Electrical interference in non-competitive pacemakers

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Patients with 41 implanted non-competitive pacemakers were investigated. A variety of domestic electrical equipment, a motor-car, and a physiotherapy diathermy apparatus were each operated in turn at various ranges from the patient. Interference effects on pacemaker function were assessed on the electrocardiograph. Medtronic demand 5841 pacemakers were stopped by diathermy while Cordis Ectacor pacemakers developed a fast discharge rate. Cordis triggered pacemakers (both Atricor and Ectacor) were sensitive to interference from many items of domestic equipment and the motor car. The Elema EM153 ran at an increased rate when an electric razor was running close to the pacemaker. The Devices demand 2980 and the Medtronic demand 5841 were not affected by the domestic equipment tested. The significance of interference effects is discussed in relation to pacemaker design.

Non-competitive pacemakers may be of three types: (1) atrial triggered; (2) ventricular triggered; (3) demand or ventricular inhibited.

In each type the pacemaker monitors spontaneous cardiac activity and must thus possess a sensing circuit capable of detecting P waves or R waves arising spontaneously. Such pacemakers have the inherent risk that they may detect electrical activity from sources apart from the heart so that their behaviour is modified by electrical interference.

The purpose of this paper is to report the results of investigation into the behaviour of different types of implanted non-competitive pacemakers when exposed to different electrical fields.

Patients and Methods

Patients with 41 implanted pacemakers were investigated; in 19 of these the pacemakers had been implanted before June 1968 and in the remaining 22 patients the pacemakers had been implanted after January 1969 (Table 1).

The apparatus used for these tests included several types of electric razor (Sunbeam, Ronson, and Phillips), hair dryers (Morphy Richards and Ronson), food mixers (Kenwood mini, Phillips, and Moulinex), vacuum cleaners (Hoover Junior and Hooverette), coffee grinders (Mouli), electric hair clippers (Clukes), and automatic electrical over-blankets (Monogram, G.E.).¹ Testing was

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¹ Domestic equipment was kindly supplied on loan from Selfridges Ltd., and John Lewis and Co. Ltd., of Oxford Street, London.

also carried out with a portable high duty electric drill (Black and Decker), a short wave diathermy apparatus (Magatherm Junior 4), a 5 watt neon bulb, and a Volkswagen 1200 c.c. motor-car.

Each patient was seated and attached to an oscilloscope and a direct writing electrocardiographic machine. Under continuous electrocardiographic monitoring each piece of apparatus was tested at distances of 183 cm. (6 ft.), 91 cm. (3 ft.), and 30 cm. (1 ft.) away from the pacemaker, then immediately above the pacemaker, and lastly over

TABLE 1 Details of implanted pacemakers exposed to electrical interference

Model of pacemaker	Type	No. tested
<i>Before June 1968</i>		
Medtronic Demand 5841	Ventricular inhibited	4
Cordis Ventricor II (now withdrawn)	Ventricular inhibited	2
Cordis Ventricor III or Ectacor	Ventricular triggered	6
Cordis Atricor	Atrial triggered	3
Elema EM139	Ventricular triggered	3
American Optical Demand	Ventricular inhibited	1
Total		19
<i>After January 1969</i>		
Devices Demand 2980	Ventricular inhibited	5
Medtronic Demand 5841	Ventricular inhibited	5
Cordis Ectacor	Ventricular triggered	5
Cordis Atricor	Atrial triggered	3
Cordis Stanicor	Ventricular inhibited	1
Elema EM153	Ventricular triggered	2
American Optical Demand	Ventricular inhibited	1
Total		22

TABLE 2 *Response of implanted pacemakers to interference from domestic equipment; these pacemakers were implanted before 30 June 1968*

