Atrioventricular (AV) node.
The atrioventricular (AV) node is positioned between the coronary sinus and the tricuspid valve. The AV node conducts the atrial impulse to the ventricles, it causes a 0.04-second delay. This allows the ventricles to relax and fill with blood, while the atria contracts.
Rapid conduction now resumes through the bundle of His, which divides into the right and left bundle branches and extends down either side of the interventricular septum. The left bundle branch then splits into 2 branches or fascicle. Impulses travel much faster down the left bundle branch that feeds the larger thicker-walled right ventricle.
This network of diffuse muscle fiber beneath the endocardium transmits impulses faster than any other part of the conduction system, this pacemaker site usually fires when the SA node and the AV junction fail to generate an impulse or when the normal impulse is blocked in both bundle branches. The Purkinje fibers have an automatic firing rate of \(15\) to \(40\) beats per minute.
Blood from all parts of the body travels from the right atrium through the tricuspid valve into the right ventricle. This blood is then pumped from the right ventricle through the pulmonic valve into the pulmonary artery, which delivers the blood to the lungs to be oxygenated.

The oxygenated blood travels from the lungs through the pulmonary veins into the left atrium. The oxygenated blood is pumped from the left atrium, through the mitral valve, into the left ventricle. Finally, during contraction of the left ventricle, the oxygen-rich blood is pumped through the aortic valve into the aorta and branching arteries to be delivered to all the organs of the body.
Cardiac muscle has especial ability to generate its own spontaneous rhythmic electrical signal, which allows cardiac muscle to contract without external stimulation.
Cells in humans act like little batteries. These cells have different ion concentrations inside and outside of their membranes which create small electric potentials called biopotentials. When there is a disturbance in a biopotential this gives rise to an action potential which is the depolarization and repolarization of the cell.

ECG signals are comprised of the superposition of the different action potentials from the heart beating.
Einthoven, Dutch physician and physiologist used a simple string galvanometer to measure the electrical field generated during the cardiac activity. Attaching electrodes to the patient, the tiny electrical potentials produced by the heart made the string, immersed in a strong magnetic field, deflect obstructing a beam of light producing shadows in a photographic paper.

Einthoven published the first organized presentation of normal and abnormal electrocardiogram. He described ventricular and atrial hypertrophies, ventricular premature beats, atrial flutter and complete heart block.

The invention of Einthoven had an enormous impact in the medical knowledge of the heart in his time and promoted the advance of cardiac electrophysiology. He was awarded the Nobel Prize in 1924 for this discovery.

Willem Einthoven
Dutch physician, developer of the first electrocardiograph.
Willem Einthoven used the String Galvanometer he invented in 1901. Rather than using today's self-adhesive electrodes Einthoven's subjects would immerse each of their limbs into containers of salt solutions from which the EKG was recorded. Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders.
The **P wave** represents the spread of electrical activation (depolarization, contraction) through the atrial myocardium. Normally, it is a smooth, rounded deflection preceding the QRS complex.

The **QRS complex** represents the spread of electrical activation through the ventricular myocardium. It is usually (not always) the largest deflection on the ECG and is "spiky" in shape.

**R wave** is the first positive wave (above the baseline) follow the P wave

**S** is a negative wave that follows The R Wave

**Q wave** is a negative wave that precede the R wave
Components of the ECG

The **T wave** represents electrical recovery (repolarization) of the ventricular myocardium. It is a broad, rounded wave following the QRS complex.

The **U wave** may be due to slow repolarization of the papillary muscles. Some causes include: Bradycardia, hypokalaemia and digoxin.

