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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.

The Electrocardiogram in Emergency and Acute Care, First Edition.
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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

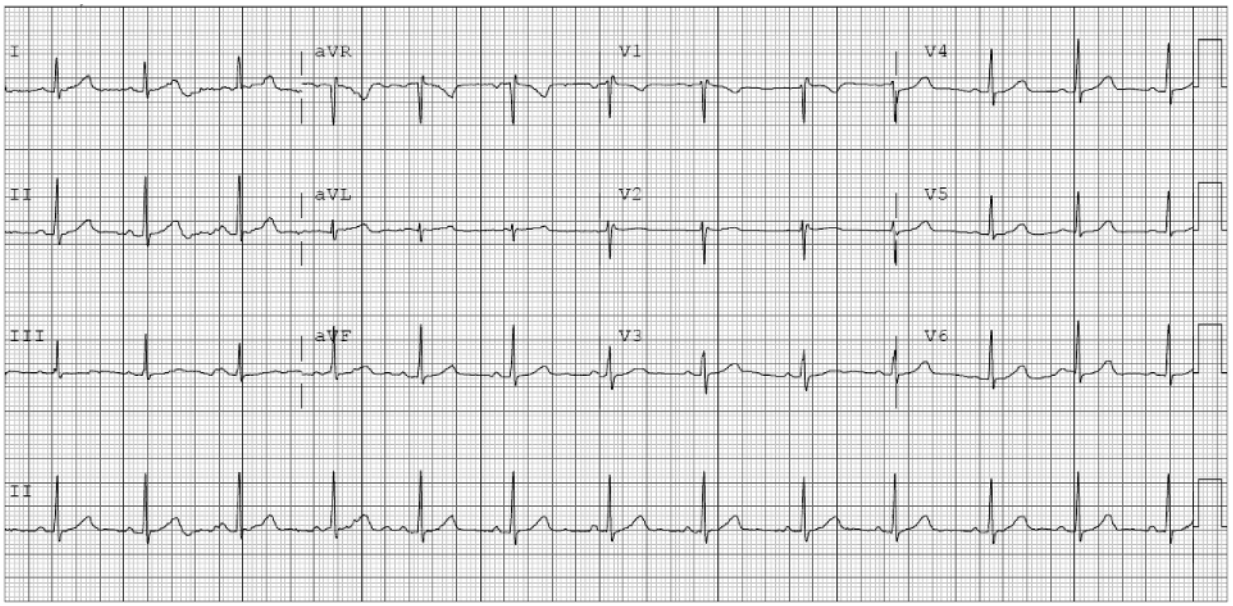


Figure 1.1 A normal 12-lead electrocardiogram.

