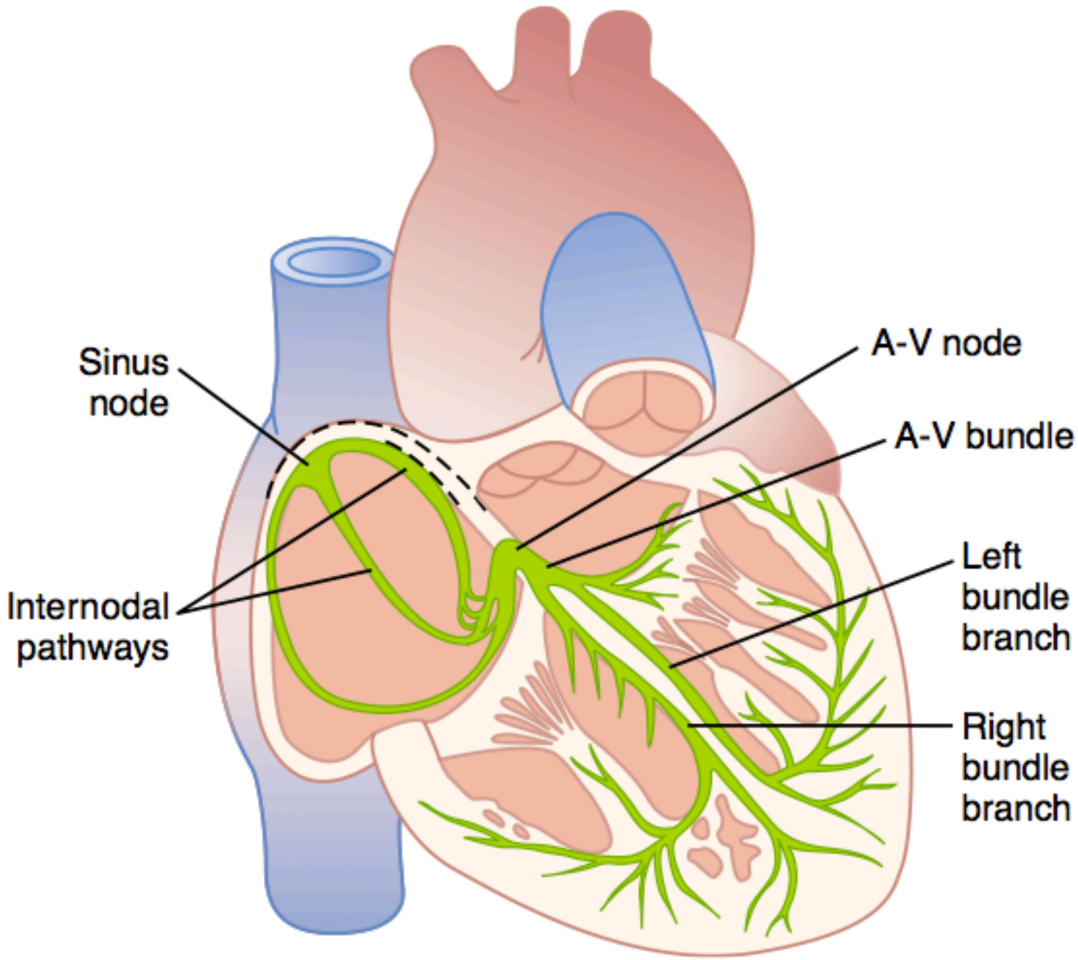
Excitation of the Heart
Chapter 10

Excitatory and Conductive System of The Heart



sinoatrial or S-A node: normal rhythmical impulse is generated

internodal pathways : conduct the impulse from the sinus node to the atrioventricular (A-V) node

A-V node: the impulse from the atria is delayed before passing into the ventricles

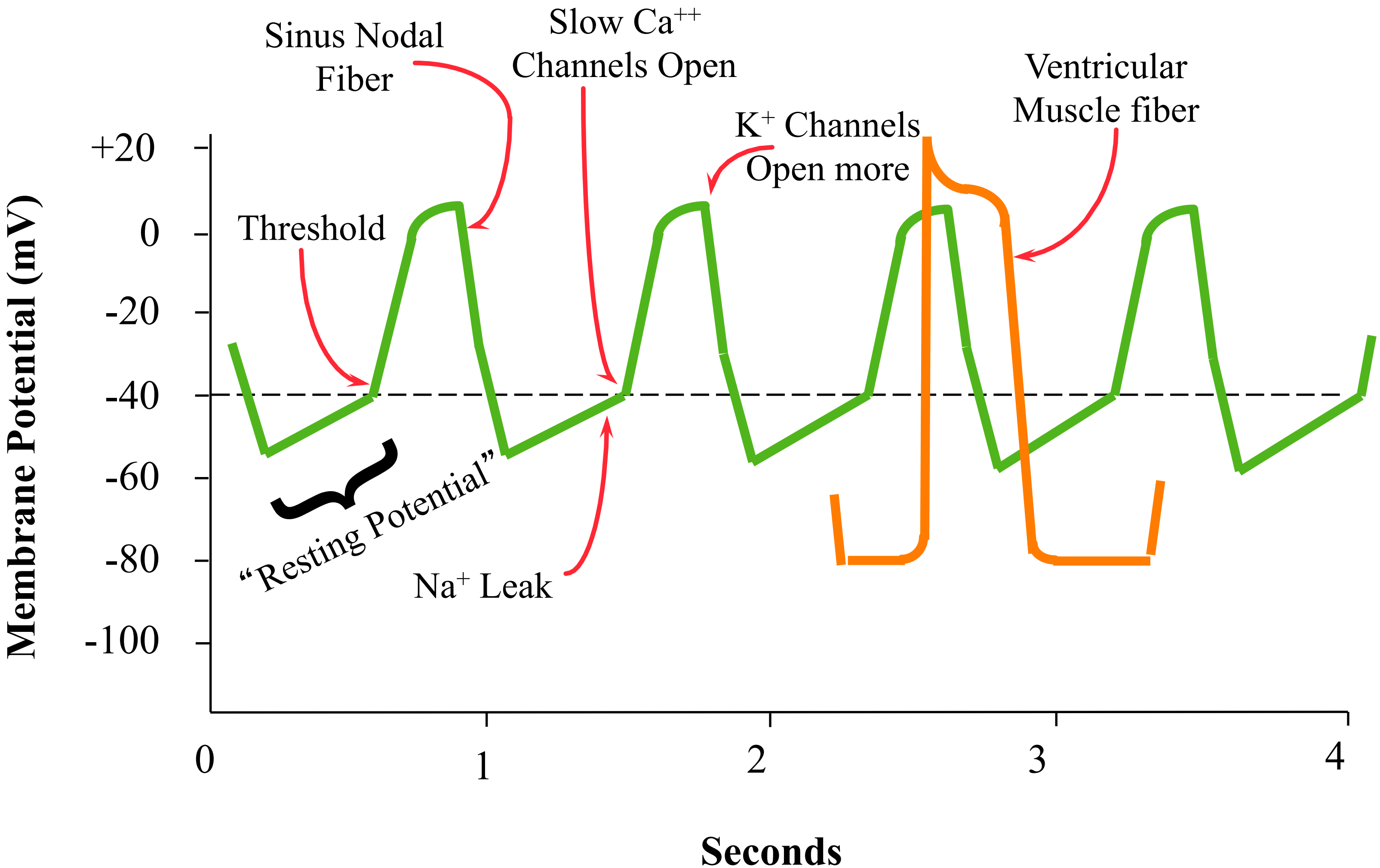
the A-V bundle (His bundle): conducts the impulse from the atria into the ventricles

the left and right bundle branche of Purkinje fibers : conduct the cardiac impulse to all parts of the ventricles

Figure 10–1
Sinus node, and the Purkinje system of the heart, showing also the A-V node, atrial internodal pathways, and ventricular bundle branches.

the sinus node ordinarily controls the rate of beat of the entire heart

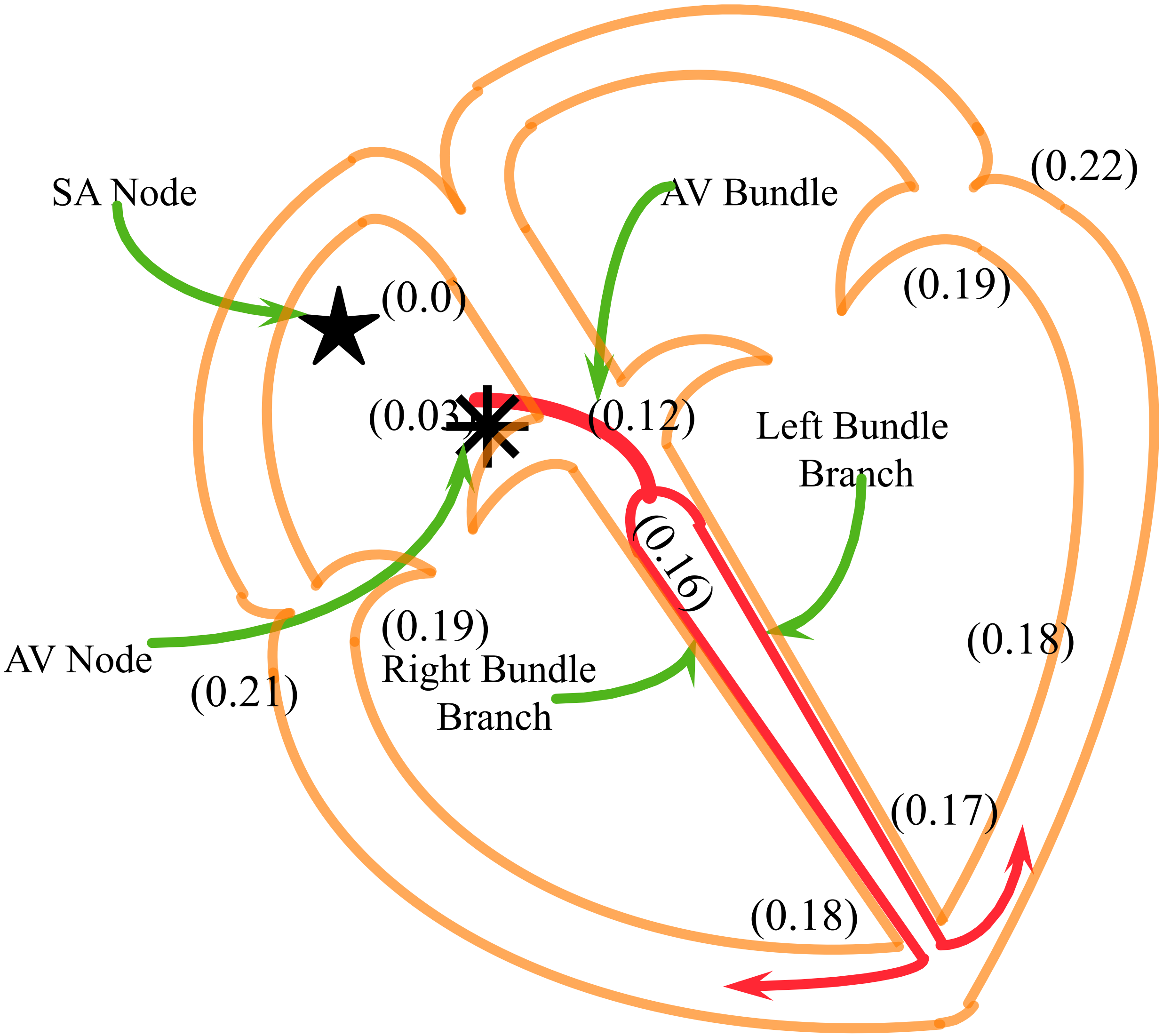
▪ Rhythmical Discharge of Sinus Nodal Fiber



- “resting membrane potential” of the sinus nodal fiber between discharges has a negativity of about -55 to -60 millivolts, in comparison with -85 to -90 millivolts for the ventricular muscle fiber.

- The cause of this lesser negativity is that the cell membranes of the sinus fibers are naturally leaky to sodium and calcium ions, and positive charges of the entering sodium and calcium ions neutralize much of the intracellular negativity.

▪ Time of Arrival of Cardiac Impulse



Note that the impulse spreads at moderate velocity through the atria but is delayed more than 0.1 second in the A-V nodal region before appearing in the ventricular septal A-V bundle. Once it has entered this bundle, it spreads very rapidly through the Purkinje fibers to the entire endocardial surfaces of the ventricles. Then the impulse once again spreads slightly less rapidly through the ventricular muscle to the epicardial surfaces.