**ST segment**

- Indicates early ventricular repolarization
- Normally not depressed more than 0.5 mm
- May be elevated slightly in some leads (no more than 1 mm)
Components of the ECG

PR interval
• Indicates AV conduction time
• Duration time is 0.12 to 0.20 seconds 120 – 200 ms

QT interval
• Measured from the Q to the end of the T.
• Represents ventricular depolarization and repolarization
• V3, V4 or lead II optimize the T-wave.
• QT usually less than half the R-R interval (0.32-0.40 seconds when rate is 65-90/minute)
• QT varies with rate. Correct for rate by dividing QT by the square root of the
The electrocardiogram is the paper or digital record of the cardiac electrical activity. In most cases it is taken at the body's surface via a noninvasive and painless procedure, not implying discomfort to the patient and extremely cheap compared with other methods to assess heart function. The electrocardiogram has been extensively used in clinical medicine for more than 80 years, and is now a primary diagnostic tool for many cardiac and other diseases.
**Lead Placement**

**DI** ----- Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode:

**D2** ----- Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode

**D3** ----- Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode
**V1:** Fourth intercostal space to the right of the sternum.

**V2:** Fourth intercostal space to the Left of the sternum.

**V3:** Directly between leads V2 and V4.

**V4:** Fifth intercostal space at midclavicular line.

**V5:** Level with V4 at left anterior axillary line.

**V6:** Level with V5 at left midaxillary line. (Directly under the midpoint of the armpit)
Standard limb Leads
Standard Leads Polarization

STANDARD LIMB LEADS (I, II, III)

I
right arm + left arm

II
right arm left arm

III
left arm right arm
Augmented limb Leads

Leads aVR, aVL, and aVF are augmented limb leads. They are derived from the same three electrodes as leads I, II, and III. However, they view the heart from different angles (or vectors).

\[ aVR = - \frac{(I+II)}{2} \quad aVL = I - \frac{II}{2} \quad aVF = \frac{II-I}{2} \]
Augmented limb Leads

A

R  L

F

$5 \, k\Omega$

$aV_L$

B

R'  L'

$CT'/aV_L$

F'

$aV_L$

R'  L'

$CT'/aV_F$

F'

$aV_F$

R'  L'

$CT'/aV_R$

F'

$aV_R$
Augmented Leads Polarization

AUGMENTED LIMB LEADS (aVR, aVL, aVF)

- aVR: Right arm to left leg
- aVL: Left arm to left leg
- aVF: Right arm to right leg
Standard limb Leads
Force vector component in the limb Leads

Einthoven Trinagle
The standard 12-lead electrocardiogram is a representation of the heart's electrical activity recorded from electrodes on the body surface.
A segment in an electrocardiogram is the region between two waves. PR segment begins at the end of the P wave and ends at the onset of the QRS complex. ST segment starts from the end of the QRS and terminates at the onset of the T wave.
An interval in an electrocardiogram includes one segment and one or more waves. PR interval starts at the beginning of the P wave and ends at the onset of the QRS. QT interval starts at the onset of the QRS and ends at the end of the T wave.
Value of the Intervals

Q-T interval - The time period indicated on the electrocardiograph encompassing the time from the beginning of the Q or R wave through the end of the T wave.

R-R interval - Time interval between 2 QRS complexes.

- PR interval 0.12 – 0.20 sec
- QRS duration 0.08 – 0.10 sec
- QT interval 0.4 – 0.43 sec
- RR interval 0.6 – 1.0 sec
QT interval: The QT interval is the time between onset of ventricular depolarization and end of ventricular repolarization. The QT interval must be corrected for heart rate using the formula:

\[ QTc = \frac{QT}{\sqrt{RR}} \]
EKG paper is a grid where time is measured along the horizontal axis. Each small square is 1 mm in length and represents 0.04 seconds. Each larger square is 5 mm in length and represents 0.2 seconds. Voltage is measured along the vertical axis. 10 mm is equal to 1 mV in voltage.
EKG paper magnified.
Each small square is 1 mm in length and represents 0.04 seconds.
Each larger square is 5 mm in length and represents 0.2 seconds.
Voltage is measured along the vertical axis.
10 mm is equal to 1 mV in voltage.

