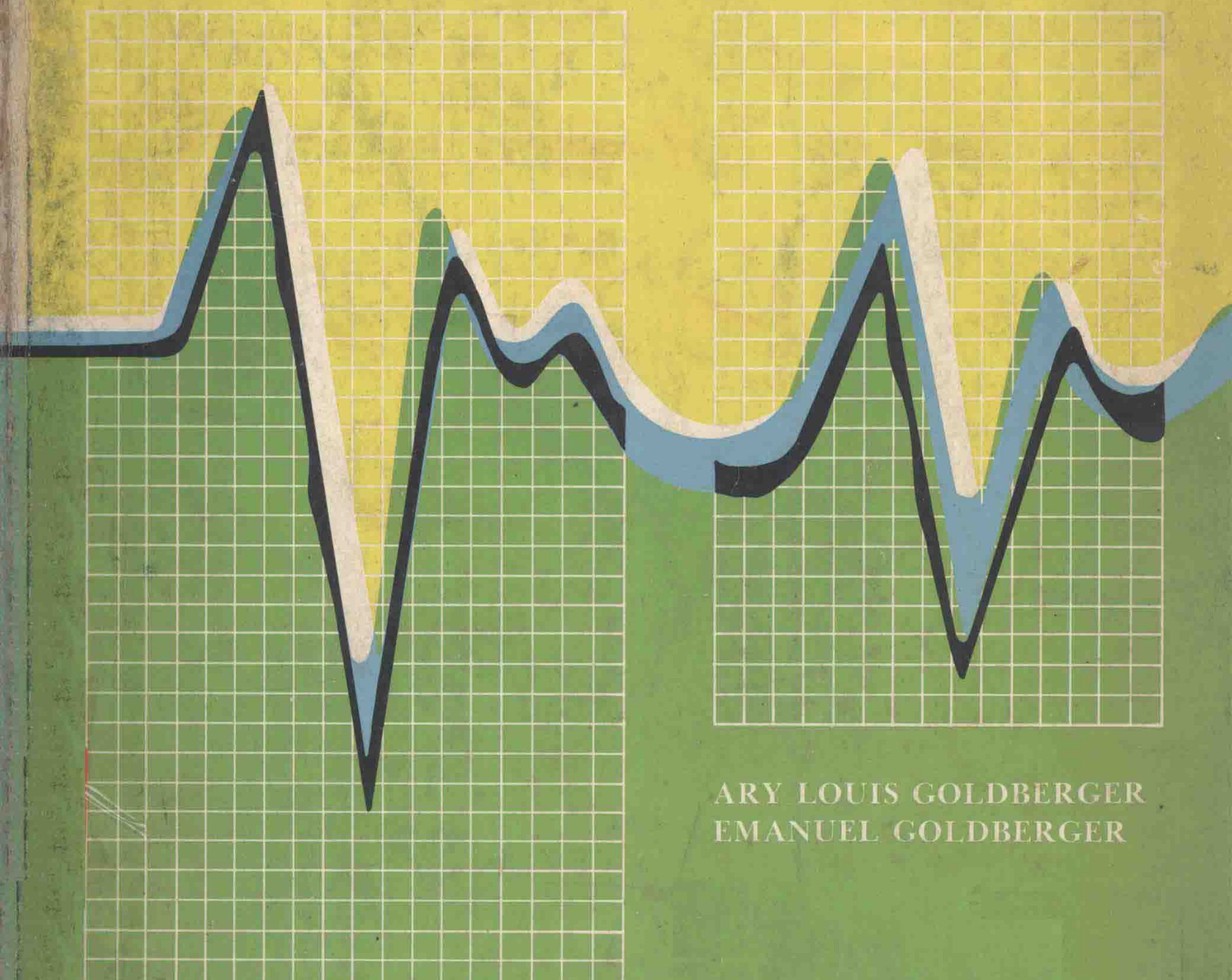
CLINICAL ELECTROCARDIOGRAPHY

A simplified approach



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A simplified approach

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For Zacky with love

PREFACE

This book is an introduction to electrocardiography. It is written particularly for medical students, nurses, and paramedical assistants and assumes no previous instruction in ECG reading. The text is based on the cumulative experience of both authors in the field of electrocardiography, beginning in 1944 with the invention of the aV_R, aV_L, and aV_F leads by one of the authors (E. G.). The text itself is closely based on a series of lectures given by the other author (A. G.) for the past four years to physician's associates and medical students at the Yale Medical School.