Main Arrival Times	
S-A Node	0.00 sec
A-V Node	0.03 sec
A-V Bundle	0.12 sec
Ventricular Septum	0.16 sec

- Sinus Node is Cardiac Pacemaker

  - Normal rate of discharge in sinus node is 70-80/min.; A-V node - 40-60/min.; Purkinje fibers - 15-40/min.
  - Sinus node is pacemaker because of its faster discharge rate

Ectopic Pacemaker

- A pacemaker elsewhere than the sinus node is called an “ectopic” pacemaker.

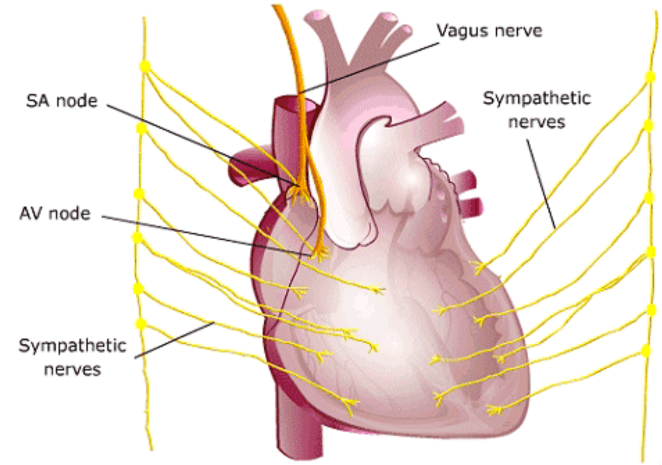
- This is a portion of the heart with a more rapid discharge than the sinus node.

- Also occurs when transmission from sinus node to A-V node is blocked (A-V block).

    - For instance, this sometimes occurs in the A-V node or in the Purkinje fibers.

▪ Control of Heart Rhythmicity and Impulse Conduction by the Cardiac Nerves: The Sympathetic and Parasympathetic Nerves

➢ Parasympathetic Effects on Heart Rate



- Parasympathetic (vagal) nerves, which release acetylcholine at their endings, innervate S-A node and A-V junctional fibers proximal to A-V node.
- Causes hyperpolarization because of increased K^+ permeability in response to acetylcholine.
- This causes decreased transmission of impulses maybe temporarily stopping heart rate.

Sympathetic Effects on Heart Rate

- Releases norepinephrine at sympathetic ending
- Causes increased sinus node discharge
- Increases rate of conduction of impulse
- Increases force of contraction in atria and ventricles

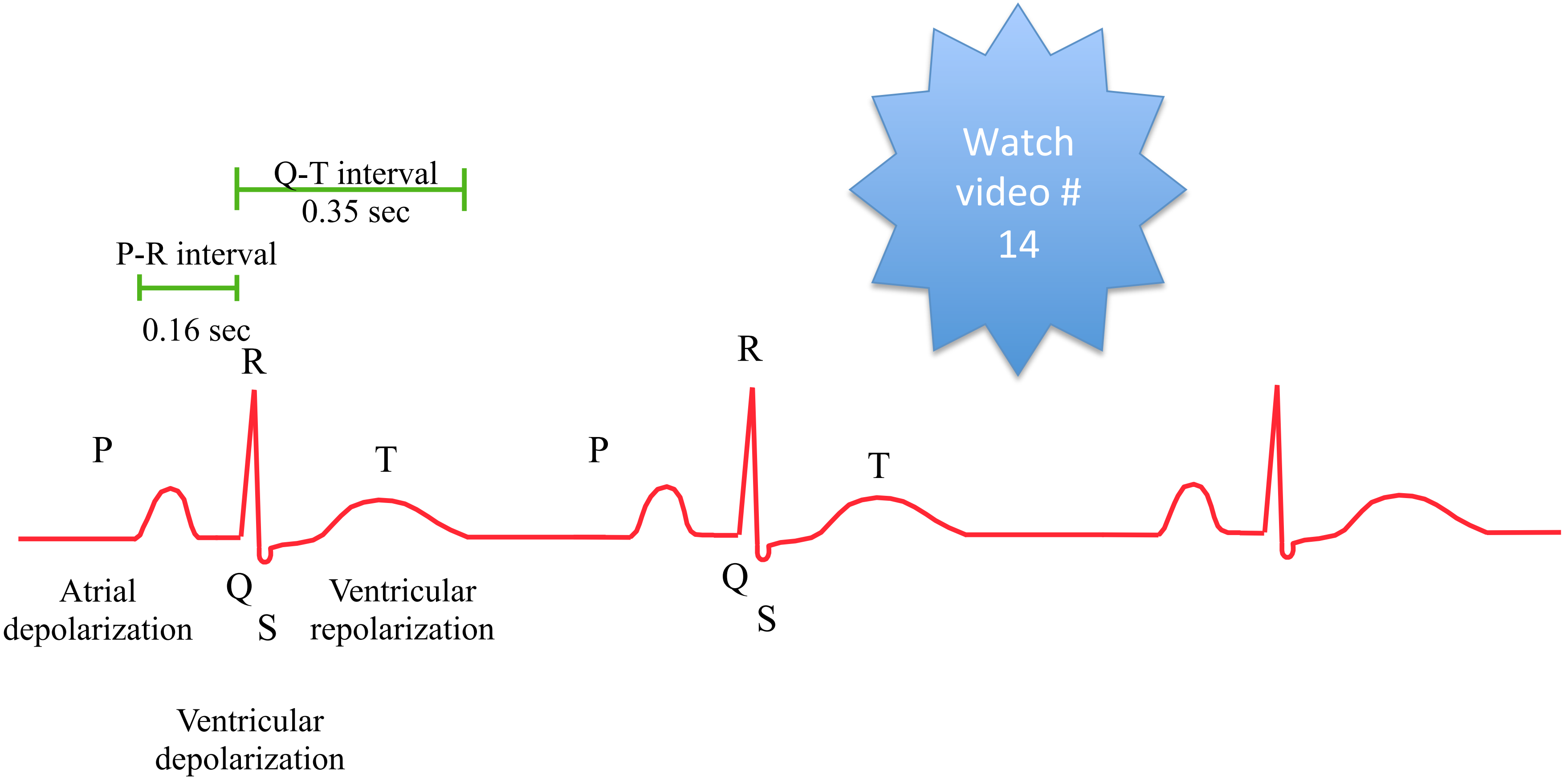
- Electrocardiogram (ECG)
- Cardiac Cycle

(chapter 11)

Characteristics of the Normal Electrocardiogram

▪ Normal ECG

- When the cardiac impulse passes through the heart, electrical current also spreads from the heart into the adjacent tissues surrounding the heart. If electrodes are placed on the skin, electrical potentials generated by the current can be recorded; the recording is known as an electrocardiogram.



- **Standardized ECGs**

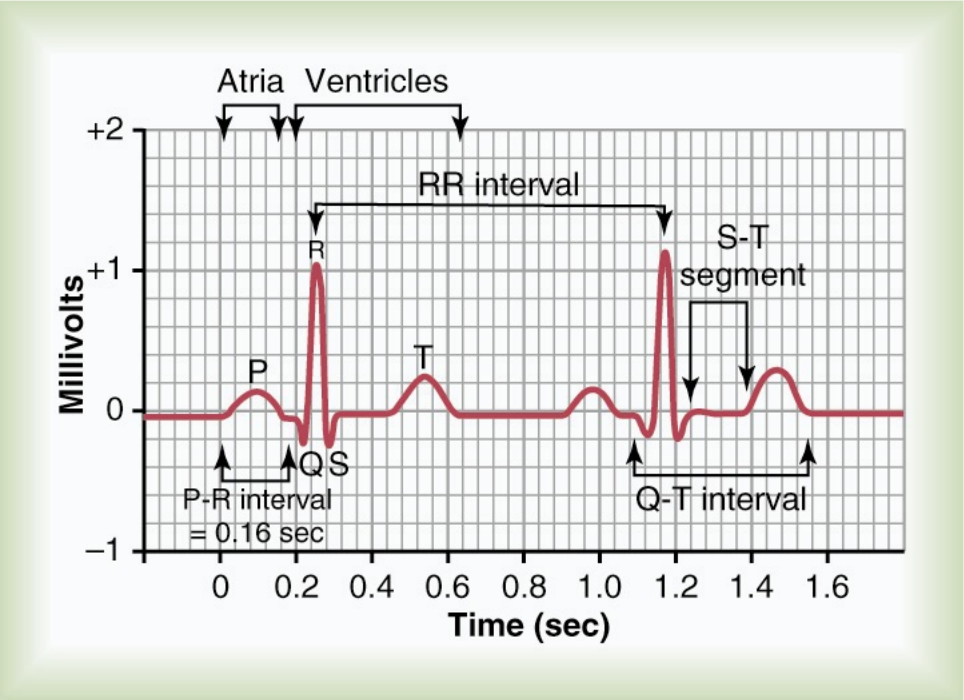


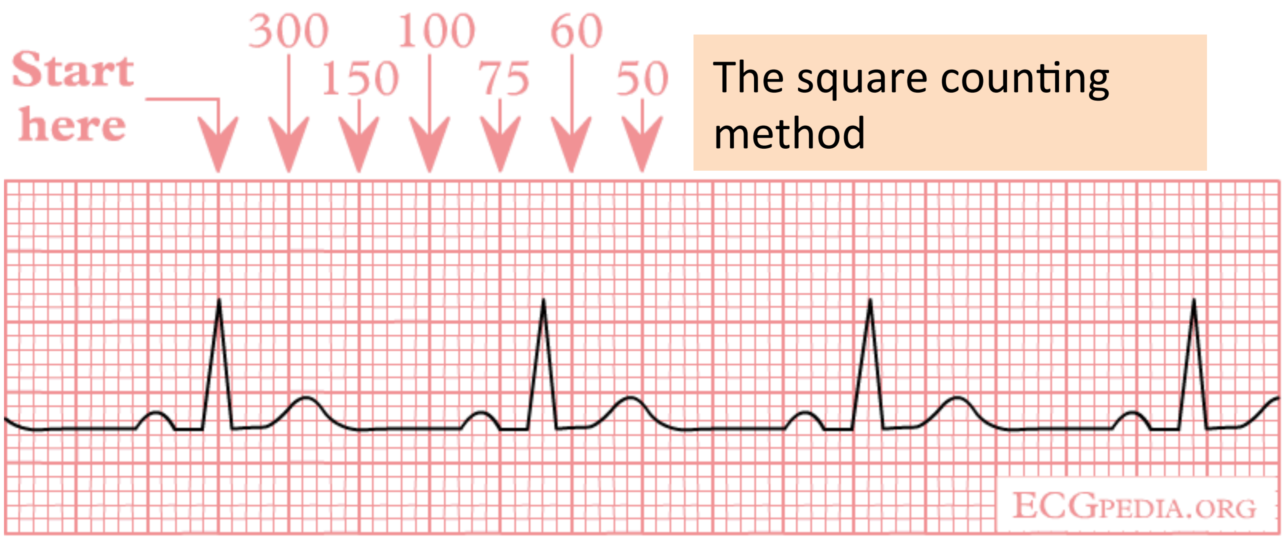
Figure 11-1; Guyton & Hall

- Time and voltage calibrations are standardized as shown on figure 11-1.

Heart Rate Calculation

- The rate of heartbeat can be determined easily from an electrocardiogram because the heart rate is the reciprocal of the time interval between two successive heartbeats. If the interval between two beats as determined from the time calibration lines is 1 second, the heart rate is 60 beats per minute. The normal interval between two successive QRS complexes in the adult person is about 0.83 second. This is a heart rate of 60/0.83 times per minute, or 72 beats per minute.

- R-R interval = 0.83 sec
- Heart rate = $(\underline{60\ \text{sec}}) / (\underline{0.83\ \text{sec}})$ = 72 beats/min



The square counting method

The count method to determine the heart frequency. The second QRS complex is between 75 and 60 beat per minute. This heartbeat is between that, around 65 beats per minute.

