

Interventional Electrophysiology and its Role in the Treatment of Cardiac Arrhythmia

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Abstract

Cardiac arrhythmias can present as benign ectopics or as life-threatening arrhythmias and sudden cardiac death. Clinical cardiac electrophysiology is the study of the electrophysiology of the heart and all aspects of management of cardiac arrhythmias. The invasive electrophysiological study was initially purely diagnostic, but recent advances in technology has allowed us to intervene and hence the term interventional electrophysiology. The interventional therapies include permanent pacing for bradyarrhythmias, arrhythmia surgery for arrhythmias, percutaneous catheter ablation and implantable devices for tachyarrhythmias.

The treatment of bradyarrhythmias with permanent pacemaker implantation represents the first interventional therapy for patients with cardiac arrhythmias. From 1973 to June 1996, a total of 791 pacemakers have been implanted at the Singapore General Hospital. Previously, patients with tachyarrhythmias could only be cured by open heart surgery utilising intraoperative map guided surgery and ablation of the arrhythmia. Only 17 patients with supraventricular tachycardia (SVT) and 3 patients with VT have undergone this procedure. Catheter ablation has completely revolutionised the treatment of these patients. From October 1991 until December 1996, 860 patients have undergone radiofrequency (RF) catheter ablation for SVT and non-ischaemic VT. Ninety-eight per cent of the patients with SVT have been successfully ablated and 94% of the patients with VT were successfully ablated. RF ablation has become the technique of choice to cure patients with recurrent paroxysmal SVT due to AV re-entrant tachycardia using an accessory pathway, AV nodal re-entrant tachycardia, atrial tachycardia and atrial flutter. It is also used for AV nodal ablation followed by pacemaker insertion or AV nodal modification in patients with poorly controlled atrial fibrillation. Patients with idiopathic non-ischaemic VT arising from the left ventricle or right ventricular outflow tract can similarly be cured. For all these patients, RF ablation offers curative therapy, thus eliminating recurrent symptoms, life-threatening attacks, tachycardia cardiomyopathy and need for life-long drug therapy. For patients with resuscitated sudden cardiac death or at high risk for sudden death, the implantable cardioverter defibrillator (ICD) is the only technique that has significantly improved survival from sudden cardiac death. Since August 1992, 11 patients have had the ICD implanted, with 9 surviving. The 2 deaths were due to cardiac failure and not to sudden death. Thus the ICD can prevent sudden death, but the main limitation is the cost of the device and it is not suitable in patients who have severe heart failure.

In conclusion, interventional electrophysiology represents a tremendous leap forward in the management of cardiac arrhythmias. With catheter ablation, it offers a safe curative therapy for patients with recurrent SVTs and VTs and with the ICD, prevents sudden cardiac death in patients who have been resuscitated from it or who are at risk for it. The future will see us improving our success in ablating patients with monomorphic ischaemic VT and even atrial fibrillation, and the role of prophylactic ICDs in high risk patients will be better defined.

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Introduction

Cardiac arrhythmias are disorders of the electrical system of the heart which can present as benign ectopics or as life-threatening arrhythmias and sudden cardiac death. Clinical cardiac electrophysiology is a sub-specialty in cardiology dealing specifically with the study of the electrophysiology of the heart and all aspects of management of cardiac arrhythmias. Advancements in the understanding of cardiac electrophysiology have contributed signifi-

cantly to the management of cardiac arrhythmias. Initially, management of cardiac arrhythmias was mainly by the use of antiarrhythmic drugs. In many cases however, it was realised that drugs had limited usefulness. This was best illustrated initially in the treatment of patients with severe bradyarrhythmias and heart block. The first pacemaker was implanted in 1958 by Elmquist and Senning, heralding the onset of interventional therapy for cardiac arrhythmias.¹

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The understanding of the mechanism of cardiac arrhythmias was then significantly advanced by the use of intracardiac electrophysiological studies.^{2,3} Modern techniques of electrophysiological studies involve the insertion of multiple electrode catheters via the vein or artery to record, map and stimulate the heart, helping us to better understand the mechanisms of bradyarrhythmias and especially supraventricular and ventricular tachycardias.^{4,5} This better understanding helped to pave the way for interventional therapy for patients with tachycardia. The cardiac surgeons must be credited for showing that tachycardias can be safely cured. This was first demonstrated by Cobb and Sealy when they successfully surgically cured a patient with the Wolff-Parkinson-White syndrome in 1968.⁶ The modern era of interventional electrophysiology however is the use of catheter ablation to map and then ablate the arrhythmogenic focus using DC energy^{7,8} initially but later with radiofrequency energy.⁹⁻¹¹ At the same time improvement in pacemaker and defibrillator technology and better understanding of sudden cardiac death led to the development of the implantable cardioverter defibrillator and its first implantation in a human by Mirowski in 1980.¹²

