What is an ECG?

The electrocardiogram (ECG) is a representation of the electrical events of the cardiac cycle.

Each event has a distinctive waveform, the study of which can lead to greater insight into a patient’s cardiac pathophysiology.
What types of pathology can we identify and study from ECGs?

- Arrhythmias
- Myocardial ischemia and infarction
- Pericarditis
- Chamber hypertrophy
- Electrolyte disturbances (i.e. hyperkalemia, hypokalemia)
- Drug toxicity (i.e. digoxin and drugs which prolong the QT interval)
ECG PAPER

• Light lines small squares- 1 X 1 mm
• Bold lines large squares 5 X 5 mm
• Horizontal axis=time
  1. Distance across small square=0.04 sec.
  2. Distance across large square=0.2 sec.
• Vertical axis=voltage
  1. Distance across small square=0.1 mV
  2. Distance across large square=0.5 mV
Anatomy of Heart and ECG signal

Normal ECG signal

- **Sinoatrial node**
- **Atrioventricular node**
- **Atrioventricular bundle**
- **Left ventricle**
- **Interventricular septum**
- **Left atrium**
- **Apex**
- **Left and right bundle branches**

**P-Wave**
Depolarization of atria in response to SA node triggering.

**PR Interval**
Delay of AV node to allow filling of ventricles.

**QRS Complex**
Depolarization of ventricles, triggers main pumping contractions.

**T-Wave**
Ventricular repolarization

**ST Segment**
Beginning of ventricle repolarization, should be flat.
1. SA node discharge: no deflection
2. Right and left atrial activation: P wave
3. Activation of AV node and bundle of His: No deflection
4A. Septal activation: Onset of QRS complex, initial septal Q wave
4B. Left ventricular free wall activation: Inscription of QRS complex
5. Full ventricular activation: No deflection
6. Ventricular repolarization: His Purkinje T wave
7. Late ventricular repolarization: His Purkinje U wave
ECG Leads

Leads are electrodes which measure the difference in electrical potential between either:

1. Two different points on the body (bipolar leads)

2. One point on the body and a virtual reference point with zero electrical potential, located in the center of the heart (unipolar leads)
ECG Leads

The standard ECG has 12 leads:

- 3 Standard Limb Leads
- 3 Augmented Limb Leads
- 6 Precordial Leads

The axis of a particular lead represents the viewpoint from which it looks at the heart.
Standard Limb Leads
Precordial Lead Placement

- $V_1$: 4th intercostal space, right sternal border
- $V_2$: 4th intercostal space, left sternal border
- $V_3$: midway between $V_2$ and $V_4$
- $V_4$: 5th intercostal space, left midclavicular line
- $V_5$: level with $V_4$, anterior axillary line
- $V_6$: level with $V_4$, mid axillary line
Precordial Leads
Precordial Leads

- V1: Septal
- V2: Septal
- V3: Septal
- V4: Anterior
- V5: Lateral
- V6: Lateral

RA: Right Atrium
RV: Right Ventricle
LV: Left Ventricle
# Summary of Leads

<table>
<thead>
<tr>
<th></th>
<th>Limb Leads</th>
<th>Precordial Leads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bipolar</strong></td>
<td>I, II, III (standard limb leads)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Unipolar</strong></td>
<td>aVR, aVL, aVF (augmented limb leads)</td>
<td>V₁-V₆</td>
</tr>
</tbody>
</table>
Arrangement of Leads on the ECG

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>aVR</th>
<th>V₁</th>
<th>V₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>aVL</td>
<td>V₂</td>
<td>V₅</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>aVF</td>
<td>V₃</td>
<td>V₆</td>
<td></td>
</tr>
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</table>
Anatomic Groups

<table>
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<tr>
<th></th>
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<th>aVR</th>
<th>V₁</th>
<th>V₄</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Lateral</td>
<td>None</td>
<td>Septal</td>
<td>Anterior</td>
</tr>
<tr>
<td>II</td>
<td>Inferior</td>
<td>aVL</td>
<td>V₂</td>
<td>V₅</td>
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<td></td>
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<td>aVF</td>
<td>V₃</td>
<td>V₆</td>
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<td></td>
<td>Inferior</td>
<td>Inferior</td>
<td>Anterior</td>
<td>Lateral</td>
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</table>
Standard Paper Speed and Voltage

