Ablation I

2019/02/28

What you can expect to learn today

- Wrap up defibrillation/ICDs
- What is ablation
- How were ablative technologies developed
- What type of electrodes are used and where are they placed for each type of ablation
- The modalities for ablation
  - Advantages/disadvantages of each
- Applications of ablation

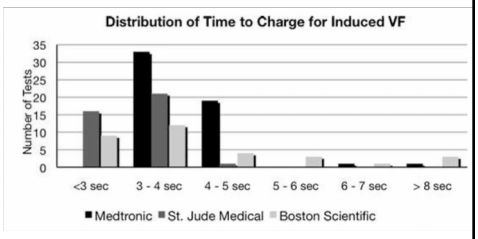
2

ICD Overview

- ICDs are indicated for two groups:
  1. Secondary prevention of SCD in patients with prior VT, VF, or resuscitated SCD thought to be casued by VT/VF
  2. Primary prevention of SCD in at-risk patients for VT/VF
     - Patients with prior MI and EF<30%
     - Cardiomyopathy NYHA class II-III and EF<35%
     - Syncope with structural heart disease and inducible sustained VT
     - Congenital LQT with recurrent symptoms
- Contraindicated for:
  - VT due to reversible, non-structural cause (e.g. drugs, electrolyte imbalance)
  - No reasonable survival with function for at least one year
  - Severe psychiatric illness that may be exacerbated
  - Active infections
  - Patients amenable to ablation

ICD Overview

- What's inside?
  - Recording of EGM events
  - Remote monitoring
  - Pacing/sensing/defibrillation electrodes



Performance Characteristics for Induced Ventricular Fibrillation

	Boston Scientific (n = 32 tests)	Medtronic (n = 54 tests)	St. Jude Medical (n = 38 tests)	P value
VF zone cycle length	>250 BPM	>240 ms	>240 ms	
Detection duration	1 second	18/24 beats	12 beats	
Rapid VT cycle length	185–250 BPM	240–320 ms	240–320 ms	
Detection duration	2.5 seconds	18/24 beats	12 beats	
Mean time to ICD charging: seconds (±SD)	4.24 ± 1.46	3.99 ± 1.03*	3.00 ± 0.4	<0.05
ICD charge starts >5 seconds: n (%)	6 (19)	2 (4)*	0 (0)	<0.05
Number of tests with ATP as first therapy for induced VF: n (%)	3 (9.4)	0	0	<0.05
Mean time to charging when ATP is first therapy for induced VF: seconds (range)	10.1 (8.2–13)			

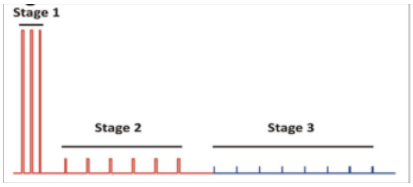
*Includes event which was adjudicated as VT.

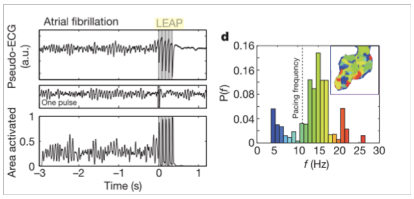
ICD Programming

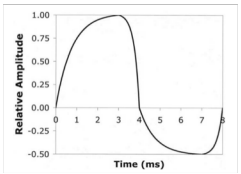
- Typically capable of pacing and CRT (if Bi-V) as well.
- Arrhythmia detection:
  - Basic algorithms rely on duration and rate.
    - Duration of arrhythmia must be long enough to warrant a response
    - Arrhythmia detection is based primarily on rate.
      - Rate cutoff of 220 bpm is safe.
      - Two groups: one with high rate cutoff and one without:
        - 20% without received inappropriate shock, 4% with did.
        - All-cause mortality was double without!
  - SVT is slower than VF but can be similar to slow VTs
    - Need discriminators for SVT -- many based on QRS templates
    - AV dissociation in VT
    - Atrial rate vs Ventricular rate (but careful with VT + AF)
    - Interval stability (if AF driven)
    - Chamber of onset (abrupt in ventricle vs gradual)
  - Noise detection
    - Physiological (e.g T/P-wave oversensing)
      - High bandpass filters, pattern matching
    - Non-physiological (e.g. electromagnetic interference)
      - Frequency content is non-physiological
      - Typically from lead failure (can monitor impedance)
  - ICD HR Zones: VT <180 bpm, VT>250 bpm, VF/VT>250
  - Cardioversion vs. Defibrillation

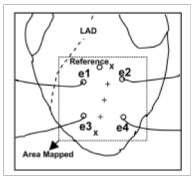
Other Attempts to Defibrillate and the Problem of Pain

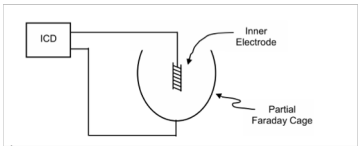
- Multistage electrotherapy
- LEAP
- Waveform Shape/lower DFT
- Multisite (SyncP)
- Prepulse inhibition
- Optogenetic
- Skeletal muscle activation





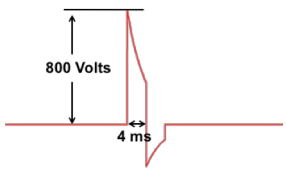


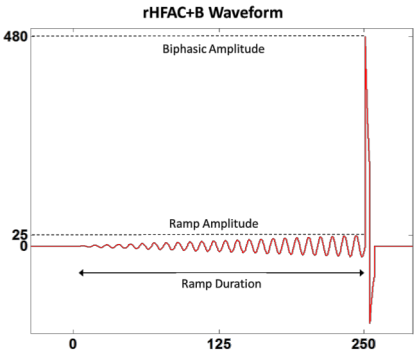




Shameless Plug:

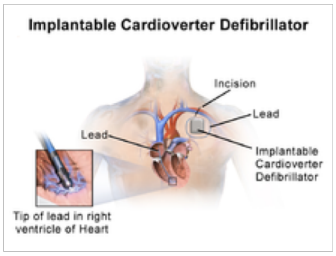
- Patients who experience an ICD shock are more anxious than those who do not, and they do not adapt well to living with an ICD
- The effects of ICDs could lead to anxiety and depression levels comparable to panic patients
- A retrospective study found that 16% of ICD patients developed anxiety disorder and that it was related to the number of shocks
- Psychological interventions may be indicated
- 5% of patients in one study said they would rather risk death without an ICD than experience another shock!
- "Endocardial cardioversion shock energy >0.1J is perceived to be uncomfortable, and patients fail to distinguish energy levels higher than this."*





Quickly revisit defibrillation leads

- Typically platinum and/or tantalum
  - Chemically inert
- Alloys to increase strength



High level view of ablation

- Used in heart, bone, liver, kidney, breast, brain, adrenal, prostate, and lung.
- Cardiac ablation was on of the earliest medical uses
- Hepatic primary and secondary tumor ablation is one of the most widely studied.
- The modalities have shifted, but radiofrequency ablation remains the most common

How was cardiac ablation developed? In 1981, not so serendipitously…

- "The first AV block induced by an electrode catheter was rather serendipitous…Inadvertently, the defibrillating electrode accidentally came into contact with an electrode catheter situated in the bundle of His—resulting in a high-voltage discharge and damage to the surrounding endocardium. The ensuing complete heart block sparked a search for a technique to terminate arrhythmias using transvenous catheters"

Ablation for Cardiac Arrhythmias

- Alternative to pharmacological treatment
  - Often effective but has high failure rate, can be proarrhythmic, and can become toxic.
- Modalities:
  - Cryothermal
  - Radiofrequency
  - Laser
  - DC ablation
- Indicated for:
  - Atrioventricular reentrant tachycardia (e.g. WPW)
    - i.e. accessory pathways!
  - AV nodal reentrant tachycardia
  - Atrial flutter
  - AF
  - Ventricular ectopy
  - VT (monomorphic!)
  - Recurrent VT/VF despite antiarrhythmic therapy (secondary prevention)

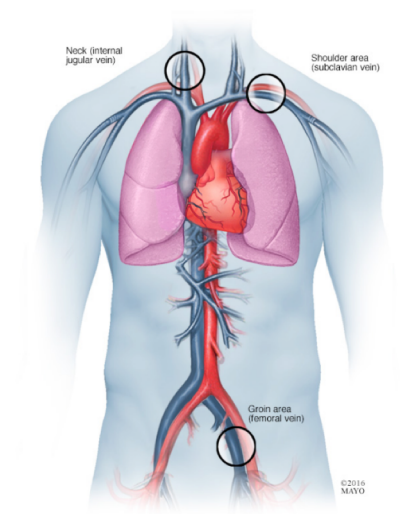
Success Rates and Complications

Procedure	First procedure success rates (%)	Commonly occurring risks
SVT ablation (AVRT, AVNRT, atrial tachycardia)	90–95	PPM (<0.5% in most but may be up to 5% if the abnormal pathway is very close to the AV node), thromboembolism (0.1%), tamponade (0.1%), death (0.05%), repeat procedure (5–10%)
AV node ablation and PPM insertion	99	Tamponade (0.1%), death (0.05%)
Atrial flutter ablation	90–95	PPM (<0.5%), tamponade (0.1%), death (0.05%)
VT ablation (normal heart)	90	PPM (<0.5%), thromboembolism (0.1%), tamponade (0.1%), death (0.05%), repeat procedure (5–10%)
VT ablation (structural heart disease, e.g. previous MI)	70–80	Thromboembolism (1%), tamponade (2%), death (0.5%)
Atrial fibrillation ablation	50–70 (with more than one procedure, success rates may be 80–90%)	Thromboembolism (0.5–1%), tamponade (2%), repeat procedure (25–40%), death (0.1%) PV stenosis (rare), atrio–oesophageal fistula (rare)

Figures shown are averages and there may be variation in individual cases.
PPM: permanent pacemaker; MI: myocardial infarction.

Cardiac ablation – How do we get there?

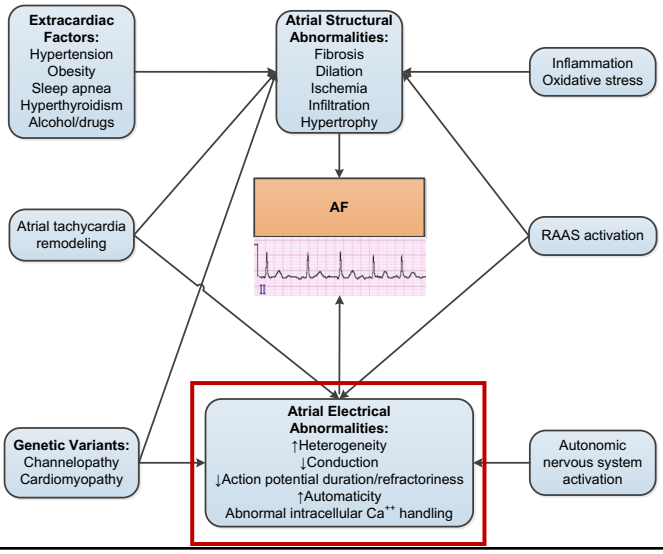
- Typically done with catheterization
- Access through the neck/shoulder or leg
- Uses fluoroscopy
- Multiple catheters
  - EGM mapping
  - Ablation
  - Intracardiac ultrasound
- 5-6 hour procedure time
  - ~half is ablation time
- Transseptal puncture for AF



Focusing on AF: Classifications

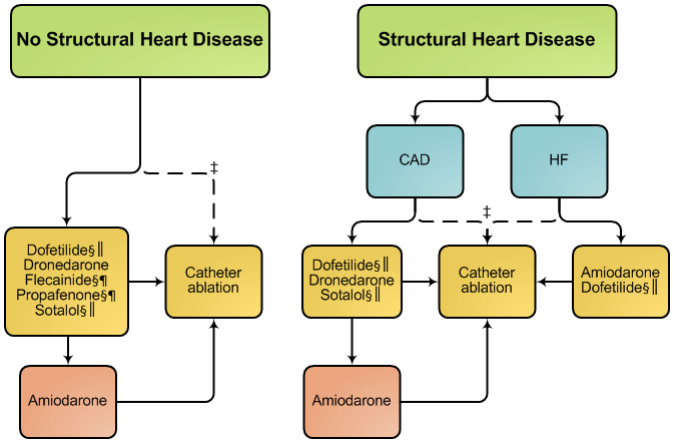
Term	Definition
Paroxysmal AF	• AF that terminates spontaneously or with intervention within 7 d of onset. • Episodes may recur with variable frequency.
Persistent AF	• Continuous AF that is sustained >7 d.
Long-standing persistent AF	• Continuous AF >12 mo in duration.
Permanent AF	• The term "permanent AF" is used when the patient and clinician make a joint decision to stop further attempts to restore and/or maintain sinus rhythm. • Acceptance of AF represents a therapeutic attitude on the part of the patient and clinician rather than an inherent pathophysiological attribute of AF. • Acceptance of AF may change as symptoms, efficacy of therapeutic interventions, and patient and clinician preferences evolve.
Nonvalvular AF	• AF in the absence of rheumatic mitral stenosis, a mechanical or bioprosthetic heart valve, or mitral valve repair.

What causes it?



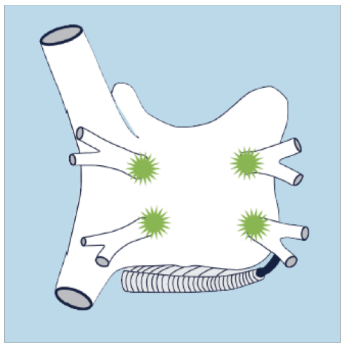
How is AF managed?

Paroxysmal and persistent† AF:



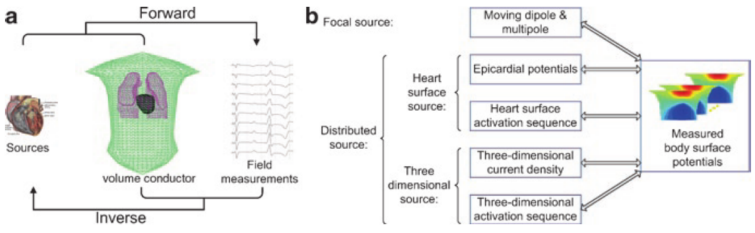
Where to ablate?

- Pulmonary vein isolation (PVI)
  - Cornerstone for paroxysmal AF
  - HRS statement:
  - "PVI is now widely accepted as the cornerstone of AF ablation procedures. Electrical isolation of the PVs is recommended during all AF ablation procedures."
- Five randomized controlled trials found no benefit beyond PVI for AF



Cardiac Mapping

- Invasive procedures (CARTO by Biosense Webster, Ensite Velocity by St. Jude Medical, etc.) use either sequential measurements from a single catheter or multielectrode arrays to map activation sites
- Noninvasive mapping: the ECG inverse problem
  - Body surface potential mapping (BSPM) places hundreds of electrodes over a patient's torso
  - Goal is to determine location, magnitude, trends, etc. of sources in the heart
  - What's the problem?
  - Under-constrained
    - Number of surface leads is smaller than the number of variables (individual cells, conductivity profiles, temperature gradients, motion, etc.)
    - The torso filters the signal. The inverse is, therefore, extremely sensitive to noise

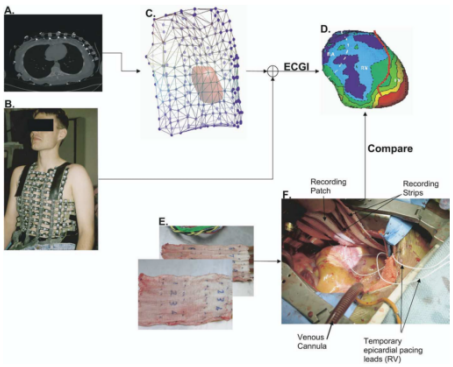


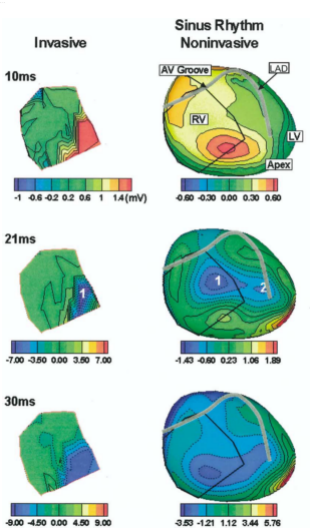
ECGI

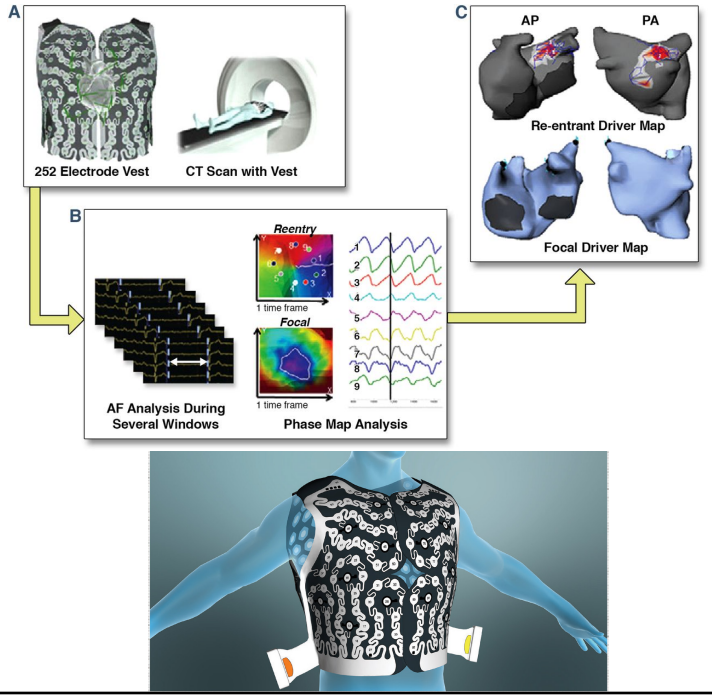
- 224 body surface electrodes (Ag/AgCl)

$$\Phi_T = A\Phi_E$$

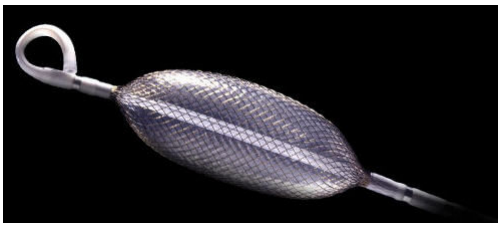
- A is the transfer matrix and is a function of geometry and conductivity

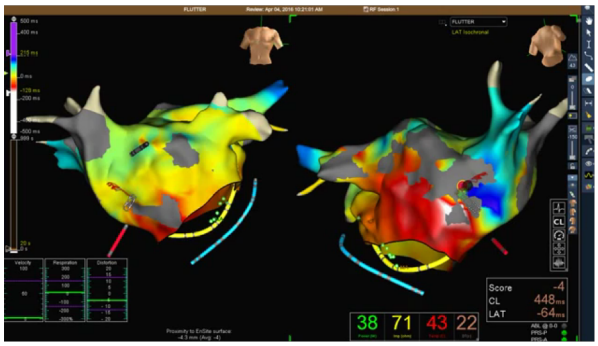






Invasive Mapping-Ensite Precision





Focusing on AF: Recommendations to maintain sinus rhythm

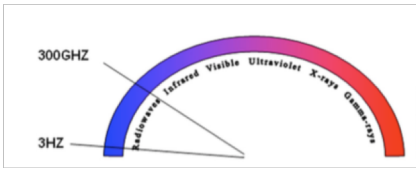
- In order of decreasing support:
  - AF catheter ablation is useful for symptomatic paroxysmal AF refractory or intolerant to at least 1 class I or III antiarrhythmic medication when a rhythm-control strategy is desired.
  - Before consideration of AF catheter ablation, assessment of the procedural risks and outcomes relevant to the individual patient is recommended.
  - AF catheter ablation is reasonable for some patients with symptomatic persistent AF refractory or intolerant to at least 1 class I or III antiarrhythmic medication.
  - In patients with recurrent symptomatic paroxysmal AF, catheter ablation is a reasonable initial rhythm-control strategy before therapeutic trials of antiarrhythmic drug therapy, after weighing the risks and outcomes of drug and ablation therapy.
  - AF catheter ablation may be considered for symptomatic long-standing (>12 months) persistent AF refractory or intolerant to at least 1 class I or III antiarrhythmic medication when a rhythm-control strategy is desired.
  - AF catheter ablation may be considered before initiation of antiarrhythmic drug therapy with a class I or III antiarrhythmic medication for symptomatic persistent AF when a rhythm-control strategy is desired.