We have divided the book into three sections. Part I covers the basic principles of electrocardiography, normal ECG patterns, and the major abnormal P-QRS-T patterns. Part II describes the major abnormalities of heart rhythm and conduction. Part III is a collection of practice questions and problems for review. In addition, we have interspersed practice questions throughout the text. In reading ECGs, as in learning a new language, fluency is attained only with repetition and review.

The clinical applications of ECG reading have been stressed throughout the book. Each time an abnormal pattern is mentioned, there is a brief discussion of the conditions that might have produced it. Although this is not intended as a manual of therapeutics, general principles of treatment and clinical management are discussed. In addition, students are encouraged to approach ECGs in terms of a rational, simple differential diagnosis, rather than through the tedium of rote memorization. It is comforting for most students to discover that the number of possible arrhythmias that can produce a heart rate of 170 beats per minute is limited to just a handful of choices. Only three basic ECG patterns are found with cardiac arrest. Similarly, there are only a few causes of low voltage patterns, of patterns where the QRS complex is abnormally wide, and so on.

In approaching any given ECG, there are always three essential questions. First, what does the ECG show? Second, what are the possible causes of this pattern? And third, what should be done about it? Most conventional ECG books focus on the first question, emphasizing pattern recognition. However, it is only a first step, for example, to note the premature ventricular contractions (PVCs) in an ECG. The more important question is what could have produced these abnormal beats: digitalis toxicity, hypoxia, myocardial ischemia, pulmonary embolism, or something else? Treatment, of course, will depend on the answer to these questions.

The aim of this book, therefore, is to present the ECG as it is used on the hospital wards, in the outpatient clinics, and in the intensive and coronary care units, where recognition of normal and abnormal patterns is only the starting point in patient care and management.

A number of people helped in the preparation of this book. Many of the ECGs were contributed by our colleagues. In particular, we would like to thank Pam

Petruzelli, Maureen O'Connor, and Karen Wilken, and the other nurses in the New Haven and Memorial Unit CCUs of Yale New Haven Hospital and the West Haven Veterans Administration Hospital. We would also like to thank Drs. René Langou, Morris Flaum, William Levy, and Lee Katz of Yale New Haven Hospital, and Frances Williams, electrocardiography laboratory of Albert Einstein College Hospital. Dr. Marc Weinberg of Yale New Haven Hospital kindly reviewed the manuscript and made many helpful suggestions. We would like to extend a special note of appreciation to Paul Moson, Executive Director of the Yale Physician's Associate Program, and to the Physician's Associate students of the 1976-1978 class for helping to nurture this work and for auditioning the material in the text. This project was sponsored by the trustees of the Dr. Louis B. and Anna H. Goldberger Memorial Foundation for Medical Research. Our good friend, Herbert F. McAuliffe, kindly proofread the text. Finally, we would like to thank Blanche Goldberger for her encouragement and Ellen Goldberger for her artwork, editorial assistance, and for enduring, once again, the karmic clutter of ECG clippings.

Ary Louis Goldberger

Emanuel Goldberger

CONTENTS

COMMONLY USED ABBREVIATIONS IN ELECTROCARDIOGRAPHY

AF	Atrial fibrillation
APC	Atrial premature contraction (same as PAC)
AVD	Atrioventricular dissociation
AWMI	Anterior wall myocardial infarction
CHB	Complete heart block
IWMI	Inferior wall myocardial infarction
LAE	Left atrial enlargement
LAHB	Left anterior hemiblock
LBBB	Left bundle branch block
LPHB	Left posterior hemiblock
LVH	Left ventricular hypertrophy
MAT	Multifocal atrial tachycardia
NSST-T change	Nonspecific ST-T wave change
PAC	Premature atrial contraction (same as APC)
PAT	Paroxysmal atrial tachycardia
PVC	Premature ventricular contraction (same as VPC)
RAE	Right atrial enlargement
RBBB	Right bundle branch block
RVH	Right ventricular hypertrophy
SSS	Sick sinus syndrome
SVT	Supraventricular tachycardia
VF	Ventricular fibrillation
VPC	Ventricular premature contraction (same as PVC)
VT	Ventricular tachycardia
WPW	Wolff-Parkinson-White pattern

PART I

Basic principles and patterns

1 INTRODUCTORY PRINCIPLES

DEFINITION

An *electrocardiogram* (ECG)* records electric currents (voltages, potentials) produced by the heart by means of metal *electrodes* placed on the surface of the body. As described in Chapter 3, these metal electrodes are placed on the arms, legs, and chest wall.

