Electrocardiography for the Anaesthetist

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ELECTROCARDIOGRAPHY FOR THE ANAESTHETIST

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TO MY WIFE

The good provider of that inestimable thing
a happy and a tranquil home

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CONTENTS

CHAPTER I

INTRODUCTION

The heart muscle is unique among the muscles of the body in that it possesses the quality of automatic rhythmic contractions. These contractions produce weak electrical currents which spread through the entire body as the latter behaves like a volume conductor. The existence of these currents has been known for over a century. As early as 1856, Kölliker and Müller placed a frog's nerve muscle preparation in contact with a beating heart and were able to demonstrate twitches of the frog's muscles with each contraction of the ventricle. That these currents were measurable was demonstrated by Waller in 1887. He experimented with the capillary electrometer and recorded the electromotive force from the precordium. But it was not until 1901 when Einthoven invented his string galvanometer that the current from the human heart beat was registered in an accurate quantitative manner (Einthoven 1903). It was not, however, until 1918 that the human ECG was studied during anaesthesia (Krumbhaar 1918; Heard & Strauss 1918).

It is known that the electric impulse in the normal heart originates in the sino-atrial node and travels through both atria to reach the atrioventricular node. The excitation wave then passes to the bundle of His proceeding along its right and left branches to the Purkinge fibres in the ventricles. Activation of the ventricular musculature takes place initially in the septum and subsequently in the free walls of both ventricles. It is primarily the electrical activity within the cardiac muscle which is recorded on the electrocardiogram. It does not record haemodynamic events, such as the efficiency or force of contraction of the myocardium. The major portion of the muscle mass consists of the free walls of the right ventricle, the left ventricle and the septum. Similarly, the major portion of the completed electrocardiogram consists of the electrical activity present in the septum and the two ventricles.

A cell is said to be polarized in the resting state, meaning that an equal number of ionic charges of opposite polarity (negative and positive) is present on both sides of the cell membrane. The positively charged ions (cations) are distributed on the outer surface and the negatively charged ions (anions) within (Curtis & Cole 1941).

Stimulation makes the cell membrane permeable to the flow of ions, so that a flow of current occurs. On stimulation, depolarization locally ensues, and this depolarized locus is propagated along the cell membrane, setting up a moving boundary of potential difference between the stimulated and the resting areas. At the head of the advancing locus of activity, where the depolarized muscle encounters the boundary of the resting polarized muscle, a series of dipoles appear (Ashman 1948). A dipole consists of a positive and a negative charge in close proximity to each other and of equal magnitude. Stimulation of the resting muscle thus produces an advancing wave of activity represented by a series of dipoles which are propagated along the cell membrane and form a moving boundary of potential difference and this phenomenon is recordable.

Such a potential difference must be present between two electrodes in order to record a deflection. If there is no difference in potential, as in a zone of completely active or completely inactive muscle, no electrocardiographic deflections will be recorded.

Each mechanical contraction is accompanied by two electrical processes, depolarization (activation) and repolarization (recovery). The advancing dipoles are so orientated during depolarization that the positive ion precedes the negative ion, i.e. the head is positive and the tail negative. When the muscle has been completely depolarized, it is referred to as apolarized. Repolarization then occurs and the outside of the membrane recovers its resting charge. During this process of repolarization the dipole is reversed, i.e. the head is negative and the tail positive. This is illustrated in Fig. 1.

The electrocardiogram is the graphic representation of the electrical forces produced by the heart. Einthoven correlated the contracting heart with the electrocardiographic waves it produced and demonstrated that the P wave was related to the atrial contraction,

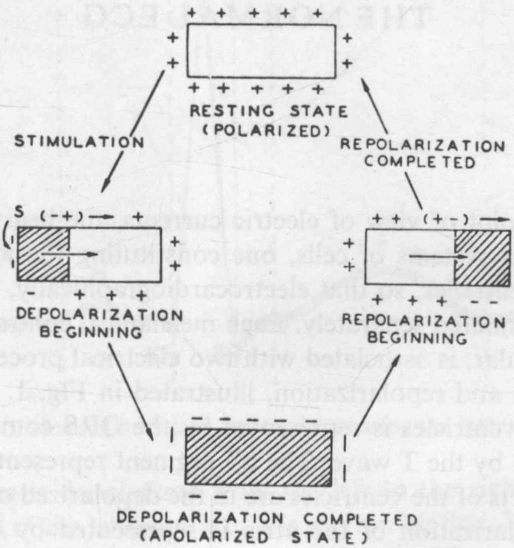

FIG. 1. Electrical activity associated with one contraction in a muscle fibre.

