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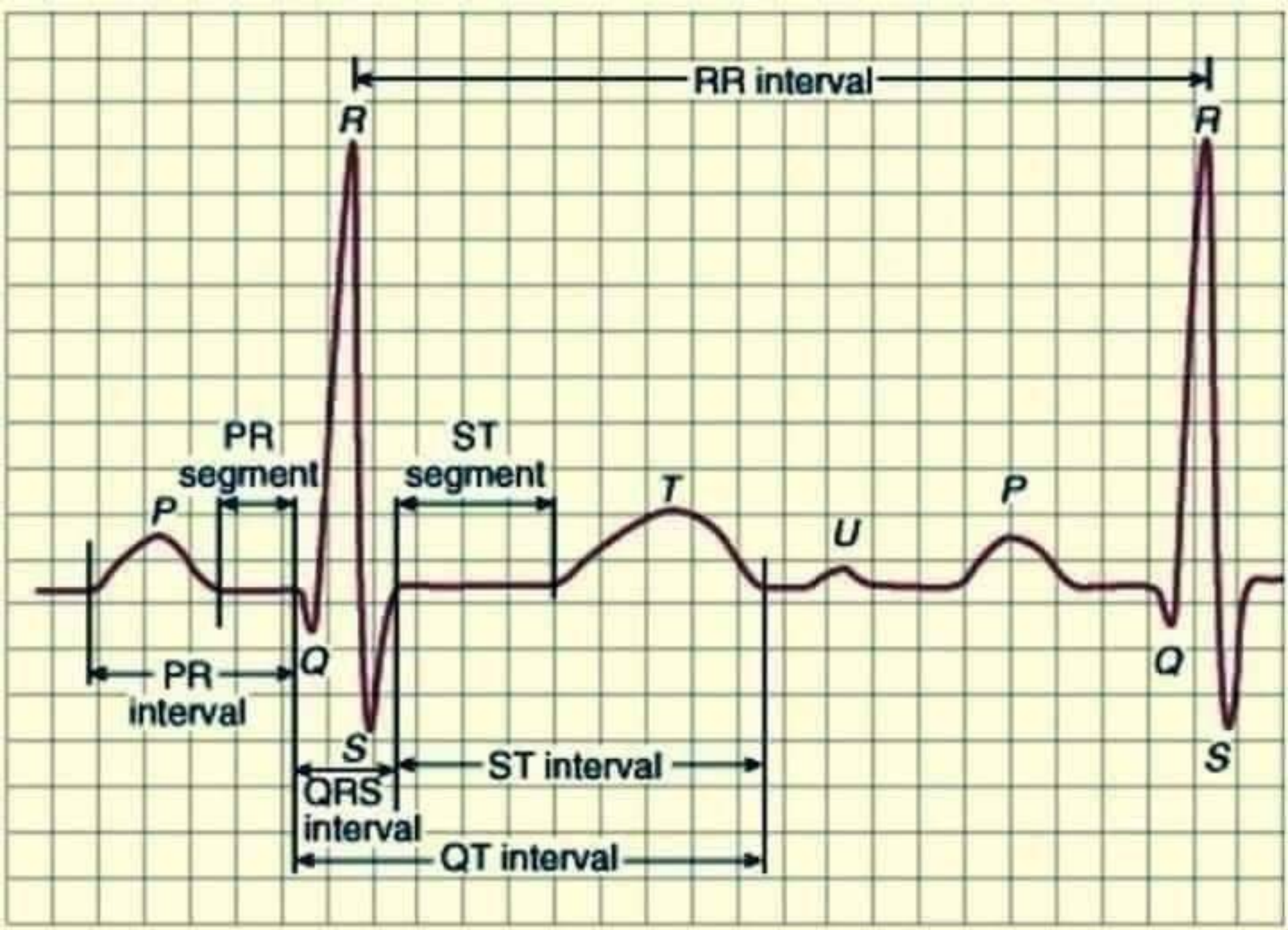
The Complete Guide to ECGs

