Examination of the Heart

PART FIVE

The Electrocardiogram

AMERICAN HEART ASSOCIATION

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Examination of the Heart

A SERIES OF BOOKLETS

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Introduction

OF ALL LABORATORY cardiac procedures the electrocardiogram provides the most information for the effort involved. It is completely noninvasive, without risk, modest in expense, and can be performed by the physician, nurse, technician, or student. In fact, it can often be interpreted by any of them. The electrocardiogram provides information about heart rate, rhythm, state of the myocardium, the presence or absence of hypertrophy, ischemia or necrosis, abnormalities of conduction, and distribution. The electrocardiogram also reflects the presence of various drugs and the effects of disturbed electrolytes. Relatively specific abnormalities accompany pericarditis, and even malignant disease of the heart is sometimes detected. Perhaps most importantly, although a normal electrocardiogram may be found in the presence of a variety of chronic disorders of the heart, it is rarely seen with acute, serious disease.

There are obvious limitations to the range of material which can be presented in a pamphlet of this size and intent. Excellent, comprehensive texts are available which deal with all aspects of electrocardiography and may be used as atlases or references. This introductory monograph is intended primarily for occasional or emergency use, as an aid to the non-cardiologist confronted with a real or possible cardiac emergency. It will present a range of normal electrocardiograms and a sampling of those acutely abnormal records most likely to appear in the emergency room. Abnormal records will also be shown that do not call for emergency measures.

Basic Principles

ELECTROMECHANICS. The electrocardiogram (ECG) is a written record of the rising and falling voltages generated by the contracting heart and recorded against time. By convention, an upward movement of the trace results from a positive voltage while a downward deflection indicates negative voltage. Time is expressed on the abscissa of the moving chart paper by vertical lines, normally 1 mm or 0.04 second apart. Each fifth line is somewhat heavier than the rest to indicate 0.20 second. The paper ordinarily moves at a rate of one inch or 2.5 cm per second (5 of the large or 25 of the small spaces). The paper also carries horizontal lines 1 mm apart to aid in the measurement of up and down excursions.

ELECTROPHYSIOLOGY. The normal electrocardiogram of man displays wave forms generated by both atria and both ventricles. Myocardium behaves somewhat like stretched, coiled spring which is restrained from shortening until triggered into action by an appropriate stimulus. It then contracts vigorously and immediately prepares itself for the next cycle while still actively contracting. This is the result of, among other things, the movement of sodium and potassium ions across the cell membrane and consequent change of voltage or electrical pressure. The process of discharge or firing is also known as depolarization (loss of polarity) and the act of recovery or reconstitution as repolarization. The ventricles have a specialized conduction system which brings the stimulus to almost all of the ventricular endocardial surfaces simultaneously. The ventricles normally depolarize within 0.10 second, usually in 0.08. Despite their much smaller mass, the atria also take up to 0.10 second to depolarize, probably because of their more primitive conducting system. In fact, the atria are activated in a relatively slow, peristaltic manner while the ventricles contract quickly and vigorously, with a wringing movement.

THE CONDUCTION SYSTEM. The atrioventricular node (AVN) is an in-series component of the atrioventricular conduction system which has for its only apparent function the interposition of a delay between the atrial and ventricular contractions. It is

