Basic Electrocardiography

NORMAL AND ABNORMAL ECG PATTERNS

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Contents

Foreword

Basic Electrocardiography: Normal and Abnormal ECG Patterns is not an additional regular textbook on electrocardiography. Professor Antoni Bayés de Luna, the author of the present textbook is a world-wide renowned electrocardiographer and clinical cardiologist who has contributed to our knowledge and understanding of electrocardiology over the years. In the present textbook, he shares with us his vast experience and knowledge, summarising the traditional concepts of electrocardiography and vectrocardiography combined with current updates on the most recent developments correlating electrocardiographic patterns with magnetic resonance imaging. This textbook is of particular value to the American physicians and healthcare providers, as it exposes the reader to the Mexican, Argentinean and European schools of electrocardiography, which some of the earlier textbooks have tended to overlook.

The present textbook provides a concise summary of the classical and modern concepts of electrocardiology and provides 22 cases covering a wide spectrum of normal variations and abnormal electrocardiographic findings. In these cases Dr. Bayés de Luna explains his approach for interpreting the electrocardiogram and integrating it with the clinical findings.

In conclusion, this textbook is an asset for every cardiologist, internist, primary care physician, as well as medical students and other healthcare providers interested in broadening their skills in electrocardiography.

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CHAPTER 1

Introduction

The electrocardiogram (ECG), introduced into clinical practice more than 100 years ago by Einthoven, constitutes a lineal recording of the heart's electrical activity that occurs successively over time. An atrial depolarisation wave (P wave), a ventricular depolarisation wave (QRS complex) and a ventricular repolarisation wave (T wave) are successively recorded for each cardiac cycle (Figures 1A–C). As these different waves are recorded from different sites (leads) the morphology varies (Figure 2). Nevertheless, the sequence is always P–QRS–T. An ECG curve recorded from an electrode facing the left ventricle is shown in Figure 1D. Depending on the heart rate, the interval between waves of one cycle and another is variable.

Other different forms of recording cardiac activity (vectorcardiography, body mapping, etc.) exist [1]. Vectorcardiography (VCG) represents electrical activity by different loops originating from the union of the heads of multiple vectors of atrial depolarisation (P loop), ventricular depolarisation (QRS loop), and ventricular repolarisation (T loop). A close correlation exists between VCG loops and the ECG curve. Therefore, one may deduct ECG morphology on the basis of the morphology of VCG loop and vice versa. This is due to loop–hemifield correlation theory (see p. 10). According to this correlation (Figures 16, 18 and 21), the morphology of different waves (P, QRS and T) recorded from different sides (leads) varies (Figure 2). As the heart is a three-dimensional organ, projection of the loops with their maximum vectors in two planes, frontal and horizontal, on the positive and the negative hemifield* of each lead is required to ascertain exactly the loop's location and allow deducting ECG morphology (Figures 3 and 4). The morphology of ECG depends not only on the maximum vector of a given loop but also on its rotation (Figure 4). This represents the importance of considering the loop and not only its maximum vector to explain the ECG morphology.

*The positive and the negative hemifield of each lead are obtained by drawing lines perpendicular to each lead, passing through the centre of the heart. The positive hemifield is located in the area of positive part of the lead, and the negative hemifield in the negative part. In Figure 4 the positive hemifield is the area located between -90° and $+90^\circ$ passing through 0°, and the positive hemifield of lead VF is the area located between 0° and 180° passing through $+90^\circ$. The other part of the electrical field corresponds to the negative hemifield of each lead (see p. 10).

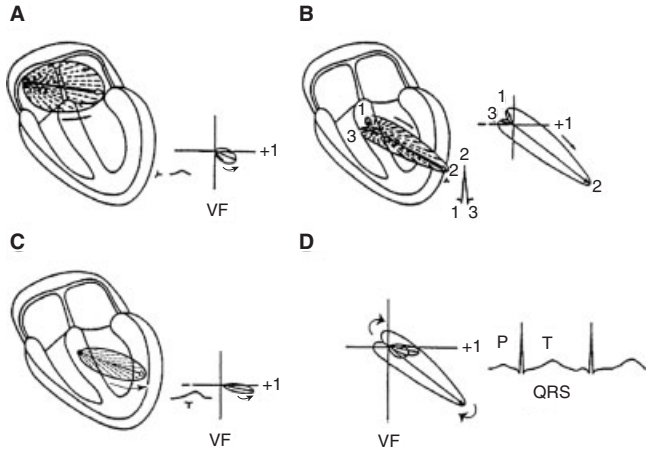

Figure 1 Three-dimensional perspective of the P loop (A), QRS loop with its three representative vectors (B) and T loop (C), and their projection on the frontal plane with the correlation loop–ECG morphology. (D) Global correlation between the P, QRS and T loops and ECG morphology on the frontal plane recorded in a lead facing the left ventricle free wall (lead I).