A Comprehensive Study Guide to Improve ECG Interpretation Skills

Third Edition



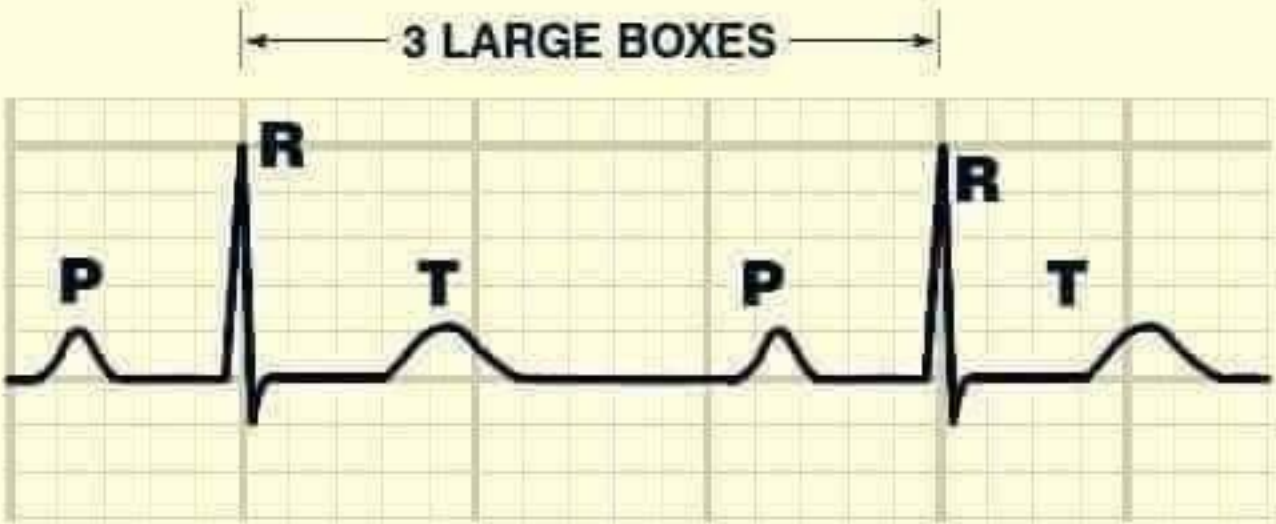
mm/mV 1 square = 0.04 sec/0.1mV

1. Heart Rate

The following method can be used to determine heart rate (assumes a standard paper speed of 25 mm/sec)

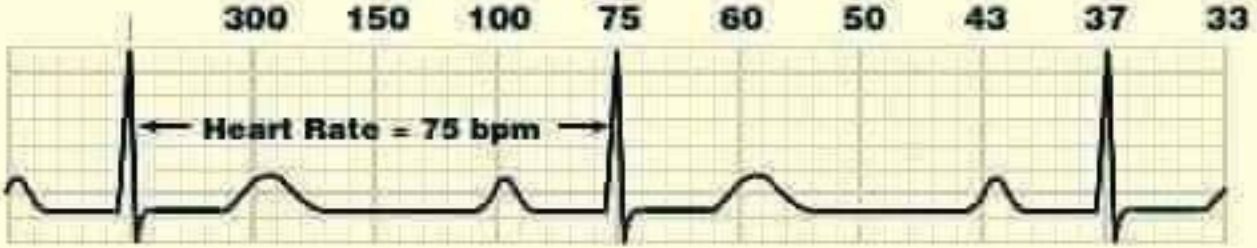
Regular Rhythm

- Count the number of large boxes between P waves (atrial rate), R waves (ventricular rate), or pacer spikes (pacemaker rate)
- Beats per minute = 300 divided by the number of large boxes

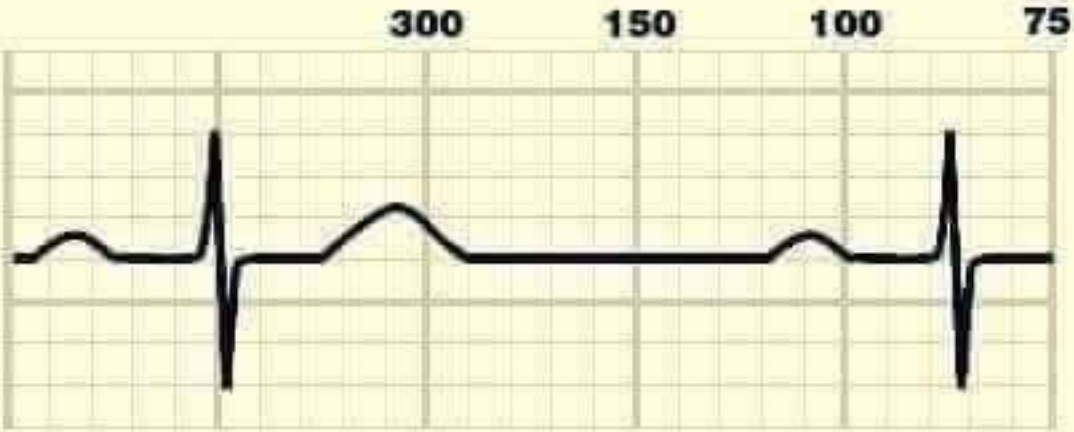


Heart Rate = 300 ∏no. large boxes between "R" Waves = 300 ∏3 = 100 bpm

Note: It is easier to memorize the heart rates associated with each of the large boxes, rather than count the number of large boxes (1 ,2, 3, etc) and divide into 300:



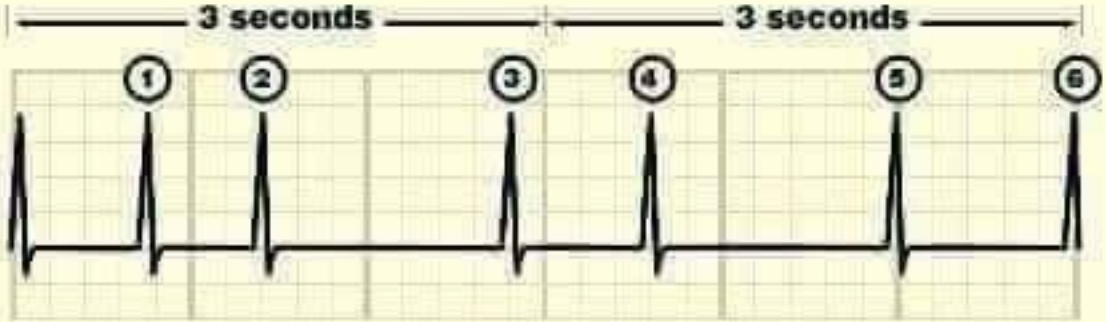
Note: If the number of large boxes is not a whole number, either estimate the rate (this is routine practice) or divide 1500 by the number of small boxes between P waves (atrial rate), R waves (ventricular rate), or pacer spikes (pacemaker rate):



ESTIMATED Heart Rate = halfway between 100 and 75 = ~ 87 bpm (or 1500 ÷ 17.5 small boxes)

Slow or Irregular Rhythm

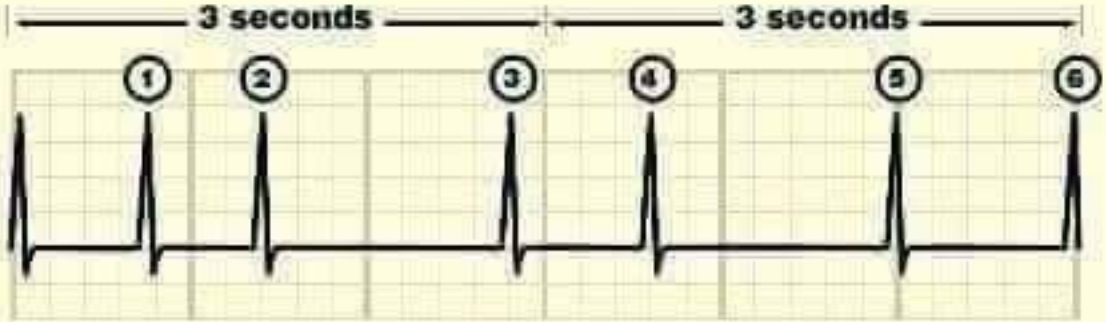
- Identify the 3-second markers at top or bottom of ECG tracing
- Count the number of QRS complexes (or P waves or pacer spikes) that appear in 6 seconds (i.e., two consecutive 3-second markers)
- Multiply by 10 to obtain rate in BPM



ESTIMATED Heart Rate = number of QRS complexes in 6 seconds x 10 = 6 x 10 = 60 bpm

Slow or Irregular Rhythm

- Identify the 3-second markers at top or bottom of ECG tracing
- Count the number of QRS complexes (or P waves or pacer spikes) that appear in 6 seconds (i.e., two consecutive 3-second markers)
- Multiply by 10 to obtain rate in BPM



ESTIMATED Heart Rate = number of QRS complexes in 6 seconds x 10 = 6 x 10 = 60 bpm

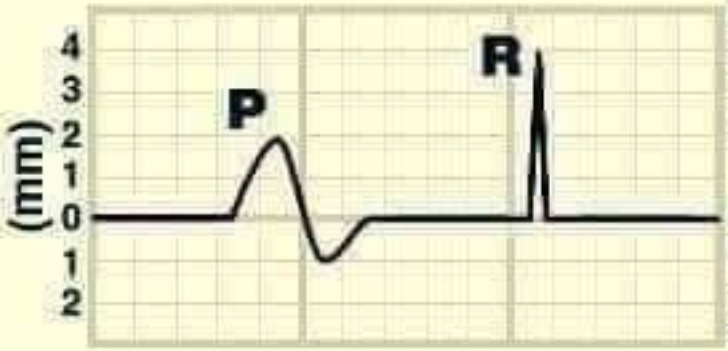
2. P Wave

What It Represents

The P wave represents electrical forces generated from atrial activation. The first and second halves of the P wave roughly correspond to right and left atrial activation, respectively.

What to Measure

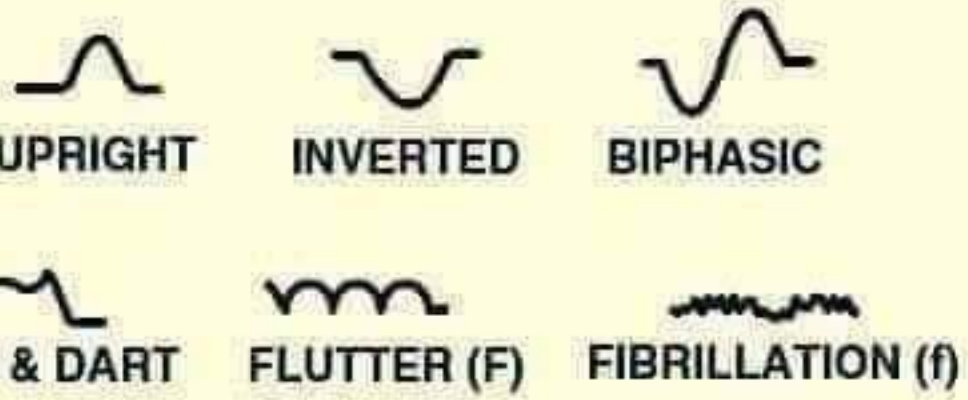
- Duration (seconds): Measured from the beginning of the P wave to the end of P wave.
- Amplitude (mm): Measured from baseline to top (or bottom) of P wave. Positive and negative deflections are determined separately. One small box = 1 mm on standard scale ECGs (i.e., 10 mm = 1 mV)