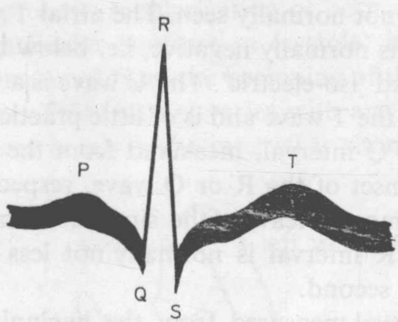

FIG. 2. Normal limb lead tracing.

whereas the QRS complex and the T wave were associated with the ventricular contraction. The waves produced by a normal cardiac contraction are shown in Fig. 2.

CHAPTER II

THE NORMAL ECG

From the point of view of electric currents, the heart consists of two complex systems of cells, one constituting the atria and the other the ventricles, so that electrocardiographically, each system may be considered separately. Each mechanical contraction, atrial and ventricular, is associated with two electrical processes, i.e. depolarization and repolarization, illustrated in Fig. 1. Depolarization of the ventricles is represented by the QRS complex and repolarization by the T wave. The ST segment represents the period when all parts of the ventricles are in the depolarized or apolarized state. Depolarization of the atria is represented by the P wave; repolarization also occurs although the electrical record is usually obscured by the QRS complex, so that the T wave of the atrium—the Ta wave—is not normally seen. The atrial T wave (unlike that of the ventricle) is normally negative, i.e. below the base line. The base line is termed 'iso-electric'. The U wave is a wave low in magnitude following the T wave and is of little practical significance.

The PR and PQ interval, measured from the beginning of the P wave to the onset of the R or Q wave, respectively, marks the time which an impulse leaving the sinus node takes to reach the ventricles. The PR interval is normally not less than 0·12 second and not over 0·2 second.

The QRS interval measured from the beginning of the Q wave to the end of the S wave, represents the process of depolarization of the ventricles. During this time the cardiac impulse travels first through the interventricular system and then through the free walls of the ventricles. It normally varies from 0·05 to 0·10 second. The normal intervals are illustrated in Fig. 3.

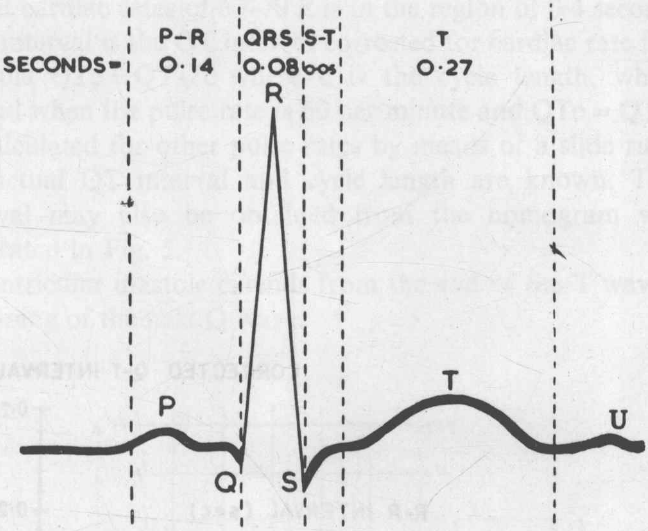

FIG. 3. Normal limb lead tracing illustrating the intervals.

The system is depolarized from the left to the right because a small branch of the left bundle of His is given off first. The subendo cardial regions of the ventricles are activated before the adjacent myocardial and subepicardial areas (Fig. 4).

The T wave represents repolarization of both ventricles. Hence one complete ventricular contraction (systole) is represented by the QT interval measured from the beginning of the Q wave to the end of the T wave. This interval varies with age, sex and cardiac rate. When the rate is rapid, the interval is short and vice versa,

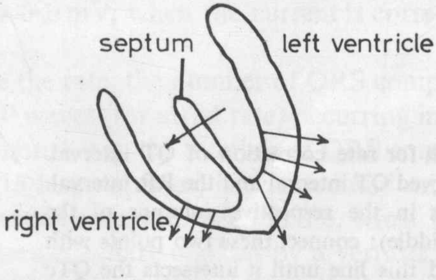

FIG. 4. Mechanism of ventricular depolarization.