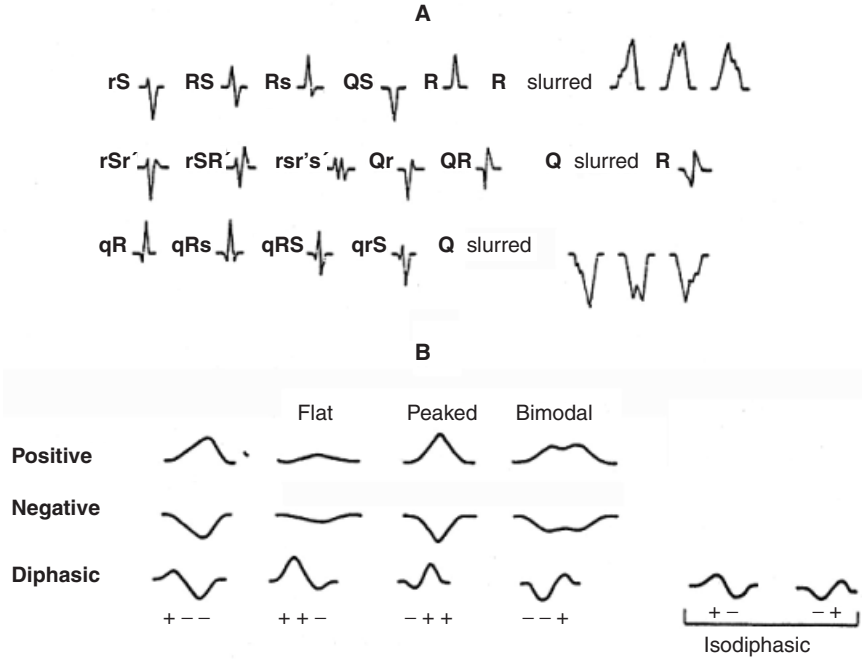

Figure 2 The most frequent QRS complex morphologies (A), P and T waves morphologies (B).

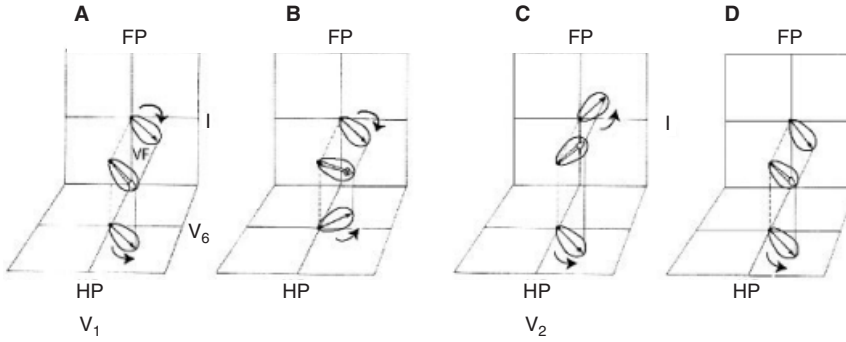

Figure 3 A loop with its maximum vector directed downwards, to the left and forwards (A) and another with its maximum vector directed downwards, to the left and backwards (B) have the same projections on the frontal plane (FP) but different projections on the horizontal plane (HP). On the other hand, a loop with the maximum vector directed upwards, to the left and forwards (C) and another with the maximum vector directed downwards, to the left and forwards (D) produce the same projection on the HP, but different projections on the FP.

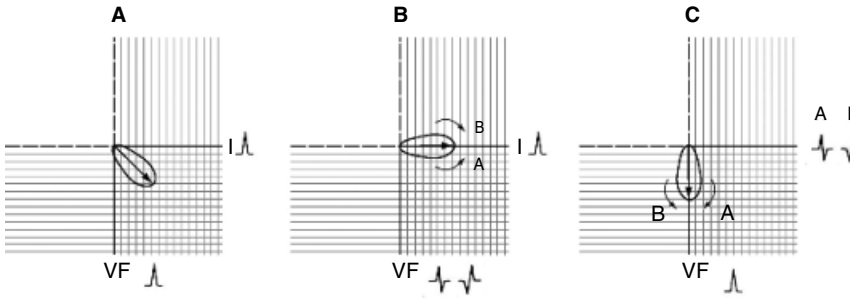

Figure 4 If the maximum vector of a loop falls in the limit of positive and negative hemifields of a certain lead, an isodiphasic deflection is recorded. However, according to the direction of loop rotation the QRS complex may be positive–negative or negative–positive (see examples for leads VF and I in the case of maximum vector directed to 0° (B) and +90° (C)). The loop with maximum vector at 45° (A) always fails in the positive hemifield of I and VF, independently of the sense of rotation.

VCG is rarely used in current clinical practice; however, it is highly useful in understanding ECG morphologies and in teaching electrocardiography. Later in this book we will explain in more detail how the loops originate and how their projection in frontal and horizontal planes explains the ECG morphologies in different leads.