EKG Paper
Paper speed = 25 mm/seg  
1 mm = 40 ms
Paper Amplitude : 1 mm = 0.1 mV  
5 mm = 0.5 mV

ECG Paper
Normal ECG
Areas of the Heart

<table>
<thead>
<tr>
<th>I</th>
<th>Lateral</th>
<th>aVR</th>
<th>V1 Septal</th>
<th>V4 Anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Inferior</td>
<td>aVL Lateral</td>
<td>V2 Septal</td>
<td>V5 Lateral</td>
</tr>
<tr>
<td>III</td>
<td>Inferior</td>
<td>aVF Inferior</td>
<td>V3 Anterior</td>
<td>V6 Lateral</td>
</tr>
</tbody>
</table>
The two dimensional force vector

Force are two dimensional force vectors.

Forces have a part that pushes *right or left*, **x-component**

And that have another part that pushes *up or down*, the **y-component**.

The shadow of the vector on the X-axis, represents the *x-component* of the force vector.

The shadow of the vector on the Y-axis, represents the *y-component* of the force vector.
If we know the size of the two dimensional force vector, the black one in the above diagram, and the angle it makes with the x-axis, then we can use trigonometry to find the values for the components.

\[
\begin{align*}
\cos(A) &= \text{adj} / \text{hyp} \\
\sin(A) &= \text{opp} / \text{hyp} \\
F_x &= F \cos(A) \\
F_y &= F \sin(A)
\end{align*}
\]
The values for the x- and y-components can be positive or negative depending which way that the component is pointing. The angle describing the direction of the two dimensional force vector is in degrees and is to be considered in standard position.
QRS Axis represents only the average direction of ventricular activation in the frontal plane.

- The length of the vector represents the magnitude of the potential created by the depolarization.
- The direction of the arrow represents the mean direction of the depolarization vectors with reference to the frontal leads.
- The mean electrical axis is the average of all the instantaneous main electrical vector occurring sequentially during depolarization of the ventricles.
- The electrode placement represents Lead II
  1- Ventricular activation impulses are first conducted down the left and right bundle branches on either side the sept. It will record a small negative deflection Q wave.
  2- Depolarization of the septum. Will produce a very tall positive deflection R wave.
  3- The mean vector is pointing toward the left arm and anterior chest as the free wall of the ventricle depolarizes from the endocardial to the epicardial surface.
  4-. Finally, the last regions to depolarize will result in vector 4 (Panel D), which will cause a slight negative deflection (S wave) of the QRS.
To calculate the net QRS deflection, add up the number of small squares that correspond to the height of the R wave (positive deflection), and subtract the number of small squares that correspond to the height of the Q and S waves (negative deflection).
This method is limited to a simple technique which uses the leads I and aVF to calculate an approximate axis.

Plot out the overall QRS size on the line representing lead I. Positive is to your right, negative to your left. Plot out the QRS size on the line representing lead F. If F’s QRS is positive, draw downward. If negative, draw up. Draw lines perpendicular to the end points of your lines, to form a rectangle. Draw a line from the centerpoint to the corner of your box. This is the electrical vector. Its orientation represents the electrical axis.
Lead 1  
Leads I and aVF equally positive. The axis will be midway between 0° and 90°.
Normal axis ~ 40°-50°

Lead aVF

Lead 1  
Leads I and aVF both positive. Lead I more positive than aVF. The axis will therefore be oriented more toward 0°.
Normal axis ~ 20° - 40°
Lead 1 positive. Lead aVF almost equiphasic. Therefore, the axis will be approaching 0°. *(Note: when a lead is equiphasic, the axis will be 90° to that lead.)*

Lead 1 positive. Lead aVF negative. The axis will be oriented negatively past 0°. Left axis deviation ~ -30°.
Lead I negative. Lead aVF positive. The axis will be oriented positively past 90°. Right axis deviation ~ -120°

Both leads I and aVF negative. The axis will be oriented between -90° and -180°. Indeterminate axis ~ -135°
1.- First find the isoelectric lead if there is one; i.e., the lead with equal forces in the positive and negative direction. Often this is the lead with the smallest QRS.

2.- The QRS axis is perpendicular to that lead’s orientation (see above diagram). Since there are two perpendiculars to each isoelectric lead, chose the perpendicular that best fits the direction of the other ECG leads.