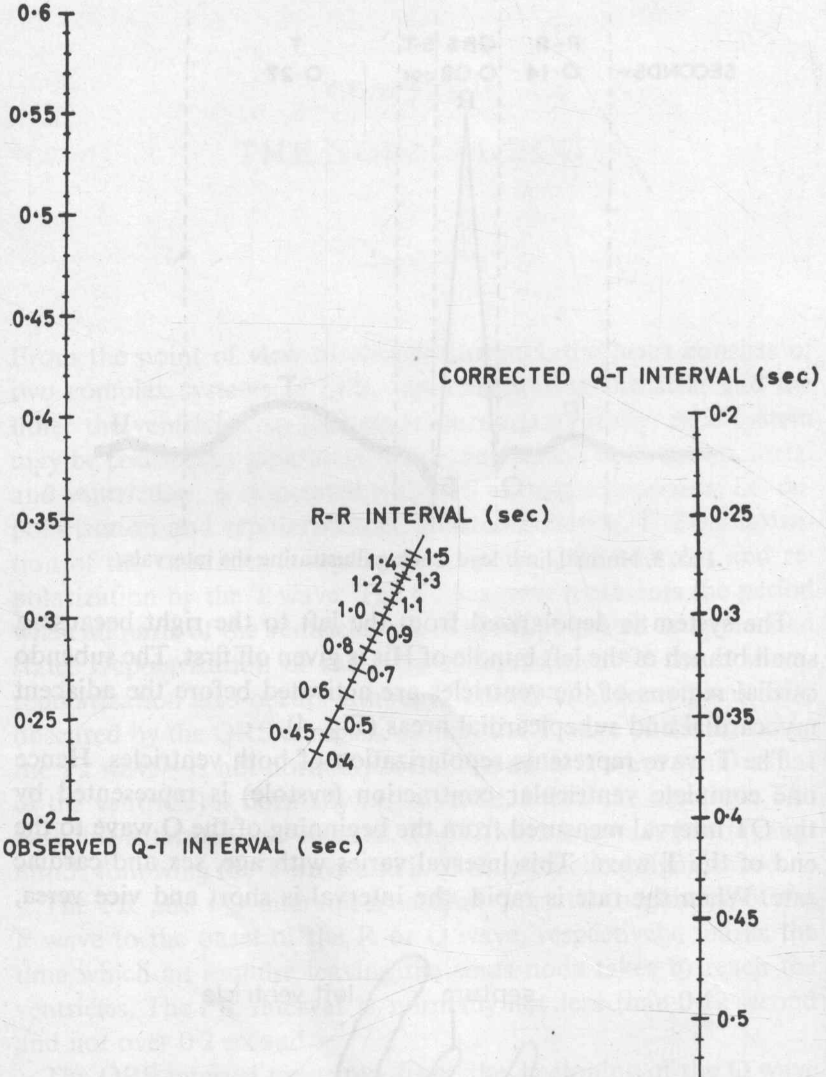

FIG. 5. Nomogram for rate correction of QT interval. Measure the observed QT interval and the RR interval. Mark these values in the respective columns of the chart (left and middle): connect these two points with a ruler and extend this line until it intersects the QTc column; this will be the QTc interval.

e.g. at cardiac rates of 60–70 it is in the region of 0·4 second. The QTc interval is the QT interval corrected for cardiac rate from the formula $QTc = QT\sqrt{c}$ where c is the cycle length, which is 1 second when the pulse rate is 60 per minute and QTc = QT. It can be calculated for other pulse rates by means of a slide rule when the actual QT interval and cycle length are known. The QTc interval may also be obtained from the nomogram which is *illustrated in Fig. 5.*

Ventricular diastole extends from the end of the T wave to the beginning of the next Q wave.