BASIC CARDIAC ELECTROPHYSIOLOGY

Before discussing the basic ECG patterns, we will review some elementary aspects of cardiac electrophysiology. Fortunately, only certain simple principles are required for clinical interpretation of ECGs. In addition, it is worth mentioning now that no special knowledge of electronics or electrophysiology is necessary despite the connotations of the term "electrocardiography."

In simplest terms the function of the heart is to contract and to pump blood to the lungs for oxygenation and then to pump this oxygenated blood into the general (systemic) circulation. The signal for cardiac contraction is the spread of electric currents through the heart muscle. These currents are produced by both specialized nervous conducting tissue within the heart and by the heart muscle itself. The ECG records these electric currents produced by the heart.

*The abbreviation *EKG* is sometimes used.

ELECTRICAL STIMULATION OF THE HEART

The electrical "wiring" of the heart is outlined in Fig. 1-1. Normally, the signal for cardiac electrical stimulation starts in the *sinus node* (also called the sinoatrial or SA node). The sinus node is located in the right atrium near the opening of the superior vena cava. It is a small collection of specialized cells capable of generating electrical stimuli (signals). From the sinus node, this electrical stimulus spreads first through the right atrium and then into the left atrium. In this way the sinus node functions as the normal *pacemaker* of the heart.

The first phase of cardiac activation consists of the electrical stimulation of the right and left atria. This electrical stimulation, in turn, signals the atria to contract and to pump blood simultaneously through the tricuspid and mitral valves into the right and left ventricles, respectively. The electrical stimulus then spreads through specialized conduction tissues in the *atrioventricular (AV) junction* (which includes the *AV node and bundle of His*) and then into the *left and right bundle branches*, which carry the stimulus to the ventricular muscle cells.

The AV junction, which functions as an electrical "bridge" connecting the atria and ventricles, is located at the base of the interatrial septum and extends into the ventricular septum as shown in Fig. 1-1.

CONDUCTION SYSTEM OF THE HEART

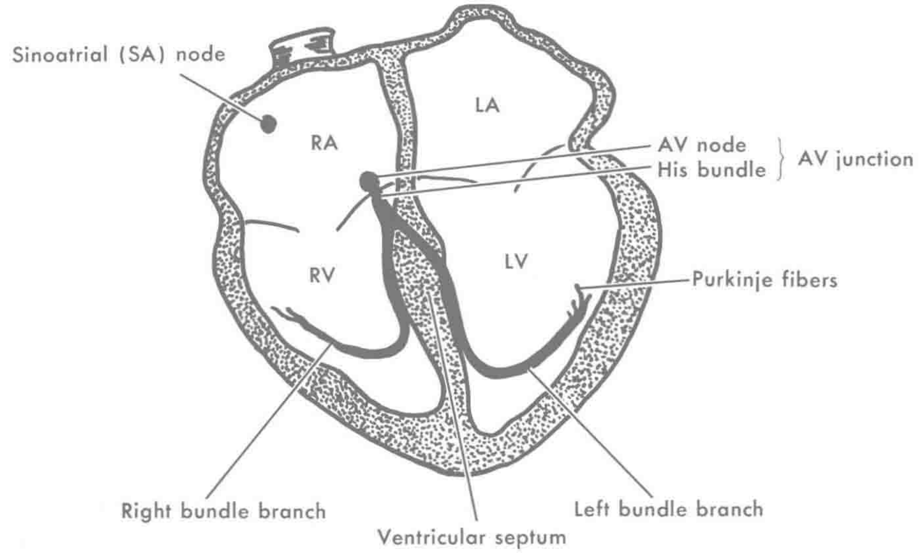

Fig. 1-1. Normally, cardiac stimulus is generated in *SA node,* in the right atrium, *RA.* Stimulus then spreads through *RA* and *LA* (right and left atrium). Next, stimulus spreads through *AV node* and *His bundle,* which comprise the *AV junction.* Stimulus then passes into the left and right ventricles (*LV* and *RV*) by way of the *left* and *right bundle branches,* which are continuations of His bundle. Finally, stimulus spreads to ventricular muscle cells through *Purkinje fibers.*

The AV junction has two subdivisions: The upper (proximal) part is the AV node. (In older texts, the terms "AV node" and "AV junction" are used synonymously.) The lower (distal) segment of the AV junction is called the bundle of His, after the physiologist who described it. The bundle of His then divides into two main branches: the right bundle branch, which brings the electrical stimulus to the right ventricle, and the left bundle branch, which brings the electrical stimulus to the left ventricle (Fig. 1-1).

