Environmental Hazards for Pacemaker Patients

EDGAR SOWTON, MD, FRCP
Cardiologist, Department of Cardiology, Guy’s Hospital, London

The first pacemaker implant was made by Dr Rune Elmqvist, the operation being performed by Dr A. Senning in Stockholm in 1958. The patient, Mr Arne Larsson, is still very active as President of the Swedish Pacemaker Patients’ Association and, of course, still has an implanted pacemaker. In the USA, Wilson Greatbatch patented his mercury battery powered pacemaker in 1959 and Dr W. Chardack reported its successful use in 1960. Over the subsequent two decades, the use of cardiac pacemakers has increased dramatically, so that in the UK at the present time approximately one person in every 2,000 of the population has a pacemaker. Even this figure is well below those for other developed countries; in the USA one person in every 800 has a pacemaker. Although it is increasing, the implantation rate in Britain is still similar to that of Poland and Czechoslovakia, being approximately one-third to one-half the rate in France, Germany, Holland, Belgium, Canada and the USA.

The indications for pacemaker treatment have multiplied and generators are now implanted for bradycardia caused by varieties of conduction system disease, including sinus node malfunction. The use of pacemakers in the treatment of tachycardia is growing and there are probably more than one million patients in Europe alone whose tachycardia would be amenable to pacemaker treatment.

Since the very early days of pacing there has been concern about the possible deleterious effects of external signals, and this article is concerned with the response of implanted cardiac pacemakers to electromagnetic and other types of interference signals.

Fixed Rate Pacemakers

This type of generator does not respond to any incoming signals, either from the heart or from other sources, and it is therefore immune from interference effects. True fixed rate pacers are now obsolete but many of the multi-programmable units (see later) can be programmed to a fixed rate mode. The manner in which different manufacturers achieve fixed rate pacing varies, and with some models there is a small theoretical risk that interference may alter the rate. In general, however, patients with fixed rate pacing will not be affected by environmental sources of interference[1].

Demand Pacemakers

The great majority of units implanted in the UK are of this type. Demand pacemakers monitor the spontaneous QRS complexes and will withhold stimuli provided a suitable incoming signal is detected. Signals with peak energy at about 30 Hertz and a repetition frequency of 60—120 per minute will be interpreted as coming from the heart and the pacemaker will be inhibited. If the signals arise from a source of interference, ventricular asystole and a Stokes-Adams attack may result.

Triggered or Synchronous Pacemakers

These pacemakers usually detect spontaneous atrial signals through one electrode and, after a suitable delay equivalent to the PR interval, provide a ventricular stimulus through a second electrode. Any input signal that is interpreted by the pacemaker as a P wave will result in delivery of a ventricular stimulus, so certain interference sources can result in a paced tachycardia.

A small number of patients in the UK have been treated with ventricular triggered pacemakers, often for specialised purposes, such as termination of episodes of tachycardia. These pacemakers detect spontaneous QRS complexes and immediately deliver a stimulus to the ventricle through the same wire. As it falls during the absolute refractory period this stimulus is ineffective and acts simply as a ‘marker’ on the ECG. If no spontaneous QRS is detected over a pre-set time interval (often 1 second), a further pacing stimulus will be delivered to drive the heart. Suitable interference signals may trigger this type of pacemaker, producing a paced ventricular tachycardia.

Both atrial triggered and ventricular triggered pacemakers are limited by the maximum rate at which they can stimulate, either when functioning normally or when driven by external interference. This maximum rate is usually about 150—170 per minute.

Other Pacemakers

Much more sophisticated pacing systems are now coming into use, such as the dual chamber dual function stimulator or the ‘universal’ pacemaker. All these require two connections, one with the atrium and one with the
ventricle, and can sense spontaneous activity with either wire. The pacemaker response to such an input signal varies with the model but may be by inhibition or triggered stimulation.