Pacemaker	Electric mixer	Hair dryer	Vacuum cleaner	Electric razor	Physiotherapy diathermy
Cordis Atracor (n=3)	No change	Tachycardia	No change	Tachycardia	No change
Cordis Ectacor (n=5)	Tachycardia	Tachycardia	Tachycardia	Tachycardia	Tachycardia
Medtronic Demand (n=4)	No change	No change	No change	No change	Pacemaker stopped
Elema EM 143 (n=4)	No change	No change	No change	No change	Tachycardia

the heart and electrodes. If the apparatus interfered with the pacemaker at any distance, a positive result was recorded and in most cases the test was concluded; in a few cases further interference testing in different positions was carried out. Most pieces of apparatus were tested in two ways. Initially the effect of switching was investigated by rapidly turning the apparatus on and off several times. Subsequently the apparatus was switched on and allowed to run continuously for a short time. In the case of the Volkswagen car, testing was carried out with the patient sitting first in the front seat, then in the back seat, then standing close to the engine at the rear of the car.

Clinical incidents

We were able to identify clinical incidents in which implanted pacemakers were affected by interference in two of the patients in this study. The first was a woman of 26 with a Cordis Ectacor implanted for congenital complete heart block, who noted that her heart beat fast when she used an electric razor (Ronson Model 31 Mk. 4) to shave her legs. The second patient was a girl of 11 with a Cordis Atracor Jr. implanted to treat complete heart block following myocarditis, who noticed an unpleasant epigastric sensation when travelling in a particular motor-car. The same sensation recurred during interference testing and was shown to be due to pacemaker-induced irregular tachycardia.

Results

The results with the pacemakers implanted before 30 June 1968 are summarized in Table 2. The Cordis Ectacor produced at that time responded with the production of a tachycardia when exposed to interference from a variety of domestic equipment and the same result was produced with the physiotherapy diathermy machine. We were unable to influence the Elema EM153 ventricular-triggered pacemaker with the domestic equipment, but this also responded with a tachycardia when exposed to the physiotherapy diathermy machine at a distance of some 183 cm. (6 ft.). The Medtronic demand pacemakers (Model 5841) were also uninfluenced by the domestic equipment, but when the diathermy was turned on the pacemaker was totally inhibited.

Cordis Atracor atrial triggered pacemakers responded intermittently with the production of a tachycardia.

Pacemakers implanted after January 1969

Switching When electrical apparatus was frequently switched on and off all pacemakers with the exception of the Devices demand were affected. Almost every item of electrical apparatus caused interference during switching, and this usually was seen when the apparatus was about 30 cm. (1 ft.) away from the pacemaker: in one case a pair of electrical hair clippers (Clukes) produced interference at a distance of 183 cm. (6 ft.) away from a patient with a Cordis Atracor Jr. Interference due to switching is illustrated in Fig. 1 and 2.

Continuous running of apparatus (see Table 3) Several were tested.

Cordis Ectacor

Many of the pieces of apparatus would induce a tachycardia in patients fitted with this pacemaker. This tachycardia was often intermittent or irregular in rate, and was nearly always slower than the maximum possible triggered

FIG. 1 *An electric razor (Sunbeam) was repeatedly switched on and off over a Medtronic demand pacemaker causing asystole.*

TABLE 3 *Response of implanted pacemakers to interference from domestic equipment; these pacemakers were implanted after 1 January 1969*

Pacemaker	Razor (n=3)	Dryer (n=2)	Mixers (n=3)	Vacuum cleaner (n=2)	Coffee grinder	Hair clippers	Drill	Blanket	Neon bulb	Physio- therapy diathermy	Motor-car
Devices Demand (n=5)	No change	No change	No change	No change	No change	No change	No change	No change	No change	(No change)*	(No change)*
Cordis Ectocor (n=5)	Tachy- cardia	Tachy- cardia	Tachy- cardia	No change	No change	No change	Tachy- cardia	No change	No change	Tachy- cardia	Tachy- cardia
Cordis Atricor and Atricor Junior (n=3)	Slowing or tachy- cardia	Tachy- cardia	Tachy- cardia	Tachy- cardia	Tachy- cardia	No change	Tachy- cardia	No change	Not tested	Not tested	Tachy- cardia
Medtronic Demand (n=5)	No change	No change	No change	No change	No change	No change	No change	No change	No change	Pacemaker stopped	No change
Elema (n=2)	Tachy- cardia	No change	No change	No change	No change	No change	No change	No change	No change	(No change)*	No change

* Not all pacemakers were fully tested against the hazard listed.

rate for this type of pacemaker. Most items of electrical equipment had to be fairly closely approximated to the pacemaker site, but the electric drill and physiotherapy diathermy apparatus produced interference at a range of up to 30 cm. (1 ft.). Interference was produced when patients stood near the back of the Volkswagen with the engine running even when the engine was not exposed. No interference was seen when the patients were seated in the car.

Cordis Atricor

Interference was produced with many items of domestic equipment at ranges of up to 30 cm. (1 ft.), but the result was not always a pacemaker tachycardia. Where a tachycardia was produced it was only occasionally at the maximum response rate of the pacemaker.

An alternative result was the production of an irregular bradycardia (Fig. 3).

In several tests, P waves were recorded which fell outside the refractory period of the pacemaker yet were not followed by a pacing stimulus until the expected 'PR' interval had been exceeded by a considerable amount (Fig. 3). This suggests that the pacemaker had failed to sense the P waves or alternatively that the interference had affected the atrio-ventricular delay circuits of the pacemaker. In two of the three Atricors, interference sometimes resulted in a reduction of PR intervals to 0.06 sec., with no change in heart rate. This again suggested interference with the atrio-ventricular delay circuits.

In two of the three patients tested, interference was produced by the engine of the Volkswagen though in both cases it was necessary for the engine compartment to be opened.

Devices Demand 2980

We were unable to interfere with the function of this pacemaker with any of the domestic apparatus, with the diathermy machine, or with the Volkswagen car. Deliberate introduction of an overwhelming interference signal (3 v. square wave impulses at 1000 c.p.s.) from a Devices testbox via skin electrodes caused the pacemaker to revert to a rapid pacing rate

FIG. 2 *The middle strip shows an irregular tachycardia caused by an electric razor (Sunbeam) repeatedly switched on and off over an Elema ventricular triggered pacemaker. The lower strip shows a tachycardia caused by continuous running of an electric razor (Phillips) over the pacemaker.*

FIG. 3 In the upper strip the 'PR' interval is 0.12 sec. The arrows indicate P waves which are not followed by a pacemaker artefact until 0.2 sec. has elapsed. The lower strip shows the tachycardia produced by the patient standing at the rear of a Volkswagen motor-car with the engine compartment open.

of 90–100 a minute. Since this was faster than the basic cardiac rate or the standby rate of the pacemaker, a regular paced rhythm resulted (Fig. 4). Our patients did not have spontaneous ectopic beats at this paced rate, so we were unable to investigate the possibility of a pacing stimulus falling on the T wave of an ectopic beat.

Elema EM153

Only two patients were available for testing and in one of these an electrical razor produced an irregular tachycardia when running in the vicinity of the pacemaker (Fig. 2).

Medtronic Demand 5841

This pacemaker was immune to interference from all the apparatus with the exception of the physiotherapy diathermy. This equipment would consistently inhibit the demand pacemaker so that either asystole or emergence of the slow idioventricular rhythm occurred.

The diathermy apparatus was capable of inhibiting the pacemaker at up to 183 cm. (6 ft.).

Other pacemakers

We were able to carry out partial testing on one example of the American Optical 'cardio-care' demand pacemaker. This unit could be inhibited by repeated switching of two brands of electric razor (Ronson and Sunbeam) but was not affected by continuous running. One other patient is being treated with a Cordis 'Stanicor', a newly introduced demand pacemaker. It was possible to inhibit this unit by switching many types of equipment (razors, mixers, vacuum cleaners) within a few feet of the patient (Fig. 5), but the pacemaker was not affected during continuous running of any of the domestic equipment, even items which drove the Cordis Ectacor into a tachycardia. We do not regard inhibition by switching as likely to produce clinical symptoms.

