

EKG Fundamentals

Review of the Anatomy of the Conduction System

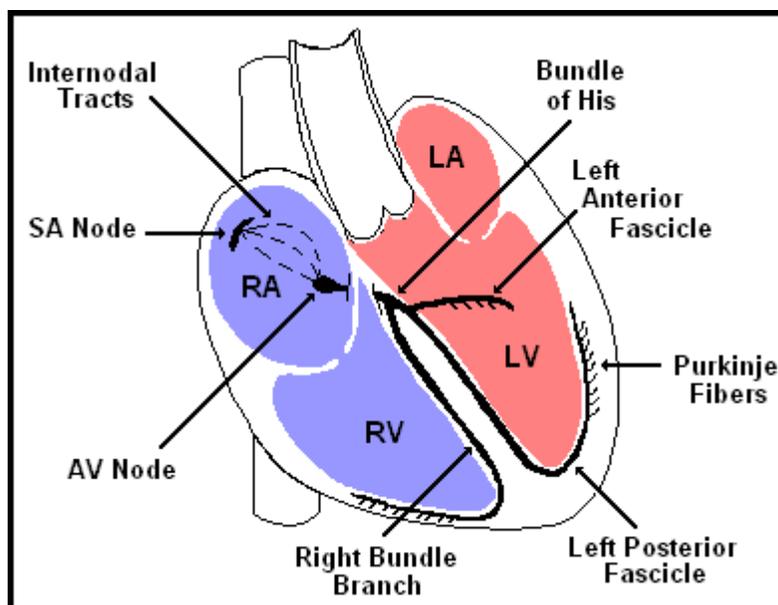
In order for the heart to pump blood in a coordinated manner, it is dependent upon a conduction system composed of specialized myocytes which instead of contracting, are capable of conducting electric current. The electrical signal that initiates myocardial contraction originates in the sinoatrial (SA) node. This signal is then carried to the remainder of the heart in a specific timed sequence.

Normal Sequence of Conduction:

1. SA node – The action potential of the heart is initiated in the SA node which acts as the heart's natural pacemaker.
2. Atrial internodal tracts – The action potential spreads from the SA node to both right and left atria (the right slightly earlier than the left), as well as to the AV node.
3. AV node – The AV node serves as the junction between the atria and ventricles. Conduction through the AV node is usually slow, which allows the ventricles to fill with blood from atrial contraction, before they contract themselves.
4. Bundle of His – This structure arises from the AV node and travels through the membranous portion of the interventricular (IV) septum, into which it sends electrical signals. Histologically, its proximal segment more closely resembles the AV node, whereas its distal segment more closely resembles the bundles branches.
5. Right and left bundle branches – At the superior margin of the muscular IV septum, the bundle of His bifurcates into the left and right bundles, which travel to the left and right ventricles, respectively. In some hearts, the left bundle then divides into a small anterior fascicle which travels to the apex and anterior papillary muscle, and a large posterior fascicle which travels to the remainder of the left ventricle. In other hearts, the anatomy of the left bundle is more diverse, comprising a variable network of fibers.
6. Purkinje fibers – These fibers connect to the terminal portions of the bundle branches and transmit signal to the endocardium such that there is near simultaneous contraction of the right and left ventricles. Electrical signal generally reaches the papillary muscles first in order to prevent regurgitation of blood flow through the AV valves.

The term, normal sinus rhythm refers to the rhythm occurring when there is a normal timing and pattern of the heart's electrical activity as outlined above, with the signal for each myocardial contraction initially arising from the SA node and propagating in grossly linear proximal to distal direction.

In all people with normal hearts, the SA node is supplied by the SA nodal artery which is the most proximal branch of the right coronary artery (RCA). In 85-90% of people, the AV nodal artery arises from the RCA at the intersection of the AV and interventricular grooves. The bundle of His is supplied by penetrating branches of both the left anterior descending (LAD) and posterior coronary arteries, making this segment of the conduction less susceptible to ischemia.