Programmability

Any of the previously described types of pacemaker can be obtained in programmable versions that allow non-invasive alterations of some of the pacemaker characteristics. An external programmer transmits a coded signal through the skin to be received by the pacemaker which adjusts its settings accordingly. The usual mode of transmission is a burst of electromagnetic impulses, and these are received by a small reed switch within the pacemaker which opens and closes appropriately. Phantom programming (the changing of pacemaker settings due to random interference signals) was reported with early programmable pacemakers but has now been almost eliminated by the adoption of highly specific codes that must be received in correct sequence, with the correct number of bits of information and within a pre-set time limit, before the pacemaker will respond. Occasional reports are received of one programmable pacemaker being affected by apparatus produced by a different manufacturer[2] but by their very nature these incidents occur only in the hospital or pacing centre and can be dealt with immediately[3]. Even when the correct programmer is used, the presence of random interference signals, such as might be produced from the closing of the switch in an adjoining electrical circuit, may introduce an extra bit of information during the reprogramming. This will block acceptance of the programme, and failure of certain manufacturers’ pacemakers to accept programming has been reported as being due to this cause. It is not a general hazard because it can occur only in a centre where reprogramming is being carried out.

Apart from the few moments during which a pacemaker is actually being reprogrammed it will behave in the same way as the types already mentioned.

Interference Protection

All pacemaker manufacturers have designed their products with input filters that reject unwanted frequencies but it is clearly impossible to reject interference signals that have the same characteristics as the signals from the heart. As most interference signals cover a wide range of frequencies the input filter will allow through the frequencies normally received from the heart. It is usually possible for the pacemakers to recognise these as interference by the repetition rate. When input signals are received above a rate pre-determined by the manufacturer, which is usually about 300 per minute, the pacemaker identifies the signals as being due to interference and not from the heart. Instead of being inhibited, a demand pacemaker will then revert to a fixed rate mode and will stimulate at a steady rate independent of cardiac activity (Fig. 1). This ‘interference rate’ or ‘noise rate’ may be the same as the normal pacing rate but is usually faster. This has the advantage that the patient recognises he is in a very strong interference field and also that the faster interference rate will overdrive the heart and be less likely to result in competition with spontaneous rhythm.

Interference signals are unlikely to penetrate the circuit of the pacemaker directly because of the metal casing in which almost all modern pacemakers are hermetically sealed. The signals will be received from the electrode, which acts as an aerial, and the strength of these signals is very much greater when a unipolar system is used than when a bipolar wire connects the pacemaker to the heart.

Sources of Interference

It is apparent that the most dangerous type of interference is a signal with a frequency content approximating to that of the endocardial QRS and recurring at a rate within the physiological range for the heart. Fifty cycles AC mains has the correct frequency content, and domestic apparatus that has a small leakage of current may easily affect pacemakers. Examples are a faulty electric blanket, kettle or iron. In such cases the pacemaker will normally revert to its interference rate and if this happens the patient should have the equipment checked as soon as possible.

When any electrical circuit is made or broken, a transient signal will occur and a short burst of electromagnetic interference may be produced. This is particularly likely to happen if the switch is controlling mains-driven equipment (or even higher voltage equipment) and if a spark is produced. Most equipment of this type is fitted with suppressors to prevent sparking, but lack of maintenance often reduces their efficiency. Examples are household or refrigerator thermostats, time switches and room lighting. Fortunately, the energy produced is usually far too little to affect pacemakers and even in exceptional circumstances only a single signal would occur so that the pacemaker would miss only one beat.

For practical purposes this hazard can be ignored. Elec-
Electronic sensor switches requiring only a very light touch can sometimes inhibit a pacemaker, but, again, only one or two beats are missed and the risk is negligible[4]. Remote cordless controls used for many TV sets utilise infra-red or ultrasound emissions and do not affect pacemakers. Mains-driven electric motors can produce considerable interference and are the cause of most reported incidents of pacemaker inhibition. The radiation levels can be very high if capacitors intended to suppress sparking have failed, so reports tend to incriminate older equipment. Cases of pacemaker inhibition from vacuum cleaners, deep freezers, refrigerators, electric mixers, electric razors, and small power tools have been reported. Pacemaker interference can occur even from a battery-operated electric razor[5]. All these reports have in common the fairly close proximity of the patient and the electric motor; in most cases the motor was found to be faulty.