- Paper speed should be set at 25mm/sec
- Voltage should be set at 10mm = 1mV
Is the Voltage Standardized? Is the Paper Speed Indicated?
Heart Rate

measurements
1) Count the number large squares between two consecutive ‘R’ waves then divide the result by 300
   i.e. 300/4 = 75 bpm

2) Count the number of ‘R’ waves in a 6 second strip (30 large squares) then multiply the result by 10
   i.e. 10 X 12 = 120 bpm
   (this method is especially good for irregular heart rates)

3) With a rate ruler
What is the heart rate?

(300 / 6) = 50 bpm
What is the heart rate?

\[(300 / \sim 4) = \sim 75 \text{ bpm}\]
What is the heart rate?

\[
\frac{300}{1.5} = 200 \text{ bpm}
\]
What is the heart rate?

\[ 20 \times 10 = 200 \text{ bpm} \]
Normal H.R.  60-90 bpm
Bradycardia less than 60 bpm
Tachycardia less than 100 bpm
Rhythm
What is the Rhythm?

- Is there a p wave in front of every QRS complex?
- Is every p wave followed by a QRS complex?
- Do the p waves all look the same?
- Is the rhythm regular? Regularly irregular? Irregularly irregular?
- Are the QRS complexes narrow, wide or a mixture of the two?
Is there a p wave in front of every QRS?

- yes

Are they all normal sinus p waves?

- yes

Normal sinus rhythm
Is every p wave followed by a QRS complex?

No

Some p waves are blocked

Blocked p wave premature?

Blocked PAC

Second or third degree heart block
No p waves at all?

Is the rhythm regular?

- No, totally irregular
  - Atrial fibrillation

- Yes
  - Narrow QRS
    - Junctional rhythm
  - Wide QRS
    - Ventricular rhythm
Wide QRS beat?

- If preceded by a sinus p wave at the appropriate PR interval, this is a sinus beat which is wide due to a block in the left or right bundle

- If no p wave, beat originates in the ventricle either prematurely (PVC) or because no other beat came along (ventricular escape beat)
Wide QRS Beats

Wide QRS with a p wave Bundle Branch Block

Wide QRS with no p wave Ventricular beat
Regular rhythm

- If H.R. is normal (normal, atrial flutter)
- If bradycardia
  - no P or inverted (nodal rhythm)
  - normal P
    - @ regular relation with QRS (complete HB, sinus bradycardia)
    - @ irregular relation with QRS (partial HB)

If tachycardia

- Abnormal QRS (vent. Tachycardia)
- normal QRS
  - @ Normal P (SVT atrial)
  - @ absent or inverted P (SVT nodal)
Irregular rhythm

• If irregular irregularity (AF)
• If occasional irregularity
  # normal QRS (Supravent. extrasystole)
  # abnormal ORS (Vent. Extrasystole)
Normal Sinus Rhythm – the rules!

• P before every QRS
• PR interval <0.2 seconds (5 baby squares)
• QRS after every P wave
• QRS <0.12 seconds (3 baby squares)
• Regular and identical
• Rate 60-100 bpm
  – <60 bpm – sinus bradycardia
  – >100 bpm – sinus tachycardia
Sinus rhythm
SINUS BRADYCARDIA

SINUS TACHYCARDIA

PAROXYSMAL ATRIAL TACHYCARDIA
SECOND DEGREE AV BLOCK - MOBITZ TYPE II

THIRD DEGREE (COMPLETE) AV BLOCK

RIGHT BUNDLE BRANCH BLOCK

© RnCeus.com
VENTRICULAR STANDSTILL (Asystole)
Bigeminy VPC
Trigeminy VPC
PSVT
Left Bundle Branch Block
Criteria

