

# Pacemakers, ICDs, and CRT-Ds

Pacemakers, implantable cardioverter-defibrillators (ICDs), and cardiac resynchronization therapy defibrillators (CRT-Ds) are critical devices used to manage cardiac rhythm disorders and improve outcomes in patients with specific heart conditions. This guide provides physician assistant (PA) students with a comprehensive framework to understand the indications, types, settings management, complications, and post-procedure care for these devices, with case scenarios to apply the knowledge.

## Introduction and Overview

Pacemakers are devices that deliver electrical impulses to maintain an adequate heart rate, primarily used for bradyarrhythmias. They consist of a pulse generator and leads inserted into the heart, typically pacing the right atrium (RA) and/or right ventricle (RV).

ICDs are advanced devices that not only pace for bradycardia but also deliver shocks to terminate life-threatening ventricular arrhythmias (e.g., ventricular tachycardia [VT], ventricular fibrillation [VF]). They include a pulse generator and leads with defibrillation coils.

CRT-Ds combine cardiac resynchronization therapy (CRT) with ICD capabilities. CRT synchronizes RV and left ventricular (LV) contraction by pacing both ventricles (biventricular pacing), improving cardiac output in heart failure (HF) patients with dyssynchrony, while the ICD function protects against sudden cardiac death (SCD).

These devices are implanted via transvenous leads or, in some cases, leadless systems, and require careful management to optimize function and minimize complications.

## Indications for Use

### Pacemakers:

- Symptomatic Bradycardia:
  - **Sick Sinus Syndrome (SSS):** Includes sinus bradycardia, sinus pauses, or chronotropic incompetence causing symptoms (e.g., syncope, fatigue, exertional dyspnea); often seen in elderly patients.

- Atrioventricular (AV) Block:
  - 2nd-degree Mobitz II or 3rd-degree AV block (complete heart block) with or without symptoms.
  - Symptomatic 2nd-degree Mobitz I (Wenckebach) or 1st-degree AV block with prolonged PR interval ( $>300$  ms) causing hemodynamic compromise (e.g., pseudo-pacemaker syndrome).
- Bifascicular/Trifascicular Block:
  - High-degree AV block risk, especially if symptomatic or alternating bundle branch block (BBB).
- Carotid Sinus Hypersensitivity:
  - Syncope with significant cardioinhibitory response (e.g.,  $>3$ -second pause on carotid massage).
- Neurocardiogenic Syncope:
  - Recurrent syncope with a dominant cardioinhibitory component (e.g., asystole  $>3$  seconds on tilt-table testing).
- Hypertrophic Cardiomyopathy (HCM):
  - Dual-chamber pacing to reduce left ventricular outflow tract (LVOT) obstruction in patients with refractory symptoms despite medical therapy.
- Post-Ablation or Surgery:
  - Iatrogenic AV block after AV node ablation (e.g., for AF rate control) or cardiac surgery (e.g., valve replacement).
- Tachy-Brady Syndrome:
  - Alternating bradycardia and tachycardia (e.g., AF with rapid rates followed by sinus pauses); pacing prevents bradycardia to allow antiarrhythmic drugs.
- Congenital Heart Disease (CHD):
  - Postoperative AV block in repaired CHD (e.g., tetralogy of Fallot) or congenital AV block with symptoms or QRS  $>120$  ms.

## ICDs:

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- Secondary Prevention:
  - Survivors of cardiac arrest due to VT/VF, not due to reversible cause (e.g., ischemia, electrolyte imbalance).
  - Sustained VT with hemodynamic instability, syncope, or structural heart disease.
- Primary Prevention:
  - Ischemic Cardiomyopathy:

- EF  $\leq$ 35%, NYHA class II-III, >40 days post-MI, on optimal medical therapy (OMT).
  - Non-Ischemic Cardiomyopathy:
    - EF  $\leq$ 35%, NYHA class II-III, on OMT for  $\geq$ 3 months.
- Inherited Arrhythmia Syndromes:
  - Long QT syndrome (LQTS) with syncope despite beta-blockers or documented TdP.
  - Brugada syndrome with syncope, spontaneous type 1 ECG pattern, or family history of SCD.
  - Catecholaminergic polymorphic VT (CPVT) with syncope or VT despite beta-blockers.
  - Arrhythmogenic right ventricular cardiomyopathy (ARVC) with sustained VT or high-risk features (e.g., family history of SCD).
- Hypertrophic Cardiomyopathy (HCM):
  - High-risk features (e.g., family history of SCD, VT on Holter, massive LVH >30 mm, syncope).
- Cardiac Sarcoidosis:
  - Documented VT or EF  $\leq$ 35% (high risk of SCD due to granulomatous infiltration).
- Congenital Heart Disease (CHD):
  - Adults with repaired tetralogy of Fallot, EF  $\leq$ 35%, and VT risk (e.g., QRS  $\geq$ 180 ms).
- Myocarditis:
  - Persistent EF  $\leq$ 35% with VT or high-risk features after acute phase.
- Left Ventricular Non-Compaction (LVNC):
  - EF  $\leq$ 35% or sustained VT, high SCD risk due to trabeculated myocardium.

## CRT-Ds :

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- Heart Failure with Dyssynchrony:
  - EF  $\leq$ 35%, NYHA class II-IV, QRS duration  $\geq$ 130 ms (especially LBBB morphology), on OMT.
  - Patients who meet ICD criteria and have dyssynchrony (CRT-D provides both resynchronization and defibrillation).
- Pacing-Induced Dyssynchrony:
  - Patients with frequent RV pacing (>40%) from a pacemaker, developing HF symptoms or reduced EF due to dyssynchrony.

- Specific Conditions:
  - HCM with HF:
    - Rarely used; for patients with  $EF \leq 35\%$ ,  $QRS \geq 130$  ms, and NYHA II-IV despite OMT.
  - Post-Ablation:
    - After AV node ablation for AF, if  $EF \leq 35\%$  and  $QRS \geq 130$  ms, to prevent pacing-induced dyssynchrony.
  - Cardiac Sarcoidosis:
    - If  $EF \leq 35\%$ ,  $QRS \geq 130$  ms, and NYHA II-IV, to address both dyssynchrony and SCD risk.
  - Non-Ischemic Cardiomyopathy with Atrial Fibrillation:
    - CRT-D considered if  $QRS \geq 130$  ms,  $EF \leq 35\%$ , and high pacing burden expected.

## Different Types

### Pacemakers :

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- Single-Chamber:
  - One lead (usually RV); used for isolated sinus bradycardia or permanent AF with bradycardia.
- Dual-Chamber:
  - Two leads (RA and RV); maintains AV synchrony, preferred for SND or AV block with intact sinus rhythm.
- Leadless Pacemakers:
  - Single-chamber device implanted directly in RV (e.g., Micra); reduces lead-related complications.
- Rate-Responsive:
  - Sensors (e.g., accelerometer) adjust pacing rate based on activity; used for chronotropic incompetence.

### ICDs :

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- Single-Chamber ICD:
  - One lead in RV; for patients needing only ventricular pacing/defibrillation.
- Dual-Chamber ICD:
  - Leads in RA and RV; allows atrial pacing/sensing, better for arrhythmia discrimination.

- Subcutaneous ICD (S-ICD):
  - No transvenous leads; subcutaneous lead for patients at risk of SCD without pacing needs (e.g., young patients, infection risk).

## CRT-Ds:

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- Biventricular ICD:
  - Three leads (RA, RV, LV via coronary sinus); synchronizes RV/LV contraction, includes ICD function.
  - His-Bundle or Left Bundle Branch Pacing:
  - Emerging techniques for more physiological pacing in CRT candidates.

## Managing Settings

## Pacemakers:

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- Mode: **Nomenclature (e.g., DDD:** dual-chamber pacing, dual-chamber sensing, dual response [inhibited/triggered]).
- DDD:
  - Most common for dual-chamber; paces/senses RA and RV, maintains AV synchrony.
- VVI:
  - Single-chamber RV pacing; used in permanent AF.
- Rate Settings:
  - Lower rate limit (e.g., 60 bpm) ensures minimum heart rate; upper rate limit prevents excessive pacing.
- AV Delay:
  - Programmed to optimize AV synchrony (e.g., 150-200 ms); shorter in HCM to reduce outflow gradient.
- Rate Response:
  - Adjust sensitivity for activity (e.g., increase pacing rate during exercise).

