Pacemakers and Defibrillators

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Disclosures

• I have no disclosures.
Educational goals

• Review bradycardia definitions and guidelines
• Review indications for pacemaker implantation
• Pacemaker modes and troubleshooting common errors
• Review post CIED complications and management
• Review indications for cardiac resynchronization therapy
• Review indications for ICD implantation
Sinus node dysfunction - Definitions

- Sinus bradycardia: Sinus rate <50 bpm
- Ectopic atrial bradycardia: Atrial depolarization attributable to an atrial pacemaker other than the sinus node with a rate <50 bpm
- Sinoatrial exit block: Evidence that blocked conduction between the sinus node and adjacent atrial tissue is present. Multiple electrocardiographic manifestations including “group beating” of atrial depolarization and sinus pauses.
- Sinus pause: Sinus node depolarizes >3 s after the last atrial depolarization
- Sinus node arrest: No evidence of sinus node depolarization
- Tachycardia-bradycardia (“tachy-brady”) syndrome: Sinus bradycardia, ectopic atrial bradycardia, or sinus pause alternating with periods of abnormal atrial tachycardia, atrial flutter, or AF.
- Chronotropic incompetence: Broadly defined as the inability of the heart to increase its rate commensurate with increased activity or demand, in many studies translates to failure to attain 80% of expected heart rate reserve (220-resting HR) during exercise.
- Isorhythmic dissociation: Atrial depolarization (from either the sinus node or ectopic atrial site) is slower than ventricular depolarization (from an atrioventricular nodal, His bundle, or ventricular site).

AV node dysfunction - Definitions

- First-degree atrioventricular block: P waves associated with 1:1 atrioventricular conduction and a PR interval >200 ms (this is more accurately defined as atrioventricular delay because no P waves are blocked)
- Second-degree atrioventricular block: P waves with a constant rate (<100 bpm) where atrioventricular conduction is present but not 1:1
  - Mobitz type I: P waves with a constant rate (<100 bpm) with a periodic single nonconducted P wave associated with inconstant PR intervals
  - Mobitz type II: P waves with a constant rate (<100 bpm) with a periodic single nonconducted P wave associated with constant PR intervals (excluding 2:1 atrioventricular block)
  - 2:1 atrioventricular block: P waves with a constant rate (or near constant rate because of ventriculophasic sinus arrhythmia) rate (<100 bpm) where every other P wave conducts to the ventricles
  - Advanced, high-grade or high-degree atrioventricular block: 2 consecutive P waves at a constant physiologic rate that do not conduct to the ventricles with evidence for some atrioventricular conduction
- Third-degree atrioventricular block (complete heart block): No evidence of atrioventricular conduction
- Vagally mediated atrioventricular block: Any type of atrioventricular block mediated by heightened parasympathetic tone
- Infranodal block: Atrioventricular conduction block where clinical evidence or electrophysiologic evidence suggests that the conduction block occurs distal to the atrioventricular node

Indications for pacemaker implantation

• Symptoms
• Symptoms
• Symptoms
Pacemaker implantation is indicated for symptomatic bradycardia in following situations:

- Sinus node dysfunction (SND), including frequent pauses
- Symptomatic chronotropic incompetence
- Symptomatic bradycardia resulting from necessary medical therapy
- HR<40 bpm with equivocal symptoms
- Syncope of unexplained origin with evidence of SND
- Any third degree or advanced second-degree AV block at any anatomic level
- Reasonable for first-degree or second-degree AV block
- Reasonable for unexplained syncope with bifascicular block
Indications for pacemaker in asymptomatic patients

• SND with persistent HR <40 bpm. (Class IIb)
• Third-degree and advanced second-degree AV block in awake patients, sinus rhythm, with documented pauses >3 seconds or escape <40 bpm or escape below AV node
• Third-degree and advanced second-degree AV block in awake patients, with AF and bradycardia, with 1 or more pause >5 seconds
• Third-degree and advanced second-degree AV block in post operative patients not expected to resolve
• Third-degree and advanced second-degree AV block in awake patients, sinus rhythm, with Avg. HR >40 bpm, with cardiomegaly or LV dysfunction
• Third-degree and second-degree AV block during exercise in absence of myocardial ischemia
• Alternating bundle branch block or advanced AV block with underlying bifascicular block