Flow of Current Around the Heart During the Cardiac Cycle

- **Recording Electrical Potentials from a Partially Depolarized Mass of Syncytial Cardiac Muscle**

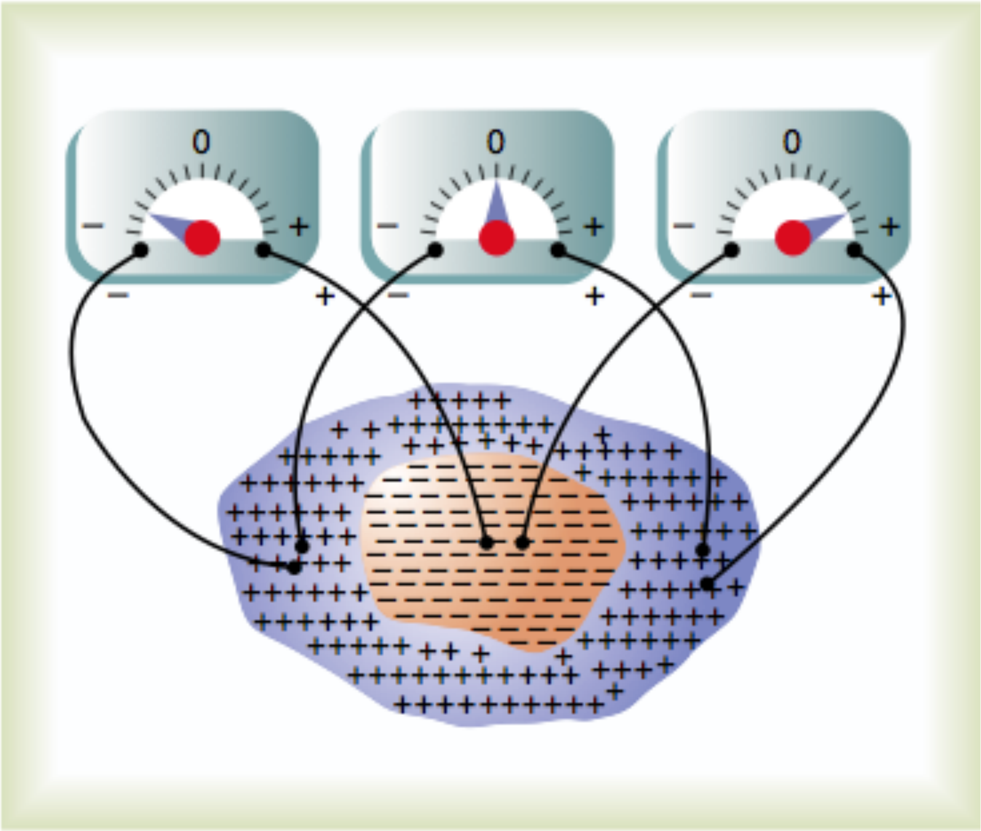


Figure 11–4

Instantaneous potentials develop on the surface of a cardiac muscle mass that has been depolarized in its center.

a meter connected with its negative terminal on the area of depolarization and its positive terminal on one of the still-polarized areas, as shown to the right in the figure, records positively.

Two other electrode placements and meter readings are also demonstrated in Figure 11–4.

▪ Flow of Electrical Currents in the Chest Around the Heart

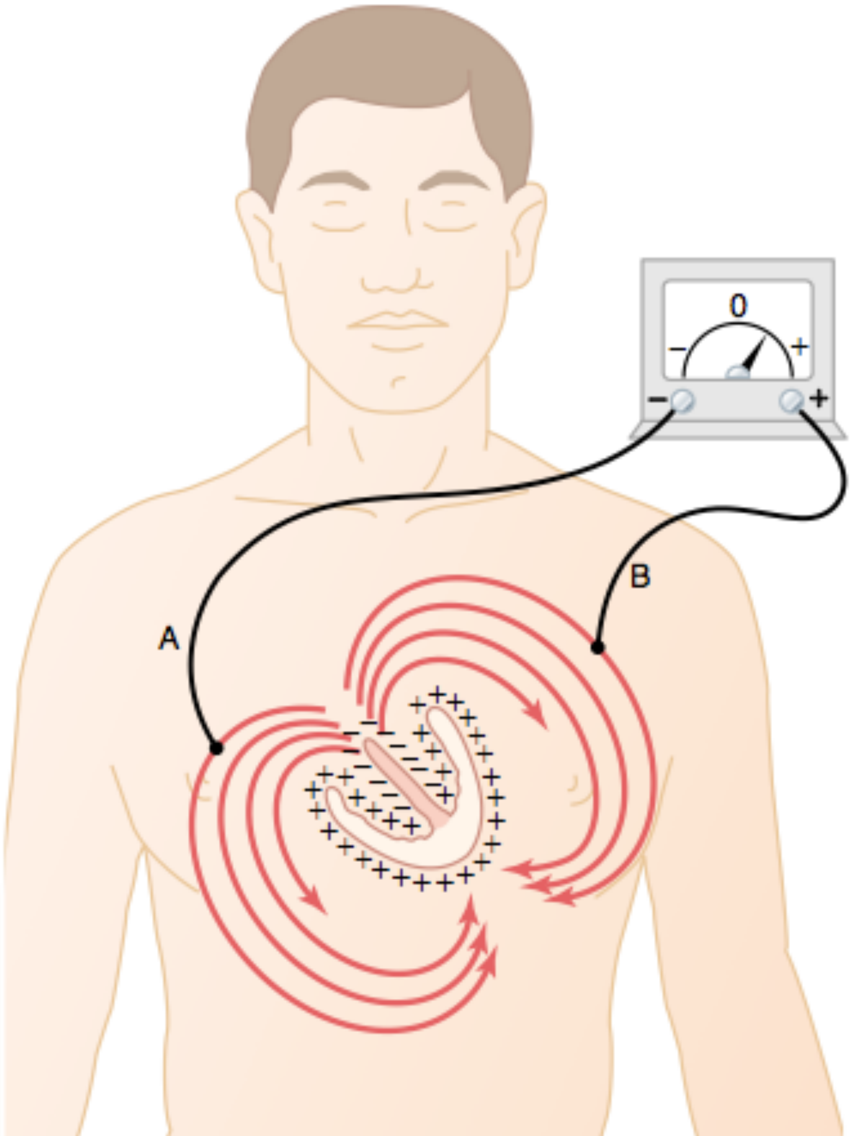


Figure 11–5

Flow of current in the chest around partially depolarized ventricles.

- the heart is actually suspended in a conductive medium
- When one portion of the ventricles depolarizes and therefore becomes electronegative with respect to the remainder, electrical current flows from the depolarized area to the polarized area in large circuitous routes, as noted in the figure

▪ Flow of Electrical Currents in the Chest Around the Heart

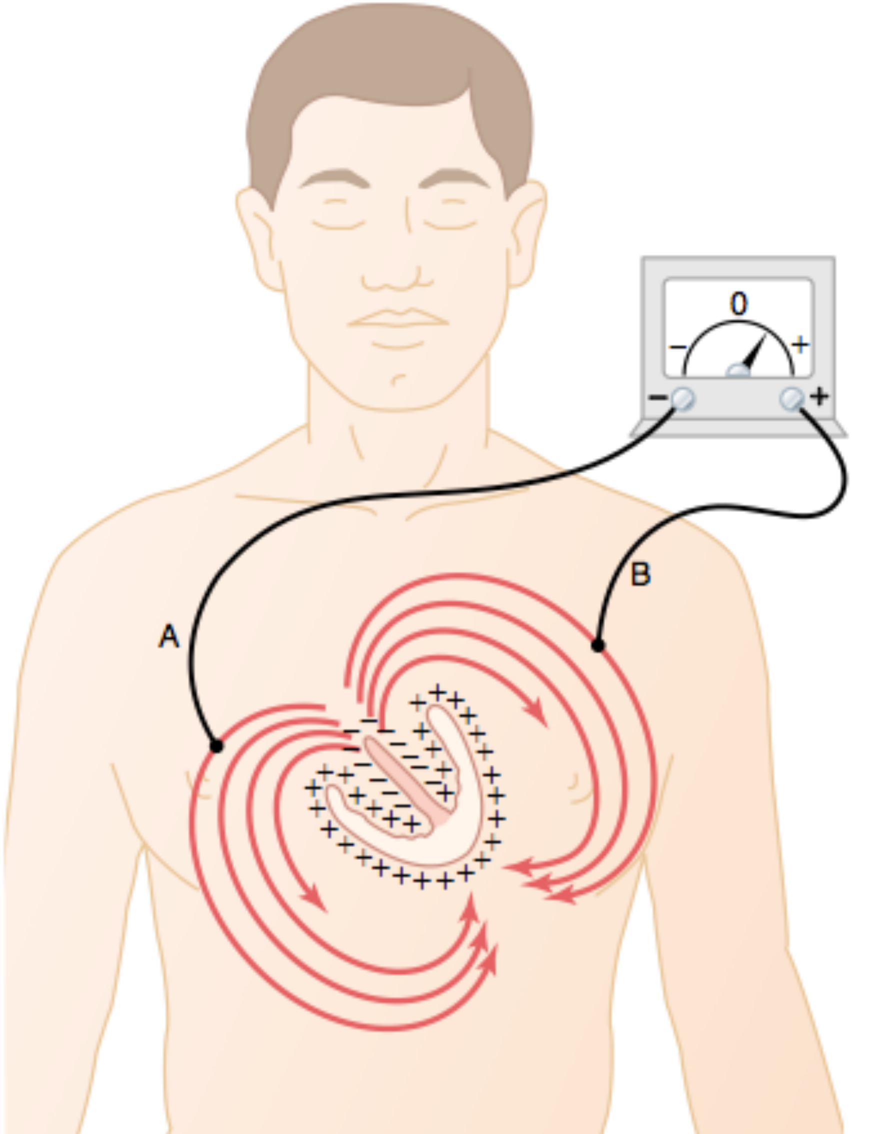
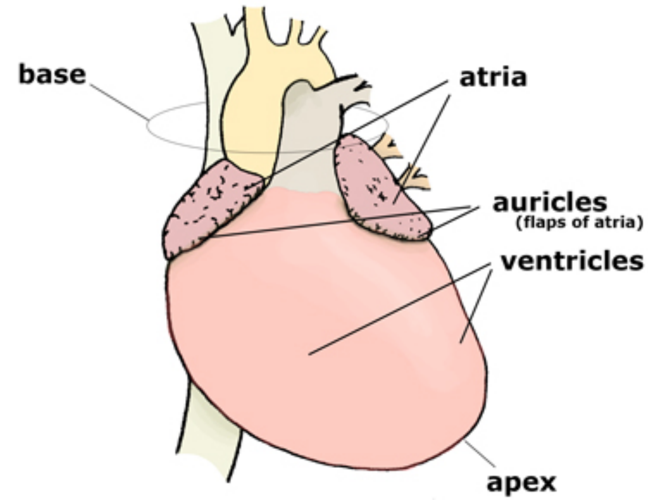


Figure 11–5

Flow of current in the chest around partially depolarized ventricles.



- in normal heart ventricles, current flows from negative to positive primarily in the direction from the base of the heart toward the apex during almost the entire cycle of depolarization, except at the very end. And if a meter is connected to electrodes on the surface of the body as shown in Figure 11–5, the electrode nearer the base will be negative, whereas the electrode nearer the apex will be positive, and the recording meter will show positive recording in the electrocardiogram.

Electrocardiographic Leads

- **Bipolar Limb Leads**

  - Bipolar means that the ECG is recorded from two electrodes on the body.

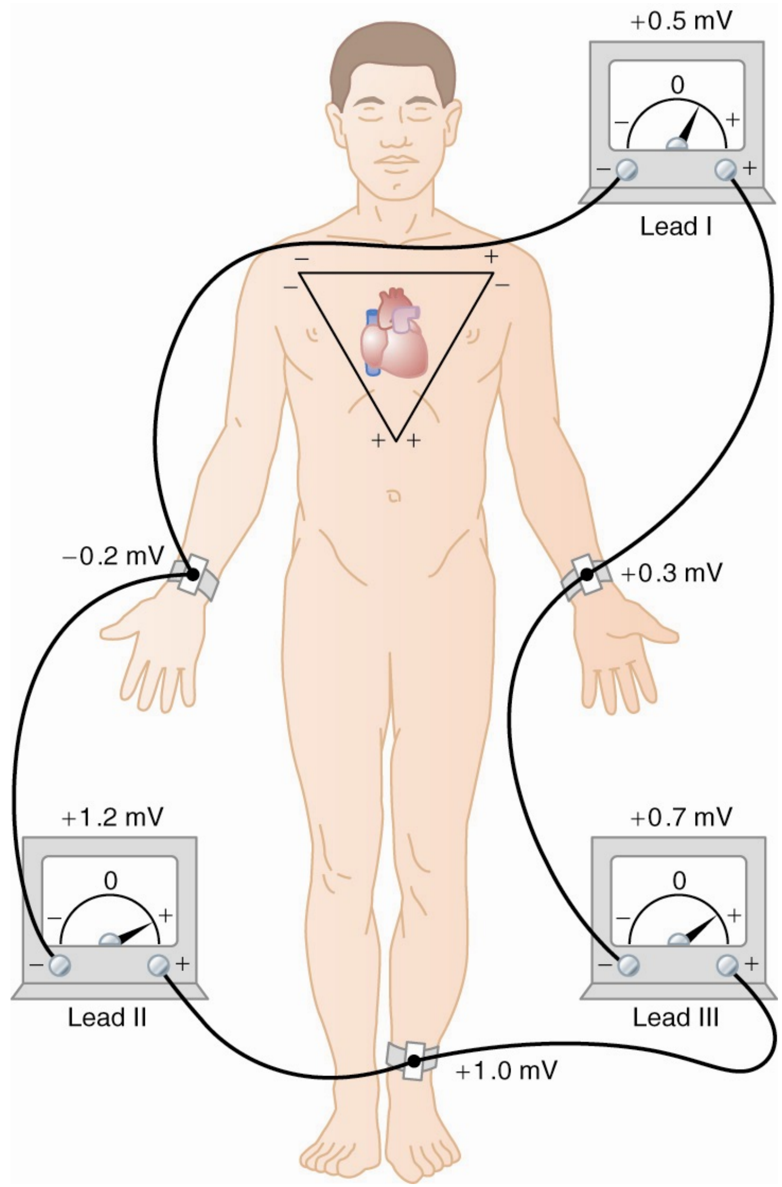


Figure 11-6; Guyton & Hall

- **Lead I.** In recording limb lead I, the negative terminal of the electrocardiograph is connected to the right arm and the positive terminal to the left arm. Therefore, when the point where the right arm connects to the chest is electronegative with respect to the point where the left arm connects, the electrocardiograph records positively, that is, above the zero voltage line in the electrocardiogram. When the opposite is true, the electrocardiograph records below the line.
- **Lead II.** To record limb lead II, the negative terminal of the electrocardiograph is connected to the right arm and the positive terminal to the left leg. Therefore, when the right arm is negative with respect to the left leg, the electrocardiograph records positively.
- **Lead III.** To record limb lead III, the negative terminal of the electrocardiograph is connected to the left arm and the positive terminal to the left leg. This means that the electrocardiograph records positively when the left arm is negative with respect to the left leg.

