Developments in clinical electrophysiology

Knowledge about arrhythmia mechanisms is expanding rapidly, as a result of molecular biology, cellular electrophysiology and whole heart studies in animals and humans. Most clinically important arrhythmias result from re-entry while others have a focal origin: both can be cured by catheter ablation. Antiarrhythmic drugs have disappointing efficacy, tolerability and safety, so attention has shifted to curative catheter ablation and use of implantable devices.

ATRIAL FIBRILLATION

The inadequacy of antiarrhythmic treatment of atrial fibrillation (AF) stimulated development of catheter-based ablation strategies to cure AF. Landmark studies identified the pulmonary veins as the source of ectopic activity which initiates most episodes of paroxysmal AF and showed that radiofrequency ablation of the ectopic foci within the veins was possible (Haïssaguerre et al, 1998). Remarkable success was seen in patients who were highly symptomatic despite comprehensive trials of antiarrhythmics: 60–70% of patients were symptom free off drug therapy during follow-up averaging 8 months.

To achieve these results, however, second or third procedures were often needed and procedures and fluoroscopy times were long. Much of the success depended on identifying ectopic foci which may have been quiescent during the procedure, with no reliable means of identifying foci in the absence of spontaneous ectopy.

This focussed attention on ablation strategies aimed at isolating each of the pulmonary veins, either by an electrophysiologically-guided procedure within the pulmonary vein (Haïssaguerre et al, 2000) or an anatomically-based procedure to encircle each of the pulmonary vein ostia (Pappone et al, 2000). The merits of each approach are widely debated and concerns remain about a range of clinical issues.

Until recently only palliation with ventricular rate control and anticoagulation has been possible for patients with persistent AF. This AF is maintained by multiple coexisting reentrant wavefronts, each of whose course is changing constantly as determined by lines of fixed and functional conduction block.

The surgical Maze procedure divides the atria into compartments by creating artificial lines of conduction block joining existing lines of conduction block. The atria cannot then support the reentrant wavefronts of AF allowing sinus rhythm to dominate. The surgical Maze procedure allows cure of persistent AF. Developments in mapping and ablation technology mean that a catheter Maze procedure may be possible.

ARRHYTHMIA MAPPING

Activation mapping to guide catheter ablation has traditionally been performed using single plane or biplane fluoroscopic guidance and electrograms recorded from the tip of the mapping and ablation catheter. Developments in mapping technology have expanded the possibilities of catheter ablation.

Electroanatomical imaging allows non-fluoroscopic catheter navigation. As the mapping catheter is moved around the chamber of interest a three-dimensional (3-D) image of that chamber is created, which may be viewed from any angle. Using electrograms recorded sequentially from the catheter tip a colour-coded activation map is superimposed upon the anatomical representation of the chamber (Shpun et al, 1997).

Non-contact mapping uses a balloon-mounted electrode array to record over 3000 simultaneous unipolar electrograms from the chamber of interest. A computer-generated 3-D image of that chamber is created with an activation map superimposed. Non-contact mapping is particularly useful where the arrhythmia is infrequent at the time of the procedure or is poorly tolerated (Schilling et al, 1999).

Both systems allow high resolution non-fluoroscopic mapping of the heart and great vessels, allowing examination of the tachycardia mechanism (focal activation or macro reentry) and the spread of activation in relation to anatomical boundaries. During mapping and ablation the heart can be viewed from any projection and in two projections simultaneously. Ablation sites can be marked, allowing the operator to return to previous sites and to construct lines of ablation with a high degree of accuracy.

The next generation of mapping systems, already in advanced stages of development, will allow information about the initiation and activation pattern of an arrhythmia to be superimposed upon 3-D images of the heart and great vessels acquired with computed tomography or magnetic resonance imaging. Such systems may allow shorter mapping time and greater accuracy of lesion placement.

A further development is stereotactic catheter manipulation, which allows the operator to navigate a catheter using computer-controlled magnetic fields that directly control the distal tip of the catheter. The feasibility of this system has been demonstrated in animal studies and the results of clinical studies are awaited with interest.

CATHETER ABLATION

For almost 20 years radiofrequency energy has been used for catheter ablation of cardiac arrhythmias. Controlled delivery of energy to the catheter tip causes localized heating of the underlying cardiac tissue. Delivering the correct amount of energy creates a transmural lesion a few millimetres in diameter, incapable of conducting an electrical activation wavefront.