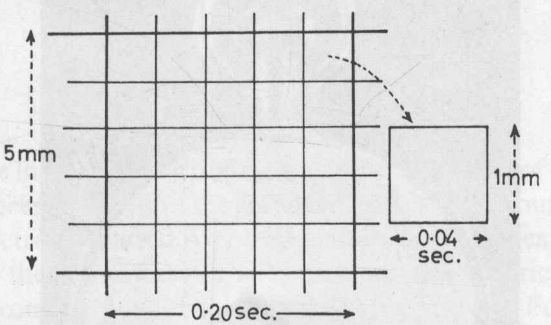

FIG. 6. Time markings and voltage lines of the electrocardiogram.

Horizontal and vertical lines appear on all electrocardiograms. The vertical lines represent time and are divided into larger and smaller squares. A large square indicates 0·2 second and a small square 0·04 second. The horizontal lines represent voltage, 1 mm being equal to 0·1 mV, when the current is correctly standardized (Fig. 6).

To calculate the rate, the number of QRS complexes (for ventricular rate) or P waves (for atrial rate) occurring in a certain period of time are counted, e.g. the number of QRS complexes occurring in 3 seconds (15 large squares) is counted and multiplied by 20 to calculate the ventricular rate per minute. Most recording graphs have every fifteenth square marked by a vertical line at the upper border of the strip. Alternatively, the rule illustrated in Fig. 7 may

FIG. 7. The arrow should be placed on a heart complex (P or QRS) and the rate is obtained when the scale intersects the same portion of a complex two cycles removed. (Applicable for regular rhythm only).

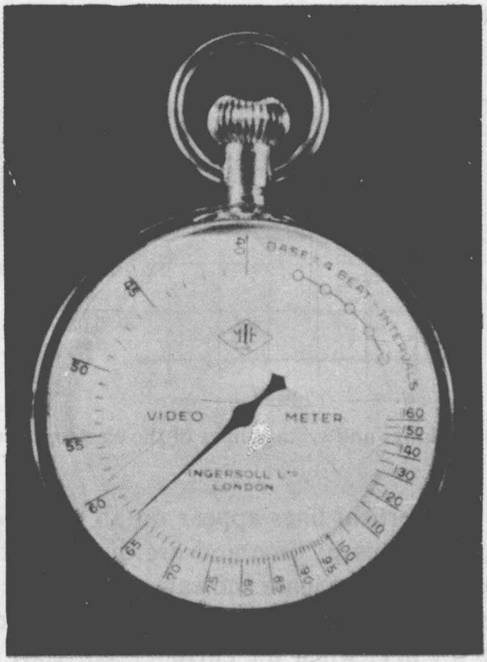

FIG. 8. The videometer. This is wound in an anticlockwise direction. By depressing the single control it will start, stop or zero the pointer sequentially.

be used. When the tracings are displayed on an ECG monitor, a videometer may be employed. This is hand operated and will record a reading of heart rate within a range of 40 to 160 per minute. It is illustrated in Fig. 8 and its method of use in Fig. 9.

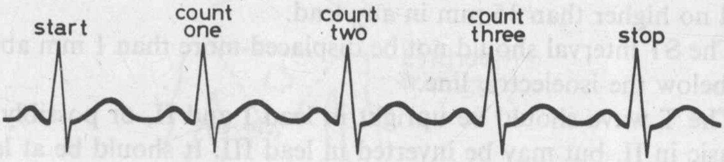

FIG. 9. Assuming the operator is viewing an ECG tracing the control having been wound and the pointer zeroed, is pressed to start at the first observed tracing and the next three tracings counted. At the fourth tracing the control is pressed to stop as shown. The pointer will then be observed at the figure representing the rate per minute.

THE ECG LEADS

STANDARD LEADS

These were introduced by Einthoven at the beginning of the century and have been adopted as the standard leads throughout the world.

Two electrodes placed over different areas of the heart and connected to the galvanometer will pick up the electrical currents resulting from the potential difference between them. For example, if under the first electrode a wave of 0·2 mV, and under the second electrode a wave of 0·6 mV occur over the same period of time, then the two electrodes will record the difference between them, i.e. a wave of 0·4 mV. A bipolar lead, therefore, records all electrical events between the two terminals by revealing the changes of one electrode over and above the changes affecting the other. The final tracing of the ECG is thus a composite recording of both electrodes.