Einthoven's Triangle. In Figure 11–6, the triangle, called Einthoven's triangle, is drawn around the area of the heart. This illustrates that the two arms and the left leg form apices of a triangle surrounding the heart. The two apices at the upper part of the triangle represent the points at which the two arms connect electrically with the fluids around the heart, and the lower apex is the point at which the left leg connects with the fluids.

Einthoven's Law. Einthoven's law states that if the electrical potentials of any two of the three bipolar limb electrocardiographic leads are known at any given instant, the third one can be determined mathematically by simply summing the first two (but note that the positive and negative signs of the different leads must be observed when making this summation).

- the sum of the voltages in leads I and III equals the voltage in lead II. Mathematically, this principle, called Einthoven's law, holds true at any given instant while the three "standard" bipolar electrocardiograms are being recorded.

- Bipolar Limb Leads (cont’d)

0.5 mV

1.2 mV

0.7 mV

Figure 11–7

Normal electrocardiograms recorded from the three *standard* electrocardiographic leads.

▪ Other ECG Leads

Unipolar Limb Leads

Unipolar means that the ECG is recorded from an electrodes on the body with respect to the indifferent electrode.

- Often electrocardiograms are recorded with one electrode placed on the anterior surface of the chest directly over the heart at one of the points shown in Figure 11–8.
- This electrode is connected to the positive terminal of the electrocardiograph, and the negative electrode, called the *indifferent electrode*, is connected through equal electrical resistances to the right arm, left arm, and left leg all at the same time, as also shown in the figure.

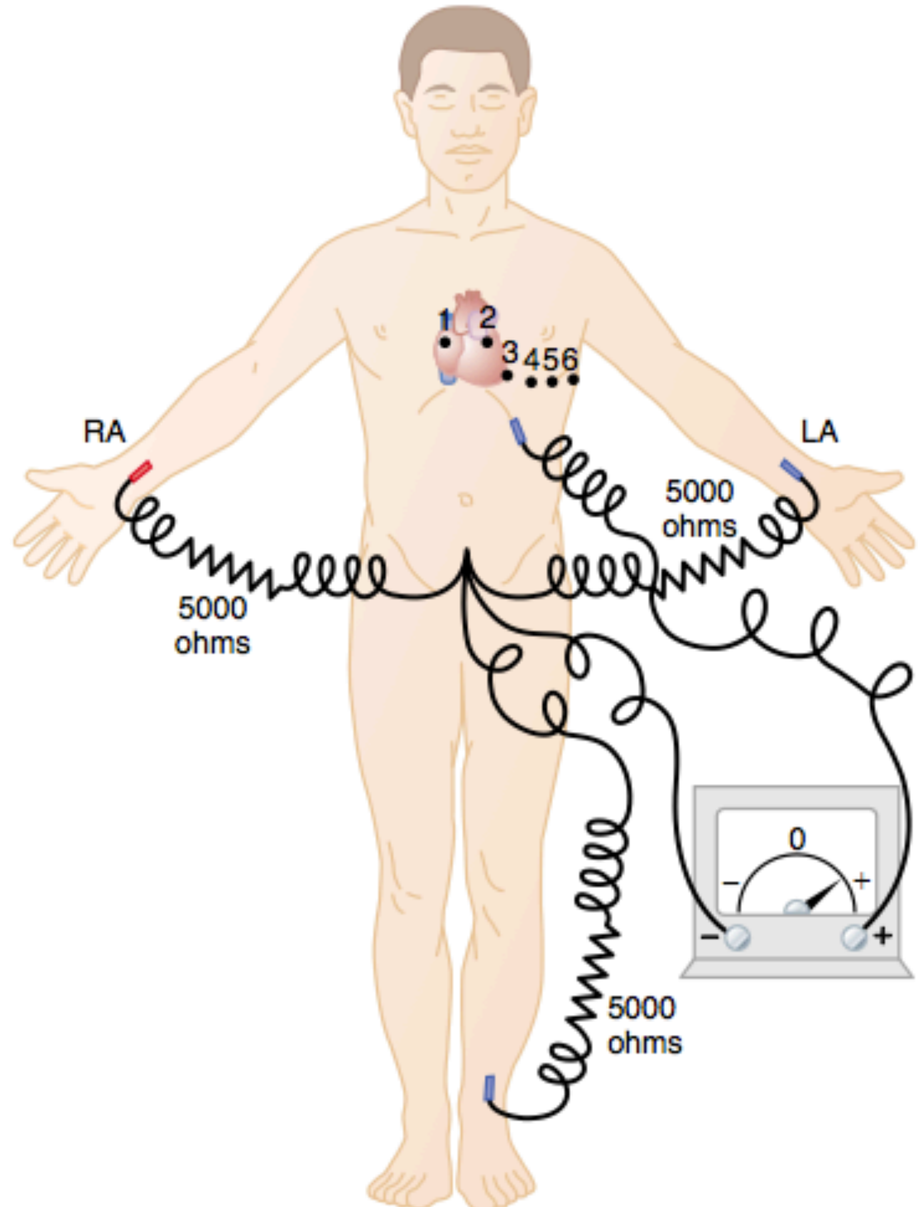


Figure 11–8

Connections of the body with the electrocardiograph for recording *chest leads*. LA, left arm; RA, right arm.

- Chest Leads (Precordial Leads) known as V_1- V_6 are very sensitive to electrical potential changes underneath the electrode.

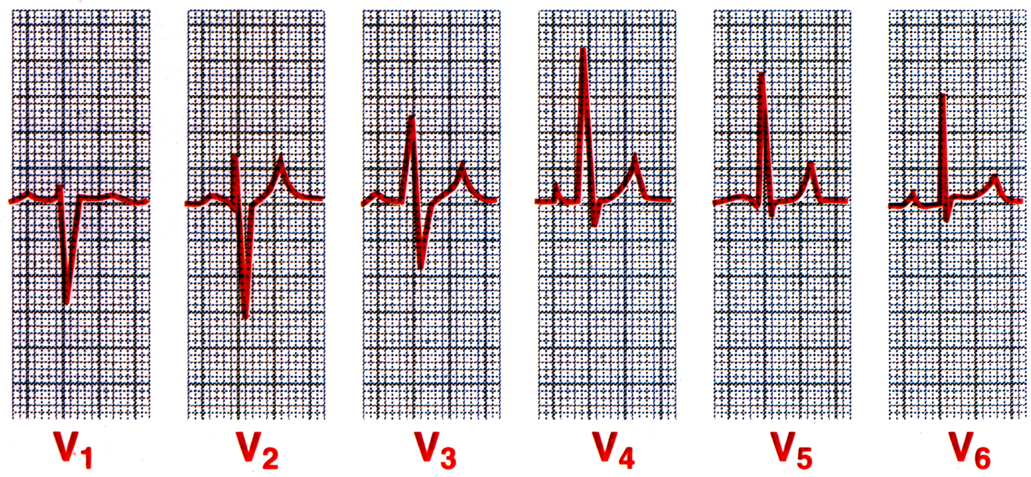
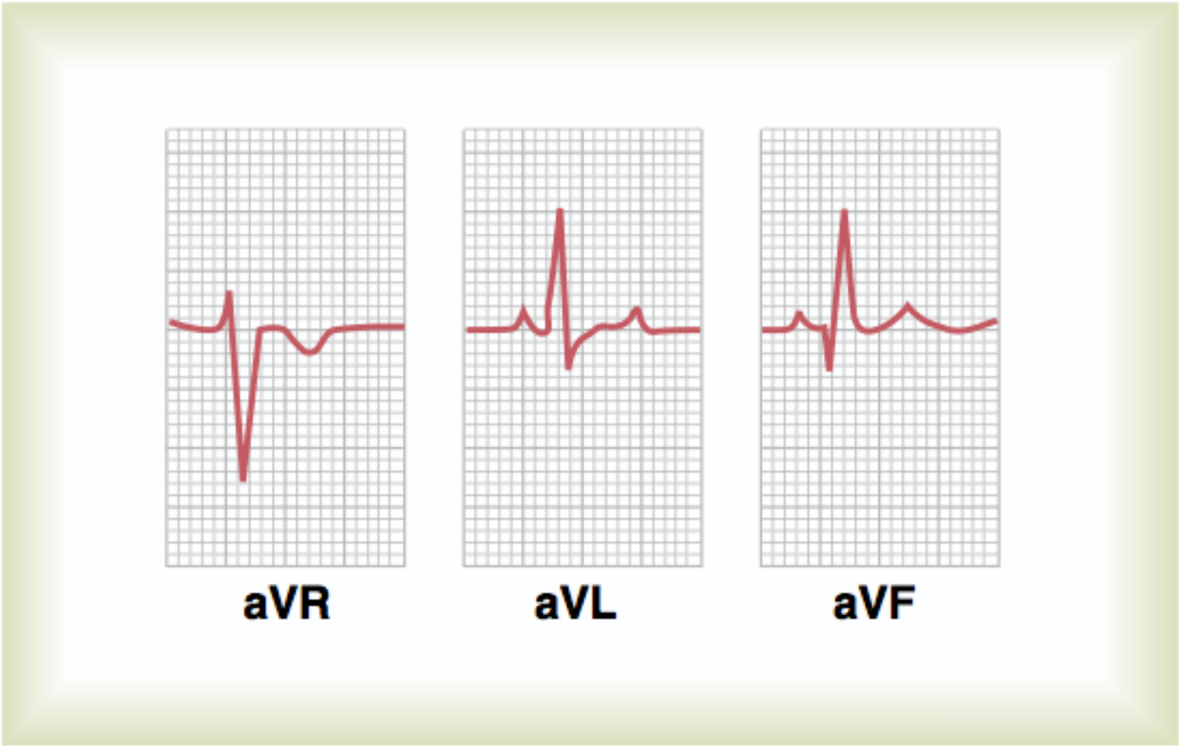


Figure 11-9; Normal electrocardiograms recorded from the six standard chest leads.

▪ Augmented Unipolar Limb Leads



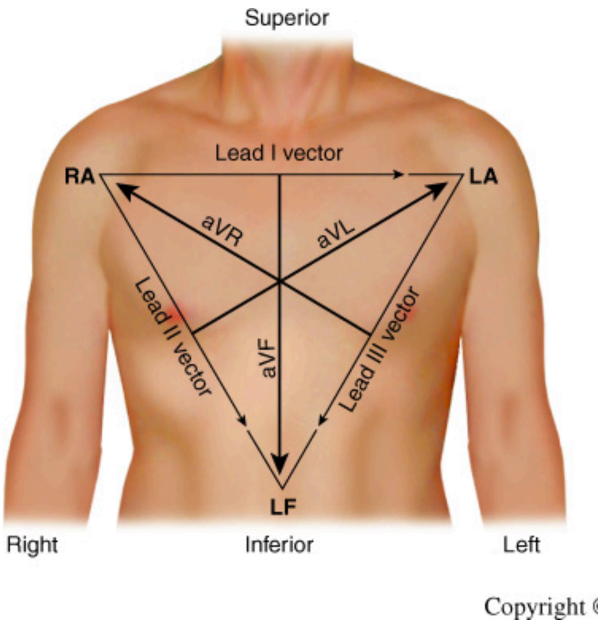


Figure 11–10
Normal electrocardiograms recorded from the three augmented unipolar limb leads.