2012 ACCF/AHA/HRS Focused Update of the 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities
Electrophysiology study

Permanent pacemaker implantation is reasonable for asymptomatic second-degree AV block at intra or infra-His levels found at electrophysiological study.
Permanent pacemaker implantation is not indicated in:
(Class III)

- SND in asymptomatic patients or bradycardia due to nonessential drugs
- Asymptomatic first-degree AV block
- Asymptomatic type-I second degree AV block (at AV node level)
- AV block that is expected to resolve (Drug toxicity, Lyme disease, hypoxia during sleep apnea in absence of symptoms)
- Bifascicular or trifascicular block in absence of symptoms
- Transient asymptomatic AV block in absence of IVCD

2012 ACCF/AHA/HRS Focused Update of the 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities
Permanent pacing in hypersensitive carotid sinus syndrome

• Indicated for recurrent syncope caused by spontaneously occurring carotid sinus stimulation and carotid sinus pressure with pauses > 3 seconds.

• Not indicated for a hypersensitive cardioinhibitory response to carotid sinus stimulation without symptoms or with vague symptoms.

• Not indicated for situational vasovagal syncope in which avoidance behavior is effective and preferred.

2012 ACCF/AHA/HRS Focused Update of the 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities
Permanent pacing after acute myocardial infarction

- Indicated for persistent second-degree AV block with alternating BBB or infra-nodal third-degree AV block (More common with anterior MI)
- Indicated for transient second or third-degree infranodal AV block and associated BBB. (2018 bradycardia guidelines recommend pacing after waiting period)
- Persistent and symptomatic second or third-degree AV block

- Not indicated for transient AV block without IVCD (More common with inferior MI)
- Not indicated for asymptomatic new BBB, fascicular block or first-degree AV block

2012 ACCF/AHA/HRS Focused Update of the 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities
Modes of pacing

• NASPE – North American Society of Pacing and Electrophysiology (HRS)
• BPEG – British Pacing and Electrophysiology Group

NBG Code (1987)

NASPE / BPEG / Generic CODE
<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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<tbody>
<tr>
<td></td>
<td>Chamber Paced</td>
<td>Chamber Sensed</td>
<td>Response to Sensing</td>
<td>Rate Response</td>
<td>Multi Sight Pacing</td>
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<tr>
<td>A-</td>
<td>Atrium</td>
<td>A- Atrium</td>
<td>I - Inhibit</td>
<td>R – Rate response on</td>
<td></td>
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<tr>
<td>V-</td>
<td>Ventricle</td>
<td>V- Ventricle</td>
<td>T - Trigger</td>
<td>Blank – Rate response off</td>
<td></td>
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<tr>
<td>D-</td>
<td>Dual (A+V)</td>
<td>D- Dual (A+V)</td>
<td>D- Dual (I or T)</td>
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<td></td>
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<tr>
<td>O-</td>
<td>Off/None</td>
<td>O – Off/None</td>
<td>O – Off/None</td>
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<tr>
<td>Single Chamber modes</td>
<td>Dual Chamber modes</td>
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<tr>
<td>VOO (Asynchronous)</td>
<td>DDD</td>
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<td></td>
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<tr>
<td>VVI</td>
<td>VDD</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>AOO (Asynchronous)</td>
<td>DDI (Synchronous and asynchronous)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAI</td>
<td>DOO (Asynchronous)</td>
<td></td>
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Selection of pacemaker modes

- Sinus rhythm, symptomatic bradycardia – DDDR/DDD
- Permanent afib – VVIR/VVI
- Paroxysmal afib, transient pauses – DDDR (mode switch ->DDIR)
Magnet Mode