- QRS duration $\geq 120$ms
- Broad R wave in I and $V_6$
- Prominent QS wave in $V_1$
- Absence of q waves (including physiologic q waves) in I and $V_6$
Left Bundle Branch Block
Right Bundle Branch Block
Criteria

- QRS duration $\geq 110\text{ms}$
- rSR’ pattern or notched R wave in $V_1$
- Wide S wave in I and $V_6$
Right Bundle Branch Block
# Normal Sinus Rhythm

<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>
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<tr>
<td>60-100 bpm</td>
<td>Regular</td>
<td>Before each QRS, identical</td>
<td>.12 to .20</td>
<td>&lt;.12</td>
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</table>
**Left Bundle Branch Block**

<table>
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<td>RR' in V5</td>
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### Right Bundle Branch Block

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</table>
Atrial Tachycardia

<table>
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<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>140-250 bpm</td>
<td>Regular</td>
<td>Abnormal P before each QRS</td>
<td>&lt;.20</td>
<td>&lt;.12</td>
</tr>
</tbody>
</table>
P wave
**P waves**

- It is important to remember that the P wave represents the *sequential* activation of the right and left atria, and it is common to see notched or biphasic P waves of right and left atrial activation.
- Does not exceed 2.5 mm (height) in lead II
- Less than 0.12 seconds (width) in lead II
- Abnormal P:
  - RAE (P Pulmonale)
  - LAE (P mitrale)
  - Atrial flutter
  - Nodal rhythm (absent with regular rhythm)
  - AF (absent with irregular rhythm)
  - Dextrocardia
Atrial flutter
Atrial fibrillation
Left Atrial Enlargement

Criteria

P wave duration in II \( \geq \) 120ms

or

Negative component of biphasic P wave in V_1 \( \geq \) 1
“small box” in area
Right Atrial Enlargement

Criteria

P wave height in II ≥ 2.4mm

or

Positive component of biphasic P wave in V₁ ≥ 1
“small box” in area
The P Wave Represents Atrial Depolarization

- Right atrial enlargement results in tall p waves, best seen in leads II, III, and aVF

- Left atrial enlargement leads to a double hump or "m" shaped p wave
The P waves should be upright in I, II, and V2 to V6
Dextrocardia
PR Interval

Look at it !
PR interval

- measured from beginning of P to beginning of QRS
- 0.12-0.20 s (3-5 small squares).
- Best seen in lead II.
PR interval

Short PR: < 0.12s

1- Preexcitation syndromes:

*WPW (Wolff-Parkinson-White) Syndrome: An accessory pathway connects the right atrium to the right ventricle or the left atrium to the left ventricle, and this permits early activation of the ventricles (delta wave) and a short PR interval.
WPW syndrome
PR interval

2- AV Junctional Rhythms with retrograde atrial activation (inverted P waves in II, III, aVF): Retrograde P waves may occur before the QRS complex (usually with a short PR interval), in the QRS complex (i.e., hidden from view), or after the QRS complex (i.e., in the ST segment).

3- Ectopic atrial rhythms originating near the AV node (the PR interval is short because atrial activation originates close to the AV node; the P wave morphology is different from the sinus P)

4- Normal variant

5- tachycardia
PR interval

Prolonged PR: >0.20s

1-First degree AV block (PR interval usually constant)

2-Second degree AV block (PR interval may be normal or prolonged; some P waves do not conduct)

Type I (Wenckebach): Increasing PR until nonconducted P wave occurs

Type II (Mobitz): Fixed PR intervals plus nonconducted P waves

3-AV dissociation: Some PR's may appear prolonged, but the P waves and QRS complexes are dissociated.

4- Rheumatic fever

5- Digitalis
First degree AV block
Second degree AV block (Mobitz I)-Wenckebach
QRS complex
Definitions

- The Q wave is the first portion of the ventricular depolarization if it is negative.
- The first upward deflection is the R wave.
- A negative deflection after an R wave is an S wave.
- If the whole thing is negative it’s a QS complex.
- If there’s no Q wave its an RS.
- A second R wave after the S is an R’ (or r’) (r prime).
The QRS Complex

- Axis
- Duration (width)
- Initial deflection
- Voltage
- Morphology
Standard Limb Leads
Augmented Limb Leads

- aVR: -150°
- aVF: +90°
- aVL: -30°
The QRS Axis

The QRS axis represents the net overall direction of the heart’s electrical activity.