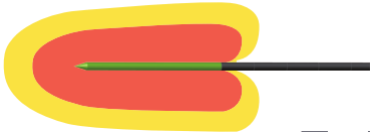
Contraindications

- AF catheter ablation should not be performed in patients who cannot be treated with anticoagulant therapy during and after the procedure.
- AF catheter ablation to restore sinus rhythm should not be performed with the sole intent of obviating the need for anticoagulation.
- Typically the same as the contraindications for catheterization:
  - Unstable angina
  - Bacteremia/septicemia
  - Acute decompensated HF unrelated to the arrhythmia
  - Major bleeding
  - Venous thrombosis
  - Intracardiac thrombus

How to ablate? Radiofrequency energy

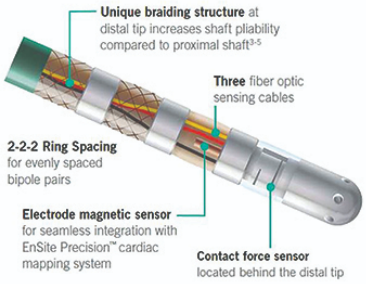
- Radiofrequency is defined as 3 Hz – 300 GHz on the EM spectrum
- RFA in clinical use is typically 350-500 kHz
- Heats tissue via joule heating – near electrode and falls off as we have discussed
- The use of these terms become muddled when we discuss microwave ablation





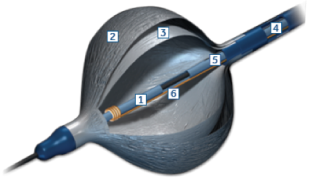
Complications of RF

- Phrenic Nerve Injury (less common than with other modalities)
- Vascular injuries (e.g. hematoma, bleeding) are the most common (from catheterization)
  - Air embolism, pneumothorax
- Cardiac tamponade (fluid build up in the pericardium compresses the heart)
- Perforation
- Third degree heart block
- Airway trauma/hematoma
  - Traumatic intubation followed by heparinzation
- Nerve palsy as a result of improper positioning
- Esophageal Stricture/Perforation



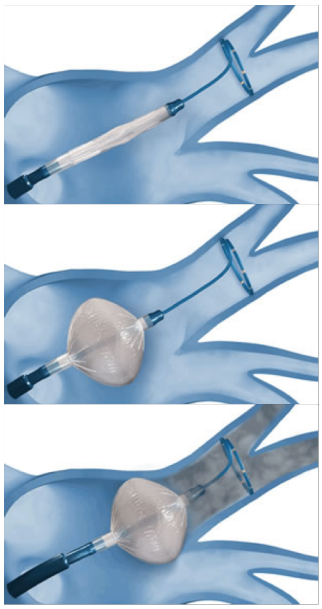
How to ablate? Cryoablation

- Two accepted modalities: Cryoablation and RF
  - Others include ultrasound and laser
- Medtronic Arctic Front Advance:
  1. Guide wire lumen
     - For injection of contrast to confirm occlusion of the vein and for guide wire.
  2. Outer balloon
     - Safety to contain refrigerant in event of inner balloon failure
  3. Inner balloon
     - Refrigerant containment
  4. Pull wires
     - Used to deflect the catheter (up to 45 degrees)
  5. Thermocouple
     - Monitor temperature for refrigerant vapor
  6. Injection tube
     - Refrigerant delivery
- Balloon diameter can be 23 or 28 mm. What are the advantages and disadvantages of different sizes?



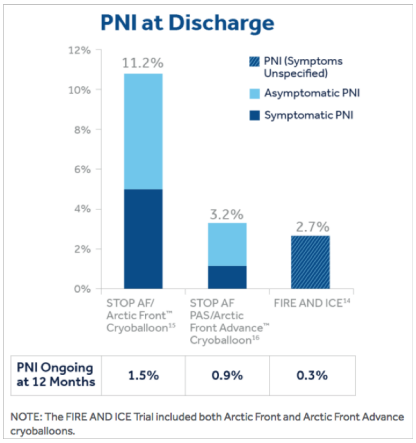
Steps:

1. Access:
   - From the groin through the inferior vena cava then transseptal to the LV
2. Inflate:
   - Positioning the balloon and releasing contrast agent to verify occlusion
3. Freeze:
   - Kill with cooling



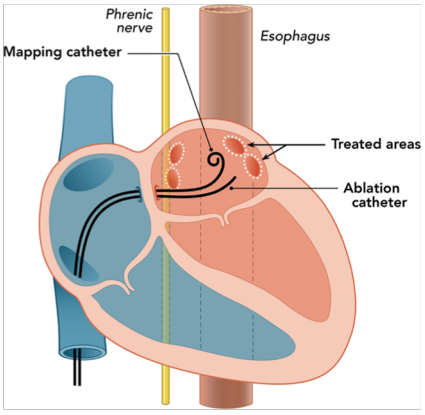
Pros and Cons of Cryoablation

- Single location
  - Creates long contiguous circumferential lesions
  - Shorter, more predictable procedure times
  - FIRE AND ICE trial: 34 % fewer cardiac-related hospitalizations and 33 % fewer repeat ablations
    - Met non-inferiority endpoint
  - Phrenic Nerve Injury (PNI)
    - Transient rate of 3.5-11.2%