Interventional electrophysiology has now emerged as the most important breakthrough in the management of patients with cardiac arrhythmia. In Singapore, permanent pacing was probably first performed in 1973, initially by the cardiac surgeons and subsequently by the cardiologists. The electrophysiological laboratory was first started at the Singapore General Hospital in 1982¹³ and arrhythmia surgery started in 1989.^{14,15} The first catheter ablation was performed in 1991¹⁶ and the first implantable cardioverter defibrillator implanted in 1992.

We review here the experience and development of interventional electrophysiology, which was started in Singapore at the Singapore General Hospital, and discuss its role in the modern management of patients with cardiac arrhythmias.

Permanent Pacemaker Implantation

There is little doubt that patients with symptomatic bradyarrhythmias due to the sick sinus syndrome and complete heart block need a permanent pacemaker and drugs are no longer used. Pacemaker implantation also represented one of the first attempts at providing a specific therapy for patients with bradyarrhythmias. The indications for permanent pacing have been well reviewed.¹⁷ In summary, the main indication for permanent pacing is for symptomatic complete heart block whether acquired, congenital or post myocardial infarction. Another major indication is for patients with the sick sinus syndrome. Other less common indications are for patients with the hypersensitive carotid sinus syndrome and the malignant vasovagal syndrome.¹⁸ Newer

and more controversial indications for pacing include patients with hypertrophic obstructive cardiomyopathy and congestive cardiomyopathy.

At the Singapore General Hospital, permanent pacing also represents the first form of non-pharmacological therapy for patients with cardiac arrhythmias. From 1973 to June 1996, a total of 791 pacemakers have been implanted. Eighty-nine per cent of the procedures were primary implants and 11% were reoperations for either pulse generator change or lead revisions. The number of implants per year increased from 9.1 per year in the 1970s, to 35.5 per year in the 1980s to 66.7 per year in the 1990s (Fig. 1). The indications for pacemaker implantation were complete or high grade AV block in 64.1%, sick sinus syndrome in 35.8% and malignant vasovagal syncope in 0.1%. The mean age of the pacemaker population increased from 59.5 ± 18.9 in the 1970s to 62.2 ± 16.9 in the 1980s to 65.5 ± 16.3 in the 1990s. Dual chamber pacemakers were implanted only from the 1980s and represented only 6.2% then but in the 1990s, represented 26% of all pacemaker implants. The use of rate responsive pacemakers also increased from 2.3% in the 1980s to 19% in the 1990s. VDD pacemaker using a single pass lead with the ability to sense the atrium (hence maintaining AV synchrony) was first implanted in 1996 and has the advantage of simplicity and ease even in the very elderly patients with complete heart block but having still relatively normal sinus node function.

Permanent pacemaker implantation is now thus the therapy of choice for all patients with symptomatic bradyarrhythmias. In patients with tachycardia-bradycardia syndrome, it allows us to treat the tachycardia with drugs, without the fear of causing asystole. The procedure is safe and relatively easy requiring less than 30 minutes usually for a single lead pacemaker implantation and 1 to 1.5 hours for a dual lead insertion procedure. There is no need to limit its use in the elderly who can similarly benefit from it, improving their quality of life and allowing them to ambulate.

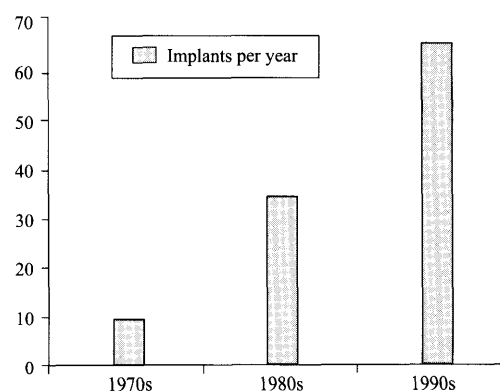


Fig. 1. Number of permanent pacemaker implants per year (Gp 1 = 1970s; Gp 2 = 1980s; Gp 3 = 1990s).