Petrol engines produce a fairly high level of interference from the ignition systems, and both petrol and diesel engines produce modulated interference from the dynamo or alternator. The levels are usually too low to affect pacemakers when the engines are contained within the metal work of a car but it is unwise for pacemaker patients to come very close to such engines while they are running. This applies to motor-cycles, lawn-mowers and outboard engines. Three feet away is generally a safe distance but the radiation from different engines and the susceptibility of different pacemakers to interference varies so widely that patients whose work or hobby involves these engines should be advised to check their own pulse when they are in the vicinity of the engine and to move away at once if they have any unusual symptoms.

Very high levels of interference are generated by certain activities such as arc welding or ‘Dodgem cars’ at a fair-ground. Triggered pacemakers will usually run at their maximum rate, but either inhibition or fixed rate pacing may be produced in demand pacemakers. If a patient’s occupation involves such high levels of interference, serious consideration should be given to implantation of a bipolar system and the pacemaker function should be checked with a continuous ECG when he first returns to work.

Microwave ovens can occasionally affect pacemakers, particularly if the seal around the door is inefficient or if the oven has not been serviced[6]. The usual response is for the pacemaker to go into its interference rate but for this reason patients should be advised not to approach too closely to industrial microwave ovens and to have domestic ovens serviced at once if they experience any symptoms when approaching. Many manufacturers of pacemakers advise patients not to approach within six feet of a microwave oven in use but this is an unnecessary restriction in the vast majority of cases.

**Anti-Theft Devices**

Many shops have now installed anti-theft devices in which a small metal tag is attached to the articles and removed when the bill is paid. If an article is stolen and carried through the exit door with the tag still attached an alarm will sound. A similar system is used in most libraries to prevent books being taken without checking. There are several systems in commercial use and occasional pacemaker interference has been reported. The system most widely used (Senelco) in stores in the UK did not affect a wide variety of pacemakers tested at Guy’s Hospital even when the patients remained within the detection field and the system was repeatedly activated. However, implanted pacemakers would often trigger the detectors in the same way as do the tags, so the patient should explain to the shop staff that he has an implanted pacemaker and is not trying to remove unpaid-for goods. The anti-theft devices (3M Tattletape) in many libraries produce a very complicated field which is generated in bursts when a light beam is interrupted at the exit gate. Each of these bursts is detected by a pacemaker and will inhibit one beat. Provided the patient passes at a normal rate through the exit gate this is of no consequence, but if he remains in the vicinity of the detectors while a large number of other people activate the device it is conceivable that each burst would affect the pacemaker and the heart rate would then drop[7] (Fig. 2). This type of device does not put the pacemaker into its interference rate but because it is not a continuous signal and although the risks are minimal it is wise for pacemaker patients to identify themselves to the library staff so that the device can be de-activated before they pass through the exit gate.

*Fig. 2. The first two beats are normally paced. A burst of interference from the anti-theft device inhibits the next beat and delays subsequent beats. Further episodes of interference prolong the bradycardia.*

Most libraries in the UK using these devices now carry warning notices.

**Airport Weapon Detectors**

Portable hand-held detectors are perfectly safe, and experimental tests with other weapon detectors usually produce only temporary disturbances[8]. Nevertheless, a large body of anecdotal information exists about patients who have collapsed while passing through weapon detectors at various airports. Since most of these detectors produce pulsed magnetic or electromagnetic fields, it is perfectly possible that they can inhibit pacemakers, and most airports now carry warning notices advising pacemaker patients to avoid them. Heathrow Airport has a particularly bad reputation (probably unjustified) and at least two pacemaker patients are known to have had symptoms in the region of the weapon detectors at Heathrow[9]. One collapsed but recovered rapidly when
he was removed from the immediate area of the detector; as the pulse was not taken at the relevant time it remains a matter of conjecture whether the pacemaker was in fact affected. In view of the theoretical possibilities and the documented incidents from airports in Europe and the USA, it is advisable for pacemaker patients to avoid passing through weapon detectors.

