

The Electrocardiogram in Emergency and Acute Care



Edited by
Korin B. Hudson | Amita Sudhir | George Glass | William J. Brady

WILEY Blackwell

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Foreword

The electrocardiogram (ECG) is an essential instrument in the evaluation of a broad array of clinical conditions related to cardiac and non-cardiac disorders. The ECG is commonly used to evaluate the electrical and mechanical function of the heart, but the tracing can also be used to detect systemic disorders such as electrolyte disarray or toxic and metabolic abnormalities. The indications for an ECG encompass all aspects of medical care. In fact, the only contraindication to obtaining an ECG tracing is patient refusal. Acquisition of an ECG tracing is an easily learned skill, but the interpretation can be difficult and nuanced, thus requiring significant effort on the part of the learner to develop competence and confidence in the skill. Reading an ECG can be a high-stakes endeavor as incorrect interpretation can have profound consequences. Because the stakes are so high, it is incumbent on any health care providers responsible for ECG interpretation to study the full spectrum of clinical conditions that may be evident on the tracing.

The history of the ECG is a relatively recent one. An understanding that electrical impulses were produced by the heart was not known until the 1850s, but it took four more decades to develop instruments to measure the myocardial action potential. Willem Einthoven, a Dutch physiologist devoted the 1890s to gain an understanding the heart's electrical activity and how to best measure it. By 1902, he had devised the first ECG machine consisting of a fine (less than 3 μ m in diameter) filament made of silver and quartz suspended in a powerful magnetic field. The electrical activity of the heart caused the string to resonate within the field and these vibrations were recorded photographically. The photographic plate was set to move at 25 mm per second, a convention that is used on paper tracings to this day. An obscure 1902 paper by Einthoven was the first known writing to describe

the device. Einthoven was awarded the 1924 Nobel Prize for his invention.

The first machines commercially available were built between 1905 and 1907, were expensive, weighed 300 kg, and required a team of highly trained personnel to operate. Refinements of the machines brought down the size and weight, but doctors needed to transmit electrical impulses from the patient at the hospital to the machine in the laboratory off-site. Early clinical applications refined the understanding of, what was termed at the time as *delirium cordis*; which became known as atrial fibrillation. These early machines grew in popularity to aid clinicians in diagnosing cardiac arrhythmias, but information was limited owing to the fact that the machine had only the three leads.

By the 1920s, hypertrophy and infarction had been identified and described as the ECG became an essential medical device. In the 1930, angina pectoris was being identified by ECG, which led to an understanding of the ailment's vascular etiology. Precordial leads were developed, initially as a single lead, but later as multiple leads. In the 1940s, our contemporary precordial leads, V1 through V6 were standardized, and a refinement of the limb leads led to use of leads AVR, AVL, and AVF. During the 1950s and 1960s, acquisition of the ECG became widespread, and training in tracing interpretation became standard for medical students. The 1970s saw the introduction of computer interpretation to assist clinicians in identifying rate, rhythm, axis, hypertrophy, intervals, ischemia and infarction, but reading by a trained eye was (and is) still required.

By 1990, 50 million ECGs were performed annually in the United States, and time from first medical contact to ECG image acquisition became a measured performance standard for emergency medicine and EMS. By

2010, ECG acquisition an essential skill for EMS Basic Life Support personnel and ECG interpretation of STEMI was an essential skill for Paramedics. By 2020, the 300 kg behemoth from 1902 had been miniaturized to something that can be worn on a wrist.

The Electrocardiogram in Emergency and Acute Care is a text where readers are guided through a systematic approach to understanding the physics behind the ECG and are given clinical examples where the tracing can be interpreted to make a diagnosis. This approach places ECG interpretation within the reach of learners at every

level making the text valuable to students learning about the ECG for the first time to experienced clinicians. Enjoy!

