PACEMAKERS

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INTRODUCTION

The primary function of a cardiac pacemaker is for the treatment of bradyarrhythmias, when the heart beat stops or responds too slowly. The clinical condition can be intermittent or permanent. If permanent, the pacemaker will control the heart continuously. If temporary, the pacemaker will respond only when necessary, avoiding competition with the heart's own natural response. As these devices are battery-powered, allowing the pacemaker to pace only when necessary also conserves pacemaker energy, extending its lifetime and reducing the frequency of replacement surgery.

Since their clinical introduction in the late 1950s and early 1960s, pacemakers have significantly improved the ability of many patients to lead normal lives. They also save lives by preventing the heart from suddenly stopping. The small size and long life of pacemakers allow patients to forget that they have one implanted in their chest. The first pacemakers were simple devices designed primarily to keep patients alive. Modern pacemakers respond to patients' needs and can regulate pacing function to enable the heart to optimize cardiac output and blood flow.

CLINICAL USE OF PACEMAKERS

The clinical problem with bradyarrhythmias is often associated with sick sinus syndrome. The heart's own natural pacing function originates from the sinus node in the right atrium. The rate of impulse formation at the sinus node is controlled by nerves feeding the node. Impulses arriving via the vagal nerve act to slow the heart down, as part of the body's parasympathetic response. When a higher heart rate is needed, the vagal nerve impulse rate to the sinus node is slowed down and the sinus node impulse rate increases.

Impulses propagating through the heart tissue are created via a series of action potential changes. Action potential changes can be triggered either naturally from one of the heart's pacing cells or by contact with a neighboring cell, causing the outside of the cell to produce a negative voltage with respect to the inside of the cell. These voltage changes are in the order of only 90 mV, but as we will see, an external voltage from a pacemaker has often to be several volts before depolarization is initiated.

Without pacemaker control, patients with bradyarrhythmias suffer from dizziness and can collapse without warning and, hence, risk injuring themselves. Heart pauses of the order of 10 s will cause unconsciousness. Most patients who collapse will recover their normal heart rhythm. They can then subsequently be examined clinically, and, if necessary, a pacemaker can be implanted to prevent recurrence of a further collapse. Sometimes the heart will stop and not recovers its normal pumping function and the patient will die, but usually there will have been preceding warning events allowing a pacemaker to be fitted to prevent death.

Many good texts exist that explain the clinical background to cardiac pacing, and these texts should be consulted (1–3). This text is primarily a description of the medical device itself.

Practical cardiac pacing started in the 1950s with the first clinical device, which was external to the body and required connection to a main power supply. This device was followed by an implantable pacemaker developed by Elmquist and surgically implanted by Senning in Sweden (4). The device only lasted a short time before failing, but it did show the potential for implanted pacemakers. This work was followed by Greatbatch and Chardack in the United States (5,6), first in an animal and then in a patient two years later. An interesting early review of this period has been given by Elmqvist (7). These first pacemakers were very simple devices and paced only at a fixed rate, taking no account of the heart's natural rhythm. Although this approach was less than ideal, it did provide the necessary spur for both clinical expectations and technical and scientific developments by research bioengineers and industry.

The next major technical development allowed pacemakers to pace on demand, rather than only at a fixed rate. Other pacing functions developed, including pacemakers that could pace more than one heart chamber, and pacemakers that could change their response rate as a function of patient physiological requirements. Three- or four- chamber pacing was an extension of basic pacing. Pacing functions have also been included in implantable defibrillators. More complicated pacing algorithms have been developed for controlling tachyarrhythmias, including ventricular tachycardia and rhythms that can deteriorate to ventricular fibrillation.

With the evolution of smaller devices and leads, their use in pediatrics has grown, including for children with congenital heart problems. Devices as thin as 6 mm are available. Reduction in size has also aided the move from epicardial to endocardial fixation of the lead. When pacemakers are implanted in children, special consideration has to be given to the type of device as children are usually active, the lead length as children continue to grow, and lead fixation as future lead replacement must be considered.

No doubt exists that, with continuing experience, pacing techniques and pacemaker devices will continue to evolve.