Normal Anatomy of the Cardiac Conduction System

Components of an EKG Tracing

The EKG is a representation of the electrical events of the cardiac cycle, graphed as a function of time. Each event is marked by a distinctive waveform, the recognition and interpretation of which can lead to a greater understanding of a patient's cardiac physiology and pathology. Pathology that can be identified and studied using EKGs include rhythm disturbances, ischemia and infarction, chamber enlargements, electrolyte abnormalities, and drug toxicities.

Waveforms

P wave – Atrial depolarization

QRS complex – Ventricular depolarization

T wave – Ventricular repolarization

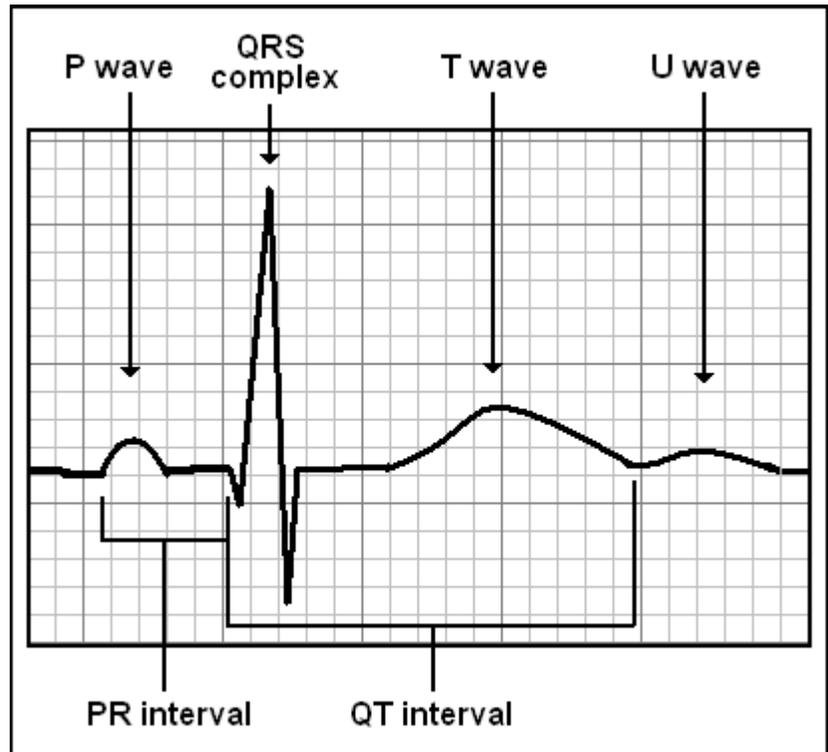
U wave (normally not seen) – Possibly represents repolarization of the His-Purkinje system

Important Intervals

PR interval – From the start of the P wave to the start of the QRS complex. Represents AV conduction delay.

QRS duration

QT interval – From the start of the QRS complex to the end of the T wave



EKG Leads

In order to record electrical activity, EKGs use leads which measure the difference in electrical potential between either two points on the body (bipolar leads), or a point on the body and a virtual reference point with zero electrical potential located in the center of the heart (unipolar leads).