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Preface

Electrocardiographic monitoring is one of the most widely applied diagnostic tests in clinical medicine today; its first application to the patient occurs in the prehospital setting, in the clinician's office or by emergency medical services (EMS) . . . its use continues on into the hospital. The electrocardiogram, whether in monitor mode using single or multichannel rhythm monitoring or in diagnostic mode using the 12-lead ECG, is an amazing tool; it assists in establishing a diagnosis, ruling-out various ailments, guiding the diagnostic and management strategies in the evaluation, providing indication for certain therapies, offering risk assessment, and assessing end-organ impact of a syndrome. As noted in this impressive list of applications, the ECG provides significant insight regarding the patient's condition in a range of presentations, whether it be the chest pain patient with ST segment elevation myocardial infarction (STEMI), the patient in cardiac arrest with ventricular tachycardia, the poisoned patient with bradycardia, or the renal failure patient with rhythm and morphologic findings consistent with hyperkalemia, among many, many other presentations. This extremely useful tool is non-invasive, portable, inexpensive, quickly obtained, and easily performed. Yet, ECG interpretation is not easily performed and, in fact, requires considerable skill and experience as well as an awareness of the limitation surrounding its use.

This textbook has been prepared to assist clinicians who wish to learn, review, and refine the skills required to interpret the electrocardiogram and develop a deeper understanding of its use across the range of presentations and applications. This textbook is arranged into five sections. Section 1 is a brief introduction and review of the ECG in the clinical setting. Section 2 focuses on

the electrocardiographic rhythm diagnosis, considering the electrocardiographic findings from an in-depth differential diagnostic perspective – in other words, rhythms with normal rates as well as bradycardia and tachycardia, allowing for the QRS complex width and regularity. Section 3 reviews the 12-lead ECG in patients suspected of acute coronary syndrome, including ST segment elevation myocardial infarction. Section 4 discusses the range of special presentations, patient populations, and uses of the electrocardiogram. Section 5 is a listing of various electrocardiographic findings, again from the differential diagnostic perspective; in this section, various rhythm and morphologic presentations are discussed, such as the narrow and wide complex tachycardias and ST segment elevation syndromes.

This textbook addresses the use of the ECG in its many forms by clinicians in a wide range of clinical settings. The novice electrocardiographer can use this text as his or her primary ECG reference; additionally, the experienced interpreter can use this textbook to expand his or her knowledge base. This work stresses the value of the ECG in the range of clinical situations encountered daily by health care providers – it illustrates the appropriate applications of the electrocardiogram in emergency and acute care scenarios.

Most importantly, this textbook is written by clinicians for clinicians, with an emphasis on the reality of the patient care. I and my co-editors and authors have enjoyed its creation – we hope that you, the clinician, will not only enjoy its content but also find it of value in the care of your patients. We thank you for what you do every day.

William J. Brady, MD
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Section I

The ECG in Clinical Care

1

Clinical Applications of the Electrocardiogram

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The electrocardiogram (ECG) is a useful tool for identifying and evaluating abnormal heart rhythms, underlying heart disease, current or past myocardial infarction, and various other metabolic conditions. It is used ubiquitously by clinicians and has proven to be one of the most valuable diagnostic tools in modern medicine. The ECG is a safe, non-invasive, and relatively inexpensive to obtain. It is particularly useful in identifying patients with acute ischemia and in identifying abnormal heart rhythms in patients with known risk factors for heart disease. The ECG may also provide timely information that can aid in early diagnostic or therapeutic decision making; for example, detection of peaked T waves in a critically ill patient with end stage renal disease may prompt timely and life-saving treatment for hyperkalemia prior to the availability of laboratory results.

ECG interpretation is an important and useful skill for any clinician, and skillful ECG interpretation requires appropriate attention and training. Section 1 of this book will cover the basics of such ECG interpretation.

Standard ECG Formatting and the Normal Electrocardiogram

In order to identify abnormal, we must first recognize “normal.” A normal ECG in the standard 12-lead ECG format is shown in Figure 1.1. In simple terms, the ECG tracing represents a time vs. intensity graph of the electrical signal (in mV) as measured by surface electrodes placed on the patient, though technically, the values for augmented leads – aVR, aVL, and aVF – are calculated,

not measured. At standard recording speed, each small box on the x-axis (1 mm of ECG paper) represents 0.04 seconds (40 msec) and each large box represents 0.2 seconds (200 ms). Each small box on the y-axis represents 1 mV.