Radar

Very high-powered radar beams can induce sufficient current in the pacemaker lead to produce an inhibiting signal[10] but this only occurs when the beam is swept across the patient or is modulated at a suitable frequency. In practice the rotating beams will cause the loss of a very occasional stimulus only. The presence of high energy radiations around certain locations such as defence establishments or airports raises the possibility of temporary pacemaker inhibition, so exposed areas (such as Heathrow Observation Platform) often carry warning notices that pacemaker patients should not be in the vicinity. Low-powered radar, such as that used by the police for speed checks, does not affect cardiac pacemakers. The hand-held radar guns have also been shown to be safe even when activated intermittently at 60 per minute (unpublished observations from Guy’s Hospital).

Cobalt or Deep X-ray Therapy

Radiation for conditions such as carcinoma of the breast is sometimes indicated in patients with pacemakers which often lie within the field of exposure. Several investigations into the effects of therapeutic radiation levels on pacemakers have produced somewhat conflicting results. In general, small changes occur in the parameters, but the pacemakers continue to function even after very large doses of radiation. The fears that programmable pacemakers might be seriously damaged, with loss of the programmability, have so far proved unfounded. The long-term effect of radiation on the electronic components is still unknown but at the present time it appears perfectly possible to treat pacemaker patients by high energy radiation, although the pacemaker should, of course, be protected as far as possible[11-13].

Diathermy

Surgical diathermy is a common source of interference signals for pacemakers and fatal ventricular fibrillation has occurred[14,15]. However, provided the indifferent plate is well away from the heart or pacemaker site and the cutting edge of the diathermy is not used near the pacemaker or the electrode, surgical diathermy can be used very cautiously for operations such as transurethral resection of the prostate[16,17]. The patient should have an ECG monitor throughout the operation because the pacemaker is very likely to enter its interference rate while the apparatus is in use. With some models of pacemaker there will be a short period of inhibition following the end of diathermy but pacing restarts spontaneously after one or two seconds. Unintentional reprogramming of a Vitatron pacemaker has been reported[18].

Other Forms of Electrical Treatment

Electroconvulsive therapy can be used for pacemaker patients provided adequate monitoring is carried out[19]. Shortwave heat treatment of the type used in physiotherapy departments should not be applied to pacemaker patients because induced currents in the electrode are almost inevitable and may cause inhibition. Other forms of electrical treatment such as faradism, transcutaneous stimulators for pain relief, or apparatus designed to improve muscle tone by repetitive electrical stimulation will in theory carry the same risks and should be avoided in pacemaker patients. Inhibition of a demand pacemaker by low frequency acupuncture has been reported[20]. Some dental apparatus including the ultrasonic cleaner is also a potential source of danger[21].

Very powerful fluctuating magnetic fields can also inhibit demand pacemakers. A field of sufficient intensity is normally met with only when a powerful magnet is applied directly to the skin over the pacemaker in order to disable its demand function and allow fixed rate stimulation for testing. If this magnet is moved slowly to and fro above the pacemaker, inhibition will usually occur[22]. Magnetic fields from domestic equipment such as loudspeakers are far too weak to affect pacemakers and this is also true of industrial magnetic fields, except perhaps in the most extreme circumstances.

Paging Systems

Our own investigations show that hospital bleeps have not inhibited a wide variety of different demand pacemakers even when the bleep is placed immediately adjacent to the pacemaker and activated. Similar results apply to radio bleeps and to industrial identification systems such as the Teletag.

Citizens’ Band (CB) Radio

There are many anecdotal stories of pacemaker inhibition by personal ‘walkie-talkie’ or CB sets, but recent reports of interference with hospital equipment[23,24] highlight the problem. We have recently investigated the effect of a typical 4 watt CB rig transmitting with AM (illegal) and FM (legal) modulation. When the aerial was within one or two feet of an implanted multiprogrammable pacemaker, operation of the ‘press-to-talk’ switch inhibited one or two beats in both the AM and FM modes. No inhibition occurred at greater distances. During the actual transmission there was no effect on the pacemaker from AM or FM, even at very close range. The monitoring ECG became unreadable throughout the transmissions but a digital pacemaker analyser was unaffected.

