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History of electrical therapy for the heart

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The history of electrical therapy for the heart can be said to have begun with the implantation of the first permanent pacemaker in Stockholm, Sweden in 1958. This paper outlines the important events in a very rapidly growing and successful therapeutic endeavour up to the present time and, in so doing, sets the scene for the series of papers that follow in this commemorative issue of the Journal.

Introduction

The advent of cardiac pacing was heralded by many important laboratory studies over many years, as well as some human experiments, which met with mixed reactions on ethical grounds. The real history of electrical therapy for the heart can be said to have begun with the first totally implanted pacing system by a team led by Senning, the surgeon and Elmqvist, the technologist.[1–3] The first implant was a limited success as it was effective only for a few hours. However, the patient survived for over 40 years and became a well-known personality in medical circles. This Swedish triumph was followed quickly by similar technological innovation in the USA based on the background of introduction of external pacing by Zoll[4] in 1952 and temporary transvenous pacing by Furman[5] in 1958. The rivalry sparked a new biotechnology industry that has revolutionized health care in the five subsequent decades. Devices are now available to stimulate, monitor, or control every electrically driven organ in the body. The future holds much promise for more such development.

Early events

Hyman in the USA devised the first experimental pacemaker in 1932.[2,3] It had a small commercially available battery and a simple electrical circuit to provide timing and duration of the delivered current. The stimulus was applied to the right atrium via a transthoracic needle. Hyman hoped to able to slow heart rhythm rather than to speed it. He first tested his device on animals but later stimulated the human heart at rates of 30, 60, or 120 b.p.m. The device was intended for use during resuscitation, but controversy surrounded it, the experiments were abandoned.

In 1950 the, Canadian group of Bigelow, Callaghan, and Hopps stimulated the right atrium by a transvenous approach during open-heart surgery using a mains-powered device.[2,3] The electrode was bipolar and proved to be the forerunner of today's stimulation leads. They concluded that this approach only had value in treating cardiac arrest due to hypothermia, which was the surgical method of choice at the time to allow sufficient operating time during open-heart surgery. Later, Callaghan, reflecting on their work, stated that they had reached the right ventricle but they had not thought to stimulate the heart from that site.

Zoll[4] in Boston, MA, USA in 1952 succeeded in pacing the heart in a patient with cardiac arrest by using two external electrodes on the surface of the chest connected to an external pacemaker. This device was later

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used to treat complete atrioventricular block and was moderately commercially successful. Most pacemaker implanting centres in the world possessed one, which was routinely attached to any pacemaker-dependant patient undergoing a pacing procedure up to the 1970s. Its disadvantages, though, were great: the electrodes caused skin burns and contraction of most muscle groups in the whole body in addition to the heart. A similar device is still available, although as part of a system that is devised to function primarily as a transthoracic defibrillator with pacing back-up.

In August 1958, Furman,[5] then a surgical resident at Montefiore Hospital, Bronx, NY, USA, introduced a transvenous electrode into the right ventricle and succeeded in stimulating the heart for 96 days. The external pacing device was a mains-powered stimulator. Also in 1958, Lillehei and Bakken in Minneapolis, MN, USA, using transistors, built a battery powered external pacemaker and reported its efficacy in 18 patients.[2,3] Later in this momentous year for this fledgling specialty Senning and Elmqvist performed the first pacemaker implant using an epicardial lead. These pioneers laid the foundations of electrical therapy for the heart.

With these innovations, there was concurrently emerging the beginning of the understanding of atrial fibrillation by the work of Gordon Moe, who developed the concept of multiple wavelets to explain the previously difficult to comprehend patterns of this arrhythmia.[6]

The first decade, 1958–1967

The initial development phase could be termed the decade of asynchronous pacing. The goal of treatment was the prevention of asystole both in cardiac arrest and in the paroxysmal asystole of Morgagni–Adams–Stokes syndrome. Complications of open-heart surgery, then a rapidly expanding technique, included precipitation of complete atrioventricular block, which demanded treatment. Permanent pacing of these patients was successful, substantially changing the prognosis from very poor to one approaching that for the normal population of similar age with greatly improved quality of life tempered by the fragility of the pacing systems.

The first pacing devices were fixed rate units consisting of a single transistor, blocking oscillator triggering a second transistor that generated the electrical impulse with duration 1.5–2.0 ms. The Swedish pacemaker had an inductive recharging circuit for non-invasive recharging of Nickel–Cadmium batteries, while Chardack and Greatbatch used Mercury–Zinc batteries, which offered about 1 year's lifetime without a need for recharging. Chardack introduced the concept of a gradual increase in stimulus rate to indicate battery depletion.[2,3]

Despite Furman's innovation of the endocardial approach, all early pacing systems were epicardial. This method of stimulation was complicated by a rise in stimulation threshold and frequent lead fracture. High output devices were used to combat the threshold rise including up to 10 batteries, which made the devices very large. Hunter and Roth devised a small sized stainless steel electrode to be pushed into the myocardium, which proved more reliable than suturing wires to the epicardial surface and less fractures occurred.[2,3]

Lead conductor fracture was also a problem as single or tinsel wire was used. Chardack devised a coiled wire and at that time the manufacturing process was becoming more refined leading to less fractures and greater reliability. Lead lifetime was then about 2 years.

In the latter part of this first decade the endocardial approach for permanent pacing began to emerge. It was attractive because it was less invasive and was possible either without or only partially with general anaesthesia. This permitted pacing to be undertaken in centres without cardiac surgery; more patients could be offered the treatment and the more benign nature of the treatment allowed more types of bradyarrhythmia to be paced.

The greatest problem of the first decade of electrical therapy for the heart was the reliability of the devices. Gradually, this was overcome by a combination of innovation and more rigorous manufacturing processes. Concurrently, attempts were being made to make a more physiological pacing system by detecting through a separate lead the signals from the right atrium, which are typically normal in complete atrioventricular block. These efforts were also frustrated by problems of reliability.

In terms of electrophysiology, the major work of Lown *et al*.[7] in 1962 to introduce cardioversion for atrial fibrillation by direct current electric shock predicated much of what is done today with control of atrial and ventricular tachyarrhythmias. Also working in Boston a little later was Ferrer,[8] who described sinus node disease or sick sinus syndrome, a phrase coined by Lown.

The second decade, 1968–1977

During the second decade, attention was increasingly paid to detection of spontaneous cardiac signals in order to use them to prevent competition between the pacemaker and naturally occurring rhythm. The innovation of the so-called demand pacemaker is attributed to Berkovits.[9] In this device, detection of a spontaneous cardiac signal reset the timing for a complete timing cycle, thus preventing a stimulus competing with the detected event and avoiding its vulnerable phase. This, at least during myocardial ischaemia, reduced the risk of inducing ventricular tachyarrhythmias.

Additional important developments during this period included hermetic sealing, hybrid technology, and improved circuitry protection. Hermetic sealing of the generator prevented ingress of body fluids and protected the vulnerable electronics from short circuits. Hybrid technology as opposed to use of all discrete components simplified the manufacturing process and made it possible to produce smaller generators. This, in turn, allowed subcutaneous generator implantation, which permitted another expansion of implanting centres. To protect the amplifier of demand pacemakers from strong electric fields, a diode was placed at the input stage preventing damage to the circuitry by defibrillator shocks and surgical cautery. Automatic rate limiting circuitry was introduced to prevent excessively high pacing rates that occasionally had occurred with component failure or short circuit. All these changes had the effect of making pacing systems much more reliable.

Most batteries at the beginning of this period were Mercury–Zinc, which were inherently unreliable. This prompted introduction of alternative energy sources: Laurens reported use of a nuclear battery in 1970, but this caused problems of potential release of radioactivity and made some states unwilling to permit entry to wearers of such devices. Furthermore, batteries with a lifetime in excess of 20 years prevented patients taking advantage of the progress in circuit technology. Quite soon, in 1972, the advent of Lithium–Iodine batteries outmoded the nuclear cell. Compared with its predecessors, the lithium battery was far superior combining lifetimes in excess of 10 years with a reliable and predictable battery depletion pattern. As a result, the majority of patients receiving pacemakers could expect only one generator in their lives. This expectation, however, was not realized because indications for pacing expanded including more patients with a better prognosis, leads were less reliable than generators and there was constant aspiration to have smaller and smaller generators, which inevitably reduced battery capacity by reduction in its size.

During this period the Nickel–Cadmium cell was reconsidered but was not a success because recharging was needed once per week and patients found that this activity served to remind them of their vulnerability.

This decade was, overall, one of overcoming many safety and reliability issues, which came about by a combination of innovation and improved manufacturing standards with greater emphasis on quality assurance.

During this consolidation phase of pacing the science of cardiac electrophysiology was advancing. Much cellular work had already been done in the laboratory but the most noteworthy event early in this decade was the recording by Scherlag *et al.*[10] of the His bundle electrogram, in 1969, which started mapping of electrical circuits within the heart. This was quickly followed by the work of Durrer and Wellens in the early 1970s triggering and mapping of the whole circuits of tachycardias.[11] In the mid-1970s drug testing was undertaken to try to assess what antiarrhythmic drug may most successfully control ventricular tachyarrhythmia, an approach pioneered by Wellens and also in the United States by Fisher *et al.*[12] and Hartzler and Maloney.[13] This usually involved an in-hospital stay of many days and, perhaps, several drugs.

The third decade, 1978—1987

Development of CMOS (complementary metal-oxide semi-conductor) technology, which was integrated electronic circuitry providing high immunity to noise and low static power supply drain. This low-power digital integrated circuit made possible a vast increase in the number of pacemaker functions without compromising the size of the generator or its service life. Telemetry through the skin allowed testing and programming of the pacemaker to offer solutions to some pacing problems, better diagnosis of problems, and more precise follow-up care. Difficulties with sensing or detection of spontaneous cardiac signals and exit block could often be overcome by reprogramming the device rather than having to resort to re-operation. The new flexibility of programming the device also permitted adjustment of the pacing system to evolution of pathology that occurred in some patients.

This decade saw increased application of more physiological pacing systems. Earlier, Folkman had tested atrial controlled ventricular pacing in the late 1950s and Nathan reported a series of patients with VAT stimulation, mainly children, in 1963.[9] The VDD pacemaker appeared in the mid-1970s, but in 1977 Funcke introduced the concept, that he called the Universal pacemaker.[9] He combined atrial synchronous ventricular pacing with atrioventricular sequential pacing orchestrated by a control circuit, the DDD pacemaker. In 1981, Rickards and Norman[14] conceived the idea that pacing rate could be controlled by detection of the evoked response. He advocated measurement by the pacemaker of the duration of the Stimulus-T interval, which is analogous to the QT interval and reflects the prevailing catecholamine drive to the heart. However, 1983 saw the advent of effective rate-modulated pacing using a sensor of vibration in the generator to appreciate the body's need for heart rate increase on activity. This indirect rate control had been a concept of the 1960s,[15] but it had proved, at that stage, neither feasible nor effective. This advance offered a means of increasing heart rate without relying on the atria and detection by an additional lead. It was valuable for patients with chronotropically inadequate sinus node function, atrial fibrillation with complete atrioventricular block or drug-induced chronotropic incompetence.[9]

As well as smaller generators, physicians were also demanding slimmer and more slippery leads. Use of polyurethane insulation[16] instead of silicone rubber seemed to address this problem but the early forms of polyurethane hardened and cracked causing important insulation defects and loss of pacing function. Later forms of polyurethane largely resolved this issue. There was a need for greater electrode stability in the heart, and the mid-1970s saw the introduction of tenacious passive endocardial fixation by placing tines on the lead near the tip. Bisping introduced a sheathed screw electrode that superseded the previously available fixed unsheathed screws for fixation.[9] This type of lead fixation was widely adopted and was termed active fixation. It permitted placement of leads effectively anywhere in the right heart but they were first applied to achieve stable atrial sensing and pacing. Both active and passive fixation mechanisms substantially reduced the re-operation rate.