UPWARD DEFLECTION
Duration = 1.5 small boxes
= 1.5 x 0.04 sec. = 0.06 sec.
Amplitude = 2 mm

DOWNWARD DEFLECTION
Duration = 1.5 small boxes
= 1.5 x 0.04 sec. = 0.06 sec.
Amplitude = 1 mm

- Morphology:



P Wave Characteristics

- Normal P wave duration: 0.08-0.11 seconds
- Normal P wave axis: 0-75°
- Normal P wave morphology: Upright in I, II, aVF; upright or biphasic in III, aVL, V_1, V_2. Small notching may be present
- Normal P wave amplitude: Limb leads: < 2.5 mm; V_1: positive deflection < 1.5 mm and negative deflection < 1 mm

3. Origin of the Rhythm

Rhythm identification is one of the most difficult and complex aspects of ECG interpretation, and one of the most common mistakes made by computer ECG interpretation programs. Proper rhythm interpretation requires integration of heart rate, RR regularity, P wave morphology, PR interval, QRS width, and the P:QRS relationship. No single algorithm can simply describe all the various permutations; however the following rhythm-recognition tables, based initially on the P:QRS relationship and heart rate, provide a useful frame of reference:

— P:QRS Relationships —

P:QRS < 1: Junctional or ventricular premature complexes or rhythms (escape, accelerated, tachycardia)

P:QRS = 1

- **P wave preceeds QRS**: Sinus rhythm; ectopic atrial rhythm; multifocal atrial tachycardia; wandering atrial pacemaker; SVT (sinus node reentry tachycardia, automatic atrial tachycardia); sinoatrial exit block, 2°; conducted APCs with any of the above
- **P wave follows QRS**; SVT (AV nodal reentry tachycardia, orthodromic SVT); junctional / ventricular rhythm with 1:1 retrograde atrial activation

No P Waves: Atrial fibrillation; atrial flutter; sinus arrest with junctional or ventricular escape rhythm; SVT (AV nodal reentry tachycardia, AV reentry tachycardia), junctional tachycardia or VT with P wave buried in QRS; VF

— Heart Rate < 100 BPM —

Narrow QRS (< 0.12 sec) - Regular R-R

- Sinus P; rate 60-100: *Sinus rhythm*
- Sinus P; rate < 60: *Sinus bradycardia*
- Nonsinus P; PR ≥ 0.12: *Ectopic atrial rhythm*
- Nonsinus P; PR < 0.12: *Junctional or low atrial rhythm*
- Sawtooth flutter waves: *Atrial flutter, usually with 4:1 AV block*
- No P; rate < 60: *Junctional rhythm*
- No P; rate 60-100: *Accelerated junctional rhythm*

Narrow QRS - Irregular R-R

- Sinus P, P-P varying > 0.16 seconds: *Sinus arrhythmia*
- Sinus and nonsinus P: *Wandering atrial pacemaker*
- *Any regular rhythm with 2°/ 3° AV block or premature beats*
- Fine or coarse baseline oscillations: *Atrial fibrillation with slow ventricular response*
- Sawtooth flutter waves: *Atrial flutter, usually with variable AV block*
- P:QRS ratio > 1: *2° or 3° AV block or blocked APCs*
- P:QRS ratio < 1: *Junctional or ventricular premature beats or escape rhythm*

Wide QRS (≥ 0.12 seconds)

- Sinus or nonsinus P: *Any supraventricular rhythm with a preexisting IVCD (e.g. bundle branch block) or aberrancy*

- No P†; rate < 60: Idioventricular rhythm
- No P†; rate 60-100: Accelerated idioventricular

† AV dissociation

— Heart Rate > 100 BPM —

Narrow QRS (< 0.12 sec) - Regular R-R

- Sinus P: *Sinus tachycardia*
- Flutter waves: *Atrial flutter*
- No P: *AV nodal reentrant tachycardia (AVNRT), junctional tachycardia*
- Short R-P (R-P < 50% of R-R interval): *AVNRT, orthodromic SVT (AVRT), atrial tachycardia with 1° AV block, junctional tachycardia with 1:1 retrograde atrial activation*
- Long R-P (R-P > 50% of R-R interval): *Atrial tachycardia, sinus node reentrant tachycardia, atypical AVNRT, orthodromic SVT with prolonged V-A conduction*