Encyclopedia of Medical Devices and Instrumentation, Second Edition, edited by John G. Webster

PHYSIOLOGICAL FUNCTION

Understanding the physiological function of a pacemaker is more important than knowing the technical details of the pacemaker. The main functional characteristics are the ones that are important for the physician or cardiologist who will want to know how the device will operate when implanted in a patient. A series of clinical questions exist. The first question asks where you want the device to pace the heart–in the ventricle, the most common location, in the atrium, or in both. The second question asks in which chamber or chambers you would like the pacemaker to sense. This location is usually the ventricle, but can be the atrium or both. The third question relates to how you want the device to work when it encounters natural heartbeats. It can either be inhibited, which is by far the most common approach, or it can be triggered to enhance the natural beat. It is also possible to switch off the device's ability to sense the heart's natural rhythm, but is rarely done as there could then be competition between the pacemaker output and the heart's natural rhythm.

The answers to these three questions provide the first three codes given to any pacemaker. This code is an international code developed by the Inter-Society Commission on Heart Disease (ICHD) (8). It was subsequently expanded to a five-code system by the North American Society of Pacing and Electrophysiology (NASPE) and the British Pacing and Electrophysiology Group (BPEG) (9,10). The first version of the NASPE/BPEG codes allowed for programmability and communication, but as they became universal functions, the latest version of the codes simplified the codes in the fourth and fifth letter positions for use with rate modulation and multisite pacing only. These codes are used throughout the world. A summary of the coding is given in Table 1.

It is useful to give a few examples to illustrate how the codes are used. VVI pacemakers, which are in common use, allow the pacemaker to pace in the ventricle if natural beats are absent (V), and sense natural beats in the ventricle (V), ensuring that the pacemaker inhibits (I) its output if a natural beat is detected. DDD pacemakers can if required pace in both the atrium and the ventricle (D), and sense in the atrium or ventricle or both (D), with inhibiting and triggering (D). With programming techniques, the pacemaker's mode can be changed after the device is implanted, and so a manufacturer may list a very large number of modes for some pacemakers.

The codes in Table 1 also show the fourth and fifth letters. The fourth tells the user if the device has an internal function for modulating its pacing rate, known as a rate responsive (R) mode. If no code is quoted in the fourth position, it can be assumed that the device is not rate responsive. The fifth letter is for multisite pacing and is used if at least two atrial pacing sites or two ventricular pacing sites exist.

TEMPORARY EXTERNAL PACEMAKERS

This review primarily concerns implantable pacemakers, but the role of temporary external pacemakers must not be forgotten. These devices provide essential support after some cardiac surgery and after some myocardial infarctions, allowing time for the recovery of the heart's own pacing function. The way these devices function is very similar to implantable pacemakers, but they are generally simpler and provide the clinician with access to controls such as for pacing rate and pacing voltage. The pacing leads do not have the tip features required for permanent fixation, and the connector to the temporary pacemaker is simpler. Also, the leads are bipolar with two electrode contacts.

CLINICAL IMPLANTATION

Briefly, pacemakers are implanted most commonly at one of three sites (Fig. 1). Implantation is undertaken by a surgeon or cardiologist using an aseptic technique. The pacemaker pulse generator and leads are delivered in sterile packages with clear use-by dates. Venous insertion of the lead allows it to be pushed through the right atrium and tricuspid valve, and into the right ventricle, where the electrode can be positioned in the apex where it is less likely to move or displace in comparison with other possible positions. If an atrial lead exists, it is positioned in the right atrium. Good contact with the atrial wall is harder to achieve, and active fixation such as with a screw contact can be used, in comparison with ventricular apex passive fixation.

Patients must be followed up at regular intervals to ensure that the device is working correctly, that its output pulse characteristics are appropriate, and that the end-of-life of the internal battery is estimated. This follow-up interval may be over a period of months initially, and then annually, with more frequent follow-up visits toward the end of the device's life.

Most countries have national registration schemes, which enables information on specific patients to be obtained if, for example, a patient develops a problem while away from home. If, however, this information is not available, the device type can be recognized by a unique

Table 1. International Pacemaker Codes

1	2	3	4	5
Chamber paced	Chamber sensed	Response	Rate modulation	Multisite pacing
O = none	O = none	O = none	O = none	O = none
A = atrium	A = atrium	I = inhibited	R = rate modulation	A = artium
V = ventricle	V = ventricle	T = triggered		V = ventricle
D = A+V	D = A+V			D = A+V

The following letters are used sequentially in 5 positions.