3.- If there is no isoelectric lead, there are usually two leads that are nearly isoelectric, and these are always 30° apart. Find the perpendiculars for each lead and chose an approximate QRS axis within the 30° range.

4.- Occasionally each of the 6 frontal plane leads is small and/or isoelectric. The axis cannot be determined and is called indeterminate. This is a normal variant.
Equiphasic lead method for QRS axis

Axis in the normal range

- Lead aVF is the isoelectric lead.
- The two perpendiculars to aVF are 0° and 180°.
- Lead I is positive (i.e., oriented to the left).
- Therefore, the axis has to be 0°.
Axis in the left axis deviation (LAD) range:

- Lead aVR is the smallest and isoelectric lead.
- The two perpendicularly are -60° and +120°.
- Leads II and III are mostly negative (i.e., moving away from the + left leg).
- The axis, therefore, is -60°.
Equiphasic lead method for QRS axis
Axis in the right axis deviation (RAD) range:

- Lead aVR is closest to being isoelectric (slightly more positive than negative)
- The two perpendiculars are -60° and +120°
- Lead I is mostly negative; lead III is mostly positive.
- Therefore the axis is close to +120°. Because aVR is slightly more positive, the axis is slightly beyond +120° (i.e., closer to the positive
Common Causes of Left Axis Deviation:
- a. Left ventricular hypertrophy.
- b. Pregnancy.
- c. Obesity.
- d. Right ventricular Infarction.

Common Causes of Right Axis Deviation:
- a. Right ventricular hypertrophy.
- b. Infarct in left ventricle.
- c. Slight right axis deviation may be normal for children and very tall, thin adults.
Left Cardiac hypertrophy is a thickening of the heart muscle (myocardium) which results in an increased production of electrical activity on the left side and then the axis will shift to the left. (Hypertension or aortic valve stenosis)
b. Pregnancy

The pressure exerted by the baby in the diaphragm will tilt the heart to the left side.
Common Causes of Left Axis Deviation:
a. Left ventricular hypertrophy.
b. Pregnancy.
c. Obesity.
d. Infarct in right ventricle.

Common Causes of Right Axis Deviation:
a. Right ventricular hypertrophy.
b. Left ventricular Infarcton.
c. Slight right axis deviation may be normal for children and very tall, thin adults.
Right ventricular hypertrophy is the increase or the enlargement in the right ventricle of the heart, which results in an increased production of electrical activity on the right side and then the axis will shift to the right. (Pulmonary arterial hypertension or large pulmonary embolism.)
Infarction is tissue death (necrosis) caused by a local lack of oxygen, due to an obstruction of the tissue's blood supply. The axis will shift to the right because of the tissue death, the right side is less capable to produce electrical activity.
The SA node generates impulses about 100 – 120 times per minute at rest. However, in a healthy individual, the resting heart rate (HR) would never be that high. This is due to continuous control of the autonomic nervous system (ANS) over the output of SA node activity. Its net regulatory effect gives real HR. In a healthy subject at rest, it ranges between 60 and 80 beats per minute.
There are two branches of the autonomic nervous system - sympathetic and parasympathetic (vagal) nervous systems that always work as antagonists in their effect on target organs. An increase in sympathetic stimulation causes an increase in HR, stroke volume, systemic vasoconstriction, etc. In contrast, the parasympathetic nervous system inhibits functioning of those organs. An increase in parasympathetic stimulation causes a decrease in HR, stroke volume, systemic vasodilatation, etc.
There are several methods for determining heart rate. Our first method is simple. Count the number of QRS complexes over a 6 second interval. Multiply by 10 to determine heart rate. This method works well for both regular and irregular rhythms. In the first image, we can count 7 QRS complexes, so the heart rate is 70. Paper speed is 25 m/s.
If there is irregularity of the cardiac rate, the number of cycles over a particular interval of time should be counted to determine the average cardiac rate. One convenient way of determining rate in this situation is to count the number of cardiac cycles in 6 seconds and multiply this by 10 (which is convenient, as the standard ECG will record for 10 seconds).
The second method uses small boxes. Count the number of small boxes for a typical R-R interval. Divide \textbf{this number into 1500 to determine heart rate. In the second image, the number of small boxes for the R-R interval is 21.5. The heart rate is 1500/21.5, which is 69.8.}
Calculating the Heart Rate (1500/Small Boxes)