## ICDs:

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- Detection Zones:
  - VT Zone: Program rate threshold (e.g., 160-200 bpm) for VT detection; delivers ATP (anti-tachycardia pacing) or shock.
- VF Zone: Higher rate threshold (e.g., >200 bpm); delivers immediate shock (e.g., 30-40 J).
- Therapies:
  - ATP: First-line for VT; delivers rapid pacing to terminate reentry.
  - Shock: For VF or failed ATP; biphasic shocks (200 J).

- Bradycardia Pacing: Similar to pacemaker settings (e.g., VVI or DDD mode).

## **CRT-Ds:**

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- Biventricular Pacing:
  - Optimize AV delay (e.g., 100-150 ms) and VV delay (e.g., LV pacing 20-40 ms before RV) to maximize synchrony.
- Percentage of Biventricular Pacing:
  - Target >98% for efficacy; adjust settings if pacing loss occurs.
- ICD Settings:
  - Same as standalone ICD (VT/VF zones, ATP, shocks).
- Optimization:
  - Use ECHO to assess dyssynchrony (e.g., septal-to-lateral wall delay); adjust timings to improve CO.

## **Complications**

### **Intra-Procedural:**

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- Pneumothorax/Hemothorax:
  - From subclavian vein access; risk 1-2%.
- Lead Dislodgement:
  - Occurs during implantation; requires repositioning.
- Perforation/Cardiac Tamponade:
  - Rare; lead perforation of RV or coronary sinus (CRT); urgent pericardiocentesis if tamponade.

### **Early Post-Procedure (Days to Weeks):**

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- Pocket Hematoma:
  - Risk increased with anticoagulation; manage conservatively unless infection or dehiscence.
- Infection:
  - Pocket infection (1-2% risk); requires device removal if systemic infection (e.g., endocarditis).
- Lead Dislodgement:
  - Leads may shift (2-3% risk); requires repositioning or replacement.

## Late Complications:

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- Device Infection/Endocarditis:
  - Risk 0.5-1% per year; often *S. aureus* or coagulase-negative Staph; requires device removal and antibiotics.
- Lead Failure:
  - Insulation break or fracture (1-2% per year); causes inappropriate shocks, pacing failure; requires lead revision.
- Inappropriate Shocks (ICD/CRT-D):
  - Due to oversensing (e.g., T-wave oversensing, lead noise) or misclassified SVT; adjust detection settings.
- Venous Thrombosis:
  - Subclavian vein thrombosis (1-3%); anticoagulation if symptomatic.
- Tricuspid Regurgitation:
  - Lead interference with tricuspid valve; monitor with ECHO.
- CRT Non-Response:
  - 20-30% of CRT patients; due to suboptimal lead placement, non-LBBB QRS morphology, or scar burden; reassess with ECHO, consider lead repositioning.

## Post-Procedure Care and Complications

### Immediate Post-Procedure:

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- Monitoring:
  - Telemetry for 24-48 hours to confirm pacing/sensing thresholds and detect arrhythmias.
  - Chest X-ray to verify lead position, rule out pneumothorax.
- Wound Care:
  - Keep incision site dry x 7 days; monitor for erythema, swelling (infection/hematoma).
- Activity Restrictions:
  - Avoid arm movement above shoulder (implant side) x 4-6 weeks to prevent lead dislodgement.
- Antibiotics:
  - Peri-procedural antibiotics (e.g., cefazolin 2 g IV) to reduce infection risk; no post-op antibiotics unless infection suspected.

## Follow-Up:

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- Device Interrogation:
  - The next day following the procedure, At 1 month, then q3-6 months; check pacing thresholds, battery life (typically 5-10 years), arrhythmia logs.
- ECHO:
  - Assess RV function, TR (pacemakers/ICDs), and LV synchrony (CRT-D) at 3-6 months.
- Adjust Settings:
  - Optimize AV/VV delays (CRT-D), adjust detection zones (ICD) based on arrhythmia burden.
- Patient Education:
  - Avoid MRI (unless MRI-conditional device), report fever/pocket site changes, carry device ID card.

## Post-Procedure Complications:

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- Infection:
  - Presents as pocket erythema, fever, or systemic symptoms; culture-guided antibiotics (e.g., vancomycin for MRSA), device removal if severe.
- Hematoma:
  - Ice packs, pressure dressing; surgical evacuation if expanding or infected.
- Inappropriate Shocks:
  - Reprogram device (e.g., adjust VT detection rate, increase ATP attempts); treat underlying SVT if present.
- Lead Dislodgement:
  - Chest X-ray to confirm, reposition lead if pacing/sensing failure.
- Device Malfunction:
  - Battery depletion, lead fracture; urgent device interrogation, lead/device replacement.