Thermocouples ensure that if the temperature at the catheter tip–tissue interface rises too far, energy delivery and hence lesion size is limited. Active cooling of the catheter tip by irrigation

with saline allows delivery of energy to deeper tissue levels, extending the scope of catheter ablation.

Ventricular tachycardia occurring in the context of a healed myocardial infarction (MI) or cardiomyopathy is a reentrant arrhythmia, dependent upon slow conduction through an 'isthmus' of viable myocardium bounded by scar tissue. The isthmus (the target for catheter ablation) may occur anywhere from endocardium to epicardium. Active cooling of the catheter tip has enhanced our ability to deal with an epicardial isthmus from the endocardium.

Occasionally, a patient will present with incessant, medically-refractory ventricular tachycardia which is not amenable to endocardial mapping and ablation despite the use of a cooled tip catheter. Novel approaches to this situation include epicardial mapping via the coronary arteries using an angioplasty guidewire to direct intracoronary ethanol ablation of an epicardial isthmus, and direct mapping of the epicardium by a catheter introduced into the pericardium.

Cryoablation has been used for many years for the treatment of cardiac arrhythmias during open heart surgery. A catheter-based cryoablation system now available offers advantages over radiofrequency ablation in certain circumstances (Skanes et al, 2000). As the temperature falls an ice ball forms at the catheter tip, anchoring the catheter to the heart. At –30 to –45°C reversible loss of conduction may occur in the underlying tissue allowing 'ice-mapping'. If the desired effect is seen (and no adverse effect) the temperature is lowered to –75°C for 4 minutes creating an irreversible lesion.

Catheter cryoablation has been successfully and safely used to ablate paraHisian accessory pathways – the stability of the catheter tip and ice-mapping help to ensure that the accessory pathway and not the His bundle is ablated. A further advantage of cryoablation is that the endothelium is left intact. The risk of thromboembolism with radiofrequency ablation is not trivial: cryoablation may be particularly relevant to procedures involving multiple lesions in the left atrium.

DEVICE THERAPY

Great advances have been made in the drug therapy of systolic heart failure, but many patients remain symptomatic despite optimal therapy. Up to 30% of patients with heart failure have intraventricular conduction delay such as right or left bundle–branch block resulting in dyssynchronous contraction between the ventricles, further impairing cardiac function. This has led to the development of devices capable of restoring the synchrony of ventricular contraction.

Such biventricular pacemakers or defibrillators pace the right ventricle via a standard right ventricular pacing lead and the left ventricle via a second lead placed in a branch of the coronary sinus. Enthusiasm has preceded good evidence of the efficacy and safety of the procedure. However, the MIRACLE (Multicentre InSync Randomized Clinical Evaluation) study provides grounds for optimism (Abraham et al, 2002). This prospective, double-blind, randomized trial recruited patients with low ejection fraction, broad QRS complex and severe symptoms of heart failure despite optimal drug therapy. A worthwhile benefit was shown for biventricular pacing, reinforcing the results of earlier, smaller trials.

No trial yet reported has been powered to detect a mortality benefit for biventricular pacing for heart failure. Many other questions remain and are the subject of ongoing trials, e.g. whether biventricular devices should routinely be capable of defibrillation. Advanced heart failure patients are at high risk of death from ventricular tachyarrhythmias. Some insight may be gained from the MADIT II (Multicentre Automatic Defibrillator Implant Trial II) trial (Moss et al, 2002). This randomized patients with an ejection fraction of ≤30% at least 1 month after a MI to best medical therapy or the same plus a defibrillator. Spontaneous or induced ventricular arrhythmias were not required for entry into the trial, which was stopped early because of a dramatic survival benefit from a defibrillator. The economic and logistic consequences of this finding will be the subject of intense debate. HM

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KEY POINTS

- Antiarrhythmic drugs have limited efficacy, tolerability and safety. Most clinically important arrhythmias may be treated by catheter ablation.
- Paroxysmal atrial fibrillation may be cured by pulmonary vein isolation although the optimal ablation strategy remains to be determined.
- Persistent atrial fibrillation may be cured by a surgical Maze procedure, and a catheter Maze procedure is a realistic prospect.
- Advanced mapping systems allow non-fluoroscopic catheter navigation to create high resolution maps integrating anatomical and electrical information.
- New methods of energy delivery have increased the scope of catheter ablation.
- Cardiac resynchronization therapy is emerging as a useful therapeutic option for some patients with systolic heart failure.