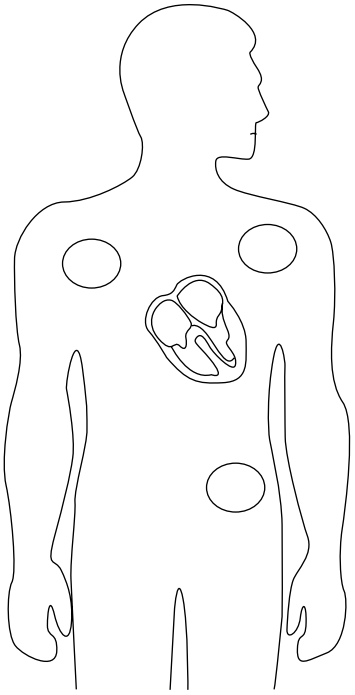

Figure 1. The location of normal pulse generator implantation sites.

radiopaque code that can be obtained by X ray. There has been discussion on whether such codes could be retrieved by a standard external interrogating device without the need for an X ray, but no such device is as yet universally available for all pacemakers.

Another goal of pacemaker registration is to provide useful data on the range of device lifetimes for each pacemaker type and information on sudden pacemaker failures, which enables clinical staff to plan any necessary replacement, and manufactures to act when it appears that failures are not random and may relate to their manufacturing process. This advance has enabled manufacturers to withdraw faulty or potentially faulty devices from the marketplace and correct production faults.

MARKET

Pacemakers have made a remarkable impact on clinical medicine. Over half a million new patients worldwide receive a pacemaker each year (11). In addition, approximately 100,000 patients worldwide receive a replacement pacemaker (11). Most implants are in the United States. When implants are related to the population size, the countries with the greatest new implant rates are Germany, the United States, and Belgium, with between approximately 700 and 800 implants per million population. Many countries with poor economies have very low implant rates. Within Europe, the implant rates are generally high, with, for example, the United Kingdom falling towards the bottom end of the implant rate, at approximately 300 per million population (12), where there are approximately 25,000 implants per year, and, of these, 75% are for new implants and 25% for replacements (12).

Table 2. Example Ranges of Pulse Generator Features

Volume	6–20 ml
Length/Width	30–60 mm
Depth	6–14 mm
Mass	13–50 g
Battery	0.8–2 Ah
Life	5–14 years
Sense threshold	0.1–15 mV
Refractory period	100–800 ms
Lower pulse rate	approximately 20/min
Upper pulse rate	approximately 185/min
Pulse amplitude	0–10 V
Pulse width	0.1–2 ms

FEATURES

Clinically, the most important pacemaker features relate to the device code, discussed above. Next in importance for both the clinician and patient is likely to be pacemaker size and lifetime. As a guide, example ranges of pacemaker features are included in Table 2. With continuous developments, these should be taken only as a guide. The shape and size of some pulse generators are shown in Fig. 2.

For a health-care system, the cost of devices is important. Costs vary significantly in different countries and also relate to the numbers purchased, so no specific figures can be given. It is, however, interesting to note the current relative costs of different types of devices. For guidance, approximate costs relative to a standard ventricular demand pacemaker type VVI are shown in Fig. 3, where the cost of the VVI pulse generator is given as unity. As the proportion of different types used will change, so will the relative costs.

The use of the unique radiopaque code for each pulse generator type is useful when a patient is referred to a medical center away from home, allowing that center to determine the pacemaker pulse generator being used.