Discussion

Interference testing of non-implanted pacemakers has been reported by several workers. Lichter, Borrie, and Miller (1965) observed ventricular fibrillation in two patients with external pacemakers when a surgical diathermy apparatus was in use and were able to show that the type of pacemaker was adversely affected by short-wave diathermy apparatus, broadcasting stations, and neon advertising lights. Carleton, Sessions, and Graettinger (1964) showed that the Medtronic fixed rate

FIG. 4 The lower strip shows the tachycardia produced by deliberate interference with a Devices demand pacemaker by the Devices testbox. The rapid interference pulses can be seen superimposed on the electrocardiogram.

pacemaker was adversely affected by interference from small petrol-driven engines and by diathermy apparatus, but Chardack *et al.* (1965) attributed this response to the fact that the pacemakers were not implanted. A powerful magnetic field has also been shown capable of interfering with certain older types of pacemaker (Silver *et al.*, 1965). More recent models of pacemakers have been studied by Kraft *et al.* (1967) but these tests were also carried out with the pacemakers outside the body. As Mansfield (1966) has pointed out, the results from tests of this type cannot be applied to patients with implanted pacemakers because the screening effect of the body and the difference in electromagnetic coupling greatly reduce the interference risk.

With the increasing use of non-competitive pacemakers which depend for their function upon detection of the intracardiac electrocardiogram the problems of interference are very much more serious than with simple fixed rate models. The fact that this is not merely a theoretical risk is illustrated by the two patients described in this paper, as well as by descriptions of early demand pacemakers being inhibited by automobile engines (Bilitch, Lau, and Cosby, 1967), by a motorcycle, and by a television set (Scheppokat *et al.*, 1969). Parker, Furman, and Escher (1969) have investigated the voltages picked up by pacemaker electrodes in both patients and animals when they were subjected to environments in which electrical interference with pacemaker function might be expected. They show a wave-form of 1.6 millivolts superimposed on the electrical activity of the heart when a small electric motor was run within 13 cm. (5 in.) of a dog's chest but were unable to show interference when a Volkswagen engine was run with the compartment open. An amplitude of 2.5 millivolts was induced 1 metre from the ignition system of a motorcycle, and it was suggested that the signals entered the pacemaker directly rather than being detected on the electrodes. This is in agreement with our earlier observations on ventricular-triggered pacemakers (Sowton, 1968). In a comparative study of different types of implanted pacemakers, Furman *et al.* (1968) showed that most types of non-competitive pacemakers could be made to respond to electrical interference, particularly from such sources as the ignition system of motor-cars.

It is well recognized that a bipolar electrode system senses far less interference than a unipolar arrangement (Parker *et al.*, 1969), but since all commercially available non-competitive pacemakers are capable of being used

FIG. 5 The lower strip shows inhibition of a Cordis Stanicor by switching transients from an electric razor (Ronson). The patient's own rhythm of 2:1 heart block emerges.

FIG. 6 During interference, stimuli are delivered at a rate equivalent to 140/min. close to the maximum triggered rate of the Cordis Ectacor pacemaker (A). At (B), a pacemaker stimulus falls on the T wave of an ectopic beat which falls at the end of the pacemaker refractory period. At (C), a pacemaker stimulus falls on a T wave which is well outside the pacemaker refractory period. This QRS complex failed to trigger the pacemaker.

for unipolar stimulation it seems sensible for the risk to be assessed under these conditions. In the present investigation the Cordis Atracor and Ectacor, the Elema pacemakers, and the Devices demand pacemakers were unipolar but the Medtronic was used with bipolar electrodes. The results we obtained in 1969 differ very little from those obtained in 1968.

Cordis and Elema ventricular-triggered pacemakers responded to interference by producing a tachycardia but in no case did this exceed the manufacturers' stated limit for the pacemaker and was frequently slower. In theory this is a safe response to interference since the pacemaker rate may be expected to exceed the sinus rate and so the heart will be driven continuously without competition. At the same time the patient would become aware of the increased heart rate and thus appreciate that he was in an interference field. Since pacing is continuous no Adams-Stokes attacks would occur. However, on at least one occasion we were able to document pacemaker stimuli falling during the vulnerable period when a Cordis Ectacor responded to interference signals (Fig. 6). The Elema EM153 pacemaker was more resistant to interference from small domestic equipment than the Cordis Ectacor, but they were both triggered by physiotherapy apparatus.

