The Surgeon's Contribution To Atrial Fibrillation Therapy: New Paradigms in Treatment

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Cox first clinically employed the Maze operation in September of 1987. It has since been modified into many different lesions sets. The operation prevents re-entry of electrical impulses in the atrium by a division of the atrial tissue into channels of tissue below a critical mass. A critical mass of cardiac tissue is required for re-entry and spiral formation to occur. The refractory period and the conduction velocity determine the magnitude of the critical mass. This is a differential equation of the action potential incorporating the effective refractory period and some part of the relative refractory period. Much attention is now being directed toward minimal invasive treatments for paroxysmal atrial fibrillation and hybrid techniques.

Many hormones, e.g., thyroid, pharmacological agents, and catecholamines effect the refractory period. Alcohol ("holiday heart syndrome") and numerous elicit drugs, e.g., cocaine can alter the refractory period and facilitate atrial fibrillation. Tachycardia mediated atrial fibrillation such as AVNRT and WPW should be evaluated particularly in young patients. All reversible causes of atrial fibrillation should be investigated prior to considering the Maze procedure.

The most common clinical association to atrial fibrillation is prolonged hypertension with valvular and ischemic cardiac disease contributing to the majority of the remaining cases. Lone atrial fibrillation occurs without any identifiable associated cardiac disease. A small proportion of these patients will have genetically identifiable anomalies in ion channel proteins. Atrial fibrillation is pathophysiologically and clinically divided into paroxysmal and chronic. A number of subdivisions create clinical continuity between the two types.

All chronic atrial fibrillation begins as paroxysmal atrial fibrillation. However, paroxysmal atrial fibrillation does not always lead to chronic AF. Surgical treatments are generally based upon these two broad distinct types of atrial fibrillation. As a general rule paroxysmal atrial fibrillation is a trigger-based phenomenon where as, chronic atrial fibrillation is a reentrant-based arrhythmia.

Three salubrious effects of the Maze procedure are realized post-operatively:

1) Maintenance of atrial transport function
2) Correction of irregular heart rate and rhythm
3) Reduction of thromboembolic risk

Indications for the Maze operation include:

1) Chronic atrial fibrillation poorly controlled with medical therapy
2) Paroxysmal atrial fibrillation of increasing frequency without identifiable reversible etiology
3) Intolerance to conventional medicinal therapy
4) Occupation requires freedom from cardiac arrhythmia, e.g., airline pilot
5) Patients at high risk for thromboembolic problems with contraindications to anticoagulant therapy
6) Frequent episodes of paroxysmal atrial fibrillation leading to acute hemodynamic deterioration not prevented by medical therapy

The Maze procedure is performed as an adjunct to mitral valve surgery in patients with chronic atrial fibrillation not likely to retain normal sinus rhythm post-operatively.

Patients with severe cardiomyopathy are excluded. Patients with severe hepatic, pulmonary, or renal dysfunction are also excluded. The Maze operation has evolved into many different lesion sets and presently, is most frequently combined with procedures, such as mitral repair and CABG. Stand-alone Maze operations are routinely performed at our institution as a result of a long and successful program (initiated in1991).

Lines of ablation employing energy delivery tools are now created rather than a cut and sew approach. The energy sources are broadly divided into hot and cold (thermo-ablation). Hot technology involves sources of energy that heats tissue to above 50 Cº thus causing irreversible necrosis that heals by fibrous scarring. Fibrous tissue will not conduct electricity at physiological voltages (90 mV). Examples of hot technology include microwave, radiofrequency, laser and high frequency ultrasound. Cold techniques employ refrigeration gases such as compressed argon or nitrous oxide. Cryoprobes are thus cooled to below -160 Cº and applied to precision targets yielding lines of ablation.

Raison d’être for The Aggressive Approach to the Treatment of Atrial Fibrillation

Atrial fibrillation occurs in 0.15%-1.0% of the general population and is the most frequently encountered cardiac arrhythmia. It has an increased frequency with age, being present in 8%-17% of the population greater than 60 years of age. The frequency in patients with mitral valve disease can be as high as 79%. Thromboembolism occurs in 1/3 of all patients with chronic atrial fibrillation (CAF). 75% of all thromboembolic episodes in patients with CAF involve the brain. 60% of CAF associated embolic strokes lead to death or permanent severe neurologic deficits.