Cardiac Cycle

- The cardiac events that occur from the beginning of one heartbeat to the beginning of the next are called the *cardiac cycle*.

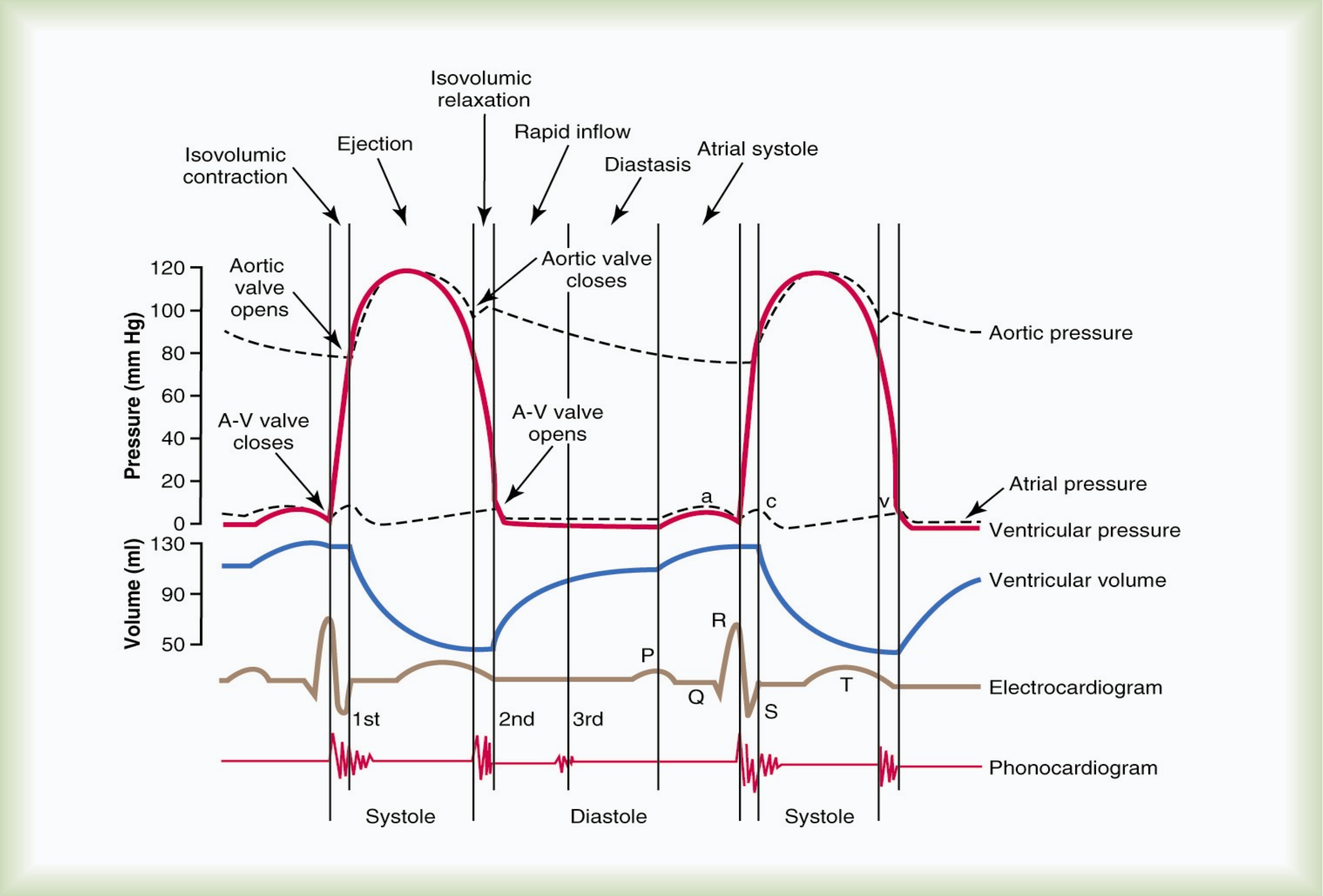
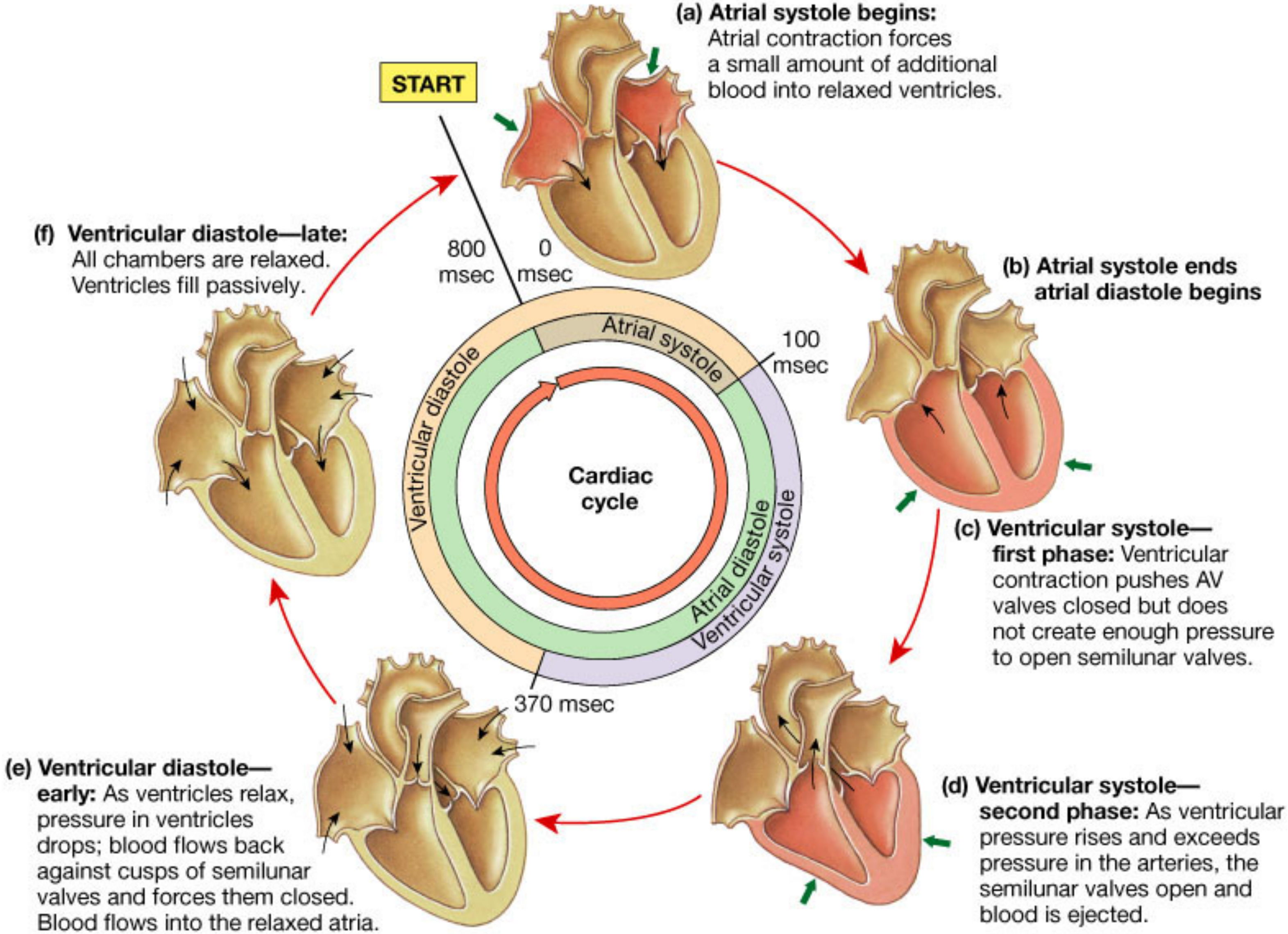
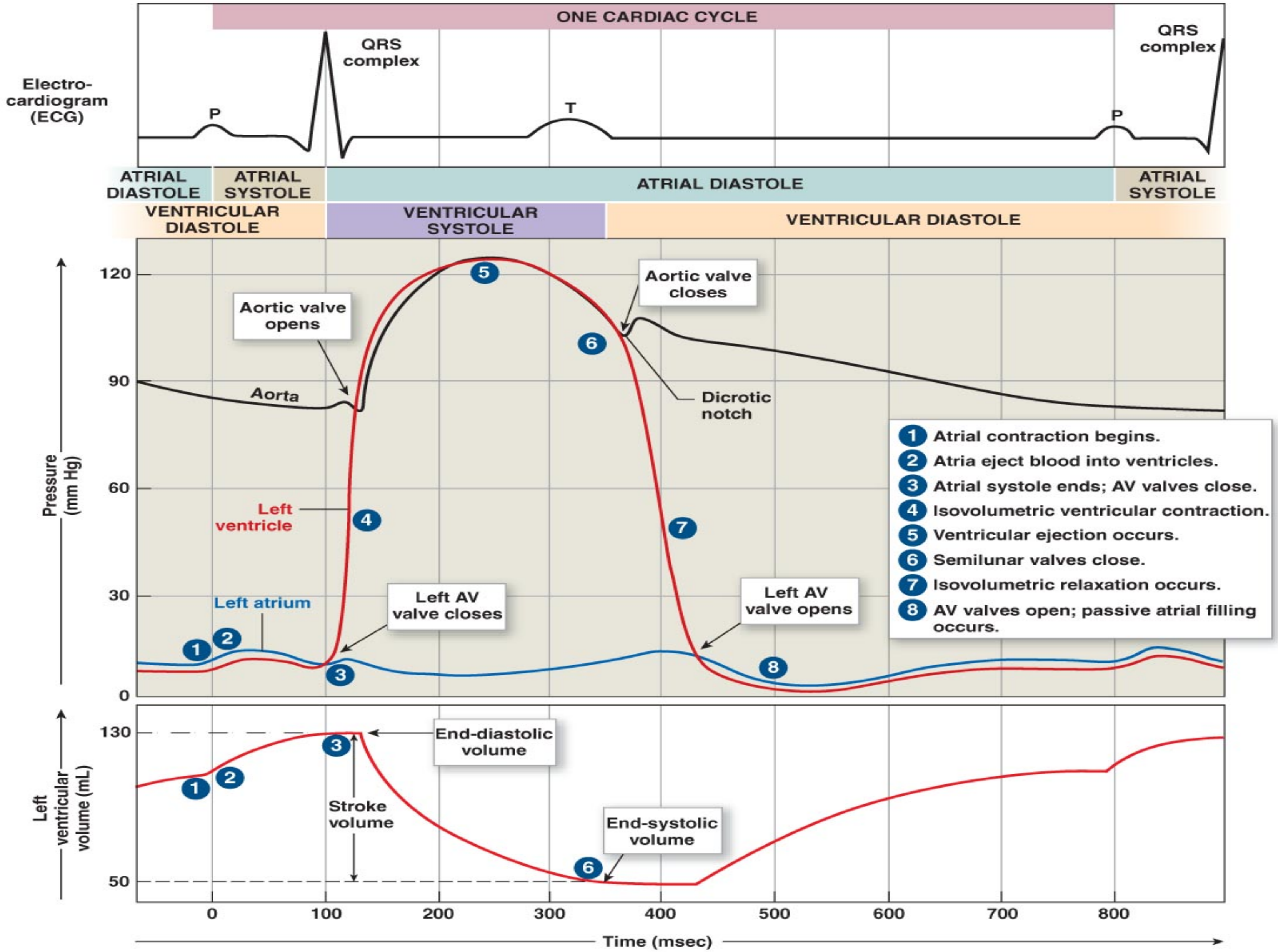


Figure 9–5
Events of the cardiac cycle for left ventricular function, showing changes in left atrial pressure, left ventricular pressure, aortic pressure, ventricular volume, the electrocardiogram, and the phonocardiogram.