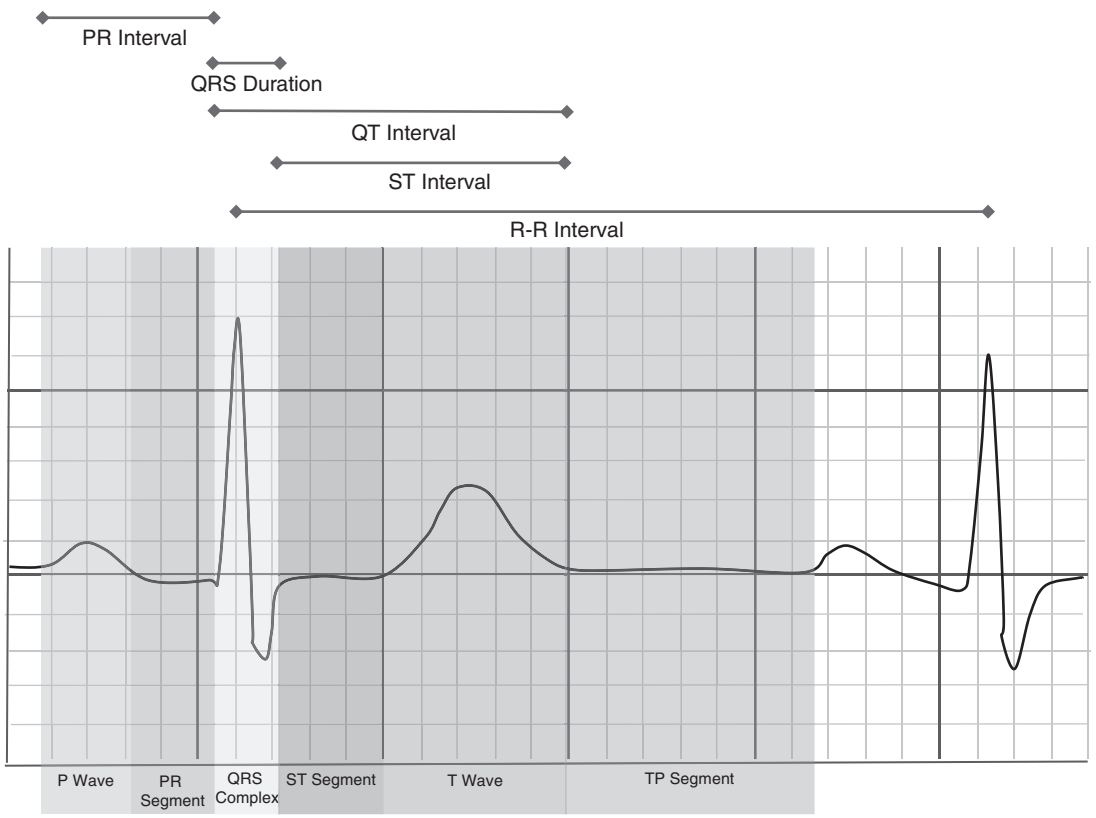


Figure 1.2 Normal cardiac cycle segments and intervals.

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 $QTc = \frac{QT}{\sqrt{RR\ Interval}}$

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).

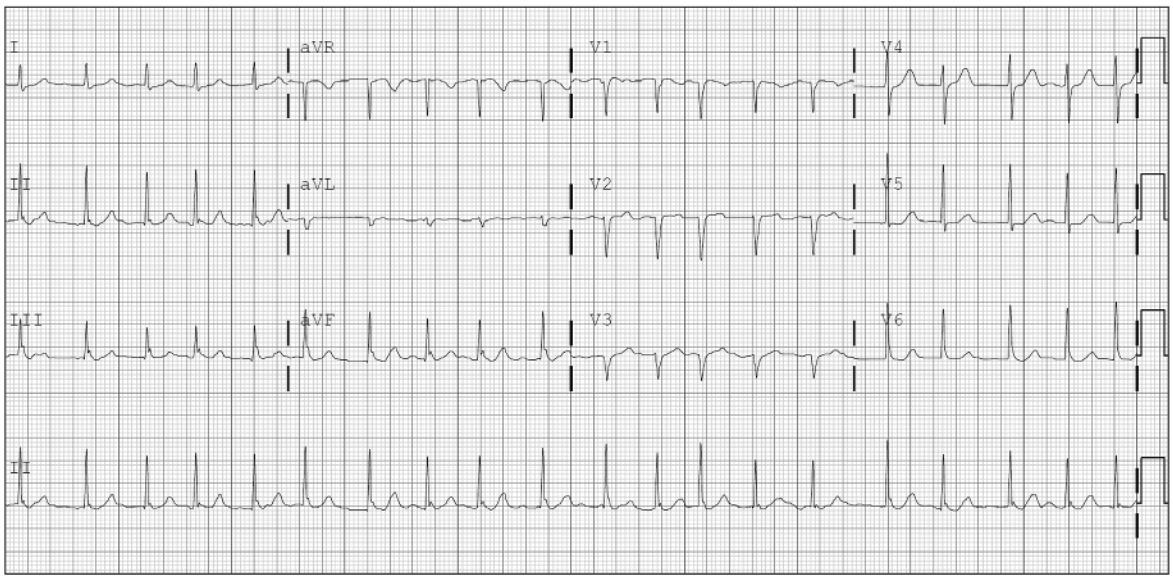
Axis deviation is helpful in diagnosing left fascicular blocks, right and left ventricular hypertrophy, or certain toxicologic and metabolic pathologies. A list of common causes of axis deviation are seen in Table 1.2.