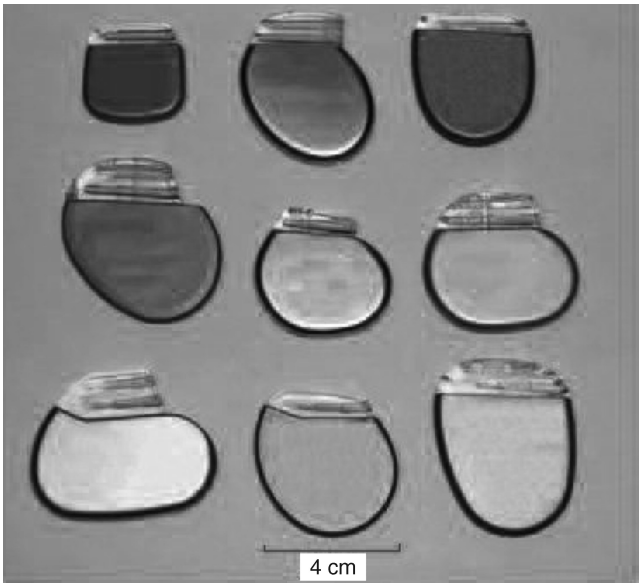

Figure 2. Illustration of some pacemaker shapes and sizes.

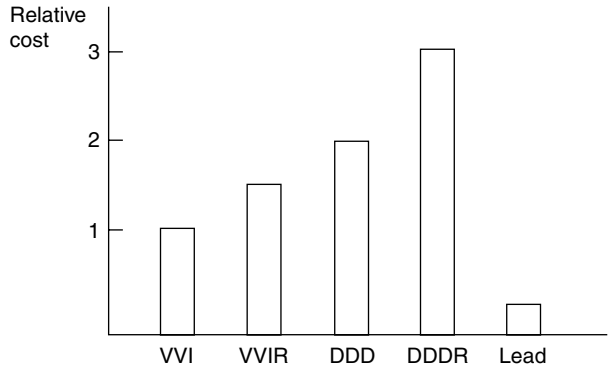

Figure 3. Relative approximate costs of pulse generators and pacing leads. The demand pacemaker (VVI) is taken as the reference.

A unipolar device has only one electrode directly in contact with the heart. In this case, the electrode is at the distal end of the lead. To complete the pacing circuit, another electrode contact is required, and this is on the pacemaker case with current flowing via the muscle in contact with the case electrode to the heart. Bipolar electrodes are also common. Here, both electrode contacts are on the lead, one at the tip and another several centimeters away. The second electrode makes contact with the ventricular wall simply by lying against the wall with the tip firmly located at the apex of the ventricle.

PACEMAKER COMPONENTS

A pacemaker refers to all components necessary for a complete clinical pacing device. At least two components will always exist, the pulse generator and the lead (Fig. 4). More than one lead any exist, such as for dual-chamber pacing, in both the atrium and ventricle. Unusual pulse generator and lead combinations may require an adaptor, but extra components should be avoided whenever possible. Extra components add to the areas where failure might occur.

When a pacemaker has been implanted or is, subsequently, to be checked, external devices will be required. An ECG recorder will confirm correct pacing, and some pacemakers generate impulses that can be visualized on an ECG recorder for relaying pacing information. In addition, a magnet or other technique may be used to put the pacemaker into various test modes, which is now commonly achieved with a programmer that communicates with the pacemaker via an electromagnetic wand using communication technology with coded sequences to prevent external interference such as from a radio telephone accidentally reprogramming the pacemaker. As well as controlling the pacing functions, the programmer can interrogate the pacemaker about the frequency of pacing, provided, of course, these features are available. Telemetry may also be available, where intracardiac waveforms can be relayed as they occur and selected pacing episodes can be recovered from the pacemaker memory.

Further useful technical information can be obtained from the books by Schaldach (13) and Webster (14).

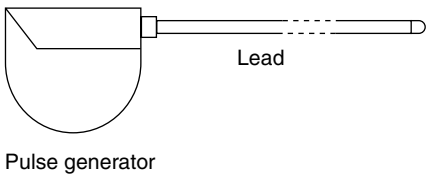

Figure 4. Pulse generator and lead are the two main components of a pacemaker.

PULSE GENERATOR

When pulse generators were first used in the early 1960s, they were simple devices with a battery power supply and a circuit to produce a regular pulse rate with a defined pulse voltage and pulse width output. Modern pulse generators are much more complex, with sensing and output control. Special electronic circuitry has been developed, often with sophisticated microprocessor control. Battery technology has also developed significantly. A block diagram of a complete pulse generator is shown in Fig. 5. Each major part is now described.