• In Pacemaker – Magnet will turn off sensing
  - Forced pacing at pre-determined rate
  - VOO/DOO mode

• In ICD – Tachycardia detection suspended
  - ‘closes eyes of the ICD portion’
  - Pacemaker portion will function as programmed
Cautery/surgery mode

- In pacemaker dependent patients – DOO/VOO
- For ICDs – Turn therapies off
- Other option is to place a magnet

Do not forget to turn therapies back on and reset to pre-op settings after procedure!
Special programming modes

- MVP (AAIR -> DDDR) – Managed ventricular pacing
- RHYTHMIQ – Boston Scientific

Managed Ventricular Pacing (MVP) is an atrial-based pacing mode that significantly reduces unnecessary right ventricular pacing by primarily operating in an AAI(R) pacing mode while providing the safety of a dual chamber backup mode if necessary.

1. When ventricular pacing is less than 40%, for each 10% increase in ventricular pacing there is a 54% relative increase in risk for heart failure hospitalization.

2. When ventricular pacing is greater than 40%, a patient's relative risk for heart failure hospitalization remains constant.

3. The risk of atrial fibrillation increases linearly as the percentage of ventricular pacing increases from 0% to 85%.

DDI

- P wave tracking occurs only when atrium is paced at the lower rate limit.
- Once atrial lead starts sensing, communication between atrium and ventricle is lost.
- Even if atrial sensed rate increases, ventricular paced rate remains at the lower rate limit resulting in loss of AV synchrony.
Mode switch

Mode Switch is a rate control feature designed to prevent the tracking of paroxysmal atrial tachycardias.

This is performed by placing the device in DDIR mode until the episode is over, preventing a rapid ventricular paced rate in response to the rapid atrial rate.
Special programming modes

- **Rate drop response** – Rate Drop Response (RDR) is intended to provide backup pacing and prevent associated symptoms in patients who experience occasional episodes of significant drop in heart rate (e.g. syncope from cardioinhibitory and mixed forms of carotid sinus syndrome).
Pacemaker Intervals

Dual Chamber Timing

Refractory and Blanking Periods

ARP  PVARP

Those affecting the atrial channel are indicated above the ECG baseline.

PVAB

VRP

Those affecting the ventricular channel are indicated below the ECG baseline.

Red: Blanking
Orange: Refractory period
Pacemaker mediated tachycardia
PMT – Pacemaker mediated tachycardia
PMT Management
- > Prolong PVARP
Pacemaker Wenckebach
Pacemaker
Wenckebach
Device malfunction

  - Usually late manifestation after procedure.

  - Usually early post procedure manifestation.

- Lead insulation failure – Fall in Impedance (<250 Ohms)

- Lead dislodgement – Normal impedance, failure to capture/high threshold.
Electromagnetic Interference (EMI)

NonSustV Event Onset

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>Avg A Rate</td>
<td>74 bpm</td>
</tr>
<tr>
<td>Avg V Rate</td>
<td>300 bpm</td>
</tr>
<tr>
<td>Event Ended</td>
<td>00:00:15</td>
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</table>
Post procedure complications

• Hematomas
• Infection
• Lead dislodgement
• Myocardial perforation
• Pneumothorax
Hematomas –
Try to manage conservatively.
2017 HRS expert consensus statement on cardiovascular implantable electronic device lead management and extraction
CIED infection

2017 HRS expert consensus statement on cardiovascular implantable electronic device lead management and extraction.
Pneumothorax. Also consider pneumothorax if DFT testing fails.
Perforation
Cardiac Resynchronization Therapy (CRT)

LV systolic dysfunction with clinical HF is frequently accompanied by inter and intra-ventricular conduction delay (most commonly LBBB). Ventricular electromechanical delay ‘dyssynchrony’ can lead to:

- Reduced ventricular systolic function
- Altered myocardial metabolism
- Functional mitral regurgitation
- Adverse remodeling with ventricular dilatation