Narrow QRS - Irregular R-R

- Nonsinus P; > 3 morphologies: *Multifocal atrial tachycardia*
- Fine or coarse baseline oscillations: *Atrial fibrillation*
- Flutter waves: *Atrial flutter*
- *Any regular rhythm with 2°/3° AV block or premature beats*

Wide QRS (≥ 0.12 seconds)

- Sinus or nonsinus P: *Any regular or irregular supraventricular rhythm with a preexisting IVCD or aberrancy*
- No P; rate 100-110: *Accelerated idioventricular rhythm*
- No P, rate 110-250: *VT, SVT with aberrancy*
- Irregular, polymorphic, alternating polarity: *Torsade de Pointes*
- Chaotic irregular oscillations; no discrete QRS: *Ventricular fibrillation*

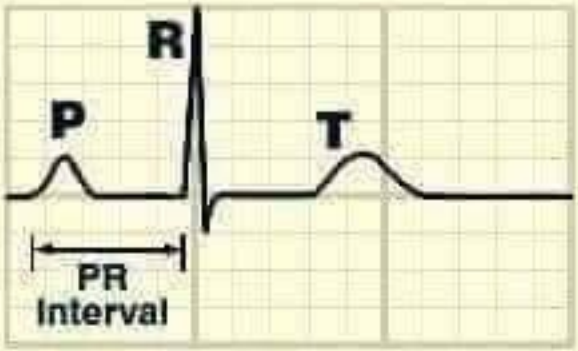
4. PR Interval & Segment

What it Represents

- PR interval represents conduction time from the onset of atrial depolarization to the onset of ventricular repolarization. It does not reflect conduction from the sinus node to the atrium.
- PR segment represents atrial repolarization.

How to Measure

- PR interval (seconds): From the beginning of the P wave to the first deflection of the QRS complex. Measure longest PR seen.



PR INTERVAL = 4 small boxes = 4 x 0.04 = 0.16 sec.

3. Origin of the Rhythm

Rhythm identification is one of the most difficult and complex aspects of ECG interpretation, and one of the most common mistakes made by computer ECG interpretation programs. Proper rhythm interpretation requires integration of heart rate, RR regularity, P wave morphology, PR interval, QRS width, and the P:QRS relationship. No single algorithm can simply describe all the various permutations; however the following rhythm-recognition tables, based initially on the P:QRS relationship and heart rate, provide a useful frame of reference:

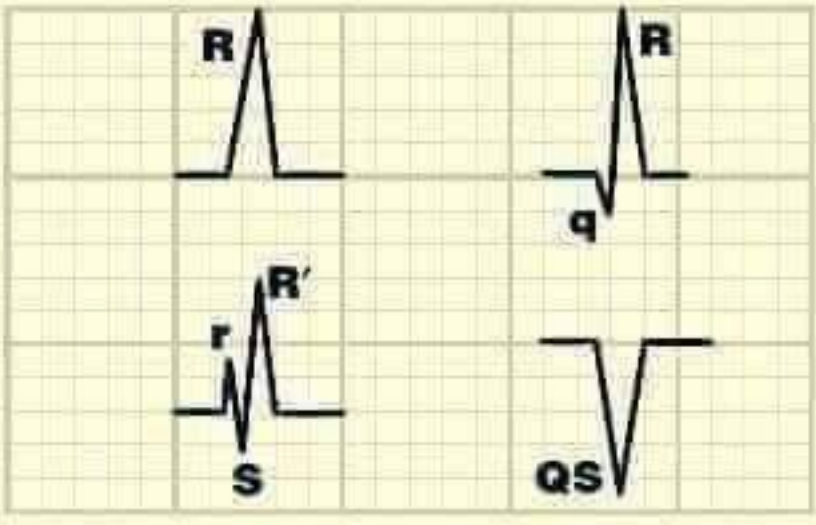
5. QRS Duration

What it Represents

Duration of ventricular activation

How to Measure

In seconds, from the beginning to the end of the QRS (or QS) complex



QRS duration = 1.5 small boxes = 0.06 sec.

Definitions

- Normal QRS duration: < 0.10 seconds
- Increased QRS duration: ≥ 0.10 seconds

  Note: For the purposes of establishing a differential diagnosis, it is often useful to distinguish moderate prolongation of the QRS (0.10 to ≤ 0.12 seconds) from marked prolongation of the QRS (> 0.12 seconds)

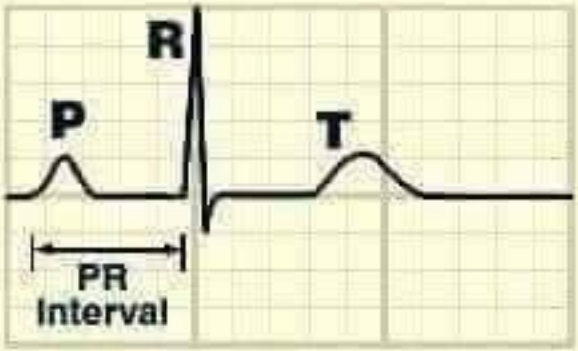
4. PR Interval & Segment

What it Represents

- PR interval represents conduction time from the onset of atrial depolarization to the onset of ventricular repolarization. It does not reflect conduction from the sinus node to the atrium.
- PR segment represents atrial repolarization.