1. Small boxes for the R-R interval = 22
   The heart rate is 1500/22 = 69.8/min

2. Small boxes for the R-R interval = 14
   The heart rate is 1500/14 = 107/min

2. Small boxes for the R-R interval = 30
   The heart rate is 1500/14 = 50/min

(69.8+107+50)/3 = 75.6 /min
1. Small boxes for the R-R interval = 18
   The heart rate is 1500/18 = 83.3/min
Calculating the Heart Rate (Rule of 300)

Rule of 300: If the rhythm is regular, the heart rate can be "estimated" by using the "Rule of 300". Count the number of large squares between two R waves and divide this number into 300. (There are 300 boxes, or 1500 tiny boxes, in a one minute strip)
Rule of 300: If the rhythm is regular, the heart rate can be "estimated" by using the "Rule of 300". Count the number of large squares between two R waves and divide this number into 300. (There are 300 boxes, or 1500 tiny boxes, in a one minute strip)
Calculating the Heart Rate (Rule of 300)

<table>
<thead>
<tr>
<th>The next block</th>
<th>1</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>The second block</td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>The third block</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>The fourth block</td>
<td>4</td>
<td>75</td>
</tr>
<tr>
<td>The fifth block</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>The sixth block</td>
<td>6</td>
<td>50</td>
</tr>
<tr>
<td>The seventh block</td>
<td>7</td>
<td>43</td>
</tr>
<tr>
<td>The eight block</td>
<td>8</td>
<td>37</td>
</tr>
<tr>
<td>The ninth block</td>
<td>9</td>
<td>30</td>
</tr>
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<td>The second block</td>
<td>2 150</td>
</tr>
<tr>
<td>The third block</td>
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</tr>
<tr>
<td>The fourth block</td>
<td>4 75</td>
</tr>
<tr>
<td>The fifth block</td>
<td>5 60</td>
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<tr>
<td>The sixth block</td>
<td>6 50</td>
</tr>
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<td>The seventh block</td>
<td>7 43</td>
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<td>The eight block</td>
<td>8 37</td>
</tr>
<tr>
<td>The ninth block</td>
<td>9 30</td>
</tr>
</tbody>
</table>

**Sinus Bradycardia**

<table>
<thead>
<tr>
<th>Heart Rate</th>
<th>Rhythm</th>
<th>P Wave</th>
<th>PR interval (in seconds)</th>
<th>QRS (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 60 bpm</td>
<td>Regular</td>
<td>Before each QRS, identical</td>
<td>.12 to .20</td>
<td>&lt;.12</td>
</tr>
</tbody>
</table>
Calculating the Heart Rate (Rule of 300)

<table>
<thead>
<tr>
<th>Block</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next</td>
<td>1</td>
</tr>
<tr>
<td>Second</td>
<td>2</td>
</tr>
<tr>
<td>Third</td>
<td>3</td>
</tr>
<tr>
<td>Fourth</td>
<td>4</td>
</tr>
<tr>
<td>Fifth</td>
<td>5</td>
</tr>
<tr>
<td>Sixth</td>
<td>6</td>
</tr>
<tr>
<td>Seventh</td>
<td>7</td>
</tr>
<tr>
<td>Eight</td>
<td>8</td>
</tr>
<tr>
<td>Ninth</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heart Rate</th>
<th>Rhythm</th>
<th>P Wave</th>
<th>PR interval (in seconds)</th>
<th>QRS (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usually 60-100 bpm</td>
<td>Irregular</td>
<td>Before each QRS, identical</td>
<td>.12 to .20</td>
<td>&lt;.12</td>
</tr>
</tbody>
</table>