Intervals

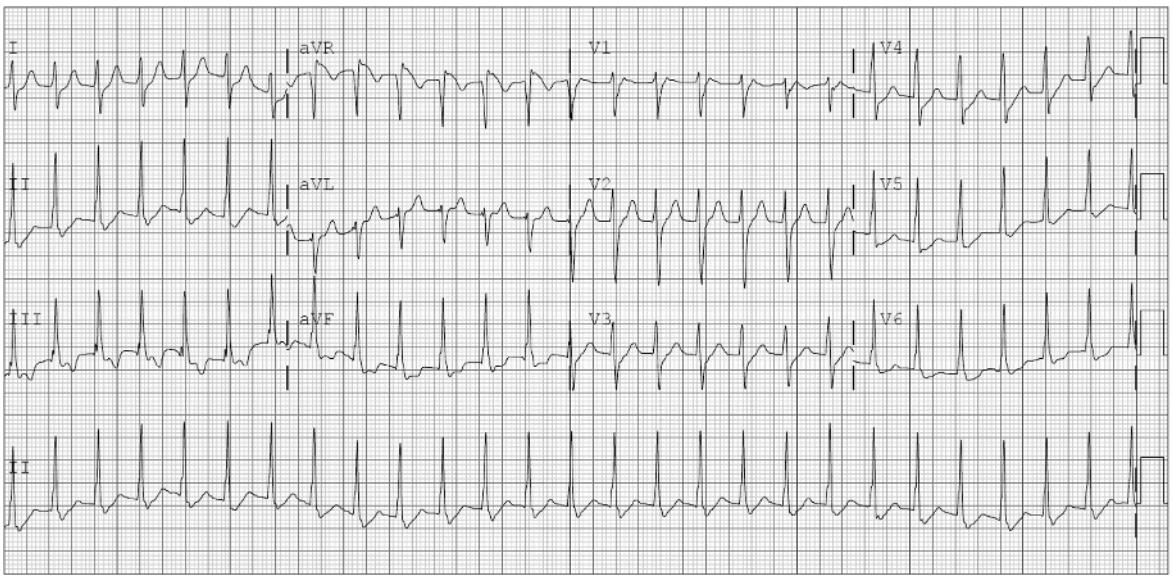
Abnormal ECG intervals may not be immediately obvious on a cursory look at the ECG. As such, they are easily overlooked, and skilled clinicians should make a concerted effort to look for such abnormalities. Deviations from normal intervals can be indicative of pathologies of the conduction system (e.g. 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



(a)



(b)

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.

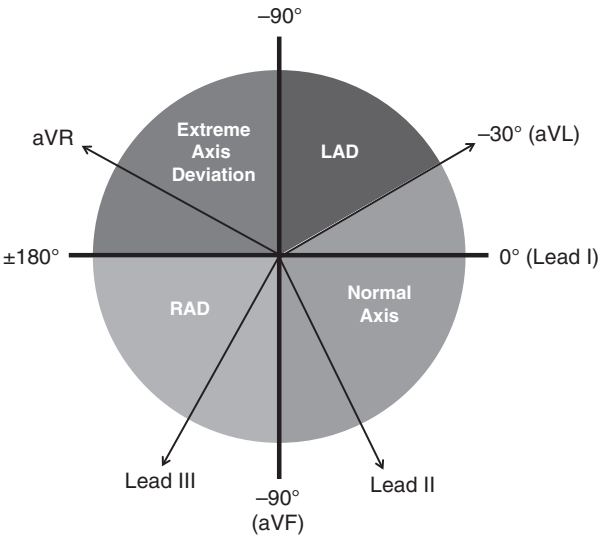


Figure 1.4 ECG axis determination.

Table 1.2 Causes of axis deviation.