Power Supply

The first battery power supplies were made up from separate zinc-mercury cells. They could often be seen through the casing before implantation, after removal, or on the X ray. The voltage of these cells quickly fell to approximately 1.35 V, which was held until the cell reached the end of its life. Unfortunately, these cells could power the early pacemakers for only about two years.

These batteries encouraged the search for other power sources, including, for a short time, nuclear power, but safety concerns discouraged these developments. Rechargeable batteries, where the recharging energy was transmitted to the pulse generator via an external coil, were also employed, and had in fact been used in the first clinical pacemaker. However, reliability and frequency of charging inhibited their use.

Fortunately, a solution was found in the form of lithium-iodide cells. Their use in pacemakers was pioneered by Greatbatch (15) and introduced into clinical use in 1971. The cell has an initial open circuit voltage of 2.8 V, which falls slowly with use until its end of life is approached, when the voltage fall is more rapid. Although other types of lithium cells have been researched, they have not replaced the lithium-iodide cell for pacemakers. Some pacemakers

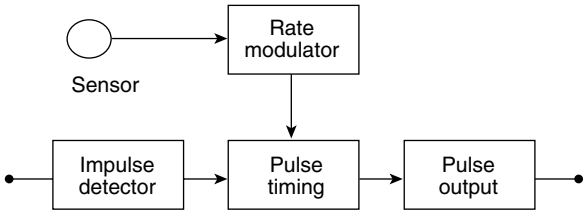

Figure 5. Block diagram of a complete pulse generator.

can now function for ten years, and, for low demand situations, 14 years can be achieved.

Ventricular and Atrial Sensing

All pacemakers sense natural cardiac impulses, which is achieved very reliably. However, the sensing circuitry needs to be able to differentiate between impulses coming from the heart and those due to external interference. The possibility of interference cannot be neglected, especially as the cardiac impulse is, at most, only a few tens of millivolts. In addition, in unipolar pacing, the sensing circuitry cannot differentiate between signals coming from the electrode at the end of the lead or the electrode on the pulse generator case, which is described more fully under leads below. It is not always possible to detect heart impulses reliably during periods of excessive interference, and in these cases, the device needs to be programmed to respond in a clearly defined way, such as by initiating fixed-rate pacing.

Pulse Interval Generator

At the heart of the pacemaker is the interval generator. As with other pulse generator functions, this is achieved with electronic circuitry or microprocessor control that generates the pacing interval measured in seconds or pacing rate measured in beats per minute. Without any means to detect patient activity or the need for a higher heart rate, this interval is fixed, other than for programmed changes that can be made at the clinic. The interval generator is connected to the sensing circuitry so that output from the interval generator can be synchronized or inhibited. Interactions for a VVI pulse generator are illustrated in Fig. 6. If a natural heartbeat is sensed, the pacemaker will time its pulse interval from that beat. If, however, the beat occurs in the refractory period set in the pacemaker, it will not respond to the beat, and the pulse interval timing will not be altered. For devices that can pace in both the atria and ventricle, such as a DDD device, the interval between atrial and ventricular pacing, known as the AV interval, will be set to optimize heart pumping function (Fig. 7).

Interval Modulator

The interval modulator, if it is available, simply attempts to change the response of the interval generator to that required by the patient. Electronic modulation of the interval is easy to achieve, and this function will usually be seen as part of the interval generator. However, determining how to modulate is difficult, and it requires a sensor to detect the patient's need for a higher or lower heart rate, usually in response to patient activity, whether determined directly or indirectly via physiological functions.

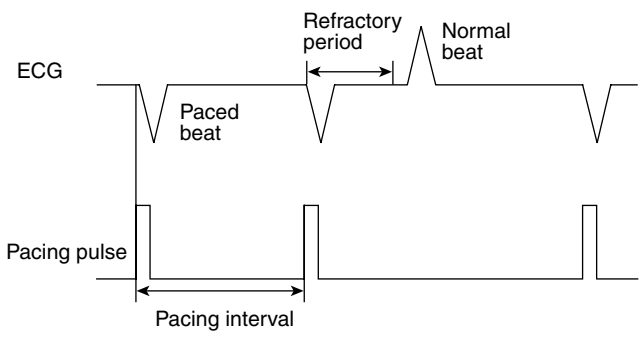

Figure 6. Illustrative example of some pacemaker-heart interactions.