Leads also changed in that the rest of the world followed the United States by adopting bipolar structures, which permitted safer detection of spontaneous cardiac signals with less risk of inappropriate detection of non-cardiac signals or interference. This was especially important in the atrium as the spontaneous signals tend to be smaller. The lead structure was multifilar and co-axial in order to achieve a slim and flexible design. Towards the end of this decade the cost of this format became evident with corrosion of some inner insulation material and short circuits developing within the lead.

Stimulation electrodes were redesigned to permit lower stimulation thresholds and better sensing. In 1983, steroid eluting leads were introduced[17] in order to limit the healing reaction of the heart to the trauma of receiving an electrode impacted into the endocardium. This had a favourable effect on this complication particularly in children, who display the most aggressive healing.

Industry agreed on a standard lead connector [IS-1] with the header on the generator, which offered interchangeability of leads and generators between manufacturers. The agreed standard was an in-line bipolar system, so permitting reduction in the size of the header on the generator.

Single-pass leads were devised to sense in the atrium without endocardial contact and stimulate in the ventricle. This permitted VDD pacing with only one lead. However, the lack of ability to use this type of lead for stimulation in the atrium hampered its acceptance.

This period also saw the assimilation of the intensive care technique of percutaneous lead insertion into the subclavian vein. This made the implantation procedure quicker and easier but brought its own problems including pneumothorax and subclavian crush, where the lead(s) passed through the tough subclavian ligament resulting in lead damage at this site. Safer techniques exist but have been inadequately adopted even today.

The decade was characterized by a great increase in pacing systems that were more physiological in their behaviour. To the surprise of some, retrograde atrioventricular conduction was shown to persist in some patients even in the presence of complete antegrade atrioventricular block and was evidently the norm when block was absent. This phenomenon was readily complicated by pacemaker-mediated tachycardia. Gradually, all dual chamber devices became equipped with algorithms to prevent this complication.

The 1970s was a time of great activity in the new clinical discipline of cardiac electrophysiology. Fundamental understanding of mechanisms of some tachycardias was gained with the precise identification of the accessory pathway in Wolff–Parkinson–White syndrome, where important contributions came from Burchell,[18] Gallagher *et al.*,[19] James,[20] and Becker and Anderson.[21] The first surgical ablation of an accessory pathway was performed at Duke University in the early 1970s. Wellens *et al.*[11] had contributed a clear understanding of the use of premature stimulation to trigger tachyarrhythmias. This approach was employed by Josephson *et al.*[22] in studies of ventricular tachycardia and he performed endocardial mapping that led to ablative surgery by his colleague Harken in the late 1970s. Around this time Gallagher and coworkers[23] devised the technique of epicardial mapping by using a sock of electrodes to fit over the heart at open-heart surgery, adding further knowledge of tachycardia circuits. Waldo *et al.*'s observations[24] on the nature of entrainment of tachycardias provided the basis for much future electrophysiological work. Greater understanding of electrophysiological mechanisms of tachycardias permitted use of pacing to achieve refractoriness in a part of the tachycardia circuit, thus breaking it. Fisher *et al.*[25] advocated antitachycardia pacing in the mid-1970s. Widespread use of such devices was quickly overtaken by the availability of endocardial ablation using at first direct current shocks aiming at the easiest target, the atrioventricular node, first performed by Gallagher *et al.*[26] and Scheinmann *et al.*[27] But these were again quickly surpassed by the introduction of radiofrequency energy, being originally applied in the mid-1980s. This energy could be much more precisely directed leading to ablation of the AV node being less often undertaken and accessory pathways were specifically sought as ablation targets. Most of this effort was directed towards comprehending and permanently treating atrioventricular re-entry tachycardias.