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Calculating the Heart Rate (Rule of 300)

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</tr>
<tr>
<td>The ninth block</td>
<td>9</td>
<td>30</td>
</tr>
</tbody>
</table>
The P wave represents the sequential activation of the right and left atria.
- P duration < 0.12 sec (120 mseg)
- P amplitude < 2.5 mm (0.25 mv)

P-wave questions to address: Are they present?.
Do they occur regularly?. Is there one P-wave for each QRS complex?.
Are the P-Waves smooth, rounded, and upright?
Do all P-Waves have similar shapes?
PR INTERVALS Normal Value

PR interval
- travel time from SA node to AV node
- beginning of P to beginning of QRS
- 120 msec to 200 msec

PR Interval questions to address:
Does the PR-Interval fall within the norm of 120 - 200 msec?
Is the PR-Interval constant across the ECG tracing?
The QRS complex: Q is the first negative deflection from the baseline. R is the first large positive deflection after the Q. S is the negative deflection that follows R. The Q and the S are very close to the R and often seem to overlap it. The QRS complex corresponds to ventricular depolarization and contraction.
When ventricular despolarisation is longer than 110 milliseconds, this is a conduction delay. Possible causes of a QRS duration > 110 milliseconds include:
- Left bundle branch block
- Right bundle branch block
- Idioventricular rhythm and paced rhythm
Multiple variations of the QRS complex.
The QT interval is measured from the start of the QRS complex to the end of the T wave - the end of the T wave was defined as the point of return to the isoelectric line.

- ventricular depolarization & repolarization
- beginning of QRS to end of T
- Q-T interval 0.35 - 0.43 sec  350 – 430 ms
- no > than ½ of R to R interval
The T wave is broad, but the tangent crosses the baseline before the T wave joins the baseline. The QT interval would be overestimated when this last definition of the end of the T wave would be used.

The ECG does not meet the baseline after the end of the T wave. Still, the crossing of the tangent and baseline should be used for measurements.

A bifasic T wave. The tangent to the 'hump' with the largest amplitude is chosen. This can change from beat to beat, making it more important to average several measurements.
Normal QT is heart rate dependent (upper limit for QTc = 0.46 sec)
Long QT Syndrome: LQTS (based on corrected QTc:
QTc 450 msec for males and 460 msec in females
The eyeballing method to estimate QT prolongation. If the QT interval ends before the imaginary boundary halfway two QRS complexes, the QTc is probably normal. If the QTc reaches beyond the halfway line, the QTc is probably prolonged. This method is only 'valid' in registrations with normal (60-100/min) heart rates.
• The amplitudes of all the QRS complexes in the limb leads are < (0.5 mV)
• or The amplitudes of all the QRS complexes in the precordial leads are < (1 mV)

Causes:
Obesity, Pneumothorax, Constrictive pericarditis, Previous massive MI
R Wave Progression

Causes of poor R wave progression:
- Anterior myocardial infarction
- Faulty ECG recording technique
- Left bundle branch block
- Ventricular hypertrophy
- Wolff–Parkinson–White syndrome
In lead V1, the R wave should be small. The R wave becomes larger throughout the precordial leads to the point where the R wave is larger than the S wave in lead V4.

10.- R Wave Progression
The Q wave represents the normal left-to-right depolarisation of the interventricular septum. Small ‘septal’ Q waves are typically seen in the left-sided leads (I, aVL, V5 and V6).