Antitachycardia pacing by itself is plagued by the problem of potential acceleration of the arrhythmia or degeneration into atrial fibrillation or ventricular fibrillation. It was never used in Singapore as the therapy for supraventricular arrhythmias but is commonly used in all third generation implantable defibrillators to terminate relatively slower and haemodynamically stable ventricular tachycardia. However a limited form of antitachycardia pacing in the form of prevention of torsade de pointes in the long QT syndrome is used in patients with complete heart block with a long QT and torsade or for patients with the acquired or bradycardia dependent type of long QT syndrome. Future use of antitachycardia pacing may include the use of multi-site atrial pacing to prevent atrial fibrillation.

Invasive Electrophysiological Studies

Invasive electrophysiological studies involve percutaneous insertion of electrode catheters from the femoral and subclavian or antecubital veins, under fluoroscopic guidance to the heart, and recording electrical signals and pacing from these catheters. Further electrode catheters may be introduced via the veins or artery to map the heart. Drugs may also be given during the study to assess the effect of drugs on the arrhythmia.

Invasive electrophysiological studies have become the gold standard in the investigation of cardiac arrhythmias, when the diagnosis cannot be determined with certainty on the 12 lead ECG. It is thus invaluable in the differential diagnosis of narrow and broad complex tachycardia, which at times cannot be determined from the 12 lead ECG alone. In some patients with recurrent palpitations which are very symptomatic or associated with syncope, the electrophysiological study will help to determine if an arrhythmia is the cause. In some cases of syncope of unknown origin, especially in patients with underlying heart disease, when a cardiac arrhythmia cannot be excluded by conventional methods, an electrophysiological study can sometime diagnose the sick sinus

syndrome, heart block or a tachyarrhythmia as the cause. The electrophysiological study also helps to elucidate the possible mechanism of the arrhythmia thus guiding therapy. It must be done before any arrhythmia surgery or catheter ablation, to define the arrhythmia and the mechanisms involved.

At the Singapore General Hospital, invasive electrophysiological studies were started on 24 August 1982.¹³ Figure 2 shows the number of invasive electrophysiological studies done over a 15-year period since 1982. A total of 2489 invasive electrophysiological studies have been performed. The important indication for electrophysiological studies were for diagnosis of narrow and broad complex tachycardia. The electrophysiological study was vital for mapping of patients with the Wolff-Parkinson-White syndrome or supraventricular tachycardia, prior to curative therapy with arrhythmia surgery or radiofrequency catheter ablation. Since 1992, about 50% of the electrophysiological studies were followed by radiofrequency catheter ablation where possible. Another use of the electrophysiological study was to determine the cause of recurrent palpitations and syncope or presyncope in patients with underlying heart disease. Electrophysiological studies have a less important role in determining sick sinus syndrome and complete heart block which are better diagnosed by serial 24 hours ambulatory ECG (Holter) studies or transtelephonic ECG monitoring. Serial studies to determine antiarrhythmic drug efficacy for patients with recurrent ventricular tachycardia are also useful.

Of note has been the safety of these invasive studies in these patients, some of whom have recurrent ventricular tachycardia or fibrillation and often poor underlying left ventricular function. We have had no mortality as a direct result of the electrophysiological studies during the 15-year period. One patient had cardiac tamponade, as a result of perforation by the catheter through the coronary sinus vein and this was immediately detected

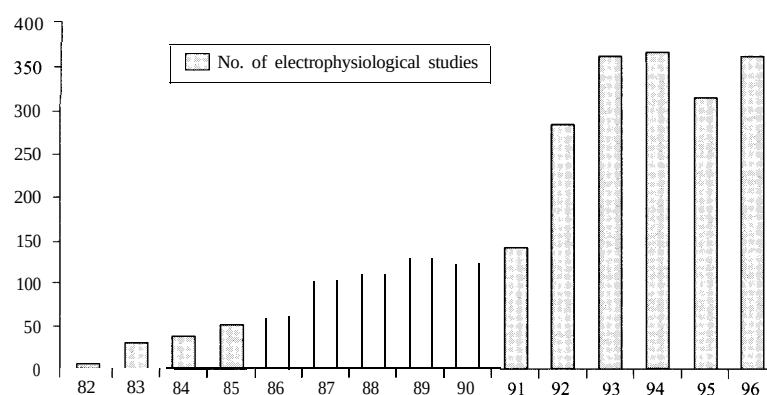


Fig. 2. Number of electrophysiological studies performed at the Singapore General Hospital from 1982 to 1996.

and drained surgically. Another patient had near anaphylactic shock secondary to the sedation given (midazolam and fentanyl) and needed immediate resuscitation with intravenous adrenaline and hydrocortisone. Electrophysiological studies are safe because they are done under strict precautions with a trained electrophysiologist and another doctor, usually at least a cardiology registrar, a cardiac technician and a nurse. The patient is monitored closely at all times with continuous ECGs, pulse oximeter and at least a non-invasive blood pressure cuff. In patients with ventricular tachycardia, arterial blood pressure monitoring is usually used. Immediate defibrillation is available and emergency cardiac drugs are all available in the laboratory.