The practical implications are that a pacemaker patient passing very close to the aerial of a CB rig using AM (for example, on a parked car) may notice one or two missed beats. Provided the equipment we tested is representative, as seems likely, prolonged inhibition does not occur.
Skeletal Muscle Potentials

It is important to identify the inhibition of a demand pacemaker caused by potentials from local skeletal muscle contractions since it must not be confused with external electromagnetic interference[25]. Myopotentials due to contraction of pectoral muscles can often inhibit the pacemakers implanted on the chest wall but in the great majority of cases only one or two beats are missed. The situation can usually be identified by asking the patient to tense the pectoralis major muscle or move one arm across the chest against some resistance while an ECG is running. The example shown in Fig. 3 indicates that in some

patients asystole can last for several seconds and cause symptoms. Very occasionally we have had to remove pacemakers for this reason, because of syncope. The symptoms can almost always be prevented by partial insulation of the pacemaker with a silicone rubber pouch so that only subcutaneous fat makes contact with the metal case. Many manufacturers already pre-coat the pacemakers in this way to reduce the problem.

Emergency or Prophylactic Action

The application of a test magnet (provided by all manufacturers) to the skin over a pacemaker disables the demand function. The pacemaker then runs at a fixed rate, and is immune to interference. This manoeuvre will re-start pacing or will prevent inhibition in high interference situations including skeletal muscle inhibition. The magnet can be strapped in position on the skin, but this should be regarded as a very temporary measure. This manoeuvre does not prevent current pick-up by the pacing electrode, so does not protect against the risk of ventricular fibrillation during surgical diathermy.

General Advice to Patients

There are clearly so many possible sources of interference that it is impractical to advise patients to avoid all of them, even if it were possible to identify them in advance. The patient should be told in general terms about the possibility of interference but assured that the risks are extraordinarily low. If a patient feels palpitation or dizziness when in a possible interference situation, such as by the door of a library or department store, or in a fair-ground, he should move away. If the symptoms persist he should mention his pacemaker to the supervisor who can check whether anti-theft equipment is in use. If similar symptoms are experienced when close to or using any domestic appliance, it should not be used again until it has been checked and serviced.

Implications for Employment

Although pacemakers are largely used in the older age groups (the average age at first implant is 68 years), about 25 per cent of patients are under the age of retirement. The majority of these wish to continue working and are perfectly capable of doing so. A survey of the Guy’s Hospital series showed that 75 per cent of such patients continued with their previous employer and 67 per cent carried on with the same job. An additional 7 per cent changed to another employer, so about four out of every five patients managed full-time employment. Many of the remaining 20 per cent or so had additional medical conditions, such as myocardial infarction, or did not want paid employment.

Some firms (25 per cent) were initially reluctant to employ pacemaker users, but a small percentage of patients (5 per cent) claimed that their pacemaker was an actual advantage in obtaining a job.

Patients whose bradycardia was the result of simple fibrosis of the conduction system are frequently remarkably fit following pacemaker implantation and in some age groups the prognosis is equal to or even better than that of the general population. This presumably relates to the absence of coronary or cerebral artery disease in subjects who have survived Stokes-Adams attacks.

From the employers’ point of view pacemaker patients are capable of an excellent attendance record and can clearly cope with office, sales, administrative or executive positions in the same way as normal subjects. It is easily demonstrable that possession of a cardiac pacemaker is no bar to practising medicine or surgery, nor to holding high political office. Work involving hard physical labour is less suitable and jobs with exposure to trauma, such as police work, should be avoided. Factory environments are usually perfectly safe, although certain occupations, such as arc welding, are contra-indicated. Test monitoring of the ECG at work can be helpful in specialised situations and patients have successfully continued working in radio stations, computer centres, as electrical service engineers and even as bomb disposal experts.

Almost all countries deny public service vehicle or heavy goods vehicle licences to pacemaker users, but licences and insurance to drive private cars are readily available. Only 10 per cent of the patients surveyed were asked for an additional premium for driving insurance.

Patients can be encouraged to enjoy leisure activities appropriate to their age and general physical condition, although they should obviously try to avoid situations in which there is a high risk of a vigorous blow being received immediately over the generator, such as boxing or karate. Despite this possibility, younger patients will often persist in playing games such as tennis or squash, and occasional incidents have occurred in which the ball has struck the pacemaker site without apparent ill-effects.

Fig. 3. The pacemaker is inhibited by potentials from contraction of the pectoral muscles, and for considerable periods only P waves can be seen.