Standard Limb Leads

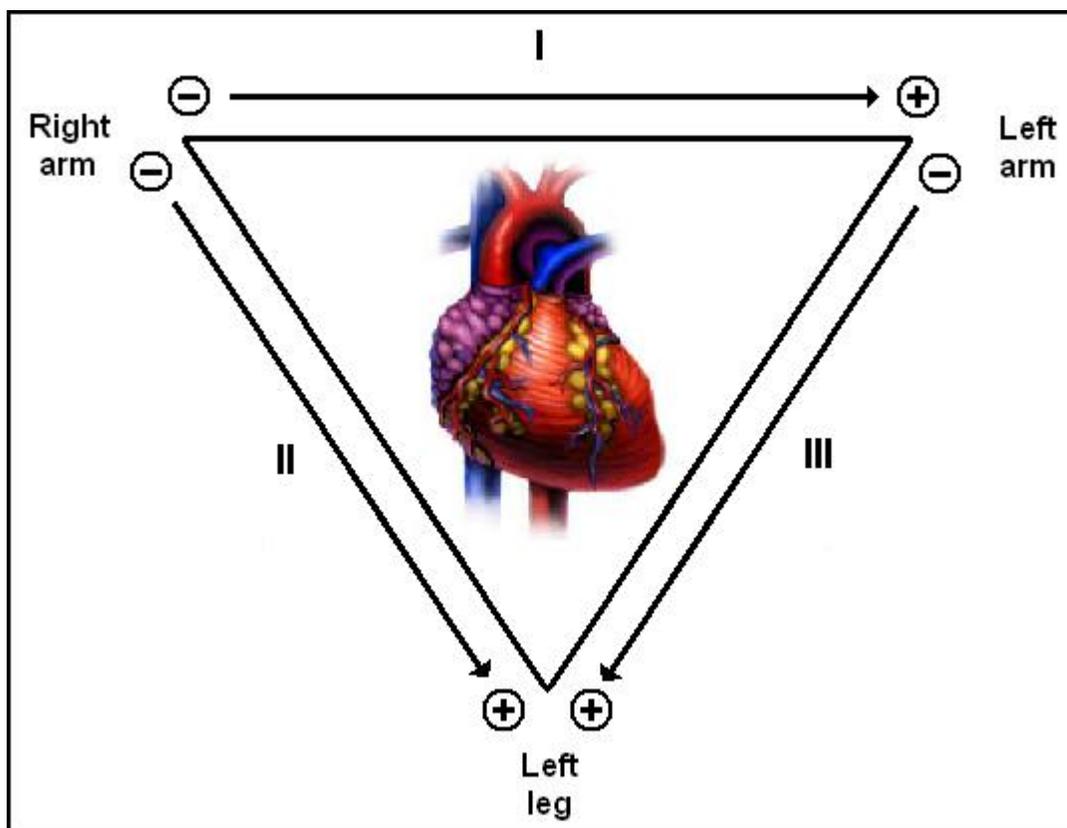
The most basic EKG leads are the 3 standard limb leads, which are bipolar leads which measure the potential difference between the right arm, left arm, and left leg. They are positioned as follows:

Lead I – Difference between the left arm and right arm

Lead II – Difference between the left leg and right arm

Lead III – Difference between the left leg and left arm

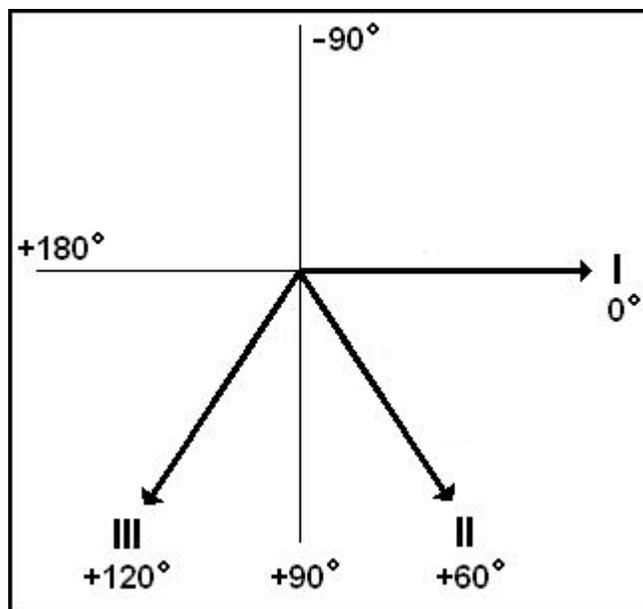
A fourth electrode is placed on the right leg to use as ground.



As can be seen from the diagram above, from the standpoint of electrical vectors, the three standard limb leads form an approximate equilateral triangle (known as Einthoven's triangle).