Potential causes of ECG axis deviation	
Right axis deviation	• Right ventricular hypertrophy • RV strain • Left posterior fascicular block • Wolff–Parkinson–White syndrome • Lateral wall ischemia/infarcation • Congenital heart defects (ASD, dextrocardia)
Left axis deviation	• Left ventricular hypertrophy • Left bundle branch block • Left anterior fascicular block • Wolff–Parkinson–White syndrome • Inferior wall ischemia/infarcation • Hyperkalemia • Congenital heart defects (double outlet right ventricle, tricuspid atresia, corrected transposition of the great arteries)

Conditions such as prolonged QT syndrome, Brugada syndrome, and hypertrophic cardiomyopathy may not provide many symptoms or additional clinical clues prior to the development of a fatal arrythmia. As such, the ECG is crucial in the diagnosis of these entities and a screening ECG should be obtained in all patients with unexplained syncope. Prolonged monitoring of the ECG tracing, through a rhythm strip, telemetry, or ambulatory monitoring (Holter monitor) may provide additional information, especially if paroxysmal rhythm abnormalities are suspected. Section 2 of this book will cover specific cardiac rhythms and dysrhythmias with their corresponding ECG and clinical findings.

Chest Pain

The ECG is used ubiquitously in the evaluation of patients with chest pain and most patients with chest pain should have a 12-lead ECG performed. Anatomically oriented ST-elevation is diagnostic for STEMI and an indication for acute reperfusion therapy (O'Gara and Kushner 2013). Additionally, other ECG changes, such as ST segment depression, left ventricular hypertrophy (LVH), or other repolarization changes can be indicative of heart disease and are useful for risk stratification in patients with suspected ischemic cardiac disease. As such, the ECG is vital component of the HEART score, a validated clinical decision tool useful in risk stratification of such patients (Six and Backus 2008). Dynamic ECG changes – that is, variability in ST segment deviation – can also be indicative of an evolving process, such as ongoing ischemia or changes associated with ischemia and subsequent reperfusion. Such changes may prompt further diagnostic testing or consideration of early intervention, potentially reducing the impact of ongoing ischemia and associated morbidity. The ECG may also be diagnostic of other causes such of chest pain, such as pericarditis, usually characterized by diffuse ST-segment elevation with associated PR-segment depression. Section 3 of the book will cover the use of the ECG in the diagnosis of ACS.

Shortness of Breath

Shortness of breath, or dyspnea, is common patient complaint. Initial evaluation may include an ECG, which may reveal signs of lung disease or underlying cardiac disease which may be contributing to the patient's symptoms. For example, patients with pulmonary embolism will often present with sinus tachycardia and may have other, more specific findings, including the "S1Q3T3 pattern" – that is, the presence of S-waves in lead I, and Q waves with associated T-wave inversion in lead III – an indicator of associated heart strain (Digby 2015). Other findings, such as right axis deviation, may be indicative of right ventricular hypertrophy, which could be due to chronic lung conditions (cor pulmonale) or valvular disease (mitral stenosis). Shortness of breath may also be associated with certain dysrhythmias or ACS.

Other Indications

Specific ECG findings may also be noted in certain clinical contexts, including certain electrolyte disorders (e.g. hyper- and hypokalemia, hyper- and hypocalcemia), use of therapeutic agents (e.g. digoxin), or ingestion or overdose on toxins or medications (e.g. tricyclic

antidepressant overdose). The findings of the "normal" ECG may also be altered in patients with certain conditions such as Wolff–Parkinson–White Syndrome or in patients with an implanted pacemaker. These special situations will be covered in Section 4. The ECG may also be significantly altered in hypothermia, intracranial hemorrhage or stroke, and trauma. A list of selected examples of non-coronary pathology that may be seen on ECG is listed in Table 1.3. Patients presenting with stable wide complex tachycardia (Figure 1.5) or bradyarrythmias may also benefit from ECG in order to elucidate the nature of the presenting dysrhythmia (Section 5).

Table 1.3 Abnormal ECG findings not related to coronary pathology.