How to Measure

- PR interval (seconds): From the beginning of the P wave to the first deflection of the QRS complex. Measure longest PR seen.



PR INTERVAL = 4 small boxes = 4 x 0.04 = 0.16 sec.

- Corrected QT interval (QTc): Since the normal QT interval varies inversely with heart rate, the QTc, which corrects for heart rate, is usually determined
  - QTc (sec) = QT interval (sec) divided by the square root of the preceding RR interval (sec). **Example**: For heart rate of 50 BPM, RR interval = 1.2 seconds, and QTc = QT ÷ square root of 1.2 = QT ÷ 1.1
  - Alternative method: Use 0.40 seconds as the normal QT interval for a heart rate of 70 BPM. For every 10 BPM change in heart rate above (or below) 70, subtract (or add) 0.02 seconds. The measured value should be within ± 0.04 seconds of the calculated normal. **Example**: For a heart rate of 100 BPM, the calculated "normal" QT interval = 0.40 seconds — (3 x 0.02 seconds) = 0.34 ± 0.04 seconds. For a heart rate of 50 BPM, the calculated "normal" QT interval = 0.40 seconds + (2 x 0.02 seconds) = 0.44 ± 0.04 seconds.

Definitions

- Normal QTc: 0.35-0.43 seconds for heart rates of 60-100 BPM. The normal QT should be < 50% of the RR interval
- Prolonged QTc: ≥ 0.44 seconds
- Short QTc: < 0.35 seconds for heart rates of 60-100 BPM

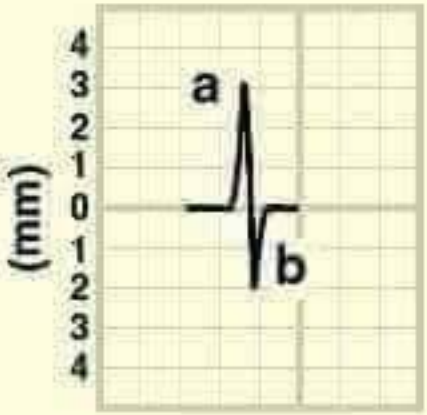
7. QRS Axis

What It Represents

The major vector of ventricular activation

How to Determine

- Determine if "net QRS voltage" (upward minus downward QRS deflection) is positive (> 0) or negative (< 0) in leads I, II, aVF:



NET QRS VOLTAGE =
upward – downward deflection (mm)
= a – b = 3 – 2 = 1 (positive)

- Determine axis category according to the chart below:

Axis	Net QRS Voltage		
	Lead I	aVF	Lead II
Normal axis (0° to 90°)	+	+	
Normal variant (0° to -30°)	+	-	+
Left axis deviation (-30° to -90°)	+	-	-
Right axis deviation (> 100°)	-	+	
Right superior axis (-90° to +180°)	-	-	

"+" represents positive (> 0) net QRS voltage
"–" represents negative (< 0) net QRS voltage

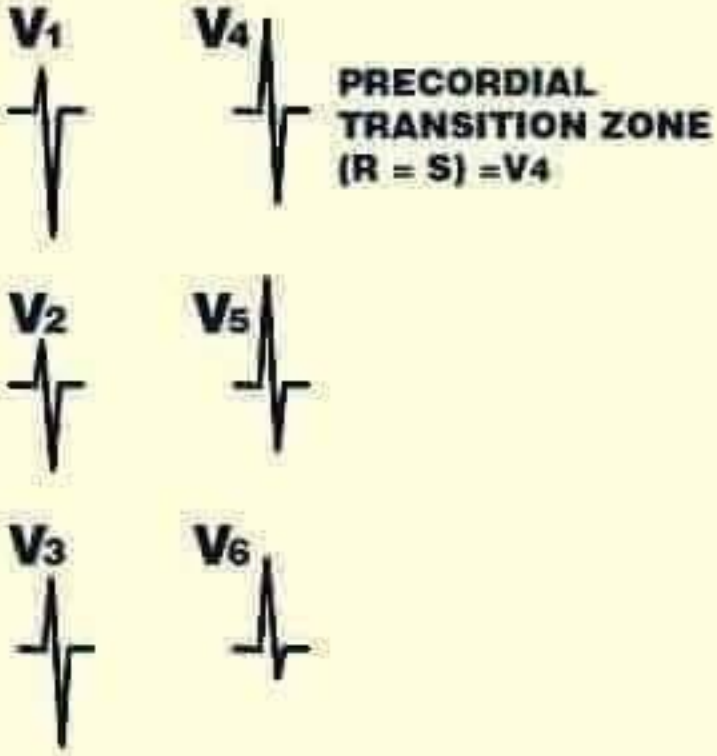
Definitions

- Normal voltage: Amplitude of the QRS has a wide range of normal limits, depending on the lead, age of the individual, and other factors
- Low voltage (from peak of R wave to peak of S wave): Total QRS amplitude (R + S) < 5 mm in all limb leads and < 10 mm in all precordial leads
- Increased voltage: See LVH (item 40, Section 4) and RVH (item 41, Section 4)