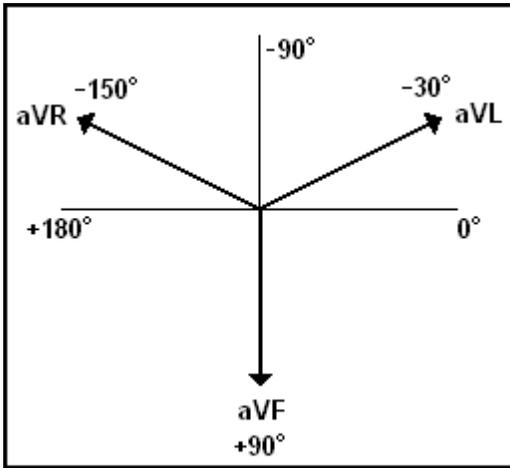
These electrical vectors can be rearranged in a fashion that will be more useful in developing a system of lead orientation.

To the right, the vectors have been moved and superimposed upon a polar coordinate system which (by universal convention), has 0° pointing directly leftward (from the patient's perspective). When this is done, leads II and III can be seen to be angled away from lead I at 60° and 120° , respectively.

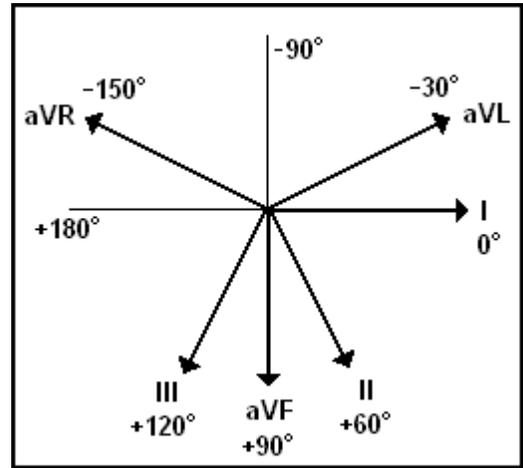


Augmented Limb Leads

In addition to the standard limb leads, there are also three augmented limb leads designated aVL, aVF, and aVR. These are referred to as "augmented" because they are unipolar leads. The axis of each lead appears to be directed from the center of the heart outwards to each respective limb.



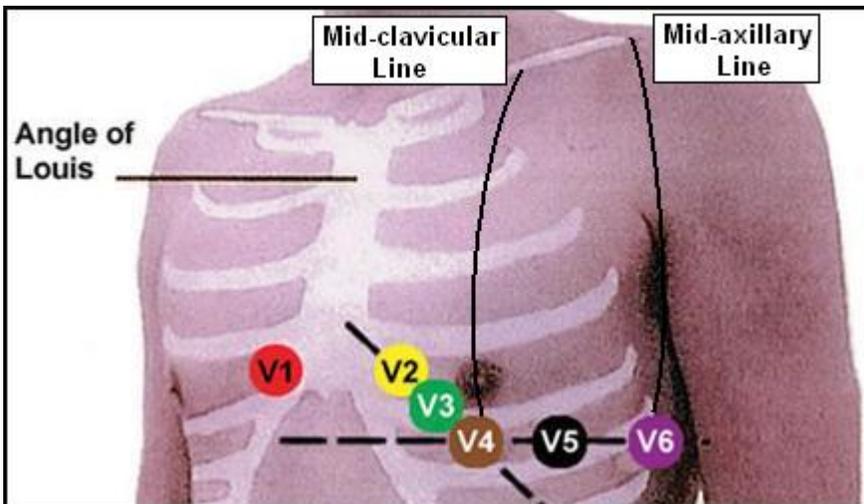
Axes of the augmented limb leads, each separated by 120°.



Axes of the standard and augmented limb leads, superimposed on one another.

Precordial Leads

In addition to the six limb leads, EKGs also have 6 unipolar leads which are placed directly on the chest wall, and are referred to as precordial leads.