The electrical stimulus spreads simultaneously down the left and right bundle branches into the ventricular muscle itself *(ventricular myocardium).* The stimulus spreads into the ventricular myocardium by way of specialized conducting cells called *Purkinje fibers* located in the ventricular muscle.

Under normal circumstances, when the sinus node is pacing the heart (normal sinus rhythm), the AV junction functions only as a shuttle, directing the electrical stimulus into the ventricles. However, under some circumstances described later, the AV junction can also function as a secondary pacemaker of the heart. For example, if the sinus node fails to function properly, the AV junction may act as an *escape* pacemaker. In such cases, AV junctional rhythm (and *not* sinus rhythm) is present. This produces a distinct ECG pattern (described in Chapter 12).

Just as the spread of electrical stimuli through the atria leads to atrial contraction, the spread of the electrical stimuli through the ventricles leads to ventricular contraction, with pumping of blood into the lungs and into the general circulation.

In summary, the electrical stimulation of the heart normally follows a repetitive sequence of five steps.

1. Production of a stimulus from pacemaker cells in the sinus node in the right atrium

2. Stimulation of the right and left atria
3. Spread of the stimulus through the AV junction (AV node and bundle of His)
4. Spread of the stimulus simultaneously through the left and right bundle branches
5. Stimulation of the left and right ventricular muscle (myocardium)

CARDIAC CONDUCTIVITY AND AUTOMATICITY

The speed with which the electrical impulses are conducted through different parts of the heart varies. For example, conduction speed is *slowest* through the AV junction and *fastest* through the Purkinje fibers. The relatively slow conduction speed through the AV junction is of functional importance because it allows the ventricles time to fill with blood before the signal for cardiac contraction arrives.

In addition to *conductivity* the other major electrical feature of the heart is *automaticity.* Automaticity refers to the capacity of certain myocardial cells to function as pacemakers, to spontaneously generate electrical impulses that spread throughout the heart. Normally, as mentioned earlier, the sinus node is the pacemaker of the heart because of its inherent automaticity. Under special conditions, other cells outside the sinus node (in the atria, the AV junction, or the ventricles) can also act as pacemakers. For example, as mentioned earlier, if the automaticity of the sinus node is depressed, the AV junction may function as an escape pacemaker. In other conditions the automaticity of pacemakers outside the sinus node may become abnormally increased, and these *ectopic* (nonsinus) pacemakers may compete with the sinus node for control of the heart beat. *Ectopy* is discussed in detail in Part II of this book in the section on cardiac arrhythmias.

If you understand this normal physiologic stimulation of the heart, you have the basis for understanding the abnormalities of heart rhythm (arrhythmias) and conduction that produce distinctive ECG patterns. For example, failure of the sinus node to stimulate the heart properly may result in various rhythm disturbances, such as sinoatrial block (SA block), discussed in Chapter 11. Similarly, blockage of the spread of the stimulus through the AV junction will produce various degrees of AV heart block (Chapter 15). Disease of the bundle branches may produce left or right bundle branch block (Chapter 7). Finally, any disease process that involves the ventricular muscle itself (for example, destruction of the heart muscle by myocardial infarction) will also produce marked changes in the normal ECG patterns.

The first part of this book, therefore, is devoted to explaining the basis of the normal ECG, followed by a detailed look at major conditions causing abnormal P, QRS, and T* patterns. The second part of the book is devoted to describing the various abnormal rhythms (arrhythmias) and AV conduction disturbances that can occur. The third part of the book is a collection of review questions and examples. A short, selective bibliography is provided at the end of the text.

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*P, QRS, and T are defined in Chapter 2.

REVIEW OF CHAPTER 1

An ECG records the electrical voltages (potentials) produced in the heart by means of metal electrodes (connected to an electrocardiograph) placed on the patient's extremities and chest wall.