Cardiac Arrhythmia Surgery

Cardiac arrhythmia surgery involves preoperative mapping of the patients' arrhythmia with an invasive electrophysiological study. The patients then undergo open heart surgery and intraoperative mapping is repeated by the electrophysiologist to confirm the site of the arrhythmia. The site is then surgically ablated either by surgical dissection or resection, with or without additional cryoablation. Cardiac arrhythmia surgery was initially the only form of interventional therapy which provided a curative therapy for patients with life-threatening or poorly-controlled cardiac arrhythmias. Its use was however limited by the morbidity of the procedure and operative mortality. Hence, patients were often reluctant to undergo the procedure, unless they were extremely symptomatic. The other problem was the lack of cardiac surgeons who were well trained in the technique of cardiac arrhythmia surgery. This together with the limited number of cases going for surgery hampered its development.

At the Singapore General Hospital, cardiac arrhythmia surgery was first performed on 15 March 1989. Since then, only 17 patients had undergone this procedure for supraventricular tachycardia. The procedure was successful in all the patients but there was a recurrence in 1 patient. There was no operative mortality. Three patients underwent ventricular tachycardia surgery, 2 of whom had map-guided endocardial resection and cryosurgery and another had blind resection of the aneurysmal area. One patient died intraoperatively.

Even though arrhythmia surgery was useful in showing that curative therapy was possible, this was associated with significant morbidity and possible operative mortality. It has now been replaced by radiofrequency catheter ablation for supraventricular tachycardia and has a limited role in the management of patients with recurrent ischaemic ventricular tachycardia. The main indication for ventricular tachycardia surgery now is a patient with a stable monomorphic ventricular tachycardia and a definite apical aneurysm where there is an

anatomical target for surgery. Aneurysmectomy aided by intraoperative mapping to surgically ablate the ventricular tachycardia is highly successful and curative in these patients. For patients with unstable ventricular tachycardia, the implantable defibrillator has also replaced arrhythmia surgery as the treatment of choice.

Catheter Ablation

Catheter ablation began in the 1980s with the use of DC energy but had only limited clinical utility because of the risk of barotrauma. In the early 1990s, the combination of radiofrequency energy as the energy source and new technology using deflectable large tip catheters enabled catheter ablation to be safely performed and with high success. The use of radiofrequency energy enables safe and controlled energy delivery with no risk of barotrauma or need for general anaesthesia. Radiofrequency energy has now completely replaced DC energy as the main source of energy used in catheter ablation.

Catheter ablation has completely revolutionised the treatment of patients with cardiac arrhythmias especially supraventricular tachycardia and non-ischaemic ventricular tachycardia. Almost all supraventricular tachycardias from sinoatrial re-entrant tachycardia, AV nodal re-entrant tachycardia, atrioventricular re-entrant tachycardia involving an accessory pathway, atrial tachycardias and atrial flutter can now be cured by radiofrequency catheter ablation. The only supraventricular tachycardia at present not completely curable by catheter ablation is atrial fibrillation. Even then new techniques are being developed which one day may lead to the curative therapy of this arrhythmia. For non-ischaemic ventricular tachycardia, such as idiopathic left ventricular tachycardia which classically presents as a relatively narrow complex tachycardia with a right bundle branch and left axis deviation and right ventricular outflow tract ventricular tachycardia, these can now all be successfully cured by radiofrequency catheter ablation.