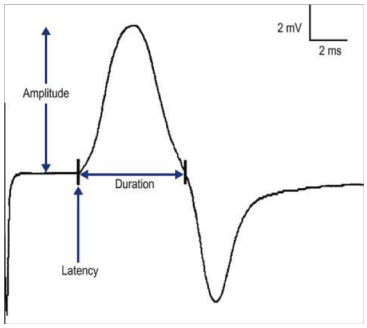
Solve the problem

- PNI is a serious complication, especially for balloon-based (cryo) ablation techniques
  - It can cause dyspnoea, tachypnoea, cough, hiccups, and thoracic pain
- The right phrenic nerve descends close to the superior vena cava and both right superior and inferior pulmonary veins
- Come up with techniques from you knowledge of measurement and stimulation to monitor/reduce PNI



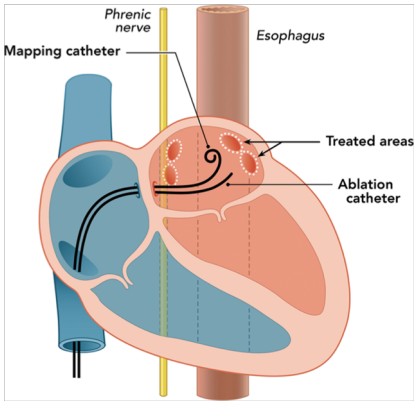
How is it actually dealt with?

- High output pacing to capture the phrenic nerve at a proposed ablation site
- Can anatomically map regions that are closer/further from the nerve using pacing
- Monitor diaphragmatic excursion (manually with palpation or with fluoroscopy/ultrasound) while pacing the nerve proximal to the ablation (from the superior vena cava or subclavian vein)
- Diaphragmatic EMG to diretly monitor diaphragm CMAP (compound motor action potential)
  - Body surface electrode, esophageal electrodes, or hepatic vein catheter electrode.
  - Decreased amplitude by 30 % has been shown to be more sensitive than abdominal palpation for predicting nerve injury



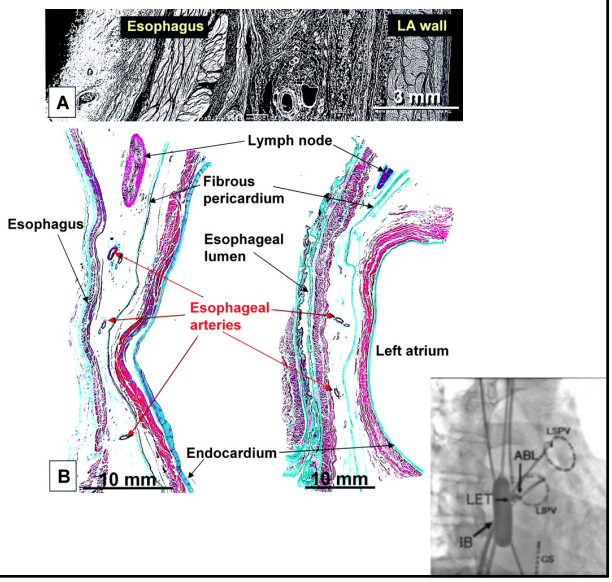
What about the esophagus?

- How close is it?
  - The "cardio-esophageal reflex"
    - Pericardial effusion leads to dysphagia
  - <5 mm from the *endocardium* in 40% of tested cadavers
- How do we deal with this?



What about the esophagus?

- An esophageal temperature probe is positioned directly behind the atrium under fluoroscopic guidance
- The esophagus can be cooled
- This anatomy paper has been cited 230 times!



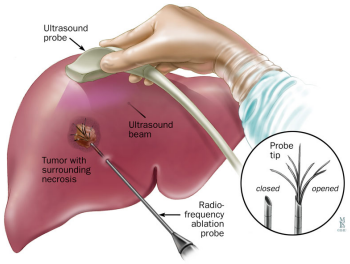
What are the alternatives to ablation?

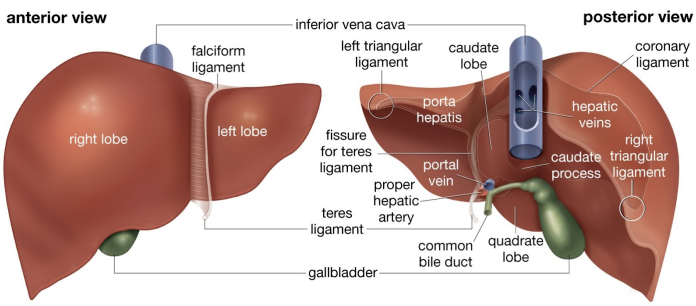
- Antiarrhythmic drugs
- Cardioversion
  - Recommended for patients with AF/flutter as a method to restore sinus rhythm. If cardioversion is unsuccessful, repeated attempts may be made after adjusting the location of the electrodes, applying pressure over the electrodes or following administration of an antiarrhythmic medication.
  - Recommended when a rapid ventricular response to AF/flutter does not respond promptly to drugs and contributes to ongoing ischemia, hypotension, or HF.
  - Cardioversion is recommended for patients with AF/flutter when tachycardia is associated with hemodynamic instability.
  - Repeated cardioversions in patients with persistent AF is moderately reasonable, if sinus rhythm can be maintained for a clinically meaningful period between cardioversion procedures. Severity of AF symptoms and patient preference should be considered if serial cardioversion is required.
- Surgical "Maze" procedure
  - Reasonable for selected patients with AF undergoing cardiac surgery for other indications.
  - As a stand-alone procedure it may be reasonable for selected patients with highly symptomatic AF not well managed with other approaches.