9. R Wave Progression

How to Identify

Determine the *precordial transition zone*, i.e., the lead with equal R and S wave voltage (R/S = 1)



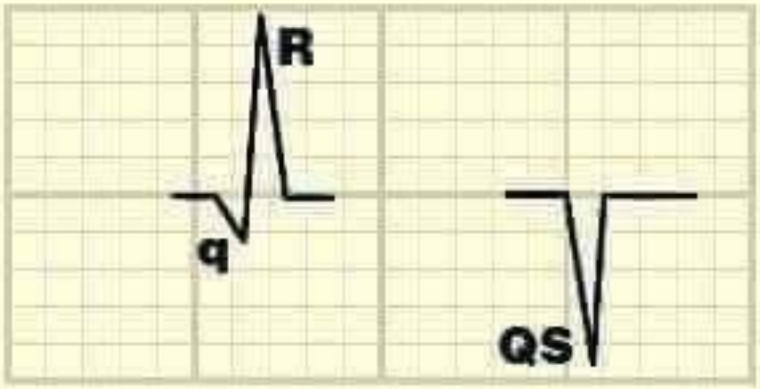
Definitions

- Normal R wave progression: Transition zone = V_2-V_4, with increasing R wave amplitude across the precordial leads. (Exception: R wave in V_5 often exceeds R wave in V_6.)
- Poor R wave progression: Transition zone = V_5 or V_6
- Reverse R wave progression: Decreasing R wave amplitude across the precordial leads

deflection, that defection is considered a Q wave, but the complex is referred to as a "QS" complex