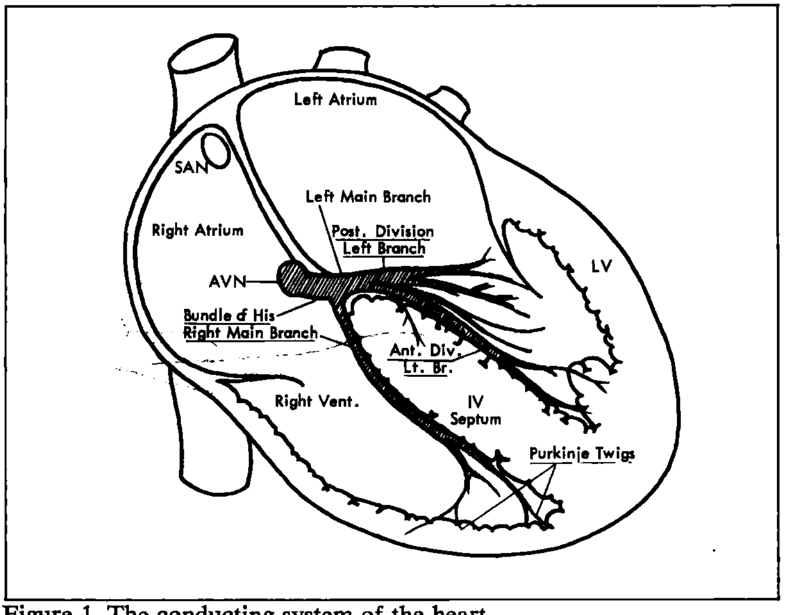

Figure 1. The conducting system of the heart.

postulated that this permits maximal atrial emptying and delays ventricular contraction to the optimal effective point within the cycle. The bundle of His carries the impulse from the atrioventricular node, of which it is a continuation, to its right and left branches. The right branch is single but the left would appear to give off an early, small septal twig before dividing into its major anterior and posterior divisions.* The terminal arborizations which end at the endocardial myocardium are designated the Purkinje system. Despite the slow passage of the impulse through the atrioventricular node, movement through the remainder of the conducting system is very fast (Fig. 1).

AUTOMATICITY. Normal ventricular myocardium requires a stimulus to initiate depolarization. However, the sinoatrial node (SAN), certain cells between it and the atrioventricular node, and the His bundle and its divisions including the Purkinje system are capable of automatic rhythmic depolarization and can cause stimulation of the entire heart by radial conduction. Cells from each of these tissues have their own rate of automaticity, with the SA node, which is also under the control of the autonomic nervous system, being the fastest. The remainder are arranged in descending order of speed with the Purkinje cells being the slowest. The SA node is, therefore, the normal pacemaker for both atria and ventricles. The other potential but slower pacemakers are regularly discharged by the most rapid pacemaker before they can attain effective stimulus levels.

THE NORMAL RECORD. As noted above, the myocardium displays voltage changes both during depolarization and recovery. One

*The electrocardiogram records a left-to-right onset of ventricular depolarization such as would result from initial stimulation of the left side of the septum by a proximal twig from the left branch. The same result, the so-called septal Q in Leads I or V_6, would occur, however, from simultaneous depolarization of both sides of the septum with preponderantly left forces.

may expect, therefore, a depolarization wave for the atria followed by an atrial recovery wave, and the same for the ventricles. However, the ventricular discharge waves are much more prominent than the atrial and, except in unusual circumstances, occur more or less simultaneously with the atrial recovery period, effectively obscuring it. The ventricular recovery, on the other hand, is unimpeded and falls immediately after the ventricular depolarization deflection. Accordingly, we can anticipate the following wave forms in the normal electrocardiogram: an atrial depolarization wave, known as the P wave, a brief inactive period occupied largely by the atrioventricular nodal delay, a rapidly changing, prominent QRS complex, the ventricular depolarization display, the T wave, a large, slow, usually upright wave generated by ventricular recovery, and often an incompletely understood, even slower wave known as the U, (Fig. 2). It is suspected that the U represents either the last vestige of ventricular reconstitution or the recovery wave of the Purkinje system which is known to be very slow and very late. At any one moment, the position of the stylus as it inscribes the ECG is the resultant or the algebraic sum of all the electrical activity taking place within the body and may change to a different value and even a different sense at the next moment. The ventricular wave form usually does just this as the net forces move from place to place. This may be more apparent from one point of view or one lead than another as the various leads are actually sampling sites from the surface of the body. Since both ventricles depolarize simultaneously or almost so and the left ventricle is normally predominant, the ventricular electrocardiogram is, for all ordinary purposes, almost wholly a levocardiogram. It is to be noted, however, that the left ventricle itself depolarizes radially and that most of its electrical output is balanced by more or less equal but opposite forces. The actual record is, in fact, the net result of numerous forces which are largely cancelled within the heart, its muscle, and the immediately surrounding tissues, but is made possible by minor degrees of asymmetry and asynchrony. The bulk of the ECG is believed to arise from the more electrically available and less completely cancelled epicardial surfaces of the heart. The deeper layers, however, are not electrically silent. Extensive alterations of the record may be seen during ischemia or injury of the subendocardial myocardium. The contribution from the right ventricle does not become separately apparent unless it becomes grossly enlarged or sufficiently asynchronous to permit its uncancelled and unobscured appearance late in the cycle.

