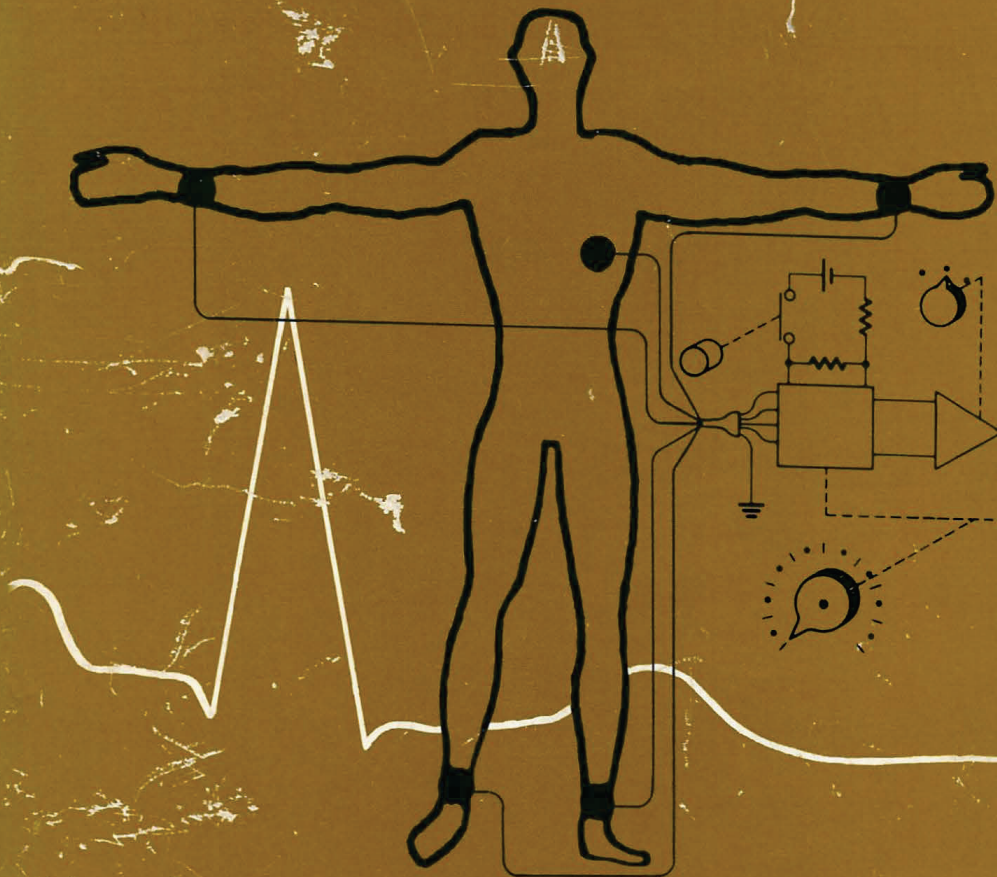


Biomedical Instrumentation and Measurements



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BIOMEDICAL INSTRUMENTATION AND MEASUREMENTS

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3.3. THE BIOELECTRIC POTENTIALS

To measure bioelectric potentials, a transducer capable of converting ionic potentials and currents into electric potentials and currents is required. Such a transducer consists of two *electrodes*, which measure the ionic potential difference between their respective points of application. Electrodes are discussed in detail in Chapter 4.

Although measurement of individual action potentials can be made in some types of cells, such measurements are difficult because they require precise placement of an electrode inside a cell. The more common form of measured biopotentials is the combined effect of a large number of action potentials as they appear at the surface of the body, or at one or more electrodes inserted into a muscle, nerve, or some part of the brain.

The exact method by which these potentials reach the surface of the body is not known. A number of theories have been advanced that seem to explain most of the observed phenomena fairly well, but none exactly fits the situation. Many attempts have been made, for example, to explain the biopotentials from the heart as they appear at the surface of the body. According to one theory, the surface pattern is a summation of the potentials developed by the electric fields set up by the ionic currents that generate the individual action potentials. This theory, although plausible, fails to explain a number of the characteristics indicated by the observed surface patterns. A closer approximation can be obtained if it is assumed that the surface pattern is a function of the summation of the first derivatives (rates of change) of all the individual action potentials, instead of the potentials themselves. Part of the difficulty arises from the numerous assumptions that must be made concerning the ionic current and electric field patterns throughout the body. The validity of some of these assumptions is considered somewhat questionable. Regardless of the method by which these patterns of potentials reach the surface of the body or implanted measuring electrodes, they can be measured as specific bioelectric signal patterns that have been studied extensively and can be defined quite well.

The remainder of this chapter is devoted to a description of each of the more significant bioelectric potential waveforms. The designation of the waveform itself generally ends in the suffix *gram*, whereas the name of the instrument used to measure the potentials and graphically reproduce the waveform ends in the suffix *graph*. For example, the *electrocardiogram* (the name of the waveform resulting from the heart's electrical activity) is measured on an *electrocardiograph* (the instrument). Ranges of ampli-

tudes and frequency spectra for each of the biopotential waveforms described below are included in Appendix B.

3.3.1. THE ELECTROCARDIOGRAM (ECG). The biopotentials generated by the muscles of the heart result in the *electrocardiogram*, abbreviated ECG (sometimes EKG, from the German *elektrokardiogram*). To understand the origin of the ECG, it is necessary to have some familiarity with the anatomy of the heart. Figure 3.5 shows a cross section of the interior of the heart. The heart is divided into four chambers. The two upper chambers, the left and right *atria*, are synchronized to act together. Similarly, the two lower chambers, the *ventricles*, operate together. The right atrium receives blood from the veins of the body and pumps it into the right ventricle. The right ventricle pumps the blood through the lungs, where it is oxygenated. The oxygen-enriched blood then enters the left atrium, from which it is pumped into the left ventricle. The left ventricle pumps the blood into the arteries to circulate throughout the body. Because the ventricles actually pump the blood through the vessels (and therefore do most of the work), the ventricular muscles are much larger and more important than the muscles of the atria. In order for the cardiovascular system to function properly, both the atria and the ventricles must operate in a proper time relationship.

Each action potential in the heart originates near the top of the right atrium at a point called the *pacemaker* or *sinoatrial (SA) node*. The pacemaker is a group of specialized cells that spontaneously generate action potentials at a regular rate, although the rate is controlled by innervation. To initiate the heartbeat, the action potential generated by the pacemaker propagates in all directions along the surface of both atria. The wavefront of activation travels parallel to the surface of the atria toward the junction of the atria and the ventricles. The wave terminates at a point near the center of the heart, called the *atrioventricular node (AV node)*. At this point, some special nerve fibers act as a “delay line” to provide proper timing between the action of the atria and the ventricles. Once the electrical excitation has passed through the delay line, action potentials are initiated in the powerful musculature of the ventricles. The wavefront in the ventricles, however, does not follow along the surface but is perpendicular to it and moves from the inside to the outside of the ventricular wall, terminating at the tip or *apex* of the heart. As indicated earlier, a wave of repolarization follows the depolarization wave by about 0.2 to 0.4 second. This repolarization, however, is not initiated from neighboring muscle cells but occurs as each cell returns to its resting potential independently.

Figure 3.6 shows a typical ECG as it appears when recorded from the surface of the body. Alphabetic designations have been given to each