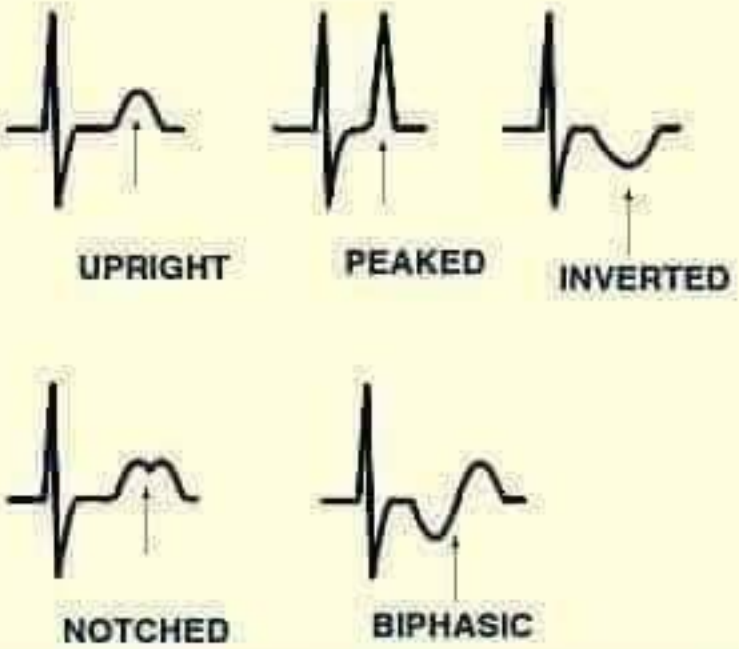
What to Measure

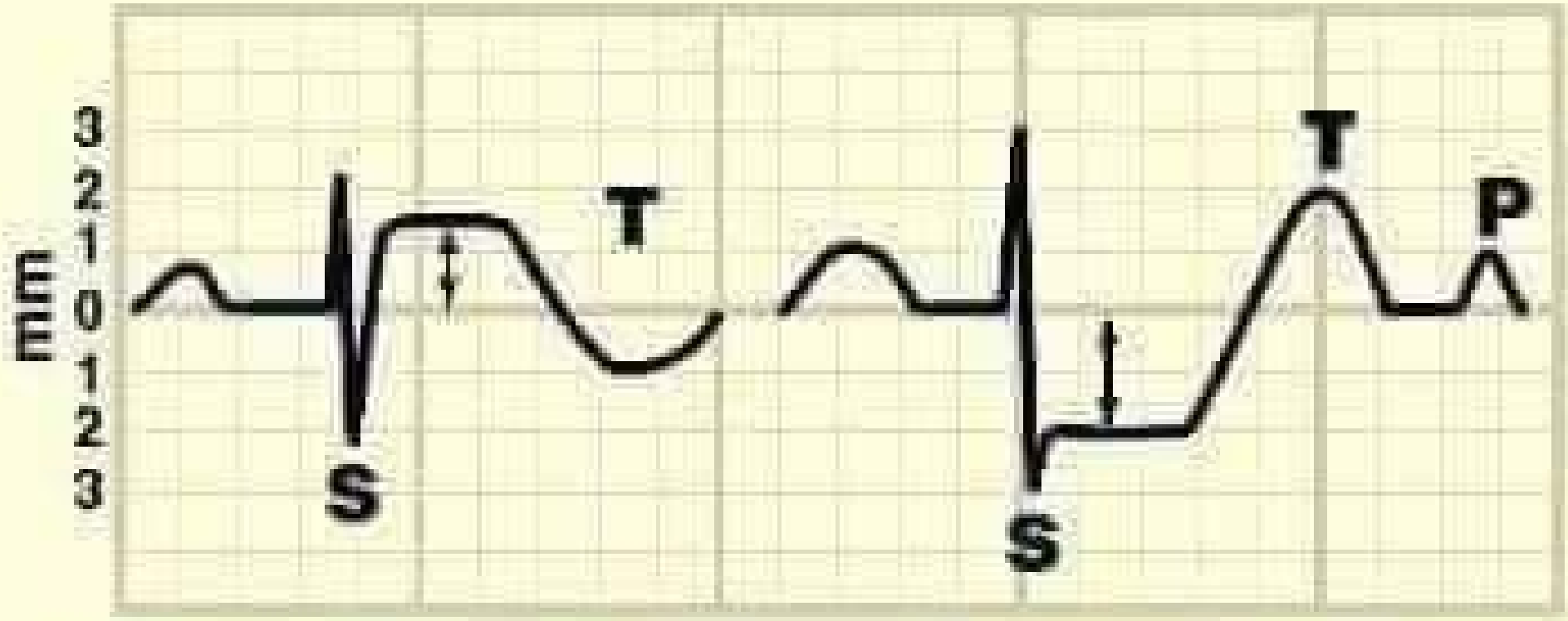
Duration, in seconds, from the beginning to the end (i.e., when it returns to baseline) of the Q wave. When the QRS complex consists solely of a Q wave, a "QS" designation is used



Q wave duration = 1 small box = 0.04 seconds

- Morphology:





ST elevation = 1.5 mm

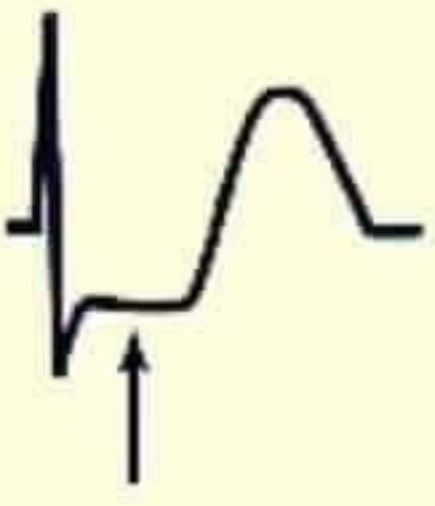
ST depression = 2 mm

ST ELEVATION:

Concave Upward

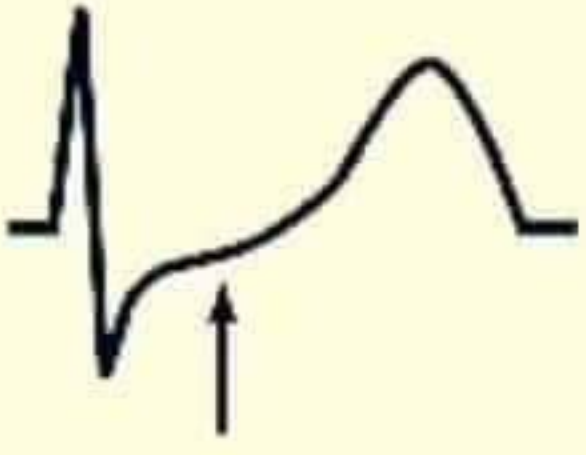
Convex Upward

ST DEPRESSION:



Horizontal

Downsloping



Upsloping

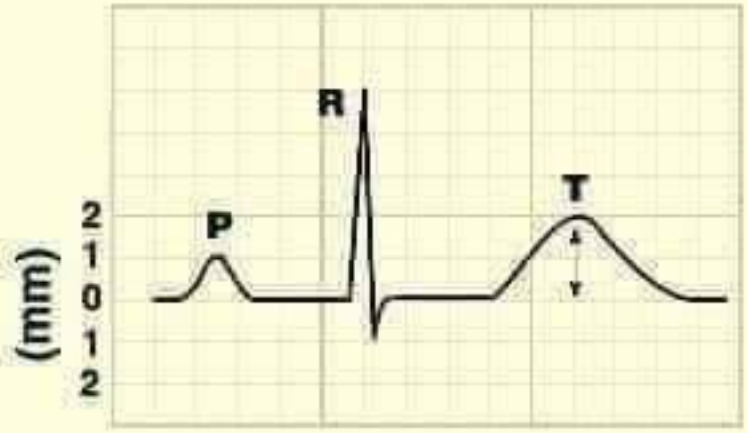
12. T Wave

What it Represents

The electrical forces generated from ventricular repolarization

What to Identify

- Amplitude: In millimeters, from baseline to peak or valley of the T wave:



T wave amplitude = 2 mm

- Morphology: