Cardiac Arrhythmias

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Electrophysiology of the Heart
- **Depolarization**
  - Shift in membrane potential away from resting negative transmembrane potential
- **Repolarization**
  - Return of membrane potential to resting negative polarization
- **Refractory Period**
  - Minimum time between depolarizations
- **Conduction Velocity**
  - Velocity of the wave of depolarization

Depolarization and Repolarization

Action Potential Variation

The QRS is the Result of Summing all of the Cardiac Action Potentials

Action Potential and Contraction
Conduction System

Basic Mechanisms of Arrhythmia

- Tachycardia
  - Reentry
  - Focal
- Bradycardia
  - Failure of impulse initiation
  - Failure of impulse conduction

Reentry

- A wavefront of depolarization self propagates through an anatomic circuit in the myocardium
- The conduction velocity, refractory period, and length of the circuit of the tissue must be such that the tissue is excitable when the wave front returns to an area in the circuit previously depolarized

Reentry

- Wavelength = distance traveled by a wave front during the refractory period
- The length of a potential re-entry circuit must be less than the wavelength of the tissue
- Slower conduction and shorter refractoriness make reentry more likely to occur

Reentry failure

- Shorten the refractory period
Reentry

The most common cause of tachyarrhythmias
Requires
- An anatomic circuit
- Slow conduction and short refractory period
- Wavelength shorter than the anatomic circuit

Paroxysmal Supraventricular Tachycardia (PSVT)

Diagnosis
Mechanisms of PSVT
Treatment

PSVT - Diagnosis

History
- Any age
- Typically sudden onset and offset
- Palpitations, chest pain, dyspnea, dizziness
- May be terminated by vagal maneuvers

ECG
- Event monitors very helpful
- Narrow complex regular tachycardia

Sinus Rhythm
Sinus Rhythm

Accessory Pathway Conduction

AV Node Re-entry (AVNRT) vs Atrial Ventricular Re-entry (AVRT)

Medical Treatment of PSVT
- Change electrophysiology to prevent reentry
- Prolong refractoriness in the AV node
  - Adenosine
  - Beta blocker
  - Diltiazem/Verapamil
- No medical therapy that speeds conduction

Medical Termination of SVT

PSVT Ablation
- Indications
  - Pre-excitation and PSVT
  - No pre-excitation recurrent episodes
- Episodes frequent or severe enough that the patient desires therapy
  - Daily medical therapy is considered
- Success rates near 95%
- Significant complications in <3%
Ablation of an Accessory Pathway

**Focal Tachycardia**
- Originates from a specific site in the myocardium
- Spontaneous focal depolarization sends wavefronts of depolarization through the myocardium
- Drug toxicity (digoxin) can cause a focal tachycardia due to “delayed after depolarizations”

**Focal Tachycardias**
- <5% of supraventricular arrhythmias
- Can be suppressed by medical therapy
  - Beta blocker
  - Calcium channel blocker
  - Type I and type III antiarrhythmic therapy
- Can be eliminated by ablation

**Atrial Fibrillation**
- The most common arrhythmia
- Mechanism is controversial
  - Multiple wandering reentry circuits
  - Focal tachycardia
  - Both
- Diagnosed by ECG (12 lead, Holter, event monitor)
  - No organized atrial activity
  - Irregular ventricular rate

**Multiple Wavelet AF**

**Before and After Ablation**
Risk Factors for Stroke in AF

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Relative Risk (multivariate)</th>
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<tbody>
<tr>
<td>Prior stroke</td>
<td>2.1 - 2.5</td>
</tr>
<tr>
<td>Age</td>
<td>1.2 - 1.4 (per decade)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>1.6 - 2.2</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.7</td>
</tr>
<tr>
<td>CHF</td>
<td>2.6</td>
</tr>
<tr>
<td>LA size</td>
<td>1.6 - 2.7</td>
</tr>
</tbody>
</table>

Absolute Risk
Age < 65 years and no risk factors, “lone AF”: ≤1%/yr.....
All others: 3.5%-8+%/yr.

Goals of Treatment
- Prevent stroke
- Prolong life
- Preserve exercise tolerance
- Eliminate palpitations

Studies of Warfarin in AF

CHADS2 Risk Factors for Stroke
- Congestive heart failure
- Hypertension
- Age >75
- Diabetes
- Secondary prevention (prior CVA or TIA) 2 points

CHADS2 Risk of Stroke

<table>
<thead>
<tr>
<th>Points</th>
<th>Stroke Rate per 100 Person Years</th>
<th>NNT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Warfarin</td>
<td>Warfarin</td>
</tr>
<tr>
<td>0</td>
<td>0.49</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>1.52</td>
<td>0.72</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>1.27</td>
</tr>
<tr>
<td>3</td>
<td>5.27</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>6.02</td>
<td>2.35</td>
</tr>
</tbody>
</table>

Who Should Take Warfarin
AHA/ACC/ESC

<table>
<thead>
<tr>
<th>CHADS2 points</th>
<th>Treatment Suggested</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ASA</td>
</tr>
<tr>
<td>1</td>
<td>Warfarin or ASA</td>
</tr>
<tr>
<td>2 or more</td>
<td>Warfarin</td>
</tr>
</tbody>
</table>

JAMA 1994;154:1449-57
JAMA 2001;285:2864-2870
JAMA 2003;290:2685-2692
J Am Coll Cardiol 2006;48:e149-e246
Wanted: Replacement for Warfarin

- Oral medication
- No need for blood draws to monitor effect
- Safe
- At least as effective as warfarin

Aspirin Plus Clopidogrel Inferior to Warfarin

Lancet 2006;367:1903-1912

SPORTIF III
Warfarin vs Ximelagatran

Lancet 2003;362:1691-98

Ximelagatran Not Approved by the FDA

- Liver toxicity with long term use
  - 1 in 200 severe liver toxicity
  - 1 in 2000 fatal liver toxicity
- Many agents under investigation
- None close to approval

Goals of Treatment

- Prevent stroke
- Prolong life
- Preserve exercise tolerance
- Eliminate palpitations

Rate Control vs. Rhythm Control

- Treat the symptoms vs.
- Eliminate the arrhythmia
Benefits of Rhythm Control

- Reduce palpitations
- Physiologic control of ventricular rate
- AV synchrony may improve cardiac function
- Regular rhythm may improve cardiac function

Downside of Rhythm Control

- Possible proarrhythmic effects of antiarrhythmic medications
- Recurrences are common
- No evidence that antiarrhythmic therapy prevents stroke
- Risks and success rates of ablation procedures not well defined
- Maze requires open heart surgery

Benefits of Heart Rate Control

- Most symptoms are related to HR not rhythm
- HR usually controlled with drug therapy
- Avoid adverse effects of antiarrhythmic drugs
- AV node ablation plus pacemaker highly effective when medical Rx fails

Downside of Heart Rate Control

- Some patients need atrial contribution even at controlled ventricular rates
- Some patients do not tolerate the sensation of an irregular rhythm
- Still in AF, “normal” sinus rhythm must be better

**AFFIRM**

- 4060 pts with AF and risk factor for CVA randomized to rhythm vs rate control
- Specific rhythm and rate control drug choices left to the local investigator
- Primary endpoint: total mortality
- Secondary endpoints: adverse events, hospitalizations, quality of life

**Rate Control in AFFIRM**

![Graph showing successful rate control over time](J Am Coll Cardiol 2004;43:1201-8)
Recurrence of AF After Cardioversion in AFFIRM

![Graph showing recurrence of AF after cardioversion in AFFIRM]

Am Heart J 2006;151: 390-396

Sinus Rhythm During Follow-up

![Graph showing sinus rhythm during follow-up]

AFFIRM Mortality Results

![Graph showing cumulative mortality over time]

N Eng J Med 2002;347:1825-33

Adverse Events in AFFIRM

<table>
<thead>
<tr>
<th></th>
<th>Rate Control n=2027</th>
<th>Rhythm Control n=2033</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Strokes</td>
<td>105 (7.4)</td>
<td>106 (8.9)</td>
<td>0.93</td>
</tr>
<tr>
<td>Ischemic Stroke</td>
<td>77 (5.5)</td>
<td>80 (7.1)</td>
<td>0.79</td>
</tr>
<tr>
<td>Off warfarin</td>
<td>25</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>On warfarin INR&lt;2</td>
<td>27</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>During AF</td>
<td>42</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Hospitalization</td>
<td>1220 (73)</td>
<td>1374 (80)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Quality of Life in AFFIRM

![Graph showing quality of life scores over time]

Am Heart J 2005:149:112-20

Risk Factors for Death in AFFIRM

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>HR</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (per year)</td>
<td>1.06</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CAD</td>
<td>1.65</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CHF</td>
<td>1.83</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.56</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Stroke or TIA</td>
<td>1.54</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Smoking</td>
<td>1.75</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sinus rhythm</td>
<td>0.54</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Warfarin</td>
<td>0.47</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Digoxin</td>
<td>1.50</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Rhythm control drug</td>
<td>1.41</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Circulation 2004;109:1509-1513
AFFIRM Implications

- No compelling reason to pursue rhythm control in patients who tolerate the rate control strategy
- Apparent rhythm control is probably not a reason to stop warfarin
- Rhythm control is still a viable option in patients who do not tolerate the rate control strategy

Who Should be Started on an Antiarrhythmic Medication?

- Patients with recurrent episodes of AF who have significant symptoms during AF despite best attempts at rate control therapy
  - Paroxysmal more often than persistent AF
  - LVH appears to be a risk for intolerance of AF
- Patients with persistent AF will usually also require cardioversion

Amiodarone vs Propafenone vs Sotalol

- 1998 Haissaguerre reports that PACs mapped to the pulmonary veins induced AF in 27 of 29 patients with recurrent paroxysmal AF
- Ablation at the sites of PAC origin in the pulmonary veins eliminated recurrent AF in 17

Atrial Fibrillation Ablation?

- PACs arise in atrial fibers that extend into the pulmonary veins
- Ablation of the fibers where they enter the veins reduces the risk of pulmonary vein stenosis
- If all veins are isolated the need to map the origin PACs that induce AF is eliminated
- Can be performed during AF

AF induced by PV PAC

Pulmonary Vein Isolation

- PACs arise in atrial fibers that extend into the pulmonary veins
- Ablation of the fibers where they enter the veins reduces the risk of pulmonary vein stenosis
- If all veins are isolated the need to map the origin PACs that induce AF is eliminated
- Can be performed during AF
Pulmonary Vein Isolation

Atrial Fibrillation Ablation

Circumferential PV Ablation

Circumferential PV Ablation

Circumferential PV Ablation (LACA) vs Pulmonary Vein Isolation (SOA) in Paroxysmal AF

Efficacy of LACA

- 146 patients
- 12 with structural heart disease
- Ave age 56 years
- Persistent AF
- 2 prior drug failures
- Recurrence within 7 days of cardioversion

Pappone developed a technique where ablation is performed circumferentially around each PV at least 5mm from the PV orifice

Do not carefully map block in and out of the pulmonary veins instead use an anatomic approach to “isolate” the veins

Pappone Circulation 2000;102:2619
Efficacy of LACA

Atrial arrhythmias-free survival

- Ablation group
- Control group

No at risk

Ablation: 68 67 53 48 46 42 41 41 39 38 38 38
Control: 69 69 23 18 14 11 7 6 6 4 4 4 4


Atrial Fibrillation Ablation Complications

<table>
<thead>
<tr>
<th>Complication</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air embolism</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tamponade</td>
<td>1.3%</td>
</tr>
<tr>
<td>TIA</td>
<td>1%</td>
</tr>
<tr>
<td>CVA</td>
<td>0.4%</td>
</tr>
<tr>
<td>Pulmonary vein stenosis</td>
<td>2.7%</td>
</tr>
<tr>
<td>Phrenic nerve injury</td>
<td>0.3%</td>
</tr>
<tr>
<td>Esophageal atrial fistula</td>
<td>?</td>
</tr>
</tbody>
</table>

Atrial Fibrillation Ablation

- Effective treatment for AF
- Still an evolving procedure
- No large randomized trials comparing ablation to medical therapy
- Should be reserved for highly symptomatic patients who have not responded to best efforts at rate and rhythm control

Bradycardia

- Failure of impulse initiation
  - Sick sinus syndrome
  - Failure of the sinus node
- Failure of impulse conduction
  - Heart block
  - Poor conduction through the AV node or his bundle

Bradycardia

- Frequently caused by medications
  - Beta blockers
  - Diltiazem/verapamil
- Often no clearly identified cause
- Pacemaker implant is indicated if the bradycardia is symptomatic and persists after medications that can be stopped are stopped

Sinus Arrest
Complete Heart Block

Ventricular Tachycardia
- Originates in the ventricle
- Often a life threatening arrhythmia
- Usually seen in patients with prior myocardial infarction or other significant heart disease (cardiomyopathy)
- Reentry in and around areas of infarcted or severely diseased myocardium
- Can occur in patients with normal hearts but is usually a benign focal arrhythmia

Ventricular Fibrillation
- Multiple wavelets or reentry in the ventricles
- Commonly (10%) seen during an acute MI
- Patients with any kind of severe structural heart disease are at risk
- Can occur in structurally normal hearts when there is an inherited electrophysiologic disorder
- Uniformly fatal without defibrillation

Dual Chamber Pacmaker

Ventricular Tachycardia
- Origins in the ventricle
- Often a life threatening arrhythmia
- Usually seen in patients with prior myocardial infarction or other significant heart disease (cardiomyopathy)
- Reentry in and around areas of infarcted or severely diseased myocardium
- Can occur in patients with normal hearts but is usually a benign focal arrhythmia

Treatment of VT and VF
- Most antiarrhythmic medications have a significant risk of proarrhythmia
- Amiodarone the most effective medication
- When amiodarone was compared to ICD implant in a large randomized trial of VT/VF survivors the ICD was superior
Anti-tachycardia Pacing Terminating VT

Defibrillation of VF

Secondary vs Primary Prevention

- 95% of patients do not survive and out of hospital cardiac arrest

- Can patients at high risk of having cardiac arrest due VT/VF be identified and can overall survival be improved by medical or device therapy?

SCD-HeFT

Risks for Sudden Death
- EF ≤ 0.35
- Class II or III CHF symptoms

Exclusions
- CABG 3 mo, PCI 3 mo
- Unstable CHF

Randomization
- ICD vs Amiodarone vs Placebo

SCD-HeFT Demographics

<table>
<thead>
<tr>
<th></th>
<th>Amiodarone (n=845)</th>
<th>Placebo (n=847)</th>
<th>ICD (n=829)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>60.4</td>
<td>59.7</td>
<td>60.1</td>
</tr>
<tr>
<td>Ejection Fraction</td>
<td>0.25</td>
<td>0.25</td>
<td>0.24</td>
</tr>
<tr>
<td>CHF</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>29%</td>
<td>32%</td>
<td>31%</td>
</tr>
<tr>
<td>Prior MI</td>
<td>50%</td>
<td>53%</td>
<td>52%</td>
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</table>
## Medical Therapy SCD-HeFT

<table>
<thead>
<tr>
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<th>Amiodarone (n=845)</th>
<th>Placebo (n=847)</th>
<th>ICD (n=829)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACEI or ARB</td>
<td>85%</td>
<td>88%</td>
<td>86%</td>
</tr>
<tr>
<td>Beta blocker</td>
<td>72%</td>
<td>79%</td>
<td>82%</td>
</tr>
<tr>
<td>Digoxin</td>
<td>59%</td>
<td>62%</td>
<td>63%</td>
</tr>
<tr>
<td>Loop diuretic</td>
<td>79%</td>
<td>80%</td>
<td>79%</td>
</tr>
<tr>
<td>Statin</td>
<td>48%</td>
<td>46%</td>
<td>48%</td>
</tr>
</tbody>
</table>

## SCD-HeFT Results

![Graph showing treatment outcomes](image_url)