Phases of the Cardiac Cycle



- Pressure and Volume Relationships in the Cardiac Cycle



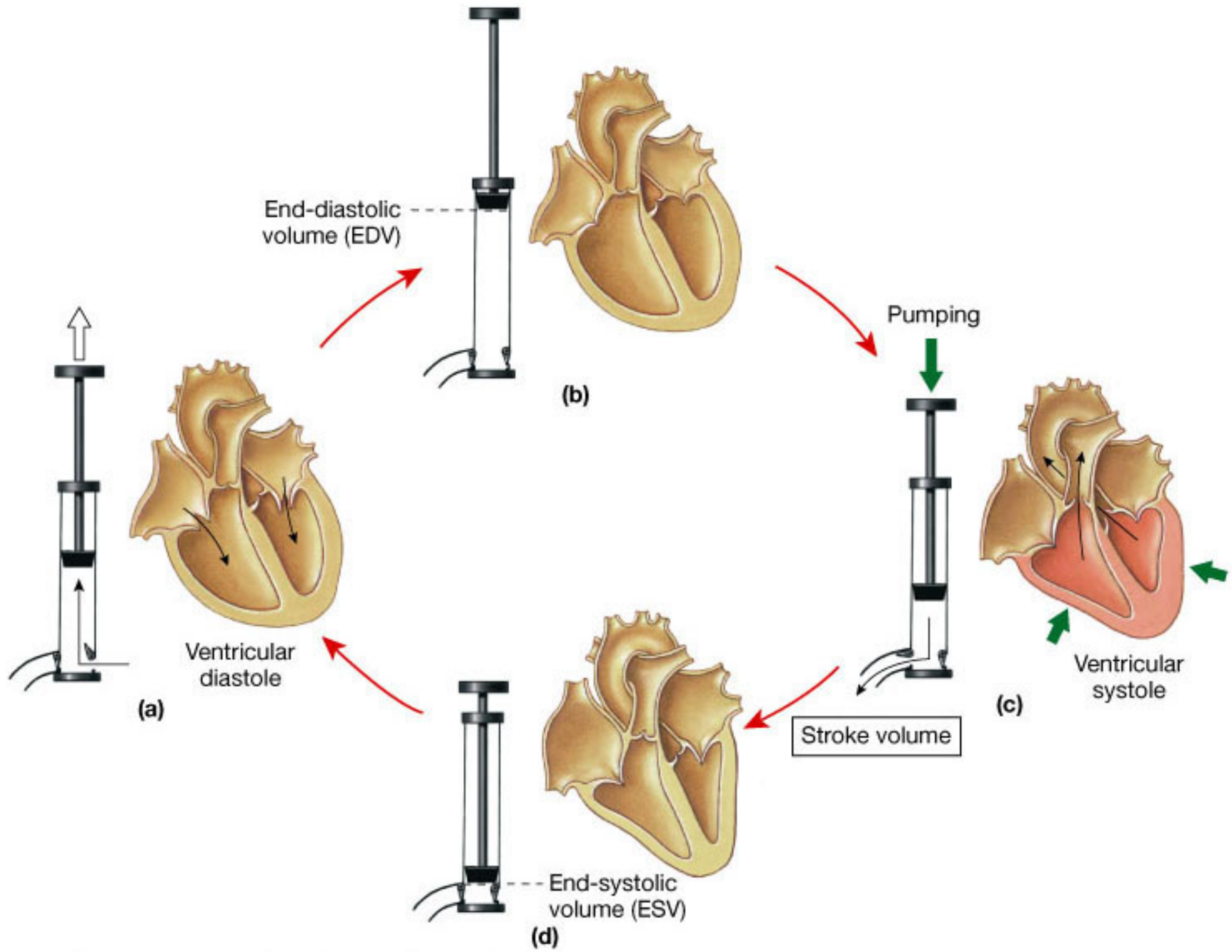
▪ Stroke Volume and Cardiac Output

- Cardiac output – the amount of blood pumped by each ventricle in one minute
  - Cardiac output equals heart rate times stroke volume

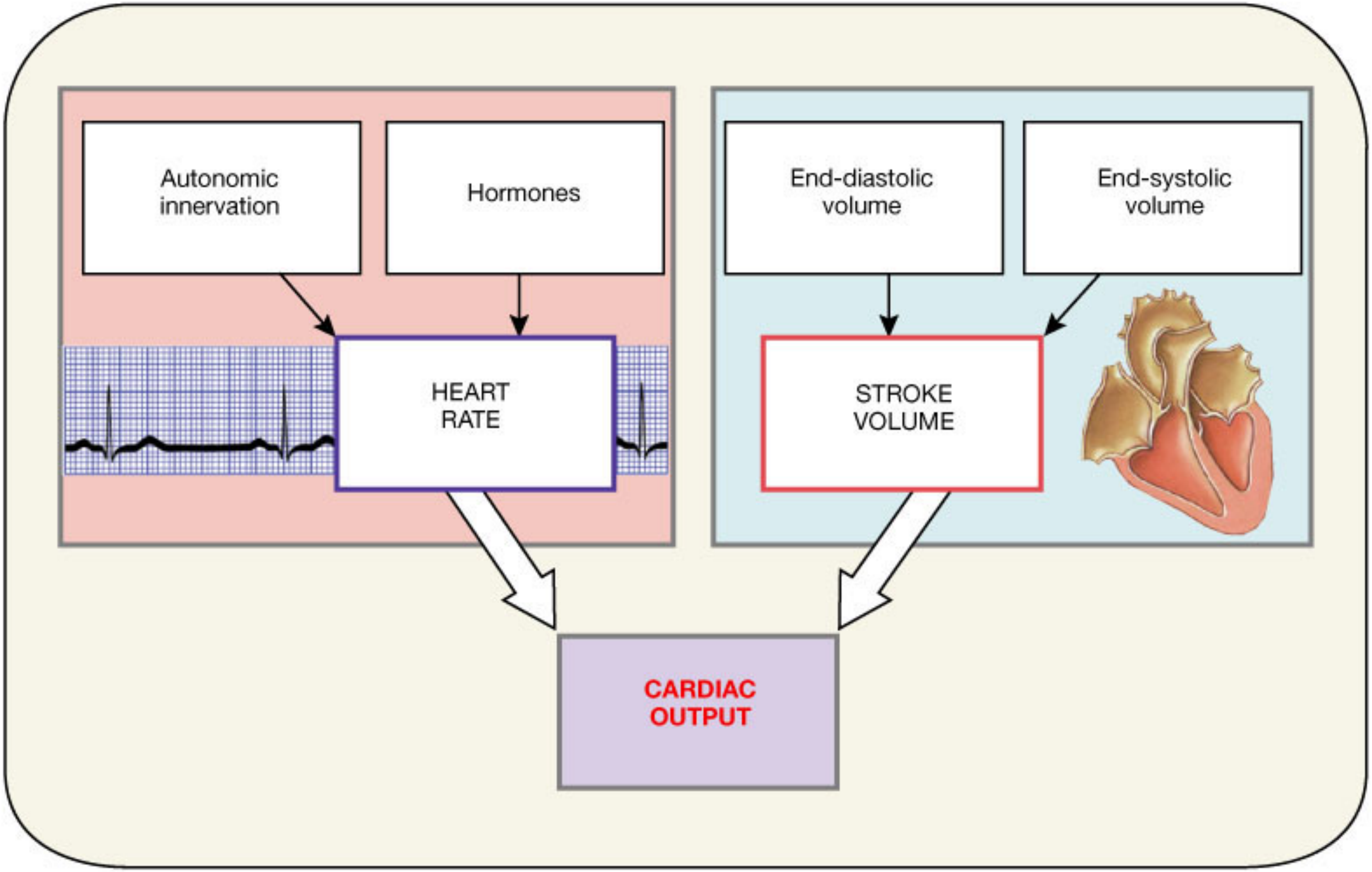
CO Cardiac output (ml/min)	=	HR Heart rate (beats/min)	X	SV Stroke volume (ml/beat)

▪ A Simple Model of Stroke Volume

During diastole, normal filling of the ventricles increases the volume of each ventricle to about 110 to 120 milliliters. This volume is called the *end-diastolic volume*. Then, as the ventricles empty during systole, the volume decreases about 70 milliliters, which is called the *stroke volume output*. The remaining volume in each ventricle, about 40 to 50 milliliters, is called the *end-systolic volume*.



- Factors Affecting Cardiac Output



Cardiac Arrythmias (chapter 13)

Abnormal Sinus Rhythms

- Tachycardia means a fast heart rate usually greater than 100 beats /min.

Figure 13-1; Sinus tachycardia (lead I).

- Bradycardia means a slow heart rate usually less than 60 beats /min

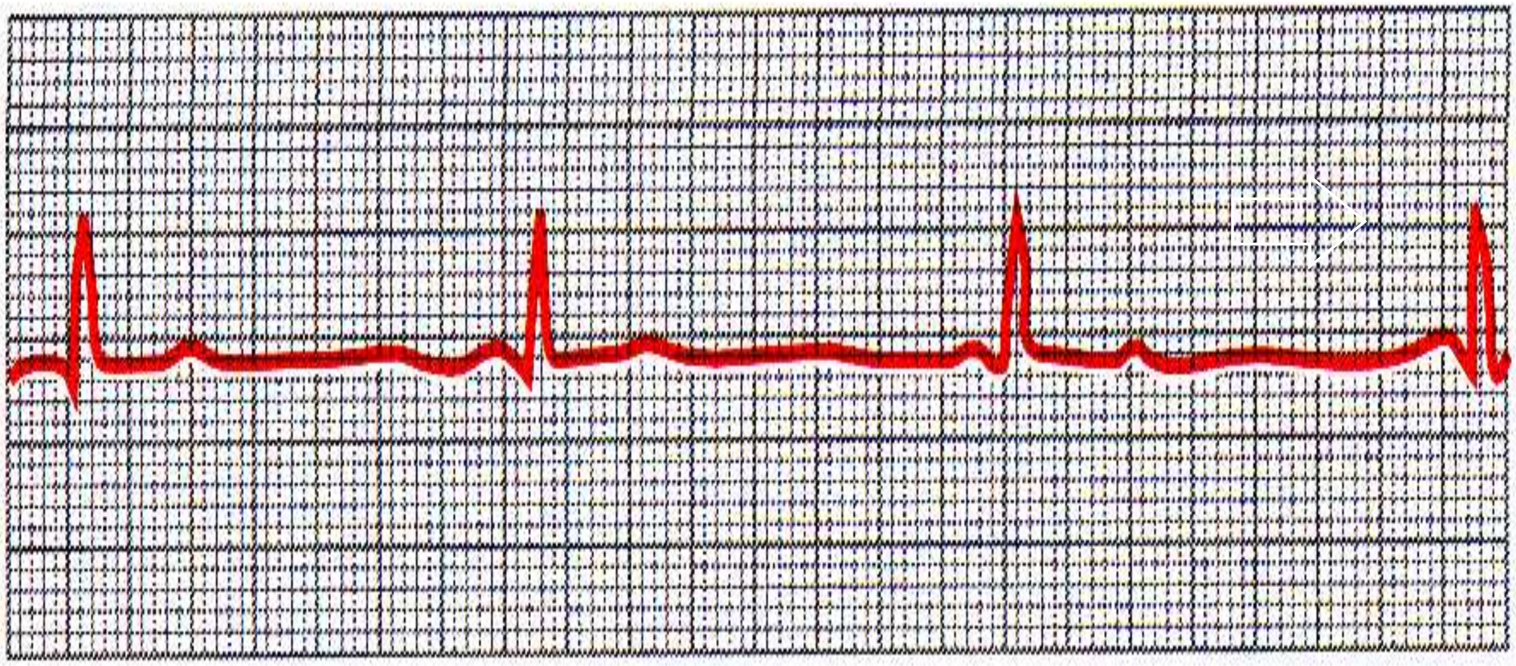
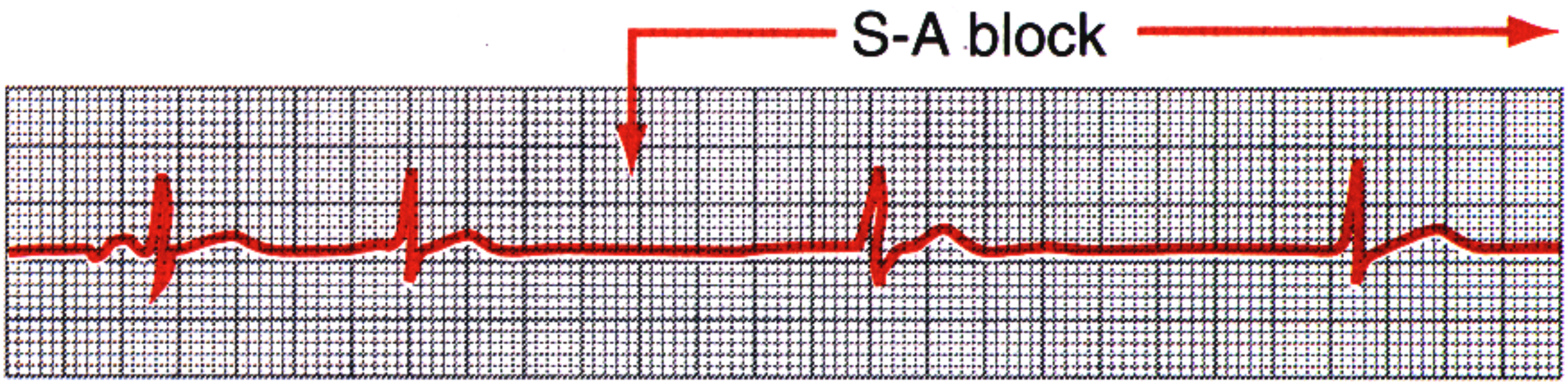


Figure 13-2: Sinus bradycardia (lead III).