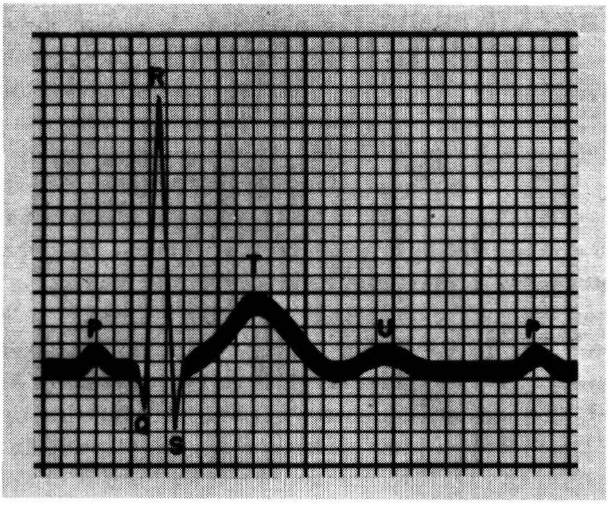

Figure 2. Normal electrocardiogram. All deflections are measured from the points of departure from or return to the baseline. The PR is measured from the beginning of the P wave to the onset of the QRS complex, the QRS from the onset of the Q or R wave, whichever appears first, to the conclusion of the R or S wave, whichever comes last. The QT is measured from the onset of the QRS to the end of the T; this is often best seen in the mid-precordial leads as V_2 or V_3.

Electrocardiographic Leads

THE BIPOLAR LEADS. Commonly, an electrocardiogram consists of 12 leads, 6 in the frontal plane of the body and 6 in the horizontal plane of the chest at the approximate level of the 4th to 5th intercostal spaces. The electrocardiograph machine is a recording voltmeter and like all electro-measuring devices carries 2 terminals or poles. The indications on its dial or the recorded deflections represent the differences in voltage applied across its terminals. Thus, the original, classic, standard, or bipolar leads represent differences between the limbs. Lead I equals the voltage on the left arm minus the voltage on the right (LA-RA), Lead II = LL-RA, and Lead III = LL-LA*. The null or zero points are located midway between the extremities, (Fig. 3a). By convention, a flow of negativity or a depolarization wave advancing from the right arm toward the left will be indicated as a positive voltage and an upright deflection on Lead I. The situation might be likened to that of an observer situated at the left shoulder noting the flight of a ball toward him and of a similar observer at the right shoulder seeing the ball receding. The limbs behave simply as conductors away from the trunk and though the left leg would seem to be eccentric, it functions in fact as the inferior angle of an equilateral triangle in the frontal plane. If the sides of the triangle are displaced centrally

*Commonly identified by the Roman numerals I, II, and III.

but parallel to their normal positions, so that their null points coincide, it will be seen that Lead I occupies a horizontal position running between 0° on the left and 180° on the right intersection with a circle inscribed around the original triangle, (Fig. 3b). Similarly, Lead II runs between +60° at its positive end and −120° on the negative; LIII is positive at +120° and negative at −60°. Since the connections are always positive for the left leg in Leads II and