In standard lead I the terminals are placed on the right and left arms (RA and LA). In lead II, the terminals are placed on the right arm and left leg (RA and LF–F = foot) and in lead III the terminals are placed on the left arm and the left leg (LA and LF).

In the standard leads the P wave should be upright in lead I and usually in lead II, but may be inverted in lead III. It should not be more than 2·0 mm in height or 0·1 second in duration.

Q must be small in leads I and II, but may be deep in lead III.

R should be at least 5 mm high in any one of the three tracings and no higher than 15 mm in any lead.

The ST interval should not be displaced more than 1 mm above or below the isoelectric line.

The T wave should be upright in lead I and II, or possibly diphasic in II, but may be inverted in lead III. It should be at least 2 mm high in one of these leads.

UNIPOLAR LEADS (V LEADS)

Here again, two electrodes are employed, but because one is inactive (the neutral or indifferent electrode) and has no electrical changes occurring in its vicinity, the electrocardiographic tracing mirrors potential alterations taking place only in the vicinity of the other, the active, or exploring, electrode.

To appreciate how one electrode has a zero potential the heart may be considered to be in the centre of an equilateral triangle, the apices of which are the right arm, left arm and left leg leads (Fig. 10). According to Einthoven, the algebraic sum of the potentials of these three leads is at any instant equal to zero. Thus if these three leads are connected to a central terminal, the potential of this terminal will be zero (Fig. 10). In practice there is also a high resistance inserted in this central terminal.

If this central terminal which constitutes the inactive, neutral, or indifferent electrode is connected to one lead of a galvanometer, that lead will always have a potential value of zero. The electrode connected to the other lead of the galvanometer will then record the true potential at any given point. This electrode constitutes the active or exploring electrode. It is also referred to as the V or 'voltage' lead.

Two types of unipolar leads are employed (a) limb leads and (b) precordial leads.

(a) *Limb leads*. The potential value in the right arm may be obtained by connecting the exploring electrode to the right arm and the indifferent electrode to the other terminal of the galvanometer. This lead is termed VR. A similar technique is employed for obtaining the left arm and left leg extremity leads VL and VF respectively. The unipolar limb lead tracings are illustrated in Fig. 11.

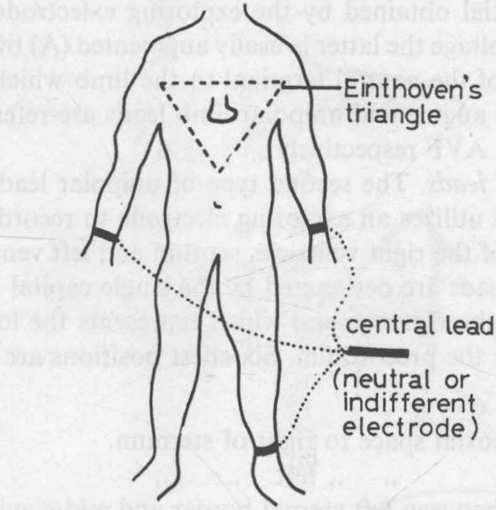

FIG. 10. Einthoven's triangle and the central terminal.

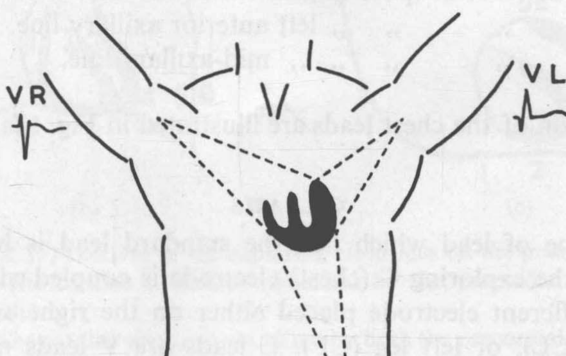

FIG. 11. The right arm lead faces the cavity of the ventricle, the left leg lead faces the inferior surface of the heart; this may be formed by the right or left ventricle or both, depending on the position of the heart. The left arm lead may face the cavity of the ventricles or the outside of the left ventricle, depending on the position of the heart. (Diagram by Dr D. S. Short.)