Abnormal Rhythms That Result from Block of Heart Signals Within the Intracardiac Conduction Pathways

Sinoatrial Block

- In rare instances impulses from S-A node are blocked.
- New pacemaker is region of heart with the fastest discharge rate, usually the A-V node.



Note: no P waves and slow rate

Figure 13-4; Sinoatrial nodal block, with A-V nodal rhythm during the block period (lead III).

▪ Atrioventricular Block

- Impulses ordinarily can pass from the atria into the ventricles is through the A-V bundle, also known as *the bundle of His*. Conditions that can either decrease the rate of impulse conduction in this bundle or block the impulse entirely are :

- 1. Ischemia of the A-V node or A-V bundle fibers often delays or blocks conduction from the atria to the ventricles. Coronary insufficiency can cause ischemia of the A-V node and bundle in the same way that it can cause ischemia of the myocardium.
- 2. Compression of the A-V bundle by scar tissue or by calcified portions of the heart can depress or block conduction from the atria to the ventricles.
- 3. Inflammation of the A-V node or A-V bundle can depress conductivity from the atria to the ventricles. Inflammation results frequently from different types of myocarditis, caused, for example, by diphtheria or rheumatic fever.
- 4. Extreme stimulation of the heart by the vagus nerves in rare instances blocks impulse conduction through the A-V node. Such vagal excitation occasionally results from strong stimulation of the baroreceptors in people with carotid sinus syndrome, discussed earlier in relation to bradycardia.

▪ Incomplete Atrioventricular Heart Block

➢ Prolonged P-R (or P-Q) Interval—First Degree Heart Block

- The usual lapse of time of the QRS complex is about 0.16 second when the heart is beating at a normal rate.
- P-R interval usually decreases in length with faster heartbeat and increases with slower heartbeat
- Figure 13–5 shows an electrocardiogram with prolonged P-R interval; the interval in this instance is about 0.30 second instead of the normal 0.20 or less.

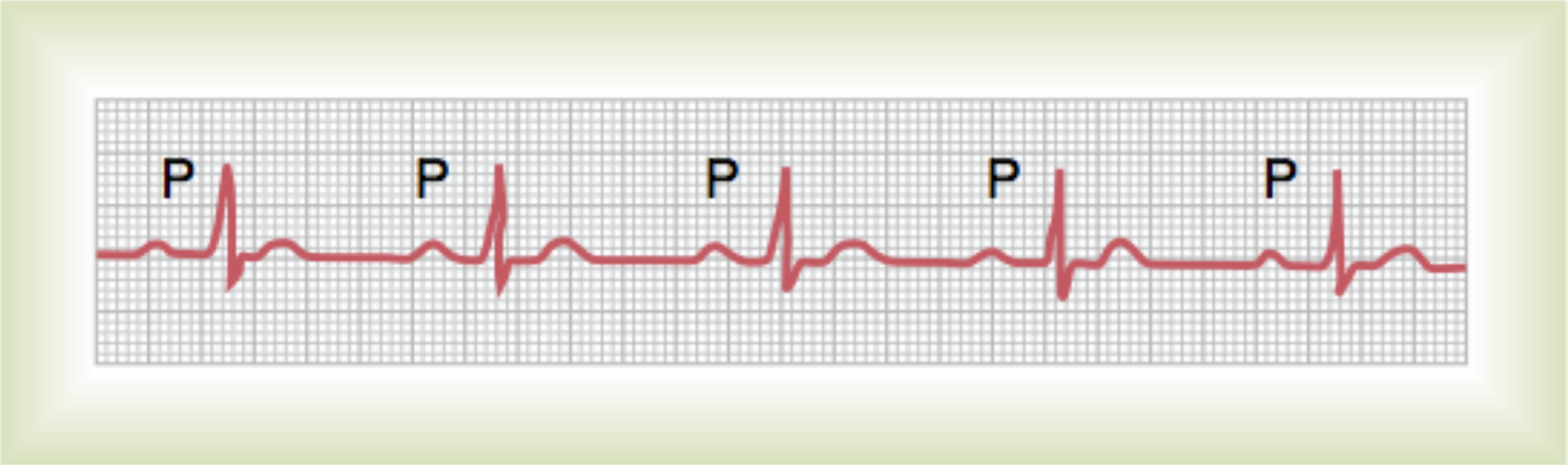


Figure 13–5

Prolonged P-R interval caused by first degree A-V heart block (lead II).

Second Degree Heart Block

- When conduction through the A-V bundle is slowed enough to increase the P-R interval to 0.25 to 0.45 second, the action potential sometimes is strong enough to pass through the bundle into the ventricles and sometimes is not strong enough. In this instance, there will be an atrial P wave but no QRS-T wave, and it is said that there are “dropped beats” of the ventricles. This condition is called second degree heart block.

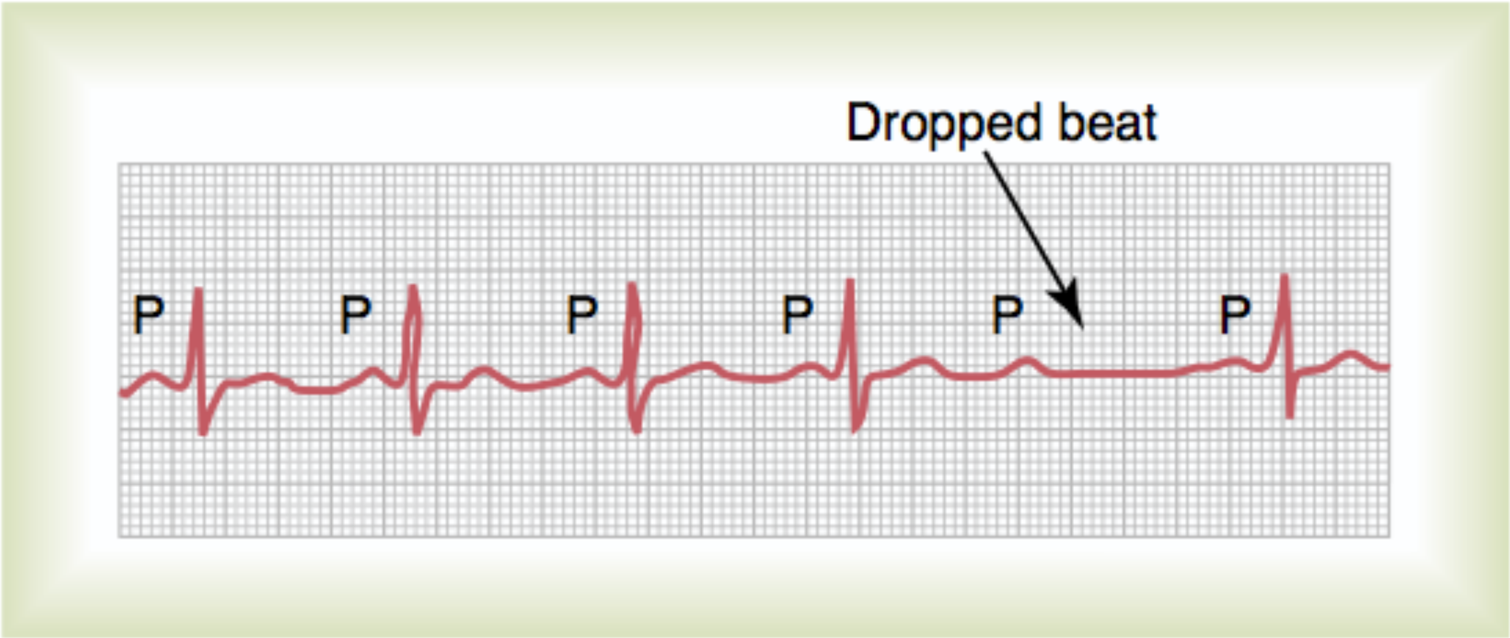
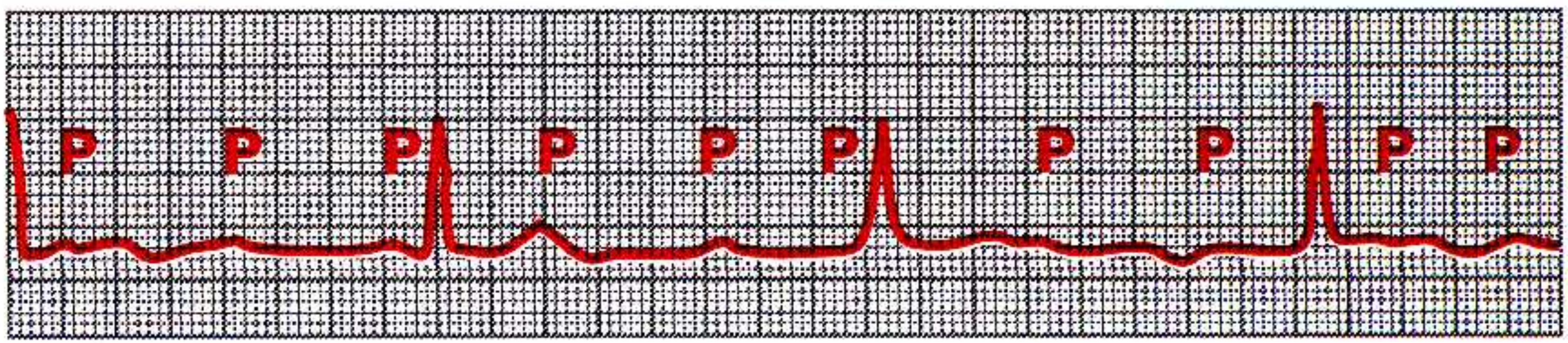


Figure 13–6

Second degree A-V block, showing occasional failure of the ventricles to receive the excitatory signals (lead V_3).

Third Degree Complete Block

- Total block through the A-V node or A-V bundle
- P waves are completely dissociated from QRST complexes



HR = 37

Figure 13-7; Complete A-V block (lead II).

Premature Contractions

- A premature contraction is a contraction of the heart before the time that normal contraction would have been expected. This condition is also called extrasystole, premature beat, or ectopic beat.

▪ Premature Atrial Contractions

- The P wave of this beat occurred too soon in the heart cycle; the P-R interval is shortened, indicating that the ectopic origin of the beat is in the atria near the A-V node.

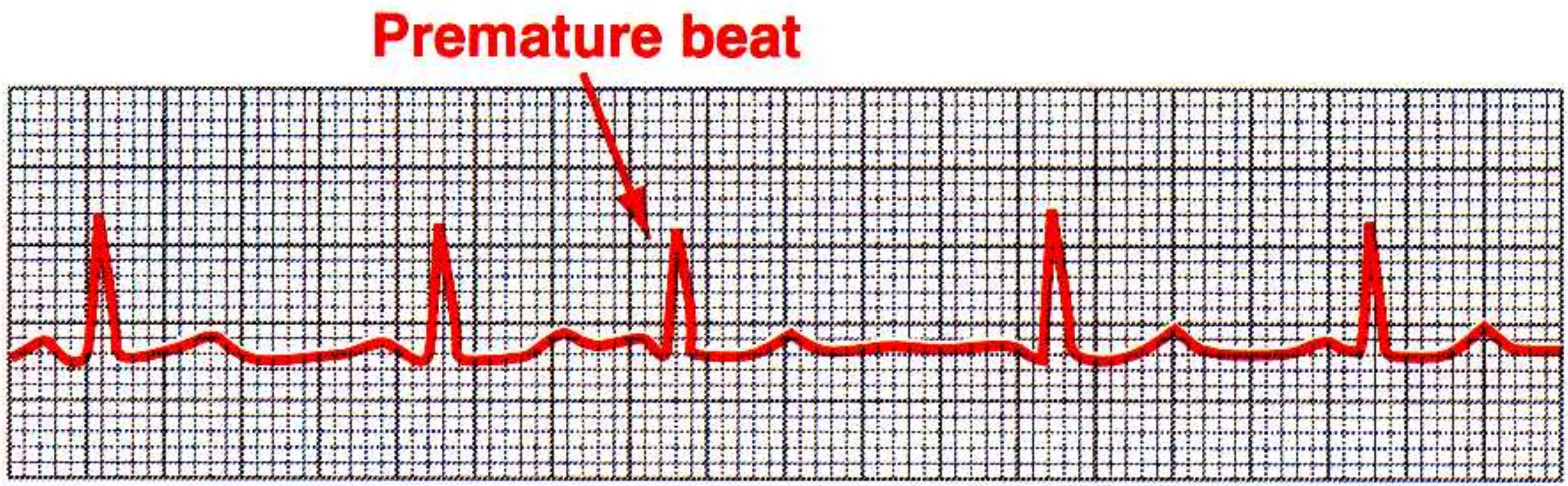


Figure 13-9 Atrial premature beat (lead I).