Pericarditis
- Diffuse non-anatomical ST segment elevation without reciprocal changes
- Diffuse PR segment depression
- Isolated ST segment depression and PR elevation in aVR

Pericardial tamponade
- Electrical alternans
- Low QRS complex voltage
- Diffuse PR segment depression hypothermia
- Osborn "J" waves
- Bradycardias and AV blocks
- Prolongation/widening of PR interval, QRS complex, and QT interval
- Atrial fibrillation with slow ventricular response

Hyperkalemia
- Diffuse non-anatomical peaked T waves
- Widening of PR interval and QRS complex widths

Central nervous system (CNS) events
- Diffuse, deep T wave inversions
- Minor ST segment elevations in leads with T wave inversions overdose and intoxication
- Rhythm disturbances
- Widened QRS complex
- Prolonged QT interval

Source: Reproduced from Brady et al., 2013/John Wiley & Sons.

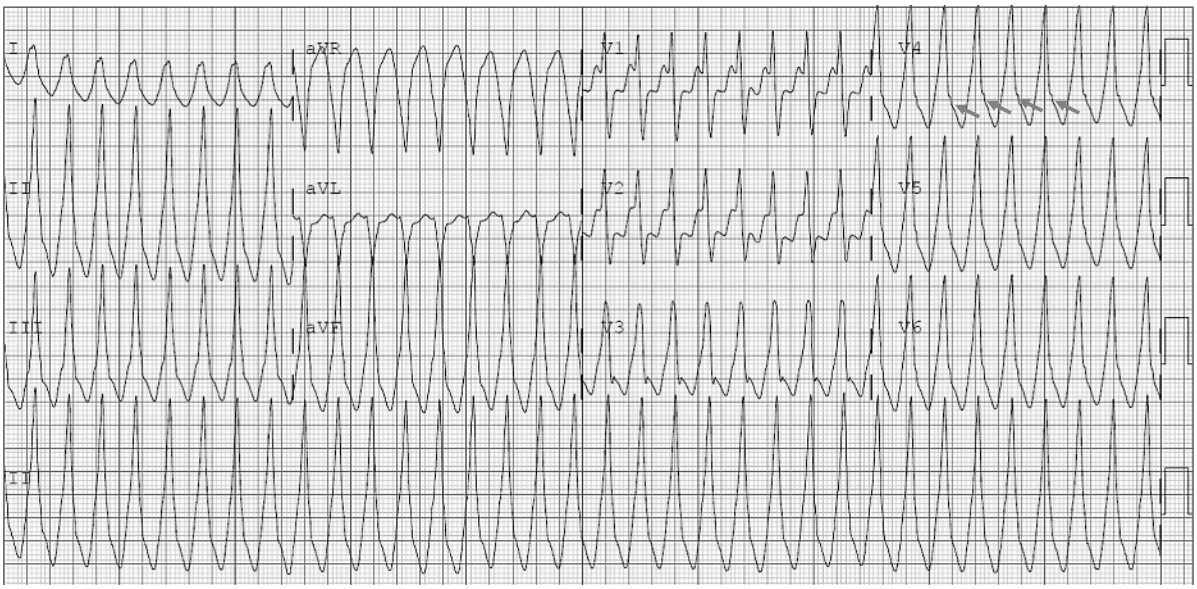


Figure 1.5 Wide complex tachycardia. The presence of retrograde P-waves (arrows) and positive concordance (similar, upright QRS axis) throughout the precordial leads is highly suggestive of ventricular tachycardia.

Clinical Context

The ECG does not exist in a vacuum; each ECG belongs to a patient with a corresponding clinical history. Appropriate ECG interpretation must occur within this context. For example, ST-elevation discovered incidentally on the ECG of an asymptomatic 18-year-old male undergoing a sports physical is clinically vastly different than a similar finding on the ECG of an elderly, obese patient with ongoing chest pain and diaphoresis. While one might split hairs about the inflection point of the ST segment and concavity or convexity of the ST segment, clinically it is highly likely that the finding in the first case represents benign early repolarization (BER), whereas the second scenario represents ACS. Clinicians who fail to interpret the ECG within the clinical context in which they were obtained do so at their own peril. The ECG contains an enormous amount of information pertaining to cardiac function. When used appropriately, the ECG is an invaluable tool, and expertise in its interpretation will undoubtedly enhance clinical care.

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