Physiologically there are three detrimental sequela of atrial fibrillation. They are:

1) Irregular heart rate (meets mathematical criteria for randomness)
2) Impaired hemodynamic function (loss of atrial primer function)
3) Increased risk of thromboembolism

Loss of atrial contraction results in minimal hemodynamic consequence in young patients with normal ventricular function unless the heart rate chronically exceeds 100 beats per minute (tachycardia mediated cardiomyopathy). Atrial contractility becomes increasingly important in patients with impaired ventricular function or advanced age accounting for up to 20% of the cardiac output. This is the result of reduced left ventricular compliance. Furthermore, maintenance of atrial transport function prevents stagnation of blood and fibrin lamination with the ensuing activation of the coagulation cascade. Patients in atrial fibrillation have a five times greater risk of stroke as compared to patients without atrial fibrillation.

Medical therapy is largely ineffective in converting chronic atrial fibrillation to normal sinus rhythm. Therefore, medical therapy is primarily directed towards rate control and reducing thromboembolic episodes. Anticoagulation with Coumadin is an essential element of medical therapy. However, this is a dangerous medication with a low therapeutic index particularly in elderly patients.

Technique of the Maze Operation:

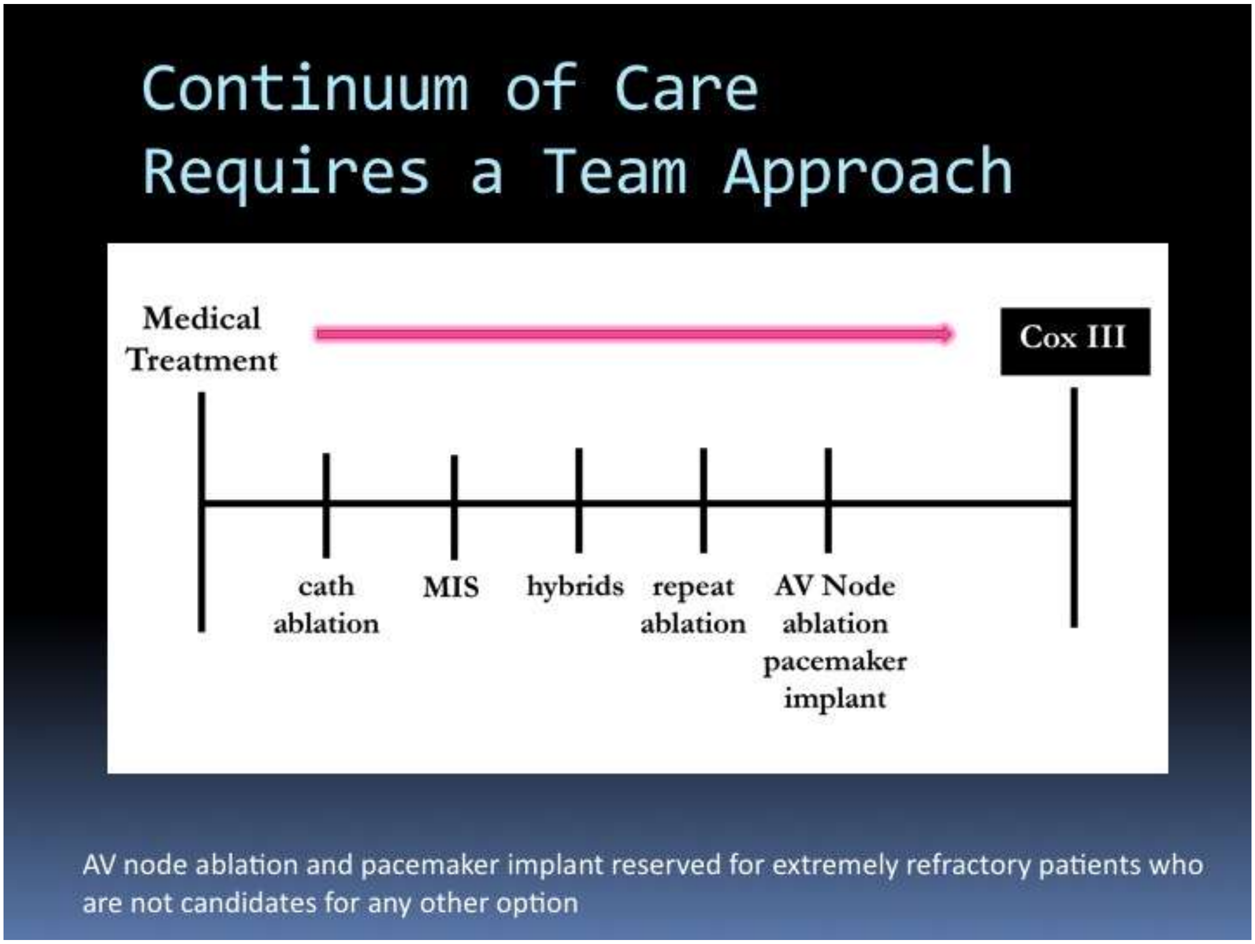
The maze operation has evolved into many different lesion sets. The likelihood of success depends on the type and duration of atrial fibrillation. Prolonged atrial fibrillation leads to extensive atrial remodeling and is unlikely to be terminated by micro-maze techniques. In other words, the triggers for atrial fibrillation become irrelevant in chronic atrial fibrillation, as it is a reentrant-based arrhythmia and thus self-sustaining.