CRT results in modification of ventricular electromechanical delay with multisite ventricular pacing ‘biventricular pacing’
Cardiac Resynchronization Therapy (CRT)
BiV Pacing
The Effect of Cardiac Resynchronization on Morbidity and Mortality in Heart Failure. NEJM April 2005
Cardiac-Resynchronization Therapy for the Prevention of Heart-Failure Events. NEJM 2009
MADIT-CRT responders

Cardiac-Resynchronization Therapy for the Prevention of Heart-Failure Events. NEJM 2009
Indications for CRT

CRT is indicated in patients with heart failure on GDMT and LVEF<35% with following criteria

- LBBB, QRS duration >150msec, NYHA class II, III, ambulatory class IV (class I)

- LBBB, QRS duration 120-149 msec, NYHA class II, III, ambulatory class IV (class IIa)

- Non-LBBB, QRS duration >150 msec, NYHA class III, ambulatory class IV (class IIa)

- Anticipated requirement for significant (>40%) ventricular pacing
• Maximum benefit of CRT is when >97% biventricular pacing is achieved.
• Common causes of suboptimal BiV pacing –
  1. Atrial fibrillation. Consider better rate control or AV node ablation.
  2. Frequent PVCs
2018 ACC/AHA/HRS Bradycardia guidelines

In patients with:

- LVEF between 36% to 50% and AV block
- Indication for permanent pacing
- Expected to require ventricular pacing >40% of the time

CRT or His bundle pacing are reasonable in preference to right ventricular pacing to prevent heart failure.
His Bundle Pacing

Central Illustration: His Bundle Pacing and Outcomes: Kaplan-Meier Survival Curves and Analysis of the Primary Endpoint in All Patients

Primary Outcome
(Death, Heart Failure Hospitalization, or Upgrade to Biventricular Pacing)

Ethics

• A patient with decision making capacity or his/her legally-defined surrogate has the right to refuse or request withdrawal of pacemaker therapy, even if the patient is pacemaker dependent.

• This should be considered palliative, end of life care, not physician-assisted suicide or euthanasia.

• However, any decision is complex, should involve all stakeholders, and will always be patient specific.


2012 ACCF/AHA/HRS Focused Update of the 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities
Implantable Cardioverter-Defibrillator (ICDs)
ICD principles

• Electrical defibrillation has been used clinically as the principal effective treatment for VF for more than half a century.

• Once a sufficient portion of the cardiac tissue is made temporarily unexcitable by a shock, the uncoordinated wavefronts of excitation that perpetuate VF would be extinguished, and would allow normal cardiac excitation and contraction to resume.

• This concept remains the underlying principle of defibrillation.

• Future directions: Painless defibrillation.

Termination of ventricular fibrillation in dogs by depolarizing a critical amount of myocardium. Zipes D et al. Am J Cardiol. 1975

<table>
<thead>
<tr>
<th>Trial</th>
<th>Year</th>
<th>LVEF less than or equal to</th>
<th>Other inclusion criteria</th>
<th>Hazard ratio</th>
<th>95% Confidence Interval</th>
<th>P value</th>
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<tbody>
<tr>
<td>MADIT I</td>
<td>1996</td>
<td>35%</td>
<td>NSVT, Positive EP study</td>
<td>0.46</td>
<td>0.26-0.82</td>
<td>0.009</td>
</tr>
<tr>
<td>MADIT II</td>
<td>2002</td>
<td>30%</td>
<td>Prior MI</td>
<td>0.69</td>
<td>0.51-0.93</td>
<td>0.016</td>
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<tr>
<td>SCD-HeFT</td>
<td>2005</td>
<td>35%</td>
<td>Prior MI or NICMP</td>
<td>0.77</td>
<td>0.62-0.96</td>
<td>0.007</td>
</tr>
<tr>
<td>CABG-Patch</td>
<td>1997</td>
<td>36%</td>
<td>Positive SAECG</td>
<td>1.07</td>
<td>0.81-1.42</td>
<td>0.64</td>
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<tr>
<td>DEFINITE</td>
<td>2004</td>
<td>35%</td>
<td>NICMP, PVCs, or NSVT</td>
<td>0.65</td>
<td>0.40-1.06</td>
<td>0.08</td>
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<tr>
<td>AVID</td>
<td>1997</td>
<td>40%</td>
<td>Prior cardiac arrest</td>
<td>0.62</td>
<td>0.43-0.82</td>
<td>&lt;0.02</td>
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<tr>
<td>CASH</td>
<td>2000</td>
<td>45%</td>
<td>Prior cardiac arrest</td>
<td>0.77</td>
<td></td>
<td>0.082</td>
</tr>
<tr>
<td>CIDS</td>
<td>2000</td>
<td>35%</td>
<td>Prior cardiac arrest, syncope</td>
<td>0.82</td>
<td>0.6-1.1</td>
<td>NS</td>
</tr>
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### Indications for ICD implantation