As the potential obtained by the exploring exlectrode of these leads is of low voltage the latter is usally augmented (A) by omitting the connection of the neutral terminal to the limb which is being tested. Thus the augmented unipolar limb leads are referred to as AVR, AVL and AVF respectively.

(b) *Precordial leads.* The second type of unipolar lead is a precordial lead and utilizes an exploring electrode to record the electrical potential of the right ventricle, septum and left ventricle. The unipolar chest leads are designated by the single capital letter 'V', followed by a subscript numeral which represents the location of the electrode on the precordium. Six chest positions are routinely used (V1–6):

V1: 4th intercostal space to right of sternum.
V2: „ „ „ „ left „ „
V3: Midway between left sternal border and mid-clavicular line on a line joining positions 2 and 4.
V4: 5th intercostal space in mid-clavicular line.
V5: „ „ „ „ left anterior axillary line.
V6: „ „ „ „ „ mid-axillary line.

The position of the chest leads are illustrated in Fig. 12a, b and c.

C LEADS

In this type of lead which like the standard lead is bipolar in character the exploring C (chest) electrode is coupled with a relatively indifferent electrode placed either on the right arm (CR), left arm (CL), or left leg (CF). C leads are V leads minus the potentials in VR, VL and VF. As VR potentials are negative, their subtraction from V in CR records make all deflections more positive. This may be useful in demonstrating P waves of low voltage which may not be obvious in other leads; alternatively the P wave can be detected in an oesophageal lead, but this is not routinely employed. The CL and CF leads are now rarely used.

The normal standard, augmented and precordial leads are illustrated in Fig. 13 and the C leads are compared with the standard leads in Fig. 14.

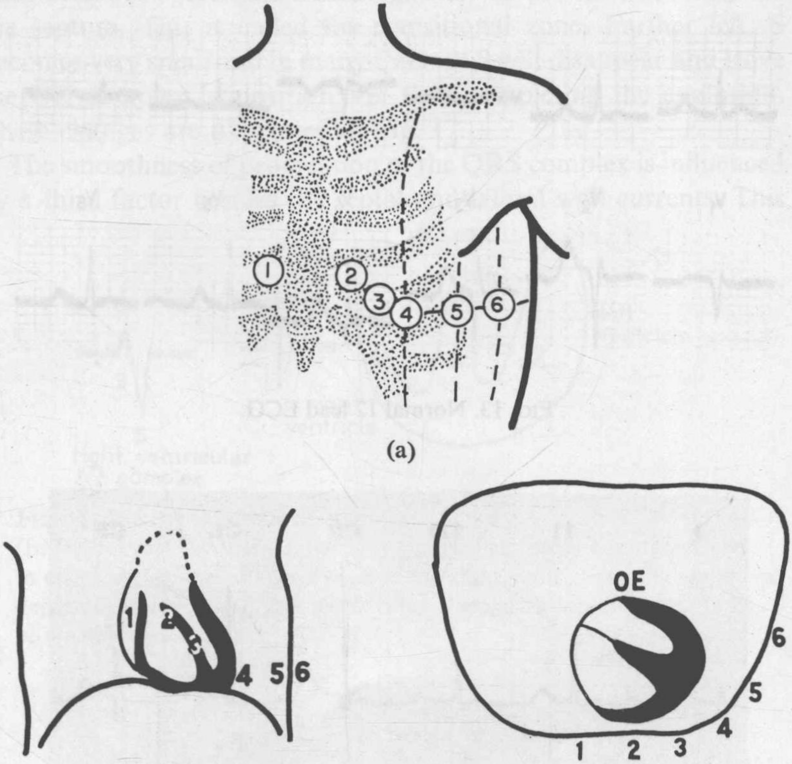

FIG. 12. (a) Position of the exploring electrodes on the precordium.
(b) The cardiac structures visualized by the precordial exploring electrodes.
(c) The cardiac structure visualized by both the precordial electrodes and the oesophageal electrode (OE).

ELECTRICAL ACTIVITY OF THE VENTRICLES

By convention, a wave is inscribed above the isoelectric line, i.e. positive when depolarization travels towards the exploring electrode from a remote area. It follows, therefore, that when an exploring electrode is placed over the right ventricle, it will receive an initial positive electrical impulse from septal depolarization (1), and a delayed negative impulse from left ventricular wall depolar-