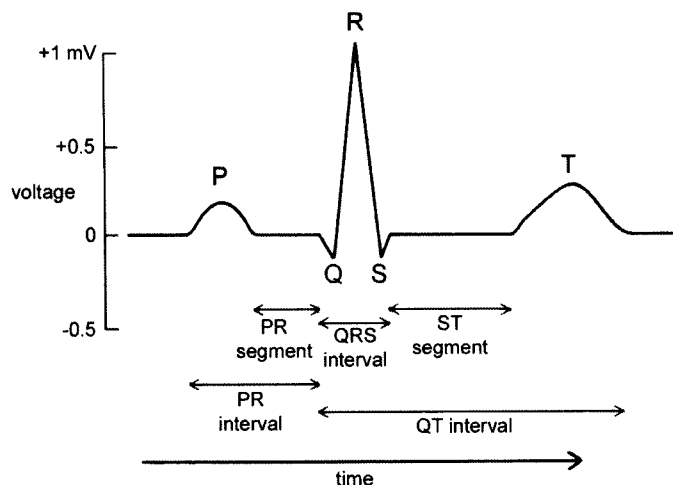

Fig. 2. A typical ECG waveform for one cardiac cycle measured from the lead II position. The P wave denotes atrial depolarization, the QRS indicates ventricular depolarization, and the T wave denotes ventricular repolarization. The events on the waveform occur on a scale of hundreds of milliseconds. Modified from D.E. Mohrman and L.J. Heller, (eds.), *Cardiovascular Physiology*, 5th Ed., 2003. Reproduced with permission of the McGraw-Hill Companies.

ages detected using electrodes on the surface of the body. When the monitored patient is essentially motionless, it is considered a "resting ECG," the type of ECG signals discussed in the majority of this chapter.

2. THE ECG WAVEFORM

When an ECG is recorded, a reading of voltage vs time is produced, which is normally displayed as millivolts (mV) and seconds. A typical lead II ECG waveform is shown in Fig. 2. For this recording, the negative electrode was placed on the right

wrist, and the positive electrode was placed on the left ankle, giving the standard lead II ECG (explained in Section 3.1.). It shows a series of peaks and waves that corresponds to ventricular or atrial depolarization and repolarization, with each segment of the signal representing a different event associated with the cardiac cycle.

The cardiac cycle begins with the firing of the sinoatrial node in the right atrium. This firing is not detected by the surface ECG because the sinoatrial node is not composed of an adequately large quantity of cells to create an electrical potential with a high enough amplitude to be recorded with distal electrodes (signal amplitude is lost as it dissipates through the conductive medium). The atria then depolarize, giving rise to the P wave. This represents the coordinated depolarization of the right and left atria and the onset of atrial contraction. The P wave is normally around 80–100 ms in duration. As the P wave ends, the atria are completely depolarized and are beginning contraction.

The signal then returns to baseline, and action potentials (not large enough to be detected) spread to the atrioventricular node and bundle of His. Then, roughly 160 ms after the beginning of the P wave, the right and left ventricles begin to depolarize, resulting in what is called the QRS complex, representing the beginning of ventricular contraction, which is around 80 (60–100) ms in duration. Typically, the first negative deflection is the Q wave, the large positive deflection is the R wave, and if there is a negative deflection after the R wave, it is called the S wave. The exact shape of the QRS complex, as explained in Section 3.2., depends on the placement of electrodes from which the signals are recorded.

Simultaneous with the QRS complex, atrial contraction has ended, and the atria are repolarizing. However, the effect of this global atrial repolarization is sufficiently masked by the much larger amount of tissue involved in ventricular depolarization and is thus not normally detected in the ECG. During ventricular contraction, the ECG signal returns to baseline. The ventricles then repolarize after contraction, giving rise to the T wave. Note that the T wave is normally the last-detected potential in the cardiac cycle; thus, it is followed by the P wave of the next cycle, repeating the process.

Of clinical importance in the ECG waveform are several notable parameters (regions), which include the P–R interval, the S–T segment, and the Q–T interval. The P–R interval is measured from the beginning of the P wave to the beginning of the QRS complex and is normally 120–200 ms long. This is basically a measure of the time it takes for an impulse to travel from atrial excitation and through the atria, atrioventricular node, and remaining fibers of the conduction system. The S–T segment is the period of time when the ventricles are completely depolarized and contracting and is measured from the S wave to the beginning of the T wave. The Q–T interval is measured from the beginning of the QRS complex to the end of the T wave; this is the time segment from when the ventricles begin their depolarization to the time when they have repolarized to their resting potentials and is normally about 400 ms in duration.

An obvious observation made concerning the QRS complex is that it has a much higher peak and shorter duration than