As cardiac myocytes depolarize, the subsequent summation of electrical current is detected by electrodes placed on a patient’s body. A positive deflection in any given lead represents that the current detected is traveling in the direction of the positive terminal of that lead. Conversely, a negative deflection represents that the dominant electrical current is traveling away from the positive terminal of that lead.

ECG Components, Durations, and Intervals

The ECG recording of a standard cardiac cycle largely consists of several distinct phases: namely, the p-wave, QRS-complex, and T-wave. The p-wave represents atrial depolarization. This is followed by the QRS complex, representing ventricular depolarization. Finally, the T-wave represents ventricular repolarization. ECG “segments” comprise the portions of the ECG between these components. The PR segment consists of the portion of the ECG from the end of the P wave to the initiation of the QRS complex. The ST segment comprises the portion of the ECG from the end of the QRS to the beginning of the T-wave. The TP segment includes the portion of the ECG signal from the end of the T-wave to the beginning of the P-wave.

The time (or distance along the y-axis) comprising the individual ECG components are known as “durations” or “intervals” (Figure 1.2). A table of normal intervals is seen in Table 1.1.

Systematic Interpretation of the ECG

It is helpful to approach reading the ECG in a systematic fashion as to assure a comprehensive evaluation. Failure to do so may result in missed findings. For example, an

ECG with findings obviously and dramatically consistent with ST-elevation myocardial infarction might also demonstrate a high degree heart block. This finding may be more subtle and easily missed, especially if one is otherwise occupied with the care of a clinically ill

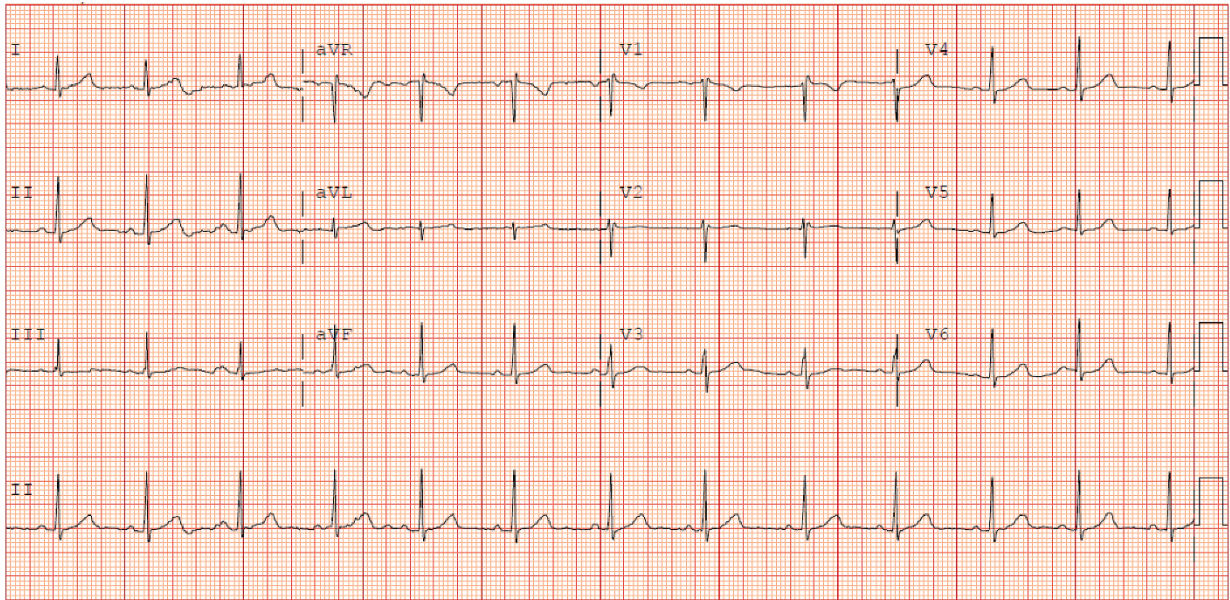


Figure 1.1 A normal 12-lead electrocardiogram.