Abnormalities of axis can hint at:

- Ventricular enlargement
- Conduction blocks (i.e. hemiblocks)
The QRS Axis

By near-consensus, the normal QRS axis is defined as ranging from \(-30^\circ\) to \(+90^\circ\).

\(-30^\circ\) to \(-90^\circ\) is referred to as a left axis deviation (LAD).

\(+90^\circ\) to \(+180^\circ\) is referred to as a right axis deviation (RAD).
Determining the Axis

• The Quadrant Approach

• The Equiphasic Approach
Determining the Axis

Predominantly Positive

Predominantly Negative

Equiphasic
The Quadrant Approach

1. Examine the QRS complex in leads I and aVF to determine if they are predominantly positive or predominantly negative. The combination should place the axis into one of the 4 quadrants below.

<table>
<thead>
<tr>
<th>Lead I</th>
<th>Lead aVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Negative</td>
<td>Negative</td>
</tr>
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</table>
The Quadrant Approach

2. 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 (in other words, the axis is normal). If it is predominantly negative, it is pathologic.
Quadrant Approach: Example 1

Negative in I, positive in aVF → RAD
Quadrant Approach: Example 2

Positive in I, negative in aVF  →  Predominantly positive in II  →
Normal Axis (non-pathologic LAD)
The Equiphasic Approach

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, than the axis of this lead is approximately the same as the net QRS axis. If the QRS complex is predominantly negative, than the net QRS axis lies 180° from the axis of this lead.
Equiphasic Approach: Example 1

Equiphasic in aVF → Predominantly positive in I → QRS axis ≈ 0°
Equiphagic Approach: Example 2

Equiphagic in II $\rightarrow$ Predominantly negative in aVL $\rightarrow$ QRS axis $\approx +150^\circ$
QRS complex

- Normal: 0.06 - 0.10s

**Prolonged QRS Duration (>0.10s):**

A-QRS duration 0.10 - 0.12s

1- Incomplete right or left bundle branch block

2- Nonspecific intraventricular conduction delay (IVCD)

3- Some cases of left anterior or posterior fascicular block

B-QRS duration ≥ 0.12s

1- Complete RBBB or LBBB

2- Nonspecific IVCD

3- Ectopic rhythms originating in the ventricles (e.g., ventricular tachycardia, pacemaker rhythm)
Left Bundle Branch Block
Criteria

• QRS duration $\geq 120$ms
• Broad R wave in I and $V_6$
• Prominent QS wave in $V_1$
• Absence of q waves (including physiologic q waves) in I and $V_6$
LBBB
Left Bundle Branch Block

![ECG Graph]

06-JAN-1997 22:24
Left Bundle Branch Block

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Right Bundle Branch Block
Criteria

- QRS duration $\geq 110$ms
- rSR’ pattern or notched R wave in $V_1$
- Wide S wave in I and $V_6$
RBBB

Transverse plane

Electrocardiogram tracings:

- V1: R
- V2: rS
- V5: QRS complex
- V6: QRS complex

Diagram showing block and wave patterns.
Right Bundle Branch Block
## Right Bundle Branch Block

**P Wave**
- Before each QRS, identical

**PR Interval** (in seconds)
- 0.12 to 0.20

**QRS** (in seconds)
- >0.12

**Characteristics**
- RSR' in V1
Wide QRS Beats

Wide QRS with a p wave Bundle Branch Block

Wide QRS with no p wave Ventricular beat
Left Ventricular Hypertrophy

- R in I + S in III > 25mm
- S in V₁+ R in V₅ (or V₆) >35 mm
- R in aVL >11mm

\{ voltage criteria \}

- Lateral ST/T changes
- Left atrial enlargement is supporting evidence
Left Ventricular Hypertrophy
Right Ventricular Hypertrophy

Although there is no widely accepted criteria for detecting the presence of RVH, any combination of the following ECG features is suggestive of its presence:

- Right axis deviation
- Right atrial enlargement
- Down sloping ST depressions in $V_1$-$V_3$ (RV strain pattern)
- Tall R wave in $V_1$
Right Ventricular Hypertrophy
Q Wave

- Normal (physiologic) or due to pathology (pathologic).
- Depth and width are determining criteria
  - Q wave >0.04 (40 ms) wide is considered a significant finding (pathologic)
Initial deflection: Is there a Q wave?