Adapted from: www.numed.co.uk/electrodepl.html

Placement of Precordial Leads

V₁ – 4th intercostal space, just to the right of the sternum

V₂ – 4th intercostal space, just to the left of the sternum

V₃ – Halfway between V₂ and V₄

V₄ – 5th intercostal space in the mid-clavicular line

V₅ – Halfway between V₄ and V₆

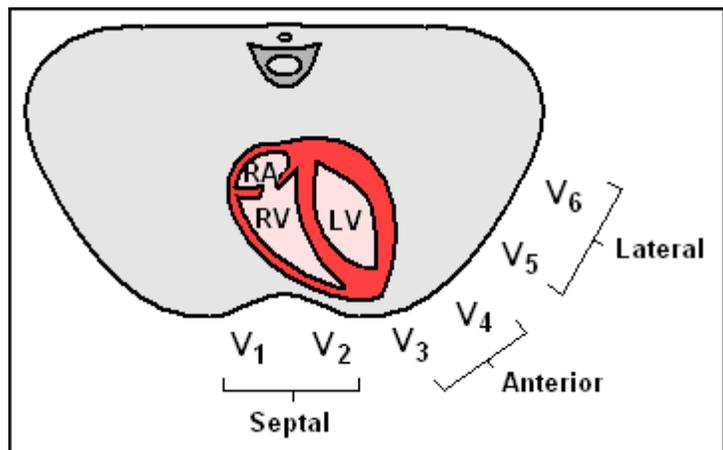
V₆ – 5th intercostal space in the mid-axillary line

Each precordial lead best visualizes the specific region of the heart over which it lies. As the position and orientation of the heart is similar in all individuals, the 6 precordial leads can be placed into 3 approximate groups:

V₁, V₂ – Best visualizes activity in the interventricular septum.

V₃, V₄ – Best visualizes activity in the anterior wall of the left ventricle.

V₅, V₆ – Best visualizes activity in the lateral wall of the left ventricle.



Each lead records the electrical activity of the heart from its own vantage point, such that a positive deflection is recorded when a wave of depolarization travels to that lead, and a negative deflection is recorded when a wave of depolarization travels away from a lead. When a wave is traveling perpendicular to the lead, an equiphasic (equally positive and negative) deflection is recorded.

Overview of Standard EKG Leads

	Limb Leads	Precordial Leads
Bipolar Leads	I, II, and III (standard limb leads)	-
Unipolar Leads	aVR, aVL, aVF (augmented limb leads)	V₁ – V₆

As with the precordial leads, the limb leads can also be grouped based upon which region of the heart they best visualize.

The diagram to the right displays the relationship these groupings have to the traditional position of each lead on the EKG printout.

I Lateral	aVR None	V₁ Septal	V₄ Anterior
II Inferior	aVL Lateral	V₂ Septal	V₅ Lateral
III Inferior	aVF Inferior	V₃ Anterior	V₆ Lateral

For a more complete discussion of the origin and physics behind the modern EKG lead system, please see: <http://butler.cc.tut.fi/~malmivuo/bem/bembook/15/15.htm>

Determining of Heart Rate

The first step in analyzing any EKG should be a determination of the heart rate. Most modern EKG machines will calculate the rate for you (one of the few interpretive tasks that the machine will do quite accurately). However, since attending physicians generally trained in the era prior to automated EKG interpretation, they will inevitably ask you do determine the rate manually, so it is thus important to know how to do so.

The Rule of 300

This is the quickest way to estimate the heart rate, which with practice can be done in under a second. Take the number of “big boxes” between two neighboring QRS complexes, and divide this into 300. The result will approximately equal to the rate.

It may be quicker simply to memorize the following table:

# of large boxes between QRS complexes	Rate
1	300 bpm
2	150 bpm
3	100 bpm
4	75 bpm
5	60 bpm
6	50 bpm

Examples
(courtesy www.uptodate.com)



6 big boxes between QRS complexes for a ventricular rate of 50 bpm.