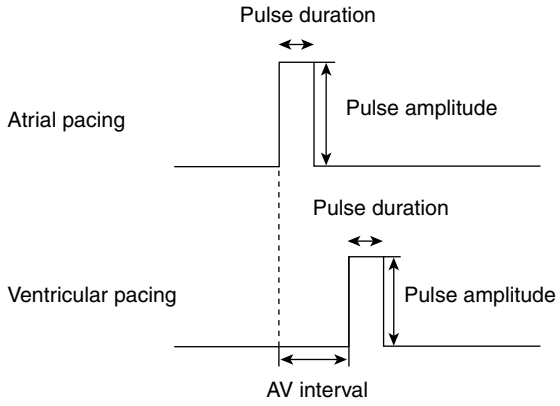

Figure 7. Atrioventricular pacing with the AV interval set within the pacemaker.

Activity Sensor

Many different sensors have been used. Some have been more successful than others. Changes in blood oxygen levels, through oxygen partial pressure or saturation levels, suggest the need for a higher heart rate when these levels fall, but this technique requires a sensor with continuous blood contact that will continue to work over many years, a difficult specification to achieve. Increased respiration rates also suggest the need for a higher rate. To detect respiration, some devices used a special lead to detect respiratory movement or electrical impedance changes but were not always successful. Special leads with inbuilt sensors add to the complexity of the pacemaker. Respiration can now be monitored using electrical impedance changes from a standard lead.

Other successful techniques used the intracardiac electrogram obtained from the sensing electrode or activity sensing from an inbuilt accelerometer. With careful analysis of the electrogram, it is possible to obtain a measure of the repolarization interval, which is known to change systematically with heart rate changes and, for this application, has been shown to shorten even without any increase in paced heart rate when the need for a higher rate is physiologically required. The use of a motion sensor using a piezoelectric sensor has been successful and is most widely applied because the technology is simple. The sensor can be built into the pulse generator housing with better reliability than for techniques requiring additional patient contacts. Movement of the sensor produces an output voltage proportional to acceleration. Algorithms have then been developed to relate changes in sensed activity to changes in pacing interval. They can also, to some extent, be programmed to individual patients. One drawback is that the sensor senses movement of the pacemaker that can be in a patient, for example, driving a car

where an increase in heart rate may not be appropriate. Improvements to deal with such situations are under continuous development, as is research into different sensor techniques.

Without doubt, rate-responsive pacemakers have made a great contribution, and patients welcome the ability of the pacemaker to adapt to their needs, even if the pacemaker response is not physiologically perfect (12).

Lead Connector

Leads and pulse generators are provided separately, which gives greater flexibility in their use and enables different lead lengths and lead types to be selected. However, a connector is then needed. Ideally, this connector should be able to connect any appropriate lead to any pulse generator, and international standards have gone a long way to achieving this. For single-chamber pacemakers, the connector takes one lead that can be either for a unipolar or bipolar lead with one or two electrode contacts.

It is important for the connector to make a good electrical contact, while preventing any body fluids penetrating into the pulse generator, which in the past, have caused pacemakers to fail. Connectors allow the electrical contact to be made easily and provide seals between leads and the pulse generator.

Case

The primary function of the case is to protect the inner electronics from mechanical damage and from penetration of blood or other fluids. It is essential for the case to be biocompatible so that the patient does not attempt to reject the pulse generator as a foreign body. Titanium has been a successful material.

For unipolar devices, the case must contain an electrode, which acts as the reference for the lead electrode. The sensed voltage is that between the case and the lead electrode. Also, when pacing, the stimulation voltage appears between the case and lead electrode. To minimize the possibility of muscle stimulation at the case electrode, this electrode has a large surface area, so reducing the current density in comparison with that at the lead electrode. Also, the output pulse is positive at the case electrode with respect to the negative voltage at the pacing electrode, which confers preference to stimulation at the negative site in the heart.

Telemetry Function and Programming

For programming and telemetry functions, the pacemaker needs to be able to communicate with an external device, usually with coded signals using electromagnetic transmission between the pacemaker and a wand of the programming unit. These devices use standard techniques, with only the coding being specific to pacemakers.

Computer Algorithms

Pulse generators usually can be seen as small microprocessor devices. As such they contain computer code or computer algorithms to control their function, delivering advantages to the patient and clinician, as the pacemaker's mode of operation can be changed, and also to the manufacturer, as it is easier to develop new and improved devices. However, reliable software is notoriously difficult to develop and test. Manufacturers have discovered, to their cost-unusual errors in their software only after devices have been implanted, necessitating a recall of devices not yet implanted and careful follow-up of patients with devices already implanted. High quality software development is taken seriously by the manufacturers and cannot be stressed enough.

Table 3. Example Ranges of Lead Features

Length	20–120 cm
Diameter	1.2–3.5 mm
Tip diameter	0.7–3.3 mm

LEAD

The lead has four main features. It needs a connector to connect it to the pulse generator, a long flexible wire, a biocompatible sheath over the wire, and at least one electrode to make contact with the heart. Table 3 provides illustrative ranges of lead features.

Connector

The connector needs to be compatible with that on the pulse generator. As with the pulse generator, there should be no ingress of fluid, this time into the wire. Also, as the wire can move with each heartbeat, the construction needs to ensure that no extra stress exists on the lead wire near the connector.

Lead Wire

The most important characteristic of the lead wire is that is has to be flexible. Normal wire easily fractures when bent repeatedly. A pacing lead wire has to move with each heartbeat, which averages approximately 100,000 movements each day. Good flexibility is achieved by using a spiral construction. All wires have some impedance, which is taken into account by the pulse generator output.

Insulated Lead Sheath

The sheath covering the lead wire also needs to be flexible and must not become brittle with age. The sheath material must be biocompatible so as not to be rejected by the body. Materials used are silicone rubber or polyurethane.

Electrode

The design of the electrode is very important. In particular, the fixation, contact area, and contact material are essential features. Illustrative examples of basic features of lead-tip electrodes are shown in Fig. 8. Unipolar electrode leads have a single-electrode contact at the tip. Bipolar electrode leads have two contacts, one at the tip and the other a few centimeters distant from the tip.

When the lead is implanted and a suitable electrode site found, the electrode needs to stay in position, which is

Figure 8. Illustrative example of pacing electrodes.

achieved by mechanical features at the tip of the lead, which can be, for example, tines or a helical electrode construction. With time, tissue will grow over the tip holding it in place. One problem is that this fixation can become so good that the lead can be difficult to remove if a problem occurs and it needs to be replaced. Electrodes positioned in the ventricular apex are easy to locate and also tend to stay in position easily, and hence require only passive fixation, such as with tines at the end of the lead. Other tip locations may require active fixation such as with a screw tip.

The electrode area needs to be high enough to ensure good electrical contact. The greater the contact area, the lower the contact impedance, which in turn reduces the electrode-tissue interface impedance and ensures that most of the pulse generator voltage appears at the cardiac tissue.

As with any electrode, the electrode contact material is important. The aim in selecting the material is to reduce polarization effects. Many electrode-coating materials have been studied, including steroid-eluting electrodes to reduce inflammation. Changes in electrode polarization are the cause of the increase in stimulation voltage in the days and early months after implantation, to be subsequently followed by a lowering of the effect and also of the required stimulation voltage.

STIMULATION THRESHOLDS

Stimulation success is a function of both pulse amplitude and pulse width. A minimum voltage and energy is required. The voltage has to be greater than that required to initiate the approximate 90 mV change in action potential. However, because of polarization and other effects, the voltage required is usually in the order of several volts and can reach 10 V soon after implantation. After a few months, this voltage will have reduced to the level of a few volts.

The initial research on stimulation pulse energy was with stimulating nerves, but the results obtained have been shown generally to hold when stimulating or pacing cardiac tissue. The energy used should be the minimum possible to induce stimulation reliably, which is controlled by varying the pulse width. Early work on nerve stimulation showed that no matter how wide the pulse width was, a minimum pulse voltage existed, called the **rheobase** voltage. At about twice this voltage, with a lower pulse width, the minimum energy required is found. If the pulse width is reduced further, the greater voltage required results in increased energy requirements to induce pacing. The pulse width for lowest energy is called the chronaxie time, shown in Fig. 9.