- The earliest part of the left ventricle to depolarize is the septum which depolarizes from left to right.

- This will lead to a small upright deflection in $V_1-V_2$ and a small negative deflection in the left leads I, aVL, and $(V_4-V_6)$ as well as sometimes in the inferior leads.

- These normal Q waves are narrow (< 0.04 seconds) and usually not deep and are known as septal Q's.
Q waves of Myocardial Infarction

- “Pathologic” Q waves are considered the hallmark of myocardial infarction
- Q must be >.04 seconds in width and/or more than 25% of the height of the R wave in the same lead
- aVR doesn’t count
- Q in III alone doesn’t count
Q Waves of Inferior MI
Q Waves of Anterior MI
Antero-Lateral MI
The QRS complex should be dominantly upright in leads I and II
QRS and T waves tend to have the same general direction in the limb leads
Rule 5

All waves are negative in lead aVR
The R wave in the precordial leads must grow from V1 to at least V4
There should be no Q wave or only a small q less than 0.04 seconds in width in I, II, V2 to V6
The ST segment
ST segment

From the end of QRS (J point) to beginning of T wave.

Isoelectric
ST Segment

• The ST segment is normally level with the T-P segment rather than the PR segment

• Examine every lead for ST segment elevation of 1 mm or more.
The ST segment should start isoelectric except in V1 and V2 where it may be elevated.
Differential Diagnosis of ST Segment Elevation

1- Normal Variant "Early Repolarization" (usually concave upwards, ending with symmetrical, large, upright T waves)

2- Ischemic Heart Disease (usually convex upwards, or straightened)  Acute transmural injury - as in this acute anterior MI

3- Persistent ST elevation after acute MI suggests ventricular aneurysm

4- ST elevation may also be seen as a manifestation of Prinzmetal's (variant) angina (coronary artery spasm)

5- ST elevation during exercise testing suggests extremely tight coronary artery stenosis or spasm (transmural ischemia)
Differential Diagnosis of ST Segment Elevation

6-Acute Pericarditis

# Concave upwards ST elevation in most leads except aVR

# No reciprocal ST segment depression (except in aVR)

# Unlike "early repolarization", T waves are usually low amplitude, and heart rate is usually increased.

# May see PR segment depression, a manifestation of atrial injury
Pericarditis
Ventricle aneurysm
ST depression

- >2mm usually indicates ischemia
- Common in normal ECG, especially in pregnancy
- But:
  - Non specific not more than 2mm below baseline
  - It is convex downward or slopes upwards from the S wave
Differential Diagnosis of ST Segment Depression

1- Normal variants or artifacts: Pseudo-ST-depression (wandering baseline due to poor skin-electrode contact)

2- Physiologic J-junctional depression with sinus tachycardia (most likely due to atrial repolarization)

3- Hyperventilation-induced ST segment depression
Differential Diagnosis of ST Segment Depression

4-Ischemic heart disease
Subendocardial ischemia (exercise induced or during angina attack)

ST segment depression is often characterized as "horizontal", "upsloping", or "downsloping"

5-Non Q-wave MI
6- Reciprocal changes in acute Q-wave MI (e.g., ST depression in leads I & aVL with acute inferior MI)
Differential Diagnosis of ST Segment Depression

7-Nonischemic causes of ST depression

#RVH (right precordial leads) or LVH (left precordial leads, I, aVL)

# Digoxin effect on ECG

# Hypokalemia

#Mitral valve prolapse (some cases)

#Secondary ST segment changes with IV conduction abnormalities (e.g., RBBB, LBBB, WPW, etc)
Acute inferoposterior MI
(note tall R waves V1-3, marked ST depression V1-3, ST elevation in II, III, aVF)
The ECG signs of Infarct!