CHAPTER 2

Usefulness and limitations of electrocardiography

ECG is the technique of choice in the study of patients with chest pain, syncope, palpitations and acute dyspnoea, and is crucial for the diagnosis of cardiac arrhythmias, conduction disturbances, pre-excitation syndromes and channelopathies. It is also very important for assessing the evolution and response to treatment of all types of heart diseases and other diseases, and different situations such as electrolytic disorders, drug administration, athletes, surgical evaluation, etc. Additionally, it is useful for epidemiologic studies and screening (check-up).

Despite its invaluable usefulness if used correctly, electrocardiography may induce mistakes if one excessively trusts on an ECG recording of normal appearance. Sometimes, bowing to the 'magical' power of ECG, physicians caring for a patient with chest pain of doubtful origin may state: 'Let's have an ECG recording done so that we may solve the problem'. It must be remembered that a high percentage of patients with coronary heart disease, in the absence of chest pain, show a normal ECG recording and that even in acute coronary syndromes ECG is normal or borderline in approximately 5–10% of cases, and without symptoms especially in its early phase. Furthermore, ECG may be normal months or years after a myocardial infarction. From the above, it can be inferred that a normal ECG does not imply any 'life insurance' as a patient may die from cardiac causes even on the same day a normal recording is taken. However, it is evident that in the absence of clinical findings or family history of sudden death, the possibility of this occurring is, in fact, very remote.

On the other hand, on occasions some subtle ECG abnormalities with no evidence of heart disease may be observed. Clearly, in such cases one must be cautious, and before considering this to be a non-specific abnormality, ischaemic heart disease, channelopathies (long QT, Brugada's syndrome, etc.) or pre-excitation syndromes should be ruled out. Therefore, it is necessary to read the ECG recordings while bearing in mind the clinical setting and, if necessary, taking sequential recordings.

In addition, normal variants may be observed in the ECG recording, which are related to constitutional habits, chest malformations, age, etc. Even transient abnormalities may be detected owing to a number of causes (hyperventilation, hypothermia, glucose or alcohol intake, ionic abnormalities, effect of certain drugs, etc.).

Electrocardiography has become even more important than it was at the beginning. In the twenty-first century, ECG is not only a technique used to

diagnose an abnormal pattern, but also serves for risk stratification in many clinical situations such as acute and chronic heart disease, cardiomyopathies, etc., and provides insights into basic electrophysiology by recognising abnormalities at a molecular level such as channelopathies [2].

These facts should be borne in mind before starting to learn a technique such as electrocardiography, so that the significant usefulness of the clinical aspects is not left aside, since ECG assessment need to be done considering the clinical setting.

In this book, we explain the origin of normal ECG and the normal and abnormal ECG patterns. The importance of surface ECG in the diagnosis of arrhythmias is not shown and will be done in another book. We recommend consulting our textbook on clinical electrocardiography [1] and our Internet course (www.cursoecg.com).

CHAPTER 3

Electrophysiological principles

The origin of ECG morphology

The origin of ECG morphology [1,3–7] may be explained by two theories: the electroionic changes generated during cardiac depolarisation and repolarisation and the sum of subendocardial and subepicardial transmembrane action potential.

Electroionic changes during depolarisation and repolarisation

Depolarisation and repolarisation of cardiac cells

There are two types of cardiac cells (Figure 5): myocardial contractile cells and specific conduction system (SCS) cells. The latter are responsible for generation (automatism capacity) and transmission (conduction capacity) of a stimulus to contractile cells. Cells with the highest automatism are those of a sinus node since they present more rapid diastolic depolarisation (see below and Figure 5). Contractile cells are polarised during the resting phase, which indicates that a balance exists between positive charges outside (due to prevalence of positive ions particularly Na^+ and Ca^{2+}) and negative charges inside (due to prevalence of negative non-diffusible anions despite the presence of positive K ions). This constant potential difference between outside and inside the cell during the resting phase constitutes the diastolic transmembrane potential (DTP) (Figure 6). Therefore, contractile cells have a rectilinear DTP; in contrast, cells of the specific conduction system have a DTP that shows spontaneous depolarisation (ascending DTP slope), which is most rapid in sinus node (Figure 5).

When a cell or different structures of the heart are stimulated, a transmembrane action potential (TAP) curve, representing the depolarisation and repolarisation processes (activation), is formed just when the DTP curve reaches the threshold. This happens spontaneously in the SCS cells and more rapidly in sinus node cells since these are cells with the highest automaticity (Figure 5). In contractile cells (atrial and ventricular muscle cells) that present rectilinear DTP, a TAP is formed only when they receive the propagated stimulus from a neighbouring cell (Figure 5).

Ionic changes accounting for TAP generation in contractile ventricular myocardium (a cell or all left ventricle, if the latter is considered to be an enormous cell responsible for the greater part of a human ECG) are shown in a Figure 7. During depolarisation (phases 0 and 1 of TAP), positive charges move from outside to inside the cell, first through the fast channel of Na^+ and later that of $Ca^{2+}Na^+$. During repolarisation of the cell or left ventricle (phases 2 and 3