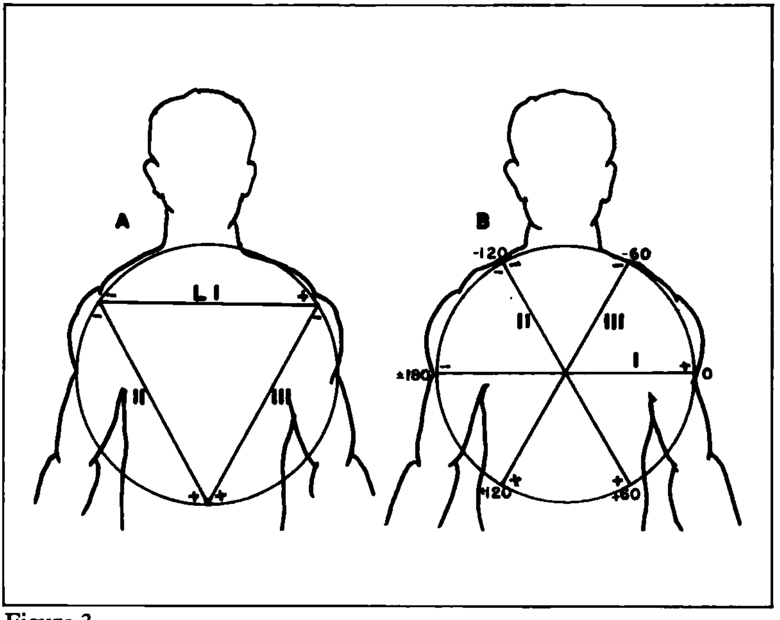

Figure 3.

a. The Standard or Classic leads as connected to the limbs. The left leg lead is shown as being displaced centrally and upward to the approximate location of the umbilicus. In fact, the ECG does not change in significant degree if either leg is used or the electrode moved to the lower abdomen.

b. The Standard leads displaced so that their null points coincide to form a triaxial reference system.

III and for the left arm in Lead I it is more convenient to consider the observer as occupying a position on the positive ends of these leads without losing sight of the negative observers on the opposite ends. For example, a wave of depolarization away from the right arm toward the left leg will be inscribed as a positive deflection in LII; the early brief wave of depolarization toward the right shoulder from the left is indicated by an initially negative deflection in Lead I. It is recalled, however, that an observer at the other end of the lead perceives the exact opposite.

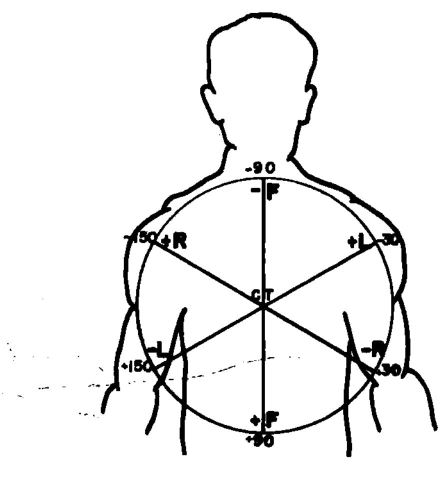

Figure 4. The Unipolar limb leads. For each lead the positive terminal of the ECG machine is fastened to the appropriate limb and the negative connection to the central terminal. Compare the unipolar extremity leads to the standard leads in Fig. 3b.

THE UNIPOLAR LEADS. The unipolar limb leads are not really unipolar but are electrically contrived so as to compare the electrical projections on each extremity separately with a zero potential level. Each limb is connected in turn to the positive terminal of the electrocardiograph machine while the negative pole is connected through a network to the central terminal, known also as the Wilson terminal. This corresponds to the center of the chest and coincides with the conjunction of the null points of the original bipolar leads. In fact, the unipolar leads are not greatly different from the bipolar; they merely occupy positions 30° away, (Fig. 4). In effect, the 3 classic and the 3 unipolar extremity leads arranged in the frontal plane with coinciding null points constitute a hexaxial reference system with 6 dimensions, 6 positive and 6 negative ends. The unipolar limb leads (Wilson) are called VR, VL, and VF for right arm, left arm, and left leg or foot.* VR is positive at −150° and negative at +30°, VL is + at −30° and – at +150°, and VF is + at +90° and – at −90°. A subsequent modification (Goldberger) now commonly employed on all ECG machines enlarges the unipolar extremity leads by 50%; they are designated a (for augmented) VR, aVL, and aVF.

THE CHEST LEADS. The positive ends of the unipolar thoracic leads occupy positions on the left anterior quadrant of the thorax and just to the right of the sternum. In the frontal plane the positive and negative ends of the limb leads are evenly spaced over the entire 360°. In the horizontal plane the positive ends of the precordial leads lie within an angle of approximately 100° on the left anterior chest with the negative ends (not ordinarily taken) on the right back. The thoracic leads are unipolar but not augmented. They are identified as V_1 through V_6, (Fig. 5). Complete normal electrocardiograms are shown in Figures 6 and 7.

*V stands for voltage, not vector.