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Clinical Aviation and Aerospace Medicine

Anti-hijacking Efforts and Cardiac Pacemakers—Report of a Clinical Study

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The history of hijacking of aircraft reveals that as of 26 July 1971 there have been 118 separate hijackings, 106 of commercial air carriers. The serious threat to lives and property that results from such crimes has necessitated considerable attention, money, and man power being directed toward decreasing or eliminating the threat. The main goal is to prevent a hijacking from starting; thus methods must be found to prevent a hijacker from boarding an aircraft. The obvious second goal, and much more critical, is to abort the hijacking while it is in progress. The use of intelligence data, hijacker profiles, passive magnetometers, and physical search have been employed to prevent hijackers from boarding aircraft. Sky marshals have been established to aid in aborting a hijacking once under way.

An external electromagnetic field used in a weapon detector system (WD-4) may produce minor changes in the rate of certain pacemakers, specifically the sensitive unipolar atrial or the atrial or atrio-ventricular pacing systems. These changes were clinically insignificant to the patient and to the pacing system. Other systems, such as unipolar fixed rate, and unipolar and bipolar ventricular pacemakers, were totally unaffected. The weapons detector studied (WD-4) was determined to be safe for use in the public environment of an airport. Recommendation for its use was made to FAA Research & Development officials. The WD-4 may now be implemented as another method for detecting objects that could be used in the hijacking of aircraft.

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Included in the wide range of research toward developing preventive methods was the construction of an active field electromagnetic unit designed to detect concealed weapons. Following FAA specifications, the Westinghouse Corporation developed, built and delivered one such unit to Headquarters, FAA. Tests had indicated that the unit was effective in detecting weapons and that it could be programmed to discriminate, for example, between a cigarette lighter and a gun. The passive magnetometers (detectors) operate on the basis of the earth's magnetic field, whereas the active magnetometers generate their own fields of electromagnetic force.

This latter fact created the potential medical problem. Almost all patients who have implanted cardiac pacemakers rely upon a battery-powered unit designed to produce the electrical stimulus necessary for cardiac contraction. In broad terms there are two types: in one the unit is timed to discharge at a *fixed rate* regardless of the natural cardiac impulse and the other type is designed to respond on *demand,* or in the absence of a natural electrical impulse.

The question: what would be the effect upon a pacemaker patient exposed to the active magnetic field of the Westinghouse unit while going through preboard screening at airport terminals?

Preliminary studies were carried out by the Westinghouse Research Laboratories[1] in which the pacemaker models manufactured by Cordis, General Electric and

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Medtronic Corporations were tested *in vitro*. All pacemakers were tested in the magnetic field of the Westinghouse weapons detector or a similar field. The tests showed, as expected, that triggered or demand, pacemakers are more affected than fixed rate pacemakers, and that the *uni*polar pacing systems are more affected than bipolar systems. In no case did any of the pacers slow down or stop. In a few there was a small increase in rate at field strengths of 1.35 gauss and above. Tests have also been carried out *in vivo* in calves in which two unipolar Cordis triggered pacemakers were exposed to 60 Hz magnetic fields.[2] Increases in rate and loss of synchrony occurred when the animals were exposed to magnetic fields of 6 gauss or higher. These field strengths are greater than those produced by Westinghouse WD-4 weapons detector.

The Chief, Aeromedical Services Division, Office of Aviation Medicine, Headquarters, FAA, has the responsibility of participating in, and monitoring, all medical aspects of the anti-hijacking efforts. A search of the literature concerning pacemaker interference revealed voluminous data on a great variety of interference sources but did not reveal clinical research involving the exposure of groups of actual patients having different types of pacemakers to known and controlled electromagnetic fields. It was determined that the FAA-procured Westinghouse (WD-4) unit would not be put into actual use at an airport until its effects upon pacemakers was known and until cleared by the Office of Aviation Medicine.

Under contract with the Potomac Fund for Cardiovascular Research,* with participation by members and consultants of the Office of Aviation Medicine, 53 volunteer pacemaker patients were evaluated while exposed to the FAA unit in a manner identical to the exposure they would receive as an airline passenger being screened for weapons. Eight different types of pacemakers were involved in this group of patients.

Certain aspects were considered important. One, that there be a preponderance of unipolar pacers in the study, since these are known to be more sensitive to external electromagnetic fields. Sensitivity to external electromagnetic interference is known to be proportional to the areas enclosed between the anode and the cathode, which is much larger in the unipolar than in the bipolar system. Also, since the test center was established in Washington, D.C., it was considered desirable that the patients to be studied reside in the Greater Metropolitan Area.