...
Most modern pacemakers are perfectly capable of withstanding accelerations well in excess of 20 g (which have been documented as occurring during postal delivery) and the cushioning effect of the surrounding subcutaneous tissue provides a good deal of protection. The Guy’s Hospital series includes patients who have achieved county standard at athletics, competitive swimmers and scuba divers, as well as many golfers and at least one who regularly plays football. Despite these successful examples, caution dictates that patients should be warned of the additional risks from trauma, and the apparatus should be thoroughly checked if any untoward incident occurs. Such situations will arise in only a very small percentage of subjects and serve only to illustrate that pacemaker patients in general need not be unduly restricted. It is always worth enquiring of the patient, before the pacemaker is implanted, whether any particular sports are contemplated, since it may be possible to take them into account in planning the implantation. A particular example, which has occurred several times, is the siting of the generator on the left side in a right-handed patient whose hobby is rifle shooting.

General Conclusions

A very large and increasing number of patients are being treated with cardiac pacemakers and, at the same time, the production of interference signals in the environment is also increasing rapidly. Fortunately, the risks to the vast majority of patients are minimal and, at worst, only one or two beats will be missed. Specific dangers can frequently be foreseen and avoided and the patients can be assured that they can enjoy normal work and the leisure activities appropriate for their age.

References

1. Valentino, A. R., Miller, D. A. and Bridges, J. E. (1972) IEEE International Electromagnetic Compatibility Symposium Record, pp. 10-16.
2. Botella Solana, S. (1979) Stimucon Medico, 7, 392.
3. Furman, S. (1980) Pace, 3, 517.
4. Bisping, H. J. and Iriuch, W. (1976) Deutsche Medizinische Wochenschrift, 101, 668.
5. Anonymous (1974) Biomedical Safety and Standards, 4, 90.
6. Neelakantawamy, P. S. and Ramakrishnan, K. P. (1979) IEEE Transactions on Electromagnetic Compatibility, 21, 272.
7. Cueni, T., Shenasa, M., Kappenberger, L. and Sowton, E. (1979) in Proceedings of the VIIth World Symposium on Cardiac Pacing, Montreal.
8. Smyth, N., Keshishian, J., Hood, O., Hoffman, A., Baker, N. and Podolak, E. (1972) Journal of the American Medical Association, 221, 162.
9. Cooper, P. R. (1979) Personal communication.
10. Rohd, D., Laun, H. M., Hauber, M. E. T., Stauch, M. and Voigt, H. (1975) ISA Transactions, 14, 115.
11. Walz, B. J., Reder, R. E., Pastore, J. O., Littman, P. and Johnson, R. (1975) Journal of the American Medical Association, 234, 72.
12. Glace, C., Dodinot, B. and Godenir, J. P. (1981) in Proceedings of the Second European Symposium on Cardiac Pacing, Florence.
13. Adamec, R., Haefliger, J. M., Killisch, J. P., Niederer, J. and Jaquet, P. (1981) ibid.
14. Protnin, F., Dodinot, B., Lefevere, J. C. and Lazenaire, M. C. (1979) Annales de l’Anesthesiologie Francaise, 20, 127.
15. Titel, J. H. and El Etr, A. A. (1968) Anesthesiology, 29, 845.
16. Schütz, W. (1979) Urology, 18, 247.
17. Greene, L. F. and Merideth, J. (1972) Journal of Urology, 108, 446.
18. Dodinot, B. (1981) Stimucon Medico, 9, 217.
19. Alexopoulos, G. S. and Frances, R. J. (1980) American Journal of Psychiatry, 137, 1111.
20. Fujitama, H., Taniguchi, K., Takeuchi, J. and Ikezono, E. (1980) Chest, 78, 96.
21. Meisel, H. H., Machens, E. and Abbbink, F. (1974) Deutsche Zahnarztliche Zeitung, 29, 917.
22. Ohm, O. J. (1981) Stimarec Prize.
23. Daily Mail, London, 12th August 1981.
24. Daily Mirror, London, 12th August 1981.
25. Breivik, K. and Ohm, O. J. (1980) Pace, 3, 470.