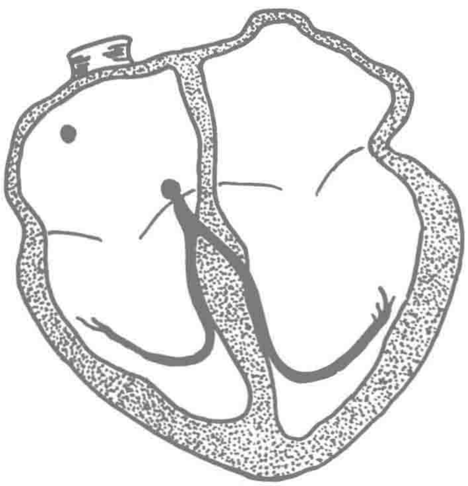
The electrical voltages of the heart are produced by specialized conduction fibers within the heart and by the heart muscle fibers themselves.

Normally, a stimulus starts in the sinus node located high in the right atrium near the superior vena cava. From here the stimulus spreads downward and to the left through the right and left atria and reaches the AV node, located at the beginning of the interventricular septum (Fig. 1-1). After a delay, the stimulus spreads through the *AV junction* (the AV node and bundle of His). The bundle of His then divides into main right and left branches. The right bundle branch runs down the interventricular septum and into the right ventricle. From there, small fibers, the Purkinje fibers, bring the stimulus outward into the main muscle mass of the right ventricle. Simultaneously, the left main bundle branch carries the stimulus down the interventricular septum to the muscle mass of the left ventricle, also by way of the Purkinje fibers.

This sequence of stimulation of the heart is the normal basic process. Disturbances of this sequence may produce disturbances in the rhythm of the heart (the cardiac arrhythmias) or disturbances in cardiac conduction (SA block, AV heart block, or bundle branch block).

REVIEW QUESTION: Chapter 1

1. Label the major parts of the cardiac conduction system in this diagram and then trace the spread of the normal cardiac stimulus from atria to ventricles.



ANSWER

1. See Fig. 1-1 on p. 4.

2 BASIC ECG WAVES

DEPOLARIZATION AND REPOLARIZATION

In Chapter 1 we used the general term "electrical stimulation" to refer to the spread of electrical stimuli through the atria and ventricles. The technical term for this cardiac electrical stimulation is *depolarization*. The return of heart muscle cells to their resting state following stimulation (depolarization) is called *repolarization*. These terms are derived from the fact that the normal myocardial cells (atrial and ventricular) are *polarized*. That is, they carry an electric charge on their surface. Fig. 2-1, *A*, shows the resting polarized state of a normal heart muscle cell. Notice that the outside of the resting cell is positive, and the inside of the cell is negative.

When a heart muscle cell is stimulated, it *depolarizes*. As a result, the outside of the cell, in the area where the stimulation has occurred, becomes negative, while the inside of the cell becomes positive. This produces a difference in electrical voltage on the outside of the cell between the stimulated depolarized area and the unstimulated polarized area (Fig. 2-1, *B*) As a result, a small electric current is formed. This electric current spreads along the length of the cell as stimulation and depolarization occur until the entire cell is depolarized (Fig. 2-1, *C*). The path of depolarization can be represented by an arrow, as shown in Fig. 2-1.