▪ A-V Nodal or A-V Bundle Premature Contractions

- P wave is superimposed onto the QRS-T complex because the cardiac impulse traveled backward into the atria at the same time that it traveled forward into the ventricles; this P wave slightly distorts the QRS-T complex.

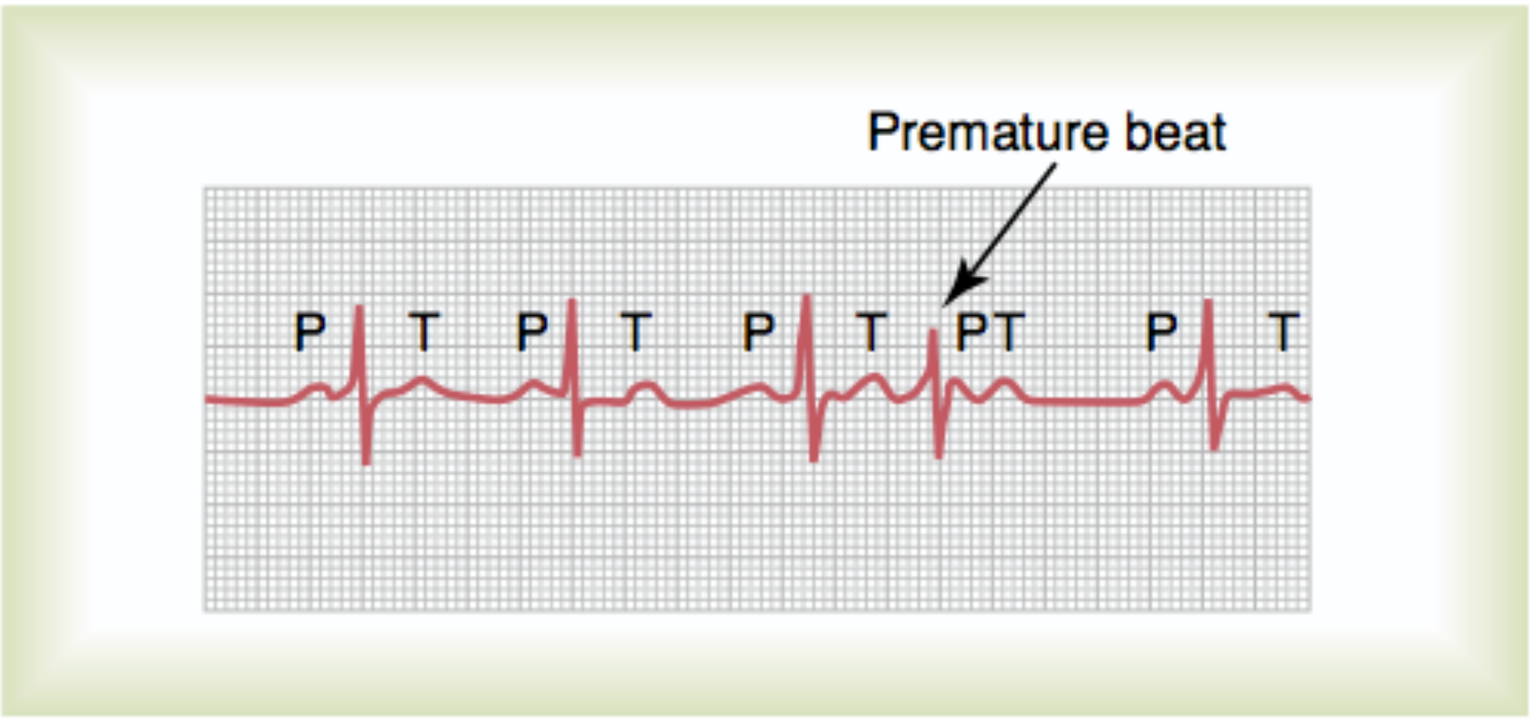


Figure 13–10 A-V nodal premature contraction (lead III).

- # Premature Ventricular Contractions (PVC’ s)

Figure 13–11
Premature ventricular contractions (PVCs) demonstrated by the large abnormal QRS-T complexes (leads II and III).

Paroxysmal Tachycardia

- Atrial Paroxysmal Tachycardia

- Paroxysmal means a series of rapid heart beats suddenly start and then suddenly stop.
- P wave is inverted if origin is near A-V node

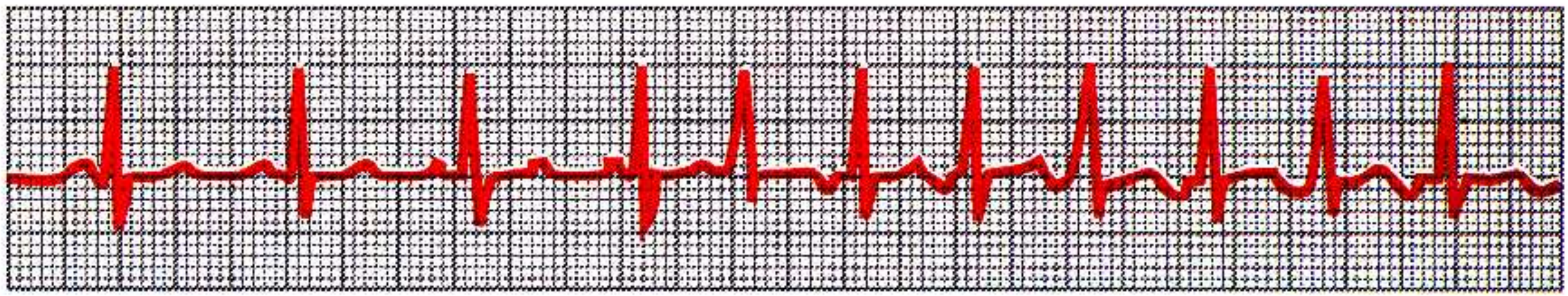


Figure 13-12; Atrial paroxysmal tachycardia—onset in middle of record (lead I).

- Ventricular Paroxysmal Tachycardia

  - Usually does not occur unless there has been ischemic damage

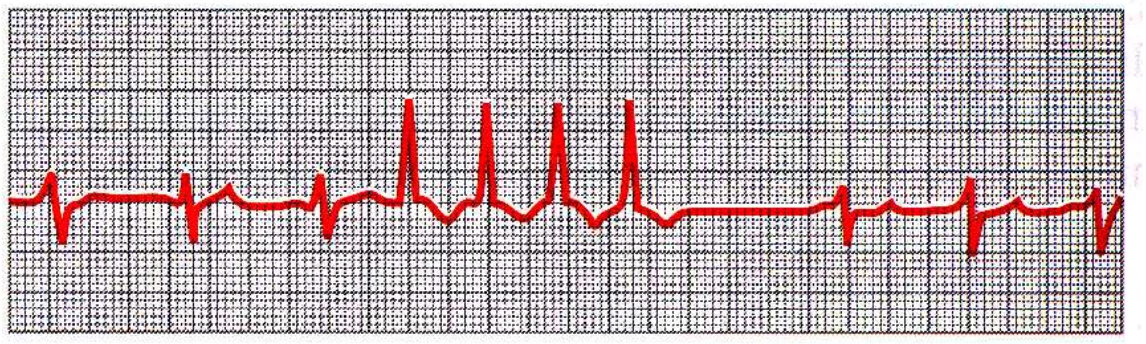


Figure 13-13 Ventricular paroxysmal tachycardia (lead III).

Atrial Fibrillation

- no P waves from the atria

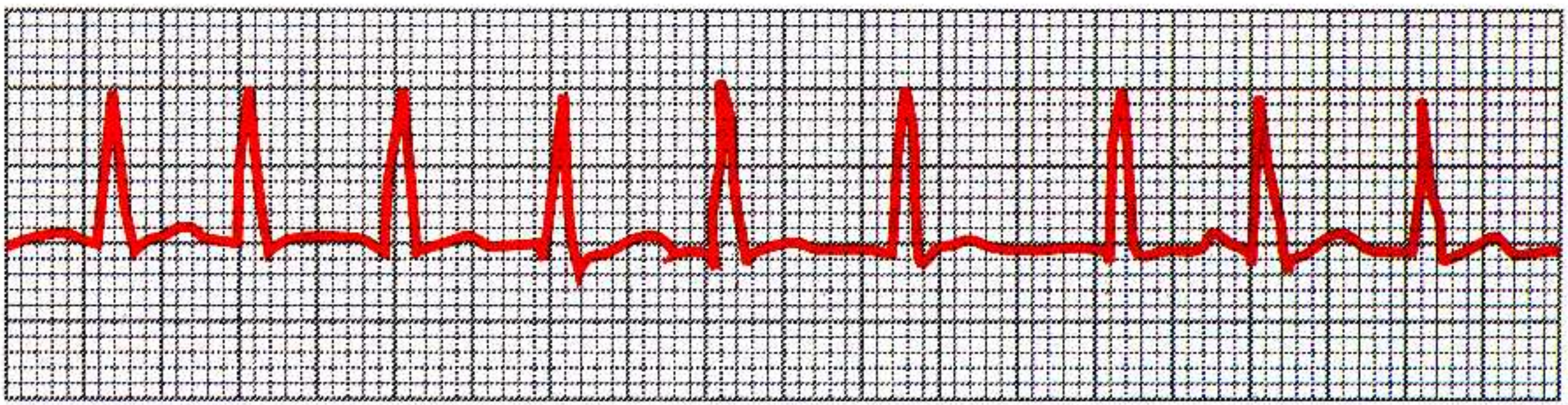


Figure 13-19; Atrial fibrillation (lead I). The waves that can be seen are ventricular QRS and T waves.

Ventricular Fibrillation

- The most serious of all cardiac arrhythmias is ventricular fibrillation, which, if not stopped within 1 to 3 minutes, is almost invariably fatal.

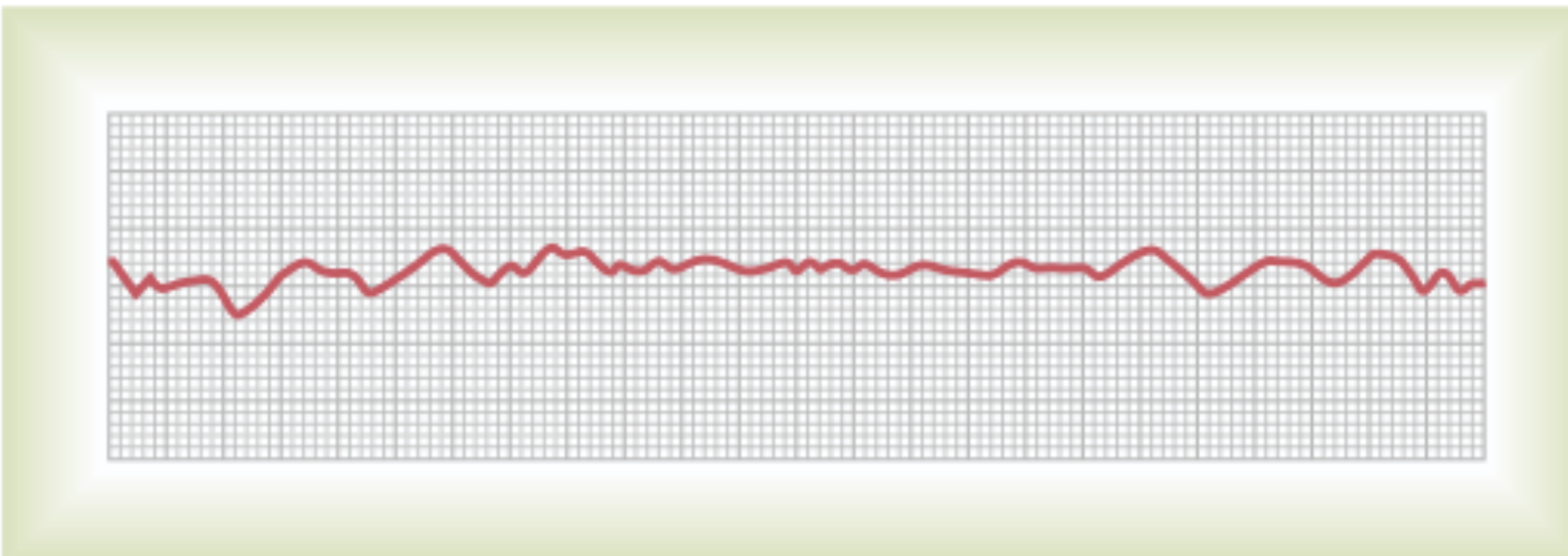


Figure 13–16 Ventricular fibrillation (lead II).