Liver Tumor Ablation

Liver anatomy and general info

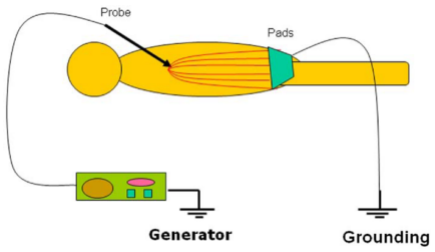
- Portal vein embolization
  - Liver regenerates very well
- Right/Left anatomy
- Problem of arteries

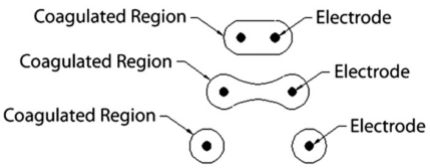


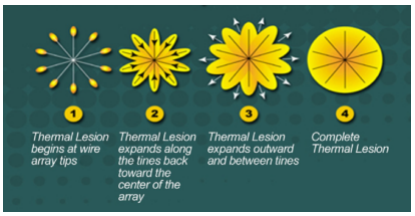


Setup for tumor ablation

- "Star" electrode
- Slow onset/offset – we'll get to why this is
- Several minutes of exposure
- Used for small tumors only



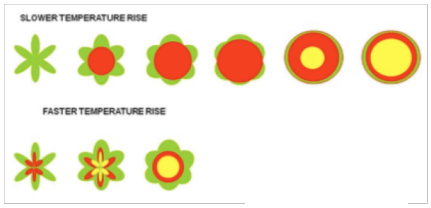


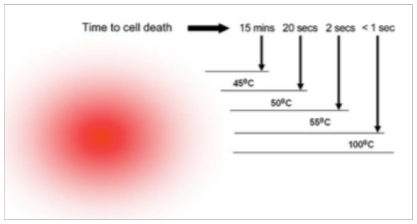


RFA of the liver

Tumor ablation

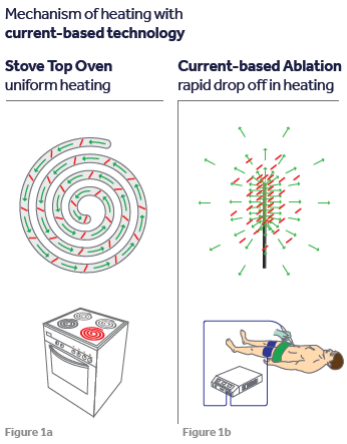
- Mostly RF, but this is changing
- The rate of temperature rise is critical. Why?
- Slower temperature rise results in a larger area of cell death





RFA and MWA (microwave ablation)

- Both are thermal ablation strategies
- RFA was initially used to thermally ablate liver tumors in the late 1980s
- MWA was developed shortly thereafter
- RFA uses joule heating, like an electric stove, where current passes through a resistive element. A stove has a uniform impedance and unchanging cross sectional size across its length, leading to a consistent current and uniform heating.
- Tissue non-uniform (think anisotropy!) and heating falls off over distance (we've seen this before).



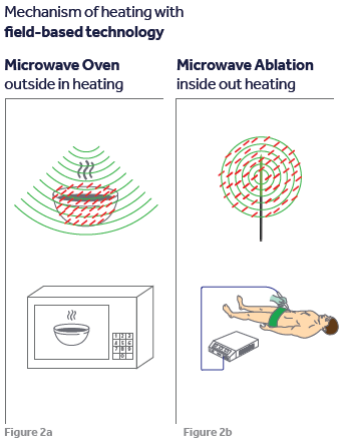
Pros and Cons of RF for tumors

- Long track record
- Familiar technology for oncologists
- Used across medicine, widely available
- Inexpensive compared to newer technology
- Small electrodes (14–17 gauge catheters)
- Proven safety
- Cauterizing effect helps with bleeding
- MRI compatible

- Concerns for needle tract seeding
- Skin pad burns
- Heat sink: RF ablation susceptible to vessel "heat sink"
- Size limitation: RF ablation of larger lesions difficult (from 5–7 cm)
- Speed: ablations are relatively slow
- Monitoring with ultrasound is limited due to gas formation
- Operator-dependent
- Dependent on additional imaging guidance

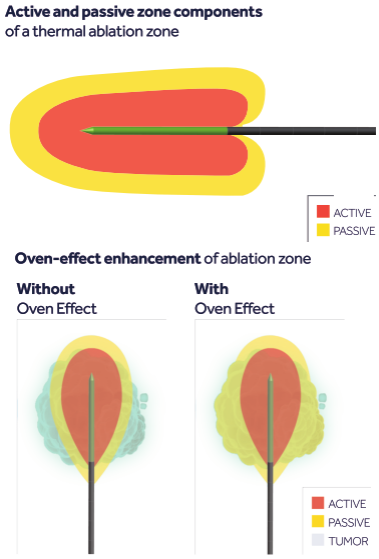
"Field-Based" Technology

- MWA creates an EM field in at ~2.45 GHz (still technically RF!)
  - Optimal water absorbency is ~10 GHz
- Acts much like a microwave oven which rotates polar molecules rapidly to heat (dielectric heating)
- Electrodes are referred to as antennas but they're not, technically.
  - The energy is not applied "far-field" like a microwave oven.
  - The electrode is in contact with the tissue