Once success had been gained in large circuit tachycardias attention was paid in the 1980s to other tachyarrhythmias such as atrioventricular nodal re-entry tachycardias and atrial flutter. By the end of the decade the stage was set for ablation of atrial flutter based on the work of Cosio *et al.*[28] and Waldo *et al.*,[24] who identified the right atrial nature of this arryhythmia and, in the most common variety of flutter, the course of the circuit always passed through the isthmus between the tricuspid annulus and the inferior vena cava. At this point the circuit could be interrupted by linear ablation. The details of the slow and fast pathways of the atrioventricular node were also understood at this time, opening the possibility of ablation of first, the fast, then later, more successfully, the slow pathway of the node. Ultimately, ablation of the more rare, focal atrial tachycardia was undertaken by Lesh *et al.*[29]

The 1980s saw genetically determined arrhythmias becoming well-recognized diseases rather than just rarely encountered syndromes, much of this change can be attributed to the efforts of Moss and Schwartz,[30] who created a registry of Long-QT patients. Another important addition to our understanding of primary arrhythmic disease was the report of the Brugada brothers in 1992 describing the clinical picture of the Brugada syndrome.[31]

Attempts were concurrently being made to gain a better understanding of the nature of atrioventricular conduction problems. In this area, two groups performed outstanding work, those of Akhtar *et al.*[32] and Rosen and coworkers.[33] Abnormalities of sinus node function were being revealed separately by Strauss *et al.*[34] and Narula *et al.*[35]

The 1980s, and earlier in experimental studies, saw the beginning of high power implantable devices for internal defibrillation. Morowski *et al.*[36] worked tirelessly to introduce this concept in the face of ethical debate and much scepticism. The latter part of this third decade recorded only slow acceptance of this new technique.

In the mid-1980s, other manufacturers became involved and Zipes *et al.*[37] presented an addition to the device offering cardioversion at first alone and later with defibrillation. These devices, then, all offered this facility together with antitachycardia pacing and they became known as implantable cardioverter defibrillators (ICDs).

The study of syncope was advanced with the recognition by Kenny *et al.*,[38] in 1986, that using a tilt table to achieve prolonged head-up tilt could induce syncope of a neurally mediated type. This concept was further extended in 1989 by Benditt and coworkers.[39] Use of a drug challenge during tilt made the test more widely diagnostic with only a small cost in false positives. These observations made it possible to understand the mode of syncope in some patients where, previously, no diagnosis was possible. Many developments followed in the management of syncope.

By the end of this decade radiofrequency energy was being used for endocardial ablation of accessory pathways and of atrioventricular nodal re-entry tachycardias by Jackman *et al.*[40,41] Surgical ablation for atrial fibrillation was conceived and refined by Cox *et al.*[42]

The fourth and fifth decades, 1988–2007

This contemporary period has seen continuation of very rapid development of electrophysiology in all its forms including some totally new. In the field of pacing there was an emphasis on consolidation and refinement of technology. In terms of use of devices, indications expanded enormously and many more patients received pacemakers with many more centres undertaking procedures. Generators became smaller, using smaller batteries, offering greater ease of implant but with some compromise in lifetime. National registries, which had been started earlier, became much more appreciated and even, in a few cases acted as the predictor of developing faults in pacing systems. The profession developed guidelines for implantation and follow-up to attempt to standardize therapy everywhere by implementation of the growing evidence base of practice.[43] In spite of these noble motives, local demographic and political factors still determine huge differences in practice, for example in two similar and neighbouring European countries such as Belgium and the Netherlands.

Pacing indications expanded to include sinus node disease especially with chronotropic incompetence. Pacing, also, was extended to disorders of the autonomic nervous control of the heart including carotid sinus syndrome, which had been recognized earlier, and vasovagal syncope, which remains controversial till today. A special algorithm was developed to attempt to define the characteristic fall in rate that these autonomic disorders display at their onset.[44]

Sensors for rate modulation became the norm in generators with more than one in some to corroborate their influence on rate but by the turn of the century only activity sensing by vibration or body movement detection or use of some form of impedance measurement to assess parameters of respiration or right ventricular function remained in routine use.