Paroxysmal AF can be terminated by pulmonary vein isolation alone in 75-90% of cases. New onset chronic atrial fibrillation can be eliminated with left sided ablation techniques that prevent re-entry around the pulmonary veins, left atrial ear and mitral annulus. Chronic atrial fibrillation of greater than one-years duration requires a full Cox III Maze operation in order to insure a high degree of success, i.e., > 95%.

The classic Cox III Maze involves 12 lines of ablation (5 on the right atrium and 7 on the left atrium). The left atrial ear is always removed as a component of the classic Maze. It is the only portion of the left atrium, which is trabeculated and thus a surface area multiplier. It is also the source of 90% of left atrial clot formation (See figure 1). The classic Cox III Maze is an endocardial technique involving a heart-lung machine and is therefore invasive. Minimal invasive thoracoscopic epicardial maze operations without cardiopulmonary bypass include pulmonary vein isolation as a single box and a line of ablation from beneath the inferior vena cava along the lateral border of the right atrium up to the crista terminalis. An additional line of ablation is created from high up on the superior vena cava and extended down to the inferior vena cava. This lesion set is probabilistic and is based upon Haissaguerre's description of spontaneous ectopic foci originating in the pulmonary veins and superior vena cava.

Destruction of the cardiac ganglionated plexus is usually performed in conjunction with all types of maze operations but will contribute to short-term success only. The long-term efficacy of ganglionated plexus ablation, as a stand-alone procedure, is not likely, as GPs tend to recover function over time. Hybrid techniques involving collaboration between surgeons and electrophysiologist will permit greater versatility in minimally invasive lesion sets and will most likely lead to the highest degree of success. The present farrago of lesion patterns and techniques makes coherent analysis of the best approach difficult.

In conclusion, improved results in the treatment of atrial fibrillation can be expected with the development of advanced ablation technologies, a better understanding of the pathophysiology of atrial fibrillation, and the ongoing alliance between electrophysiologist and surgeons. Atrial fibrillation is the most studied arrhythmia in the history of medicine. Atrial fibrillation is a disease process, which requires a continuum of care. No patient should be denied the opportunity to live without atrial fibrillation.



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Glossary of Terms

Ablation: The destruction of normal or diseased tissue by various energy sources which, leads to fibrous healing (scar). Fibroblasts are not capable of propagating an action potential. Ablations can be designed to destroy or isolate ectopic foci and to breakup re-entry.

Action Potential: The change in membrane potential occurring in nerve, muscle, or other excitable tissue when excitation occurs. Fibrous tissue will not propagate an action potential. This is the bases of all ablations.

Anisotropy. Tissue heterogeneity at a cellular or molecular level. This leads to variable conduction, impulse fractionation, and spiral formation.

Argon beam coagulation: Instrument that produces homogeneous destruction of tissue by conducting high-energy electrical impulse along a beam of argon gas.
Atriotomy: Surgical incision of the atrium.

AV node: Atrioventricular node. A small node of specialized cardiac muscle fibers located near the ostium of the coronary sinus: it gives rise to the atrioventricular bundle (His bundle) of the conduction system of the heart.

AVNRT: Atrial Ventricular Node Reentrant Tachycardia.

Bipolar radiofrequency probe: A radiofrequency technique in which tissue is compressed between two antennae that emit and receive a radiofrequency impulse. Produces very rapid dielectric heating, i.e., both antenna have high current density.

Conduction velocity: Conduction velocity = $\frac{\text{Myocardial tissue traversed}}{\text{Time}}$. Normal atrial conduction velocity is 0.5m/sec.

CO_2: Carbon dioxide. 20 times more soluble in blood than diatomic nitrogen, which comprises 80% of the atmosphere. Utilized in open-heart surgery to mitigate the consequences of air embolus.

Cryo-lesion: A homogeneous area of destruction produced by freezing tissue to -160^{0}C for two minutes.

Cryoprobe: Instrument placed in apposition to tissue in which a cryo-lesion is intended to be produced. Available in various sizes, e.g., 3 mm, and 1.5 cm in diameter.

Depolarization: The loss of electrical polarization (separation of charge) across a cell membrane barrier. Charge separation is created by Na/K ATPase enzyme systems and other ion currents defined by the Nernst equation.

Dielectric heating: Radio frequency heating in which power is dissipated in a non-conducting medium (tissue) through dielectric hysteresis.

Differential equation: An equation of the variables of a function with respect to changes in independent variables. Simply put, the study of slopes and curves.

Effective Refractory Period: That period of the action potential following excitation when no response is possible regardless of the intensity of the stimulation. One of the determinants of impulse wavelength.

Faraday's Law of electromagnetic induction: Electromagnetic induction underlies the operation of electric generators, electric motors, solenoids, and all hot ablation tools except high frequency ultrasound. Its principles are well defined mathematically and quantifiable and thus the invention of precise temperature controlled ablation devices.

Ganglionated plexus: a collection of cholinergically mediated parasympathetic tissue arrayed around the cardiac tissue. Cholinergic stimulation shortens the effective refractory period.

Incidence: Number of new case developing within a given population during a specified time period, usually a year.

Mapping: Methodology employed to reliably locate an arrhythmogenic focus or point of earliest activation. Computer assisted analysis of time activation sequence allows a "solution" to be plotted very rapidly.

Maze Procedure: A sequence of atrial incisions or lines of ablation placed in such a manner as to permit activation of the entire atrium while prohibiting atrial re-entry. Employed to permanently terminate atrial fibrillation while maintaining atrial transport function.

Microwave heating: Heating (induction or dielectric) of tissues in which the current frequency is in the range 0f $10^9 – 10^{12}$ Hz. This induces water molecules to oscillate creating molecular friction and thus heat.

MIS: Abbreviation for Minimal Invasive Surgery.

Prevalence: Number of total cases existing within a given population in a specified period of time, usually a year.

Radiofrequency energy: Electromagnetic spectrum > 10^4 Hz but < $3.0X10^{12}$ Hz. Suitable for dielectric heating.

Refractory period: That period of the action potential that is effectively or relatively resistant to further depolarization.

Re-entry: The process whereby an action potential is prematurely initiated due to differential conduction of electrical impulses over areas of contiguous cardiac tissue. Slowed conduction results in the expiration of the refractory period in adjacent tissue allowing the slowed impulse to reactivate the adjacent tissue. Unidirectional block is an essential component of this process.

Repolarization: The reestablishment of cell membrane polarity by energy dependent Na/K ATPase ion pumps and other ion currents particularly the K current.

SA node: Sinoatrial node. Fundamental pacemaker of the heart. Located on the lateral anterior aspect of the superior vena cava right atrial junction. Conduction to other chambers of the heart gives rise to coordinated rhythm. Normally possess the highest degree of automaticity in cardiac tissue.

Septotomy: Incision in the septum, as in the atrial or ventricular septum.

Thermal-ablation: Delivery of a hot or cold energy source to precisely destroy tissue leading to fibrous healing.

Thoracoscopy: Technique for illuminating and visualizing intrathoracic structures through small ports.

Tissue necrosis: Permanent destruction of precisely defined corridors of tissue, which leads to fibrous healing. Fibrous tissue does not conduct electrical impulses at physiological voltages.

Unidirectional block: Unidirectional conduction block is required for the initiation of reentry. This conduction block can be anatomic or functional. Conceptually this is very analogous to a diode in a rectifying circuit.

Wave length: The product of the conduction velocity and the effective refractory period $\lambda = ERP \times \theta(L \text{ or } T)$. One of the determinants of critical mass required for multiple wavelets of re-entry to occur and alternatively spiral formation.

WPW syndrome: Tachyarrhythmia produced by an accessory pathway between the atria and ventricles.

Figure 1: Excised left atrial ear with associated thrombus