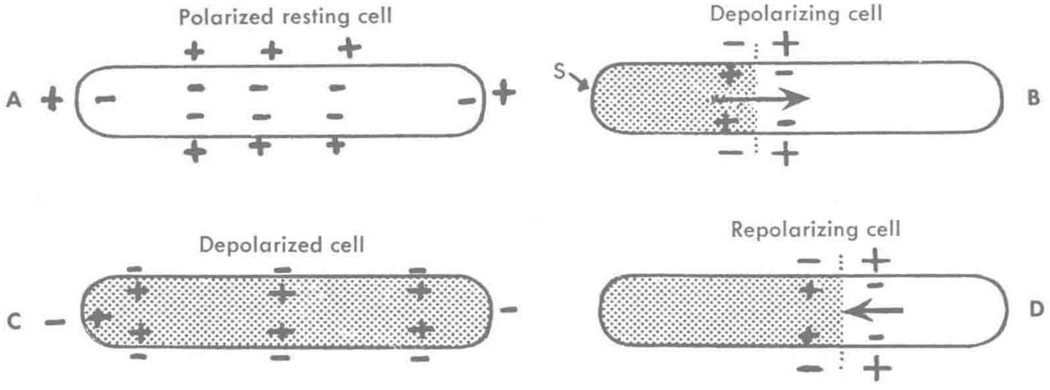


Fig. 2-1. Depolarization and repolarization. Resting heart muscle cell, **A,** is polarized; that is, it carries an electric charge, with the outside of the cell positively charged and the inside of the cell negatively charged. When the cell is stimulated, *S,* as in **B,** the cell begins to depolarize (stippled area). Fully depolarized cell, **C,** is positively charged on the inside and negatively charged on the outside. Repolarization, **D,** occurs when stimulated cell returns to resting state. Direction of depolarization and repolarization is represented by arrows. Depolarization (stimulation) of the atria produces the P wave, while depolarization of the ventricles produces the QRS complex. Repolarization of the ventricles produces the ST-T complex on the ECG.

This depolarizing electric current is recorded by the ECG as a P wave (when the atria are stimulated and depolarize) and as a QRS complex (when the ventricles are stimulated and depolarize).

After a period of time, the fully stimulated and depolarized cell begins to return to the resting state. This is known as *repolarization.* A small area on the outside of the cell becomes positive again (Fig. 2-1, *D*). The repolarization spreads slowly along the length of the cell until the entire cell is once again fully repolarized. Ventricular repolarization is recorded by the ECG as the S-T segment, T wave, and U wave. (Atrial repolarization is discussed later.)

The ECG records the electrical activity of a large mass of atrial and ventricular cells, not just the electrical activity of a single cell. Since cardiac depolarization and repolarization normally occur in a synchronized fashion, the ECG is able to record these electric currents as specific waves (P wave, QRS complex, S-T segment, T wave, and U wave).

To summarize, regardless of whether the ECG is normal or abnormal, it merely records two basic events: (1) depolarization—the spread of a stimulus through the heart muscle—and (2) repolarization—the return of the stimulated heart muscle to the resting state.

BASIC ECG COMPLEXES: P, QRS, S-T, T, AND U WAVES

This spread of a stimulus through the atria and ventricles and the return of the stimulated atrial and ventricular muscle to the resting state produce, as noted previously, the electric currents recorded in the ECG. Furthermore, each phase of cardiac electrical activity produces a specific wave or complex shown in Fig. 2-2. These basic ECG waves are labeled alphabetically beginning with the P wave as follows:

P wave: atrial depolarization (stimulation)
QRS complex: ventricular depolarization (stimulation)
S-T segment:
T wave:
U wave:
} ventricular repolarization (recovery)

BASIC ECG COMPLEXES

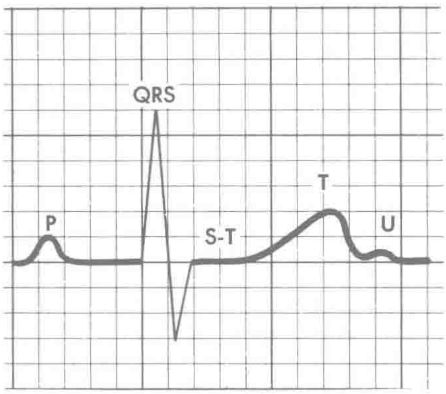


Fig. 2-2. P wave represents atrial depolarization. P-R interval represents time from initial stimulation of atria to initial stimulation of ventricles. QRS represents ventricular depolarization. S-T segment, T wave, and U wave are produced by ventricular repolarization. See text.

The P wave represents the spread of a stimulus through the atria (atrial depolarization). The QRS complex represents the spread of a stimulus through the ventricles (ventricular depolarization). The S-T segment and T wave represent the return of the stimulated ventricular muscle to the resting state (ventricular repolarization). The U wave is a small deflection sometimes seen just after the T wave. It represents the final phase of ventricular repolarization, although its exact significance is not known.

You are probably wondering why there is no wave or complex representing the return of the stimulated atria to the resting state. Actually, the routine ECG generally does not record atrial repolarization (the atrial T wave or the Ta wave) because it occurs simultaneously with the QRS complex and is therefore usually obscured by it. Similarly, the routine ECG is not sensitive enough to record any electrical activity during the spread of the stimulus through the AV junction (AV node and bundle of His). The spread of the electrical stimulus through the AV junction occurs between the beginning of the P wave and the beginning of the QRS complex. This interval,