Cardiac Pacemaker
Premature Beats

When one of ectopic foci becomes irritable, it may spontaneously fire, leading to one or more premature beats. Atrial and junctional foci may become irritable from excess epinephrine or norepinephrine. Ventricular focus may become irritable when they experience either hypoxemia (low oxygen) or hypokalaemia (low serum potassium). When one premature beat follows and is coupled to a sinus beat, the group of two beats is called **bigeminy**. When two premature beats follow the sinus beat, the group of three beats is called **trigeminy**.

![ECG Traces](image.png)

(A) Sinus rhythm with premature atrial beats 2 and 6 (see Lead II).

A **premature atrial beat** can be identified by the change in heart rate and P-wave shape. After that, the original heart rate continues.
Premature Beats

A premature junctional beat can be identified by the change in heart rate and the lack of an associated P wave. After that, the original heart rate continues.

A premature ventricular contraction (PVC) can be identified by the change in heart rate and larger beat height and duration. A very wide ventricular complex is produced. After the PVC, a pause is observed because the SA node is not reset.

Two junctional beats, followed by nine sinus beats and then two premature junctional beats.

Ventricular bigeminy in patient with atrial fibrillation.
Heart Blocks

**Sinus block.** A sick sinus (SA) node temporarily stops pacing for at least one beat, may lead to an escape beat from one of the ectopic foci. Sinus block is characterized by identical P waves before and after the pause.

![Sinus block printed from Rivertek RSIM-1500 Simulator](A)
First-degree (1°) AV block. The impulse from the atria to ventricles is delayed, resulting in a longer than normal pause before ventricular stimulation (P-R interval). In 1° AV block, normal sinus rhythm is present, but the P-R interval exceeds 0.2 s.

(B) 1° AV block with heart rate of 88 bpm and P-R interval of 0.28 s
Heart Blocks

Second-degree (2°) AV block, there is a periodic dropped beat.

Type I (Wenckebach) 2° AV block, the P-R interval becomes progressively longer with each beat, until the AV node no longer conducts an impulse from the atria. Type I 2° AV block is caused by parasympathetic excess or by drugs that mimic these parasympathetic effects. In both cases, AV conduction is slowed.

Type I 2° AV block. P-R intervals for beats 36 are 0.23, 0.33, 0.37, and 0.41 s.
Heart Blocks

• **Type II (Mobitz II) 2° AV block**, the P-R interval remains consistent, but a QRS complex does not follow every P wave. Two to four P waves may occur before ventricular depolarization and a QRS complex are observed. The number of P waves and resulting conduction ratio of P waves to QRS complex relate to the increasing severity of the block.

(B) Type II 2° AV block, with a 2:1 conduction ratio.
Heart Blocks

- **Ventricular third-degree AV block, or complete AV block,**
  The atrial rate becomes completely dissociated from the ventricular rate, or R-R interval. No atria signal reaches the ventricles; so an ectopic focus below the block escapes overdrive suppression. If R-R interval is 40-60 bpm, then the AV junctional focus is pacing. If the R-R interval is 20-40 bpm, the ventrical focus is pacing. When a slower ventricular rate occurs in ventricular 3° AV block, blood flow to the brain becomes inadequate, which causes the patient to lose consciousness (Stokes-Adams syndrome).
Heart Failure

Heart failure: the reduced pumping capacity of the heart, may causes by bundle branch block. It is a consequence of coronary artery disease, high blood pressure, or diabetes. The body compensates by increasing sympathetic nervous stimulation. When this compensation is insufficient to balance outgoing versus returning blood flow, chronic heart failure occurs.

- increased QRS duration (>0.13s)
- chronic low blood pressure
- resting tachycardia
- left ventricle remodells: changes in sphericity, wall thinning, functional mitral regurgitation (backflow of blood through the mitral valve), and increased wall stress
# Heart Failure

## TABLE 3.1  New York Heart Association Heart Failure Functional Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Patient Reaction During Physical Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No symptoms and no limitation in ordinary physical activity</td>
</tr>
<tr>
<td>II</td>
<td>Mild symptoms and slight limitation during ordinary activity. Comfortable at rest.</td>
</tr>
<tr>
<td>III</td>
<td>Marked limitation in activity due to symptoms, even during less-than-ordinary activity. Comfortable only at rest.</td>
</tr>
<tr>
<td>IV</td>
<td>Severe limitations. Experiences symptoms even while at rest.</td>
</tr>
</tbody>
</table>
Heart Failure

(A) Left BBB, with QRS duration of 0.16 s and two R peaks visible in V4 and V5.
Heart Failure

(B) Right BBB, with QRS duration of 0.15 s and two R peaks visible in V1
Direct electrical stimulation of the ventricle may act as therapy to elicit ventricle contraction. The earliest implantable pacemakers were designed to control the Stokes-Adams syndrome. Sensor-based enhancements, which include an accelerometer, can detect motion and cause the heart rate to be adjusted during physical activity. Other optional sensors can detect respiration, the presence of thoracic fluid, or pressure.
Leads