## Key Pearls

**Indications:** Pacemakers for SSS, AV block, tachy-brady; ICDs for SCD prevention (post-arrest, EF  $\leq 35\%$ , inherited syndromes); CRT-Ds for HF with dyssynchrony (QRS  $\geq 130$  ms).

**Types:** Single/dual-chamber pacemakers, leadless pacemakers, S-ICDs, biventricular CRT-Ds.

**Settings:** DDD mode for pacemakers, VT/VF zones for ICDs, optimize AV/VV delays for CRT-D.

**Complications:** Infection (1-2%), lead dislodgement (2-3%), inappropriate shocks (ICD), non-response (CRT).

**Post-Procedure:** Telemetry x 24-48h, restrict arm movement x 4-6 weeks, regular device checks q3-6 months.

**Patient Care:** Educate on device ID, avoid MRI (unless conditional), monitor for infection signs.

## References

**UpToDate:** "Pacemakers and ICDs: Indications and Management" (2025). UpToDate Devices

**AHA/ACC:** "Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities" (2024). AHA Guidelines

**ESC:** "Cardiac Resynchronization Therapy in Heart Failure" (2023). ESC Guidelines

**NEJM:** "Complications of Cardiac Implantable Electronic Devices" (2024). NEJM CIED

## Case Scenarios

### Case 1: A 75-Year-Old Male with Syncope

- Presentation: A 75-year-old male presents with recurrent syncope. Exam shows HR 40 bpm, BP 110/70 mmHg, no murmurs.

- Labs/ECG: ECG shows 3rd-degree AV block with ventricular escape rhythm. ECHO normal.
- Diagnosis: Symptomatic 3rd-Degree AV Block → Syncope, complete heart block.
- Management: Admit for pacemaker placement. Implant dual-chamber pacemaker (DDD mode, RA/RV leads). Set lower rate at 60 bpm, AV delay 150 ms. Post-procedure: telemetry x 24h, chest X-ray confirms lead position, no pneumothorax. Restrict arm movement x 6 weeks. Device check at 1 month shows normal pacing thresholds. Discharge with follow-up.

## Case 2: A 60-Year-Old Male Post-Cardiac Arrest

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- Presentation: A 60-year-old male with ischemic cardiomyopathy (EF 30%) presents after a VT arrest, resuscitated with defibrillation. Exam post-arrest shows HR 80 bpm, BP 100/60 mmHg.
- Labs/ECG: ECG shows sinus rhythm, QRS 110 ms. ECHO confirms EF 30%, no new ischemia.
- Diagnosis: VT Arrest (Secondary Prevention) → Cardiac arrest, ischemic cardiomyopathy.
- Management: Admit to ICU. Implant single-chamber ICD (RV lead). Set VT zone (160-200 bpm, ATP), VF zone (>200 bpm, 30 J shock). Post-procedure: telemetry confirms sensing thresholds, no pneumothorax on X-ray. Monitor for pocket hematoma (patient on apixaban; ice packs applied). Device check at 1 month; adjust VT zone to 170 bpm after inappropriate shock (SVT). Discharge with cardiology follow-up.

## Case 3: A 55-Year-Old Female with Heart Failure

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- Presentation: A 55-year-old female with non-ischemic cardiomyopathy (EF 25%, NYHA III) presents with dyspnea and fatigue despite OMT. Exam shows HR 70 bpm, BP 100/65 mmHg, S3 gallop.
- Labs/ECG/ECHO: **ECG:** LBBB, QRS 150 ms. ECHO: EF 25%, LV dyssynchrony (septal-to-lateral delay).
- Diagnosis: HF with Dyssynchrony → EF  $\leq$  35%, LBBB, QRS  $\geq$  130 ms, NYHA III.
- Management: Admit for CRT-D placement. Implant biventricular ICD (RA, RV, LV leads). Set AV delay 120 ms, VV delay (LV 20 ms before RV), VT zone (160 bpm), VF zone (200 bpm). Post-procedure: ECHO shows improved synchrony, pacing >98%. Monitor for infection (cefazolin 2 g IV given). Restrict arm movement x 6 weeks. Device check at 3 months; EF improves to 35%. Discharge with HF follow-up.

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