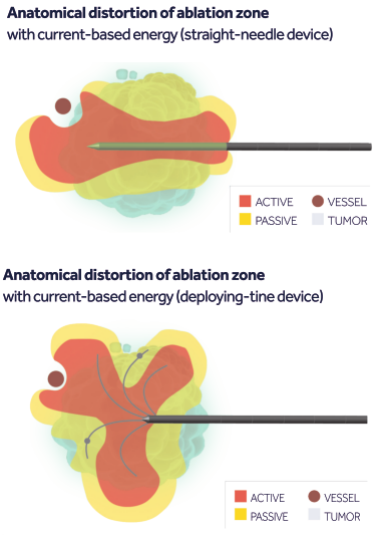
Tissue influence

- The "active" heating occurs near the electrode where the field strength is highest
  - Fast absorption by the tissue
  - Tissue can dissipate heat quickly enough to prevent damage
  - Ablation is achieved in <5min
- The "passive" zone neighbors the active zone with lower field strengths
  - Is coupled via conduction to the active zone.
  - The field strength alone would be insufficient to ablate
  - Is determined based on tissue properties/ability to dissipate heat
- "Oven effect" when tissue boundaries act as insulators



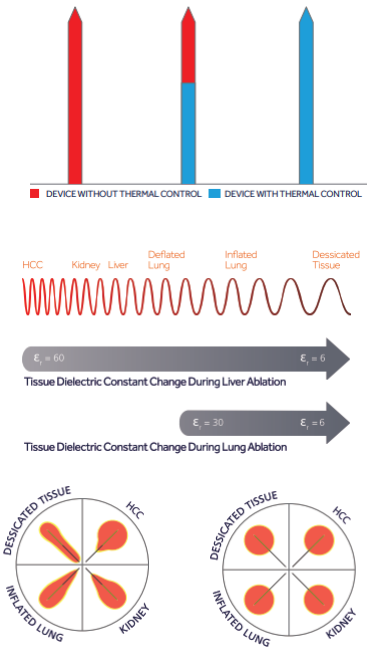
Tissue influence

- Heat sink effect
  - Large vasculature can remove heat from the ablation region
  - Particularly problematic in the passive zone
- Electrical sink effect
  - Vasculature tree, nerves, and other tissue can be conductive and shunt current away from the tumor
- RFA near vessels is not recommended
  - Can get recurrence of tumor and damage to vessels



Latest technology

- The newest MWA catheters use a fluid-cooled lumen to reduce joule heating effects
- "Antennae" are carefully designed to produce the desired field shape
- What about tissue changes?
  - The dielectric constant indicated the 'polarizability' of a material, and it changes during ablation
  - This changes the optimal frequency of vibration/heating
  - If the frequency is not altered then the ablation pattern will be



Proposed benefits of MWA

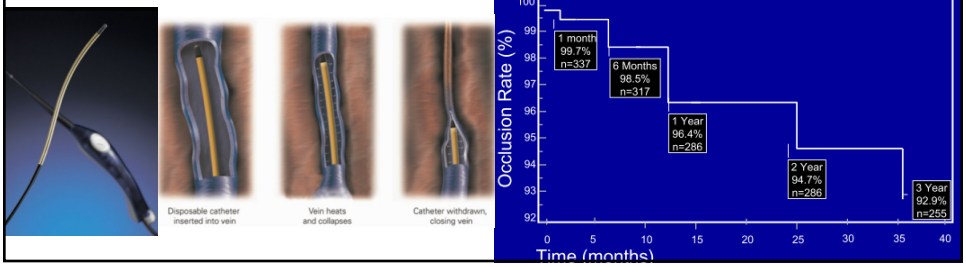
- Faster heating
- Larger, more uniform heating zone
- Less tissue-dependent
- Bipolar -- No grounding pad or second catheter
- Tissue contact is not necessary
- Independent of applied pressure

Lung Ablation

- Similar techniques as liver ablation (e.g. grounding pad, needle, typically RFA)
- Used for palliation
  - Tumor can invade chest wall and cause pain/difficulty breathing
  - Can lead to secondary pulmonary dysfunction
- Not FDA approved
- Has caused deaths and there is a general lack of efficacy
- No medical indication
- Has been used off-label and many medical centers have years of experience despite side-effects
- There is a need for more clinical trials

Other applications of ablation

- Dermatology (aesthetic)
  - Skin resurfacing (laser)
- Varicose veins
  - Catheter is inserted into the vein causing closure
    - Used on the great saphenous vein, the small saphenous vein, and the perforator veins
    - Segmental vs. Continuous



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    - Segmental vs. Continuous
- Obstructive sleep apnea
  - Targets the base of the tongue and other airway structures. Takes ~45 minutes.
- Pain management
  - Rhizotomy to destroy nerve roots
    - Lower back pain, knee pain
    - Nerves recover function (in 3-15 months)
- Barret's esophagus
  - Precancerous condition related to acidic damage to the esophagus