Myocardial infarction
Cardiomyopathies — Hypertrophic (HOCM), infiltrative myocardial disease
Rotation of the heart — Extreme clockwise or counter-clockwise rotation
Lead placement errors — e.g. upper limb leads placed on lower limbs

- > 40 ms (1 mm) wide
- > 2 mm deep
- > 25% of depth of QRS complex
- Seen in leads V1-3
The ST segment represents the early part of ventricular repolarization. This is the area from the end of the S (QRS) to the onset of the T wave. It can be a little bit above or below the baseline. Note if it significantly dips below the baseline (depressed), goes above the baseline (elevated),
“In this acute anterior MI
Persistent ST elevation after acute MI suggests ventricular aneurysm
ST elevation during exercise testing suggests extremely tight coronary
artery stenosis or spasm (transmural ischemia)
ST segment changes
ST segment depression -- most likely associated with ischemia
ST segment elevation - less specificity, but suggestive if it is known that the patient has coronary vascular disease

**ST Segment Depression**
The **T wave** can be positive, negative, or biphasic (having two deflections, one negative, one positive); in this example it is positive. The T wave corresponds to ventricular depolarization or relaxation.
T Waves Inversion

Q wave and non-Q wave MI (e.g., evolving anteroseptal MI): Myocardial ischemia. Subacute or old pericarditis. Myocarditis Myocardial contusion (from trauma)
Different forms of T wave morphology
1. P wave: upright in leads I, aVF and V3 - V6, normal duration of less than or equal to 110 ms; polarity is positive in leads I, II, aVF and V4 - V6;
2. PR interval: Normally between 120 ms and 200 ms.
3. QRS complex: Duration less than or equal to 110 ms, amplitude greater than 0.5 mV in at least one standard lead, and greater than 1.0 mV in at least one precordial lead. Upper limit of normal amplitude is 2.5 - 3.0 mV.
4. ST segment: isoelectric, slanting upwards to the T wave in the normal ECG can be slightly elevated (up to 2.0 mm in some precordial leads). never depressed greater than 0.5 mm in any lead
5. T wave: T wave deflection should be in the same direction as the QRS complex in at least 5 of the 6 limb leads, normally rounded and asymmetrical, should be upright in leads V2 - V6, inverted in aVR
6. QT interval: Durations normally less than or equal to 400 ms for males and 440 ms for females.
ECG Recorder Specification

- 12 leads real time data acquisition
- Sampling rates: 1000 samples/sec.
- Frequency response: 0.05 - 300 Hz
- Resolution: 16 bit A/D conversion
- Sensitivity: Better than 0.4 μV
- CMRR : 120 dB
- Defibrillator protected input circuits and patient cable
- Power Consumption: 280 mA max. from USB port
- Suspend Current: Less than 500 μA
- Dimension: 113x80x30 (mm), Weight: 300 gr

Patient Safety and Regulations
- Patient Leakage Current: Less than 10 μA
- EN 60601-1 Electrical Safety
- EN 60601-1-2 EMC
- CE Directive 93/42/EEC
JIAPU PAN AND WILLIS J. TOMPKINS, in 1985 have developed a real-time algorithm for detection of the QRS complexes of ECG signals. It reliably recognizes QRS complexes based upon digital analyses of slope, amplitude, and width.

**R-Pick detection algorithm**
The ECG waveform contains, in addition to the QRS complex, P and T waves, 60-Hz noise from power line interference, EMG from muscles, motion artifact from the electrode and skin interface, and it is necessary to extract the signal of interest, the QRS complex, from the other noise sources such as the P and T waves.

**QRS Power Spectra Based on FFT**
First, in order to attenuate noise, the signal passes through a digital band-pass filter composed of cascaded high-pass and low pass filters.

**Low-Pass Filter**

The transfer function of the second-order low-pass filter is

\[ H(z) = \frac{(1 - z^{-6})^2}{(1 - z^{-1})^2}. \]  (1)

The amplitude response is

\[ |H(\omega T)| = \frac{\sin^2 (3\omega T)}{\sin^2 (\omega T/2)} \]  (2)

where \( T \) is the sampling period. The difference equation of the filter is

\[ y(nT) = 2y(nT - T) - y(nT - 2T) + x(nT) \]

\[ - 2x(nT - 6T) + x(nT - 12T) \]  (3)

where the cutoff frequency is about 11 Hz and the gain is 36. The filter processing delay is six samples.
The most noticeable result is the attenuation of the higher frequency QRS complex. Any 60-Hz noise or muscle noise present would have also been significantly attenuated.