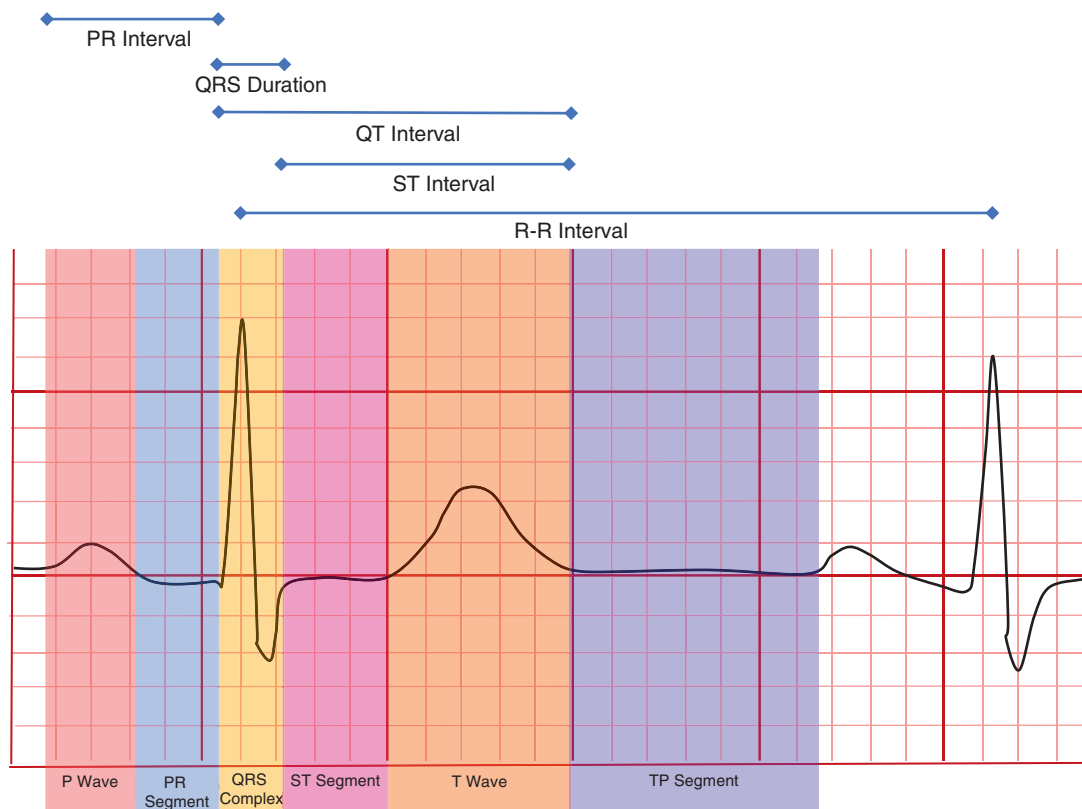


Figure 1.2 Normal cardiac cycle segments and intervals.

Table 1.1 Normal ECG Intervals.

ECG component	Normal duration
P-wave	≤120 msec
PR interval	≥120 and ≤200 msec
QRS duration	Usually ≤100 msec ≥120 msec in bundle branch block
QT interval	Prolonged QT is normally defined by a corrected QT (QTc) >440 msec $QTc = \frac{QT}{\sqrt{RR \text{ Interval}}}$

patient. Appropriate identification of an abnormal rhythm may profoundly influence clinical decision making, however, and is key to optimal patient care.

Rate

A normal heart rate in the adult patient is generally between 60 and 100 beats per minute. Rates faster than this represents tachycardia, whereas slower rates represent bradycardia. A simple method for calculating the rate is to count the number of large squares between two QRS complexes and then divide 300 by this number. For example, if two QRS complexes are four large squares apart, then the calculated rate is 300/4, or about 75 beats per minutes. Note that this method is only effective for regularly spaced QRS complexes – in the case of irregular spacing (atrial fibrillation, or frequent premature contractions, for example), it is more appropriate to average the rate over a longer time period. One way to do this is to count the number of QRS complexes on a 10-second rhythm strip, then multiply this by six to determine the average rate over that 10-second interval.