- Abnormal Q waves
- **ST segment elevation** (Greater than 1mm in 2 or more adjacent leads)
- Inverted T waves
ST Elevation - Myocardial Infarction

• ST elevation in two or more leads
  – Must be at least 1mm in limb leads
  – Must be at least 2mm in chest leads
Evolution of Acute MI
Antero-Lateral MI
Old inferoposterior MI (note tall R in V1-3, upright T waves and inferior Q waves)
T wave
T wave

- T waves are normally upright in most leads but are always negative in aVR and often negative in leads III and V₁
- The T wave axis should be similar to the QRS axis
- T waves should be symmetrical
- Abnormal T waves can be caused by ischemia or infarction, hypertrophy, abnormal conduction patterns, drugs, metabolic changes, CNS events, etc.
The T wave must be upright in I, II, V2 to V6
T wave: tall T waves (more than 2 big squares)

- Hyperkalaemia
- Hyperacute myocardial infarction
- Left bundle branch block (LBBB)
T waves: small, flattened or inverted

- Ischemia
- age, race
- hyperventilation, anxiety, drinking iced water
- LVH
- drugs (e.g. digoxin)
- pericarditis, PE
- intraventricular conduction delay (e.g. RBBB)
- electrolyte disturbance
Evolution of Acute MI
**Right Bundle Branch Block**

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Abnormal T waves

- Inverted or flat where they should be upright
- Often asymmetric
- Often associated with abnormal ST segments (ST/T changes)
QT Interval
QT interval

- measured from beginning of QRS to end of T wave
- QT Interval ($QT_c < 0.40$ sec) upper limit for $QT_c = 0.44$ sec

1- Bazett's Formula: $QT_c = (QT)/\sqrt{RR}$ (in seconds)
2- Poor Man's Guide to upper limits of QT: For HR = 70 bpm, $QT \leq 0.40$ sec; for every 10 bpm increase above 70 subtract 0.02 sec, and for every 10 bpm decrease below 70 add 0.02 sec. For example: $QT \leq 0.38$ @ 80 bpm

$QT \leq 0.42$ @ 60 bpm
QTc = \frac{QT}{\sqrt{RR}} = \frac{0.71}{\sqrt{1.11}} = 0.67 \text{ seconds}
• Prolonged QT:
  A. Familial long QT Syndrome (LQTS)
  B. Congestive Heart Failure
  C. Myocardial Infarction
  D. Hypocalcemia & Hypokalaemia
  E. Hypomagnesemia
  F. Type I Antiarrhythmic drugs & Cispride
  G. Rheumatic Fever
  H. Myocarditis
  I. Congenital Heart Disease

• Short QT:
  A. Digoxin (Digitalis)
  B. Hypercalcemia
  C. Hyperkalemia
U wave
The U wave is the only remaining enigma of the ECG, and probably not for long. The origin of the U wave is still in question, although most authorities correlate the U wave with electrophysiologic events called "afterdepolarizations" in the ventricles. The normal U wave has the same polarity as the T wave and is usually less than one-third the amplitude of the T wave. U waves are usually best seen in the right precordial leads especially V2 and V3. The normal U wave is asymmetric with the ascending limb moving more rapidly than the descending limb (just the opposite of the normal T wave).
Prominent upright U waves

1- Sinus bradycardia accentuates the U wave

2- Hypokalemia (remember the triad of ST segment depression, low amplitude T waves, and prominent U waves)

3- Quinidine and other type 1A antiarrhythmics
Negative or "inverted" U waves

1- Ischemic heart disease (often indicating left main or LAD disease)  Myocardial infarction (in leads with pathologic Q waves)

2-During episode of acute ischemia (angina or exercise-induced ischemia)

3- During coronary artery spasm (Prinzmetal's angina)

4- Nonischemic causes  Some cases of LVH or RVH (usually in leads with prominent R waves)
Thanks