At the Department of Cardiology, Singapore General Hospital, 880 radiofrequency catheter ablations have been performed since it was started on 10 October 1991.¹⁶ Figure 3 shows the number of cases performed at the Singapore General Hospital from 1991 to 1996. Initially the procedure was done only for patients with the Wolff-Parkinson-White syndrome but AV nodal re-entrant tachycardias, atrial tachycardias and atrial flutter are now routinely curable with radiofrequency catheter ablation (Fig. 4). In patients with poorly-controlled atrial fibrillation or proarrhythmic effect (e.g. torsade de pointes), AV nodal ablation, followed by pacemaker implantation can be performed to control the ventricular rate. A total of 847 patients have undergone radiofrequency catheter ablation for supraventricular tachycardia. The mean age of the SVT patients was 41 ±

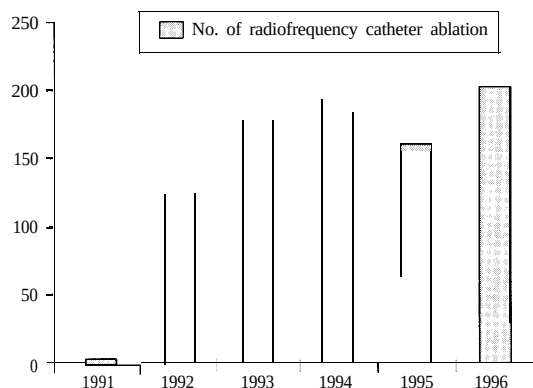


Fig. 3. Number of radiofrequency catheter ablation performed in the Singapore General Hospital from 1991 to 1996.

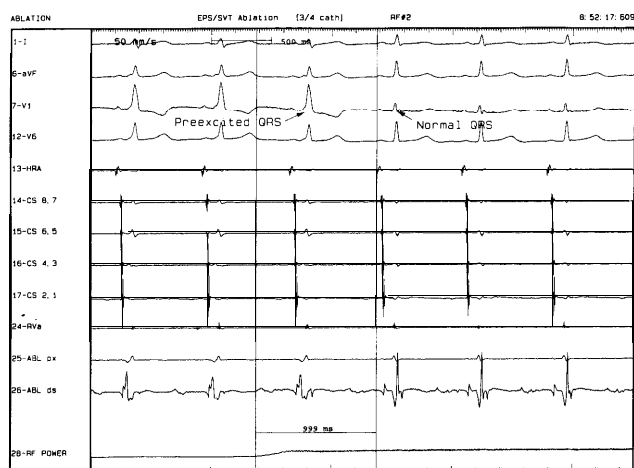


Fig. 4. Radiofrequency catheter ablation of Wolff-Parkinson-White syndrome.

15 years (range 10 to 80 years). The mean duration of procedure was 108 ± 60 minutes (range 15 to 480 minutes) and the mean fluoroscopy time was 19 ± 17 minutes (3 to 122 minutes). Ninety-eight per cent of the patients are completely cured on the first ablation attempt. Three patients needed a second ablation attempt to achieve complete cure. The recurrence rate is low and occurred in 3.9% of the patients and the majority were successfully reablated. Thirty-three patients have undergone radiofrequency catheter ablation for non-ischaemic ventricular tachycardia. The mean age was 35 ± 14 years (range 19 to 65 years) and the mean duration of the procedure was 185 ± 63 minutes (range 110 to 285 minutes) and the duration of fluoroscopy was 33 ± 16 minutes (range 14 to 68 minutes). Ninety-six per cent of the patients were initially successful but 21% of the patients had recurrence and needed a second ablation to successfully cure the patients. The overall complication rate for radiofrequency catheter ablation for both supraventricular and ventricular tachycardia has been less than 1%.

Radiofrequency catheter ablation has thus replaced drug therapy as the treatment of choice for patients with

supraventricular tachycardia. It provides curative therapy without the need for life-long drug therapy. For patients with ventricular tachycardia, the improvement in technique has reduced the recurrence rate and should now also be considered in patients who do not respond to drug therapy or do not want life-long drug therapy.

Implantable Cardioverter Defibrillator (ICD)

The ICD represents a major advance in the management of patients who are at risk for sudden cardiac death. For patients who have been resuscitated from a sudden cardiac death episode the recurrence rate is extremely high. Present day antiarrhythmic therapy including amiodarone has a high recurrence rate and failure of up to 10% to 20%.¹⁹ Worse still, the class I antiarrhythmic agents were shown in the Cardiac Arrhythmia Suppression Trial (CAST) study to have significant proarrhythmia and increased mortality by 2 to 3 times when compared with placebo.²⁰ Surgical revascularisation alone may not be completely effective and ICDs may be needed in some cases.²¹ Arrhythmia surgery is limited by the significant morbidity and mortality of the procedure and the lack of widespread surgical expertise in these very complicated procedures.²² On the other hand, the ICD has low operative morbidity and mortality and has been demonstrated to significantly reduce the risk of sudden cardiac death^{23,24} even in the patients with significant impaired left ventricular function.²⁵ What remains controversial is whether the ICD results in a significant decrease in total mortality. These are now under vigorous investigations in the Amiodarone versus Implantable Defibrillator (AVID) trial in the US and Canadian Internal Defibrillator Study (CIDS) Trial in Canada. The recently completed Multicenter Automatic Defibrillator Implantation Trial (MADIT) in high risk post anterior myocardial infarction patients with non-sustained ventricular tachycardia showed an improved survival benefit with the ICD when compared to conventional medical therapy.²⁶