**Outer jacket:** polyurethane or a polyurethane hybrid, silicone rubber or polyurethane insulation.

**Conductor:** one or two metal coils of titanium or platinum/iridium that terminate as textured-surface electrodes

- unipolar lead administers a voltage between one electrode as the catheter and a portion of the pulse generator can as the anode.
- bipolar lead administers a voltage between a so-called tip electrode (cathode) and a ring electrode (anode), spaced about 10-30 mm apart at the end of the lead.
Leads

- A bipolar lead positioned in the atrium records the atrial P wave with greater amplitude than a far-field R wave from the ventricles.
- A unipolar lead positioned in the atrium may record a far-field R wave of greater amplitude than the atrial P wave.
Leads

To minimize impedance increase, cause by scar tissue development, steroid-eluting electrodes have been developed. In an early design, each electrode consists of a silicone core, impregnated with a small dose of dexamethasone sodium phosphate, in contact with porous titanium, coated with platinum (Stokes, 1987). The mechanism by which dexamethasone sodium phosphate prevents an impedance increase is not fully understood.
Pulse Generator

- Pulse generator is sealed titanium “can” containing a battery and circuitry. It is implanted in a small-incision, subcutaneous pocket in the pectoralis fascia below the clavicle, on the patient’s nondominant side.
Capture Tests

• For these pulses to be therapeutic, the voltage must be sufficient to “capture” the heart, that is, to generate depolarization. During implantation, a capture test is conducted for each lead. For each test, assuming a constant preselected pulse width, the pulse amplitude voltage is decreased from a maximum setting to the point at which depolarization no longer occurs. The last pulse amplitude of capture is known as the capture threshold. Typically, the pacing threshold is then set at twice the capture threshold. An empirical applied current density adequate for stimulation is 5.0 mA/cm² which, assuming a tissue resistivity of 500 Ωcm, gives an applied field of 2.5 V/cm

Electrogram from two patients, measured from tip of a pacemaker lead placed at right ventricle apex, referenced to the can. These patients were at high risk for acute coronary syndromes
Pacemaker Sensing Parameters and Modes

- Atrial and ventricular sensitivities: the minimum voltage thresholds for sensing a P wave and R wave, respectively. These waves are sensed from the bandpass-filtered electrogram.
- AV delay: the time interval after an atrial pacing pulse at A, during which an R wave may be detected. If an R wave is not detected, a ventricular pulse, V, is fired.
- PV delay: the time interval after a P wave, during which an R wave may be detected. If an R wave is not detected, a ventricular pulse is fired.
- PVARP: the time interval after R wave or ventricular stimulus, which atrial sensing is disabled. PVARP prevents retrograde P waves (which often occur following paced beats) from being sensed by the atrial amplifier and causing a pacemaker mediated tachycardia.
- Ventricular refractory period (VRP): the time after R wave or ventricular stimulus, which ventricular sensing is disabled. VRP prevents T waves from being sensed by the ventricular amplifier.
### Revised NBG Pacemaker Code (Bernstein et al., 2002)

<table>
<thead>
<tr>
<th>Position</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Chamber(s) paced</td>
<td>Chamber(s) sensed</td>
<td>Response to sensing</td>
<td>Rate Modulation</td>
<td>Multiside</td>
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<tr>
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<tr>
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<td>V = Ventricle</td>
<td>I = Inhibited</td>
<td></td>
<td>V = Ventricle</td>
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<tr>
<td></td>
<td>D = Dual (A+V)</td>
<td>D = Dual (A+V)</td>
<td>D = Dual (T+I)</td>
<td></td>
<td>D = Dual (A+V)</td>
</tr>
</tbody>
</table>

Rate modulation: adaptive pacing to achieve more realistic physiological behavior.
Pacemaker Modes

Two pacemaker modes. 

A: DDDxx. Both the right atrium and right ventricle are sensed and paced.

B: VVIxx. Only the right ventricle is sensed and paced. In these beats, which occur during atrial fibrillation, the first two ventricular depolarization are spontaneous (S), but the third ventricular depolarization is paced (P)
Key Features

• To address unknown lead failure mechanisms, leads may undergo three tests, according to British Standard EN 45502-2-1:2003 Active Implantable Medical Devices—Part 2-1: Particular Requirements for Active Implantable Medical Devices Intended to Treat Bradyarrhythmia (Cardiac Pacemakers) (BSI, 2003).

• **Battery.** A pacemaker system is only as good as its battery, which typically lasts about 7-10 years. The battery is replaced by replacing the pulse generator.

• **Sensitivity.** According to British Standard EN 45502-2-1:2003, sensitivity error must be within ±10%.

• **Minimum Susceptibility to Electromagnetic Interference.** Modern pulse generators are designed to minimize the effect of EMI radiating from 16.6 Hz, which is present on some European railways, to 3 GHz, the radiation field from cell phones. EN 45502-2-1:2003 specifies seven tests to assess the effects of electromagnetic nonionizing radiation.
References

1. Fundamental of Anatomy and Physiology, Frederic H. Martini
2. Biomedical Instrumentation: Application and Design, John G. Webster
4. The Biomedical Engineering Handbook, Joseph D. Bronzino
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