<table>
<thead>
<tr>
<th>ICMP</th>
<th>NICMP</th>
<th>CLASS III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survivors of cardiac arrest due to VF/sustained VT after excluding completely reversible cause.</td>
<td>Survivors of cardiac arrest due to VF/sustained VT after excluding completely reversible cause.</td>
<td>Expected survival &lt; 1 year</td>
</tr>
<tr>
<td>LVEF &lt;35%, atleast 40 days post MI or 90 days post revascularization, NYHA class II or III HF</td>
<td>LVEF &lt;35%, NYHA class II or III HF</td>
<td>Incessant VT or VF</td>
</tr>
<tr>
<td>LVEF &lt;30%, atleast 40 days post MI or 90 days post revascularization, NYHA class I HF</td>
<td></td>
<td>Significant psychiatric illnesses</td>
</tr>
<tr>
<td>NSVT, Prior MI, LVEF &lt;40% and inducible VF or sustained VT at EP study. (MUSTT trial)</td>
<td></td>
<td>NYHA class IV drug refractory HF in patients who are not candidates for transplant or CRT-D</td>
</tr>
</tbody>
</table>
Guidelines for patients not well represented in ICD trials – HRS/ACC/AHA expert consensus

ICD recommended in patients with abnormal cardiac biomarkers that are not thought to be due to an MI and who otherwise would be candidates for ICD implantation.

HRS/ACC/AHA Expert Consensus Statement on the Use of Implantable Cardioverter-Defibrillator Therapy in Patients Who Are Not Included or Not Well Represented in Clinical Trials.
ICD within 40 days after MI

Implantation of an ICD is not recommended within the first 40 days after the MI unless other potential reasons for an ICD implant are present.

**DINAMIT**

- Cumulative Risk of Death from Any Cause
- No. at Risk: ICD group 315, 299, 258, 211, 172, 123, 82, 25
- No. at Risk: Control group 318, 305, 272, 217, 172, 124, 79, 31
- Months after Randomization: 0, 6, 12, 18, 24, 30, 36, 42, 48
- P = 0.66

**IRIS**

- Cumulative Risk of Death from Any Cause
- No. at Risk: ICD group 445, 390, 366, 338, 303, 253, 207, 163, 137, 106, 78, 48, 40
- Months since Randomization: 0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, 72
- P = 0.76, P_\text{adj} = 0.78
- ICD group 116 Deaths
- Control group 117 Deaths
ICD within 40 days after MI or 90 days of revascularization or < 9 months from initial diagnosis of NICMP.

- Patients require non elective permanent pacing and meet primary prevention criteria for ICD implantation.
- Sustained VT or syncope thought to be due to VT.

HRS/ACC/AHA Expert Consensus Statement on the Use of Implantable Cardioverter-Defibrillator Therapy in Patients Who Are Not Included or Not Well Represented in Clinical Trials.
ICD within 90 days of revascularization

- Patients who previously met ICD criteria for secondary prevention of SCD and have abnormal LV function.
- Patients who previously met ICD criteria for secondary prevention of SCD (unlikely due to myocardial ischemia) and normal LV function.
- Patients who previously met ICD criteria for secondary prevention of SCD due to VT/VF – not related to acute MI and subsequently found to have CAD that is revascularized.