The presence of a back-up defibrillation mode has revitalised the use of antitachycardia pacing for pace termination of patients with haemodynamically better tolerated ventricular tachycardia not responding to antiarrhythmic drug therapy. This is now present in all third generation ICDs, allowing the safe and comfortable termination of ventricular tachycardia. Newer technological advances including the development of biphasic shocks and the active can design have simplified the implantation of the device to that of a single defibrillator lead and an active can, similar to that of a single lead pacemaker. The operative mortality has thus been reduced from about 4% to 5% previously with the thoracotomy, epicardial lead systems to less than 1% for the non-thoracotomy, transvenous systems.

At the Singapore General Hospital, the first ICD was

implanted in August 1992. Up to March 1997, 11 patients, consisting of 10 males and 1 female, have undergone this procedure. There was no immediate postoperative mortality. The mean age of the patients was 50 ± 17 years (range 25 to 83 years). All patients had documented ventricular tachycardia or fibrillation. All patients had failed 1 or more antiarrhythmic drugs. Two patients had an epicardial system while the others had non-thoracotomy systems. Two patients have died on follow-up. The patients developed arrhythmic storms which were successfully controlled by the defibrillator and antiarrhythmic drugs, but the patients eventually succumbed to heart failure and a bradyarrhythmic asystolic death. All the other 9 patients have remained well with appropriate sensing and therapy from the device.

The ICD represents a quantum leap in the management of patients who are at high risk for sudden death. The main limiting factor at present is the tremendous cost of the device. The other problem is the identification of those at high risk of developing sudden cardiac death. The present tests to identify those at high risk have relatively low predictive values of 20% to 30% only. It is hoped that future research will help identify these patients better and allow us to identify the patients before they sustain a cardiac arrest. For those who have been fortunate to have survived a resuscitated sudden death episode, and with no evidence of a reversible cause or an acute myocardial infarction, these patients should have an ICD. For patients who have recurrent haemodynamically unstable ventricular tachycardia, not controlled by antiarrhythmic drug therapy, especially in those with impaired left ventricular function, the ICD should be considered as the risk for recurrence of ventricular tachycardia and sudden death is significant.

Conclusion

Interventional electrophysiology has completely revolutionised the treatment of patients with cardiac arrhythmias. No longer is it an approximation, but a precise science, when treating patients with cardiac arrhythmias. With the invasive electrophysiological studies, the exact cause of the arrhythmia and sometimes the underlying mechanism can be elucidated. The best therapy can be determined, based on the patient's history, clinical presentation and underlying heart disease if any. With the availability of multiple interventional therapies using non-pharmacological approaches, there is now a whole armamentarium for the management of these sometimes life-threatening arrhythmias. Pacemaker implantation represented the first interventional therapy that has now completely replaced drugs as the treatment for patients with symptomatic bradyarrhythmias and new indications may include pacing to prevent arrhythmias such as multi-site atrial pacing for

prevention of atrial fibrillation. Arrhythmia surgery was instrumental in paving the way for curative therapy of tachyarrhythmias and still has a limited role especially in patients with relatively stable ventricular tachycardia with a definite localised substrate such as an apical left ventricular aneurysm. Its role in the treatment of supraventricular tachycardia and non-ischaemic ventricular tachycardia has been almost completely replaced by radiofrequency catheter ablation. New catheter mapping systems and electroanatomical mapping may in future allow us to have higher success in treating the ischaemic ventricular tachycardia and atrial fibrillation. For the patient at risk of or has been resuscitated from sudden cardiac death, the ICD represents the treatment of choice as it clearly decreases sudden cardiac death more than any form of drug therapy at present available. Thus interventional therapy is the standard therapy for most patients with significant cardiac arrhythmias and should be considered in almost all such patients.

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