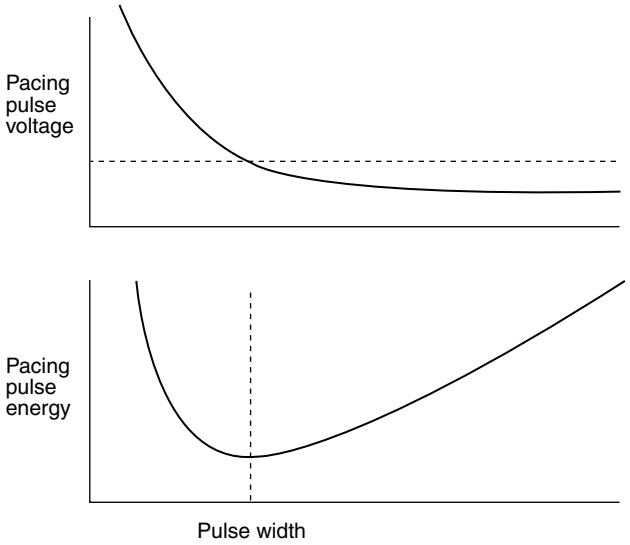

Figure 9. Pulse energy as a function of pulse width.

As the pulse energy is only to initiate cardiac depolarization, and not for providing pumping energy, the energy levels required are low and on the order of only a few microjoules (16).

PROBLEMS IN USE

Interference

Interference is a well-understood problem. Muscle interference at the case electrode in a unipolar system can be a problem in active people, especially when the pulse generator is implanted beside the pectoral muscles. If this particular problem is anticipated, a bipolar system can be used.

Threshold Voltage Changes

Threshold voltages do change. If the pacing voltage is set too high, energy will be wasted, reducing the lifetime of the device. If set too low, changes in threshold voltage may result in the pacing voltage being below the pacing threshold. These factors have to be balanced. Some devices automate the selection of an appropriate voltage output.

Early Failure

Pacemakers are complex devices, and like all devices they can fail. Failure is not a common problem, but because pacemakers are implanted and are life supporting, failure can have fatal consequences. Reporting of individual problems is essential, allowing manufacturers and national health bodies to identify a common problem early and, if necessary, withdraw stocks before they are used in new patients and take action to review patients who already have the device implanted.

SPECIAL DEVICES

This review has concentrated on the main use of pacemakers for treatment of bradyarrhythmias. Other options

are used, but these options are based on the standard pacing approaches.

Implantable defibrillators can have an additional pacing function so that if the heart stops rather than developing ventricular fibrillation, pacing can be initiated. The pacing technology is exactly the same as for pacemakers described above, except that the electrode system will be different.

Devices are used for control of tachyarrhythmias. These devices, rather than using the regular pacing interval, usually use a series of pacing intervals at different rates to terminate the arrhythmia.

Some patients in heart failure were, in the past, often assumed to be untreatable unless by heart transplantation. Much can now be done for these patients, including pacing in all four cardiac chambers, which maximizes the pumping function of the heart by pacing the left as well as the right heart chambers, and pacing the atria and ventricles with an appropriate atrio-ventricular delay. This solution requires complex and multiple leads, and as these leads are used in sick patients, success is not always assured. Many of these patients may also require a defibrillation function.

FUTURE

Cardiac pacing had a small beginning but has grown at a steady rate each decade. With an aging population, the need for pacing will continue to grow. The development and production of pacemakers will remain a major medical device industry.

Of those devices currently available, increased use of physiological or rate responsive devices is likely as clinical studies prove their clinical value to patients, especially those who are active.

Technical advances will, to some extent, be dependent on the production of improved batteries, and then the decision will be either to make them smaller, last longer, or power more microprocessor technology. Improved electrode design to reduce energy requirements could also make a significant impact in reducing pacing pulse energy, and hence overall energy requirements. Improvements in setting the optimum AV delay will help many patients and, in particular, children who are active. Increased ability to store intracardiac data for review will ensure more research into effective use of pacing.

Pacing will continue as an essential therapeutic technique, saving lives and bringing some normality to patients with abnormal physiological heart rate control.

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See also AMBULATORY MONITORING; BIOELECTRODES; BIOTELEMETRY; DEFIBRILLATORS; MICROPOWER FOR MEDICAL APPLICATIONS.