- In patients with cardiac arrest related to acute MI who undergo complete revascularization and have normal LVEF, ICD is not recommended.

HRS/ACC/AHA Expert Consensus Statement on the Use of Implantable Cardioverter-Defibrillator Therapy in Patients Who Are Not Included or Not Well Represented in Clinical Trials.
Subcutaneous ICD

- For ICD implantation in young patients, subcutaneous ICD implantation is now an option.

- Subcutaneous ICDs should be considered as an alternative to transvenous when there is –
  - no need for pacing
  - anti-tachycardia pacing unlikely to be effective
Thank You and Stay Safe!
Obstructive Sleep Apnea

Both sleep disorders of breathing and nocturnal bradycardias are relatively common, and treatment of sleep apnea not only reduces the frequency of these arrhythmias but also may offer cardiovascular benefits.

The presence of nocturnal bradycardias should prompt consideration for screening for sleep apnea.

However, nocturnal bradycardia is not in itself an indication for permanent pacing.

### Recommendations for Sleep Apnea Evaluation and Treatment in Patients With Documented or Suspected Bradycardia or Conduction Disorders

Referenced studies that support recommendations are summarized in Online Data Supplement 5.

<table>
<thead>
<tr>
<th>COR</th>
<th>LOE</th>
<th>Recommendations</th>
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<tbody>
<tr>
<td>I</td>
<td>B-NR</td>
<td>1. In patients with documented or suspected bradycardia or conduction disorder during sleep, screening for symptoms of sleep apnea syndrome is recommended with subsequent confirmatory testing directed by clinical suspicion.</td>
</tr>
<tr>
<td>I</td>
<td>B-NR</td>
<td>2. In patients with sleep-related bradycardia or conduction disorder and documented obstructive sleep apnea, treatment directed specifically at the sleep apnea (eg, continuous positive airway pressure and weight loss) is recommended.</td>
</tr>
<tr>
<td>IIA</td>
<td>B-NR</td>
<td>3. In patients who have previously received or are being considered for a PPM for bradycardia or conduction disorder, screening for sleep apnea syndrome is reasonable.</td>
</tr>
</tbody>
</table>
Recommendations for Conduction Disturbances after TAVR

• Class I: In patients who have new atrioventricular block after transcatheter aortic valve replacement associated with symptoms or hemodynamic instability that does not resolve, permanent pacing is recommended before discharge.

• Class IIa: In patients with new persistent bundle branch block after transcatheter aortic valve replacement, careful surveillance for bradycardia is reasonable.

Post TAVR

**CENTRAL ILLUSTRATION:** Strategy Algorithm Proposal for the Management of Patients With Conduction Disturbances Post-Transcatheter Aortic Valve Replacement

- **TAVR Candidate**
  - Pre-procedural risk evaluation of conduction disturbances
  - Procedural aspects to minimize the risk of conduction disturbances
  - Procedural telemetry and 12-lead (6-lead) ECG at the end of the procedure

- **No ECG changes**
  - No pre-existing RBBB
  - No temporary pacing
  - Telemetry for 24 hrs (or at least overnight)

- **No ECG changes**
  - Pre-existing RBBB

- **ECG changes**
  - Further ECG changes in the presence of prior conduction disturbances
  - New-onset LBBB
  - HAVB/CHB
  - Temporary pacing for 24 hrs (or at least overnight)*

- **No further evaluation/observation**
- **Further evaluation/observation** (temporary pacing, EP studies, continuous ECG monitoring)

*Consider earlier discontinuation of temporary pacing if regression of ECG changes in <24 h (except for pre-existing RBBB).

Danish Trial

Defibrillator Implantation in Patients with Nonischemic Systolic Heart Failure. NEJM 2016

1. Reduction in SCD
2. Mortality benefit in patient <59 years old
3. Patients with less severe CHF