Slightly under 4 big boxes between QRS complexes, for a ventricular rate slightly over 75 bpm.



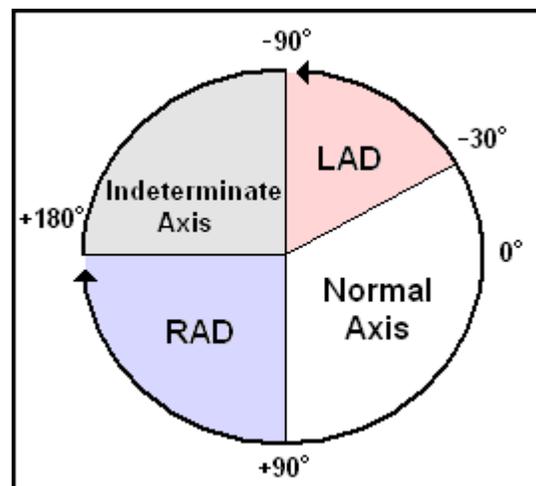
About 1.5 big boxes between QRS complexes for a ventricular rate of about 200 bpm ($300 / 1.5$).

The 10 Second Rule

The rule of 300 works well for all regular rhythms, but when the RR interval varies from beat to beat (in atrial fibrillation for example), another method of estimating the rate must be used. The 10 second rule utilizes the fact that most 12 lead EKGs record a total of 10 seconds on a single sheet. One can simply count the number of beats visible on the paper and multiple by 6 to reach the number of beats per minute.

Determining the QRS Axis

The QRS axis represents the average direction of the heart's electrical activity. There is no pure consensus on what constitutes a "normal" axis, though most consider -30° to $+90^\circ$ to be normal. An axis further clockwise than $+90^\circ$ is considered to be a right axis deviation (RAD), and an axis further counterclockwise than -30° is considered to be a left axis deviation (LAD). An alternative definition of "normal" axis refers to 0° to $+90^\circ$ as normal, 0° to -30° as a normal LAD, and beyond -30° as a pathologic LAD. In both ranges of "normal", an axis between -90° and $+180^\circ$ is referred to as indeterminate.



As there is no consensus on the range of normal, there is also no consensus on the clinical significance of an axis that is abnormal. In general, the axis of an EKG can suggest abnormalities of the conduction system (such as hemiblocks) and ventricular enlargement.

There are many systems to determine the QRS axis. The two easiest will be presented here. For both, one must first be able to classify QRS complexes as either predominantly positive, predominantly negative, or equiphasic.



Predominantly positive



Predominantly negative



Equiphasic

The Two Quadrant Approach

The key leads to look at in this approach are I and aVF. The QRS complex in each of these leads is classified as positive or negative. Each of the four possible combinations corresponds to either a normal axis (0° to $+90^\circ$), LAD (0° to -90°), RAD ($+90^\circ$ to $+180^\circ$), or an indeterminate axis.

In the event that LAD is present, examine lead II to determine if this deviation is pathologic. If the QRS in II is predominantly positive, the LAD is non-pathologic. If it is predominantly negative, it is pathologic.

		Lead aVF	
		Positive	Negative
Lead I	Positive	Normal Axis	LAD
	Negative	RAD	Indeterminate Axis

The Equiphasic Approach

There are two steps to this method.

1. Determine which lead contains the most equiphasic QRS complex. The fact that the QRS complex in this lead is equally positive and negative indicates that the net electrical vector (i.e. overall QRS axis) is perpendicular to the axis of this particular lead.
2. Examine the QRS complex in whichever lead lies 90° away from the lead identified in step 1. If the QRS complex in this second lead is predominantly positive, then the axis of this lead is approximately the same as the net QRS axis. If the QRS complex is predominantly negative, then the net QRS axis lies 180° from the axis of this lead.

For example, if step 1 identified the most equiphasic lead as lead II, aVL would be examined in step 2. If the QRS complex in lead aVL was predominantly negative, then the net QRS axis would be approximately $+150^\circ$.