Rhythm

Sinus rhythm is present if there is a p-wave preceding every QRS complex, as well as a QRS complex following every p-wave. A normal rate, combined with sinus rhythm, is aptly called “normal sinus rhythm.” Deviations from a normal rate are termed either sinus tachycardia or sinus bradycardia. P waves should generally be upright in leads I, II, and III. A deviation from this may indicate an ectopic atrial rhythm or another atrial dysrhythmia (atrial flutter, for example).

The appropriate identification of the underlying ECG rhythm is essential for appropriate care. Sinus bradycardia, for example, is seldom pathologic and usually does not require emergency intervention. Bradycardia

associated with a Mobitz II second-degree or third-degree heart block, however, represents a patient at high risk for decompensation. Atrial fibrillation and supraventricular tachycardia (SVT) can both present with rapid, narrow complex tachycardia, but acute management and follow-up needs may differ (Figure 1.3).

ECG Orientation and Axis

Utilizing standard ECG lead placement, the 12-lead ECG will provide information in six leads in a vertical or coronal plane (frontal or limb leads – I, II, III, aVL, aVR, aVF), as well as six in the axial plane (precordial leads – V1 through V6). The major direction of QRS vector in the frontal plane is commonly referred to as the ECG “axis.” This can be calculated via several methods. The simplest method is to look at leads I and aVF. A positive deflection in the QRS complex in a given lead indicates an axis in the same direction as that lead. A positive deflection in leads I and aVF would therefore indicate an axis between 0 and 90°. The relative magnitude of the deflection can help indicate the amplitude of the true ECG “vector” in the direction of that lead. For example, a large, positive deflection in lead I and a near isoelectric deflection in lead aVF would indicate a true EKG vector of about 0°. A normal ECG will have an axis of –30° to 90°. Axis deviation of –30° to –90° is considered “left axis deviation,” whereas deviation of 90°–180° is considered “right axis deviation.” An axis of –90° to 180° is indeterminate (could be due to severe right or left axis deviation) and is termed extreme axis deviation (Figure 1.4).

Axis deviation is helpful in diagnosing left fascicular blocks, right and left ventricular hypertrophy, or certain toxicologic and metabolic pathologies. A list of common causes of axis deviation are seen in Table 1.2.

Intervals

Abnormal ECG intervals may not be immediately obvious on a cursory look at the ECG. As such, they are easily overlooked, and skilled clinicians should make a concerted effort to look for such abnormalities. Deviations from normal intervals can be indicative of pathologies of the conduction system (e.g. heart block, long or short QT syndromes, or Wolf-Parkinson-White syndrome).

Morphology

Deviations in morphology can occur in any segment of the ECG and may indicate a wide array of pathologies. The ST-segment, for example, should be closely