In 1994, the first report of cardiac resynchronization therapy appeared.[45] This new application of pacing to improve coordination of ventricular contraction with resulting functional benefit only gained acceptance slowly in the 1990s but publication of a series of large randomized controlled trials in the early years of the present decade saw widespread adoption by specialists in heart failure as well as electrophysiologists. Most recently, the devices, which deliver resynchronization have additional antitachycardia pacing and defibrillation capabilities. Concurrently, ICDs acquired pacing capacity. A tendency was established to bring together the functions of all three types of device, pacemakers, resynchronization devices, and defibrillators. This tendency has evolved in the last few years when they have been termed, in general, rhythm management devices.

In 1990, ICDs started to be implanted using transvenous leads which have now become the favoured approach but the leads still lag behind those used in pacing systems in respect of stimulation threshold and reliability. Other developments, which occurred in the 1990s, were adoption of biphasic shocks, inclusion of the generator's case in the defibrillation circuit, known as the 'active can' and dual coil leads. These advances made ICD treatment more available to more patients and, at the same time, easier to deliver permitting more centres to undertake this form of treatment.

These two decades witnessed an explosion of electrophysiological diagnosis and treatment. Use of radiofrequency ablation was widely adopted and a huge number of patients received treatment that was tantamount to cure of their condition surpassing the palliation that had previously been offered. As patients with untreated accessory pathways and troublesome atrioventricular nodal re-entry tachycardias started to diminish, the problem of atrial fibrillation became amenable to ablative therapy. This was made possible by the landmark observation by Haisseguerre and coworkers[46] that the pulmonary veins display electrical activity that can trigger atrial fibrillation. Ablation of this activity showed considerable success in preventing paroxysmal atrial fibrillation but later techniques from Pappone *et al.*[47] and also from the Bordeaux group[48] to isolate the pulmonary veins from the left atrium proved yet more successful with less likelihood of complication. Another important finding in the understanding of atrial fibrillation came from Allessie and coworkers, which, in 1995,[49] demonstrated that atrial fibrillation begets atrial fibrillation by imposing electrophysiological changes on the atria that do not readily reverse. It can be said that the heart tends to develop the habit of atrial fibrillation making it increasingly difficult to return it to normal sinus rhythm. Today, the last arrhythmic frontier is being attacked by ablation with results in paroxysmal atrial fibrillation looking very good and those in treatment of the persistent and permanent types slightly less so.

Workers in the field of atrial fibrillation ablation have been much helped by new technology including three-dimensional mapping of the spread of electrical waves across the heart beginning in the late 1990s and now an essential part of every electrophysiology laboratory. These techniques are now being further advanced by the use of magnetic catheter guidance and robotic technology. These offer the prospect of more precise and repeatable catheter movement and positioning together with less radiation exposure for hard-pressed operators.

During the rapid progress of ablation for atrial fibrillation, similar approaches using mapping have been applied to the management of ventricular tachycardia. In cases with macro-re-entry, ablation could be the first treatment option although this is tempered by the types of pathology encountered in the ventricles, which may be widespread implying that many re-entry circuits exist and that it may not be possible to treat them all. In some patients, ventricular tachycardia ablation is seen as an adjunctive therapy to reduce shocks from the ICD. In this area, pioneering work has been performed by Stevenson *et al.*[50] in the 1990s, probably inspired by the earlier work of Josephson *et al.*[51] Catheter ablation of ventricular tachycardias has continued to be refined into the current decade. More recently, Sosa and Scanavacca[52] have used a similar approach to epicardial ablation of ventricular tachycardia.

The last two decades have been ones of great advance in the understanding and exact characterization of genetic abnormalities leading to arrhythmic diseases not only among the Long-QT syndromes but also in the newly described Brugada syndrome[31] and most recently the short-QT syndrome. Gene therapy has not yet proved possible and the only treatment today for most is implantation of an ICD.

Another new device for implantation has been introduced by Lesh and coworkers[53] in the current decade, which aims to prevent systemic embolism by occlusion of the left atrial appendage. At this early stage it is not yet clear how successful this technique will prove to be.

The study of syncope was rendered easier and much more possible to make a precise diagnosis by the advent of the implantable loop recorder, which was first studied by Krahn *et al.*[54] A flow of studies has since emanated from this group and from Brignole *et al.*[55] to help to define the role of pacing in various types of neurally mediated syncope and in ventricular conduction tissue disease.

The current decade can be considered one of the large clinical trials aimed at establishing an evidence base for new and not so new but widely practised techniques. They began in 1998 with the PASE trial of pacing in the elderly,[56] which drew attention to the enormous potential for pacemaker syndrome in those paced VVI. It was followed by the Canadian trial of physiological pacing,[56] CTOPP, which failed to demonstrate much benefit of more complex pacing systems. However, it did show that dual chamber pacing was superior to VVI/VVIR in control of atrial fibrillation in the medium- to long-term. Both of these trials had been preceded by the first Danish trial, which compared atrial with ventricular pacing in sinus node disease and it showed clear superiority of the atrial mode on all counts.[57] CTOPP was followed by the MOST study[58] in patients with sinus node disease and the UKPACE study of older patients with atrioventricular block.[59] All of these trials disappointed in that they failed to show that a mode of pacing, dual chamber, which is closer to normal sinus rhythm, did not yield expected benefits. This prompted some to seek an explanation and the DAVID trial seemed to offer this.[60] A trial performed in patients with reduced left ventricular function and ICDs resoundingly indicated that dual chamber pacing, implying much ventricular pacing in a group not requiring it, increased ventricular dysfunction with an appreciable mortality. Attention has since been turned to avoidance of unnecessary pacing in the right ventricle by special algorithms in dual chamber devices to prevent it. This has also increased interest in the techniques of CRT. It cannot yet be said that the complications of left ventricular pacing parallel those of pacing the right ventricle, although this may be attainable.

CRT has had a very large exposure to trials of its efficacy. Early trials such as MUSTIC, MIRACLE, and PATH-CHF[61–64] combined to place the technique on the scientific map. They have been followed by COMPANION and CARE-HF,[65,66] which extended the efficacy data to include mortality benefits of CRT. These have convinced many specialists in heart failure that this therapy is a necessary part of heart failure patient management.

In ICD practice, data has been published consistently over the last 10 years to underline the effectiveness of these devices in saving lives and gradually more types of patients have been shown to benefit, extending to primary prevention of ventricular tachyarrhythmias and to patients with reduced left ventricular function but without coronary artery disease. These trials include AVID, CASH, CIDS, MADIT 1, CABG-patch, MUST, MADIT 2, and SCDHeFT.[67–74] Now every post-myocardial infarction patient and most of those with dilated cardiomyopathy, even without ischaemia as its basis, have to be considered for ICD implantation.

Conclusions

The field of electrophysiology is the fastest growing subspecialty in cardiology. It may be anticipated that this will continue at its present pace or even faster. The specialty is already large enough to be represented either by its own groups, such as the Heart Rhythm Society, or by large subdivisions of national and international groups such as the European Heart Rhythm Association, which is part of the European Society of Cardiology.

The achievements of electrophysiology have been vast and some of those responsible for the innovations mentioned in this article. There are many more who have worked very hard but have not been included. This work can and already has been applied to other body systems, which depend on electrical activity for their function, such as brain, stomach, intestines, and bladder. Frequently, such activity can be influenced favourably by a device, which is similar to a pacemaker. Much more can be expected in coming years.

While these advances in electrophysiology have been taking place, the cost of devices has progressively fallen but Health Care administrators repeatedly demand ever further economies in our practice, thereby presenting barriers to advancing technology and to more healthy patients. As always it will be the duty of the profession to cross these barriers to avoid potential detriment to patients.

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