Low Pass Filter attenuation
Figure 12.1 Relative power spectra of QRS complex, P and T waves, muscle noise and motion artifacts based on an average of 150 beats.
The ECG passes through the bandpass filter. Note the attenuation of the T and P wave due to the high-pass filter.

High Pass Filter attenuation
The ECG passes through the bandpass filter. Note the attenuation of the T and P wave due to the high-pass filter.
ALGORITHM FOR R PEAK DETECTION

LOW PASS FILTER

HIGH PASS FILTER

Derivative Filter

SQUARING FUNCTION

MOVING WINDOW INTEGRAL

THRESHOLDING & PEAK IDENTIFICATION

Detected R peak locations

Figure 3: Schematic of the R-peak detection algorithm

R-Pick detection algorithm
Derivative

After filtering, the signal is differentiated to provide the QRS-complex slope information. We use a five-point derivative with the transfer function

$$H(z) = \frac{1}{8T} (-z^{-2} - 2z^{-1} + 2z^{1} + z^{2}). \quad (7)$$

The amplitude response is

$$|H(\omega T)| = (1/4T) [\sin(2\omega T) + 2 \sin(\omega T)]. \quad (8)$$

The difference equation is [7]

$$y(nT) = \frac{1}{8T} [-x(nT - 2T) - 2x(nT - T)$$

$$+ 2x(nT + T) + x(nT + 2T)]. \quad (9)$$

Fig. 4 shows that the frequency response of this derivative is nearly linear between dc and 30 Hz (i.e., it approximates an ideal derivative over this range). Its delay is two samples.

Fig. 4. Amplitude response of the digital derivative filter.
Band-Pass Filter and Differentiation

Electrocardiogram sampled

Low-pass filtered ECG.

Ban-dpass-filtered ECG

ECG after band-pass filtering and differentiation
Squaring Function

After differentiation, the signal is squared point by point. The equation of this operation is

\[ y(nT) = [x(nT)]^2. \] (10)

This makes all data points positive and does nonlinear amplification of the output of the derivative emphasizing the higher frequencies (i.e., predominantly the ECG frequencies).

The squaring process intensifies the slope of the frequency response curve of the derivative and helps restrict false positives caused by T waves.
Band-pass filtered ECG after subjecting to derivative filtering and squaring function.
Moving-Window Integration

The purpose of moving-window integration is to obtain waveform feature information in addition to the slope of the \( R \) wave. It is calculated from

\[
y(nT) = \frac{1}{N} \left[ x(nT - (N - 1) T) + x(nT - (N - 2) T) + \cdots + x(nT) \right]
\]

where \( N \) is the number of samples in the width of the integration window.

Generally, the width of the window should be approximately the same as the widest possible QRS complex.

**Moving-Window Integration**
Fiducial Mark. The QRS complex corresponds to the rising edge of the integration waveform. The time duration of the rising edge is equal to the width of the QRS complex.

Output from Moving Integral Filter
The thresholds are automatically adjusted to float over the noise. Low thresholds are possible because of the improvement of the signal-to-noise ratio by the bandpass filter.

**Adjusting the Thresholds**
If the program does not find a QRS complex in the time interval corresponding to 166 percent of the current average RR interval, the maximal peak detected in that time interval that lies between these two thresholds is considered to be a possible QRS complex (the lower of the two thresholds is applied). **Adjusting the Thresholds**
The higher of the two thresholds in each of the two sets is used for the first analysis of the signal. The lower threshold is used if no QRS is detected in a certain time interval so that a search-back technique is necessary to look back in time for the QRS complex.

**Adjusting the Thresholds**
ECG Waveform with R-Peaks Identified
Typical steps of Pan-Tompkins algorithm for detecting QRS complex: (a) band-pass filtered ECG signals; (b) after differentiation; (c) after performing squaring operation; (d) moving window integration; and (d) R peak detection.
Identification of inflexion points

- P wave
- T wave
- P–R interval
- S–T interval
- Q–T interval
- P–Q segment
- S–T segment
- QRS interval
- Atria contract
- Ventricles contract