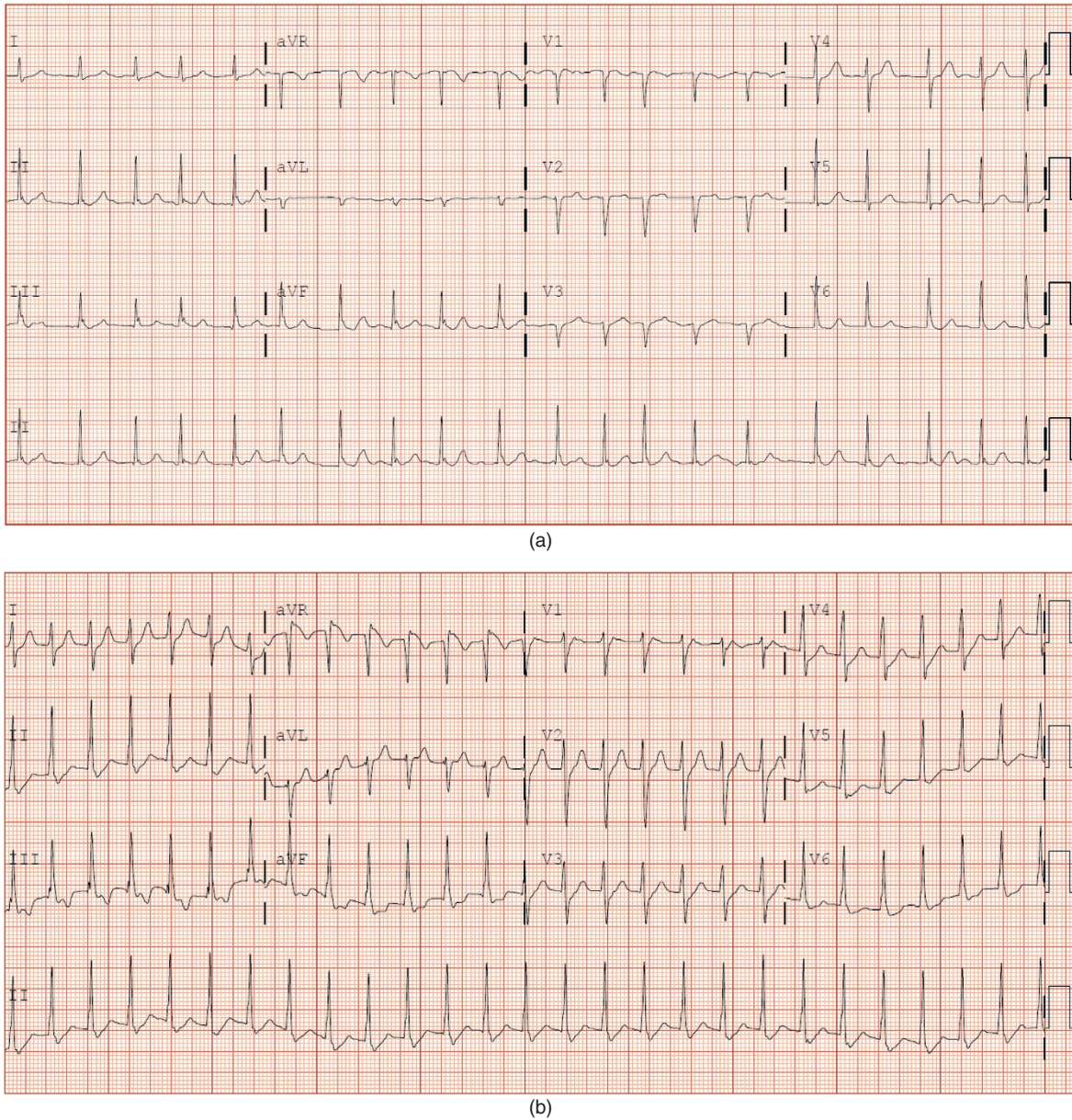


Figure 1.3 Rapid, narrow complex tachycardia. (a) Demonstrates an irregular rhythm with rapid rate and no discernable p waves, most consistent with atrial fibrillation. (b) Demonstrates a regular, narrow complex tachycardia. Note the p-waves in leads II and III that follow the QRS complex, most consistent with SVT with retrograde p-waves.

scrutinized in patients with suspected acute coronary syndrome (ACS), as ST-elevation and ST-depression may both be indicative of acute myocardial ischemia. ST-elevation myocardial infarction (STEMI), for example, is specifically defined as the presence of ST-elevation of a specific magnitude in two anatomically contiguous leads.

Another key morphologic change, “peaked T-waves,” may be the first indicator a clinician may have of life-threatening hyperkalemia. Specific morphologic changes and their corresponding clinical findings will be discussed in later chapters.

Common Indications and Clinical Applications

Syncope

The ECG represents critical data in the evaluation of syncope. In fact, in addition to a thoughtful history and physical exam, the ECG may be the most important diagnostic test in this setting. Many causes of sudden cardiac death may present with an initial episode of syncope and the ECG may be diagnostic. Careful interpretation of the ECG can assist in risk stratification.