The Cordis Atracor was also fairly sensitive to interference but the resulting rhythm was usually a small increase in rate due to extra beats and was not of great consequence. We have not been able to test the present model Elema atrial-triggered pacemaker, but Dodinot *et al.* (1969) reported patients who experienced a tachycardia when in an interference field from electric razors.

The potential hazard of interference completely inhibiting a demand pacemaker is more serious, and we were able to show both with earlier and with present models of the Medtronic 5841 demand unit that physiotherapy apparatus is capable of producing this result. A. J. Federico (1970, personal communication) reports inhibition of an implanted Medtronic demand pacemaker (Model 5841) by a 'walkie talkie' radio transmitter worn on the chest, and B. P. Dodinot (1970, personal communication) has noted inhibition due to leakage current from an electrocardiogram machine powered by the 50 cycle AC supply.

The risk of total inhibition can be avoided if the pacemaker reverts to asynchronous (fixed-rate) pacing in the presence of severe interference. This feature was first introduced in American Optical 'cardiocare' demand pacemakers, but is also utilized in the new Cordis 'Stanicor' and the Medtronic demand model

5842. In all three pacemakers the 'interference rate' is similar to the standby rate or only slightly faster, so that competition occurs if sinus rhythm is present. The rapid pacing rate produced by the Devices model 2980 in the presence of overwhelming interference is likely to avoid this by suppressing sinus rhythm.

The main clinical importance of our findings is to emphasize the dangers of diathermy apparatus to patients with non-competitive pacemakers even when these are implanted. In most cases it is probably sufficient to warn patients to avoid bringing electrical equipment into close proximity to their pacemakers and not to stand close to coil ignition engines. Motorcycles have less shielding around their ignition systems than motor-cars and may therefore represent a greater hazard. Specific testing should be carried out in patients whose occupation represents a special hazard, such as servicing small electrical motors.

All non-competitive pacemakers must be expected to respond to the presence of pulsed interference (such as repeated switching on and off) if this contains the appropriate frequencies corresponding to R (or P) waves. Though operation of electrical switches interfered with many types of pacemaker, this would be of clinical significance only if the machine had a faulty switch or loose electrical connexion.

We found no particular model of domestic equipment which was especially liable to interfere with pacemakers, nor any which was completely free from this complication, but it was usually necessary for the pacemaker and domestic appliances to be fairly closely approximated before any effect could be detected. Even so, in most instances it was impossible to influence the pacemaker apart from the production of a single ectopic beat when the apparatus was switched on or off, so that we feel that the risk to patients is very low. The appliances we have investigated might be brought near enough to the pacemaker during normal use to produce interference effects, but a fairly minor movement would then separate the pacemaker from the interference source so that normal pacing resumed.

The resistance of the Devices demand (Model 2980) pacemaker to interference may be due to the fact that its entire circuit is contained in a hermetically-sealed metal can. The new model of the Medtronic demand pacemakers (5842), which is based upon an integrated circuit and was introduced early in 1970, may also be expected to show improved interference rejection for a similar reason,

when compared with the Model 5841 we have tested. The German Biotronik ventricular-triggered pacemaker (Model RIP-44) is completely encased in stainless steel and this should prevent interference signals entering the pacemaker circuit directly. Though screening of this type will not prevent interference signals entering the pacemaker along the electrode, it seems likely that both routes are clinically important and so the screening should improve the performance in this respect.

Conclusions

Implantable non-competitive pacemakers are sensitive to interference from physiotherapy diathermy apparatus, and patients with pacemakers should not be treated with medical diathermy. Elema and Cordis pacemakers (both Atracor and Ectacor) were sensitive to interference from small electric motors but responded with irregular intermittent tachycardia or bradycardia, which was unlikely to be dangerous. The Devices demand 2980 and the Medtronic demand 5841 were not affected by the domestic appliances tested.

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