It was recognized that not all types of pacers were represented in the Washington, D.C., area; however, as long as the study group contained a significant number of sensitive unipolar pacers it was not considered necessary to study every make of pacemaker. To do so would have added greatly to the time taken to complete the study without a proportionate increase in useful knowledge. Researchers and manufacturers are constantly improving and modifying pacemakers throughout the world; however, it was recognized that a base line of clinical data was needed at this time. The seriousness of the threat of hijacking demanded the utilization of every possible method of preventing these crimes. The WD-4 weapons detector held great promise and it was determined that an actual study of its effects on pacemaker patients was mandatory.

MATERIALS AND METHODS

The entire study was conducted in the Washington Medical Clinic, FAA, 800 Independence Avenue, S.W., Washington, D.C. In addition to the research team, the resources of the clinic were available for conducting the study. Included were physicians, nurses and assistants, and normal emergency equipment and supplies. In the immediate area of the study were positioned a defibrillator/cardioverter, a combination oxygen resuscitator-suction aspirator, an automatic external cardiac massage press, and a crash cart containing all appropriate drugs and emergency tracheotomy instruments. No emergency care was required throughout the study. One incident that could have been a complication was the fact that one volunteer patient expired at home the day before he was to come to the clinic in downtown Washington to participate in our study.

Pacemakers—A brief description of the eight types of pacemakers involved in this study follows.

A. *Cordis Pacers**

1. *Ectocor* 129E7, (R wave stimulated). This pacer senses the ventricular electrical activity (R wave), and immediately delivers a pulse to the ventricle. If no R waves are sensed, the ventricle is paced at a predetermined fixed rate, usually 72 beats per minute. It also has a protective 2:1 blocking mechanism at a maximum rate of 150 beats per minute. A magnetic switch may be used to convert it temporarily to fixed rate. A sensitive unit, 129K7, (1 mv instead of 2 mv) is also available and was used in this study for atrial pacing.[3]

2. *Stanicor,* 143E7. (R wave inhibited). This unit also senses the R wave (standard R wave sensitivity 2 mv), and if an R wave is seen, no pulse is delivered to the ventricle. If no R wave is seen, the unit paces the ventricle at a predetermined fixed rate, usually 68 beats per minute. A magnetic switch may be used to convert it temporarily to fixed rate. It also has a "noise" rate slightly higher than the basic rate as protection against unwanted inhibition by external electrical signals.

3. *Ventricor,* 11167, (Ventricular asynchronous). This fixed rate pacer simply paces the ventricle at a predetermined unvarying rate, usually 70 beats per minute. It has no sensing system.

4. *Atricor,* 133A6, (A-V synchronous). This pacer senses the electrical activity of the atrium (P wave), and after a suitable delay (120 milliseconds) delivers a stimulating pulse to the ventricle, causing it to contract. Normally, this unit is sensitive to 1 mv, but units sensitive to 0.5 mv are available, (133B6), and were used in the three patients studied who had transvenous A-V synchronous pacers.[4] The pacer has a 2:1 blocking

*Contract #DOT-FA71WA-2578, Washington, D.C.

*Cordis Corporation, Miami, Florida.

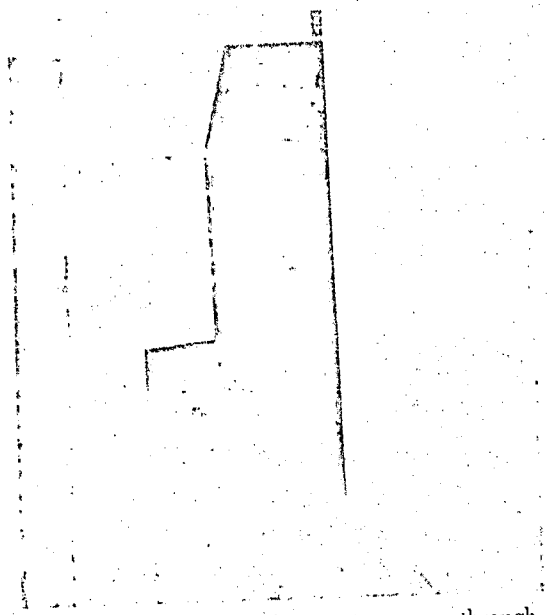

Fig. 1. Weapons detector showing passway through which passenger walks on his way to the airplane. Control console is seen in the background.

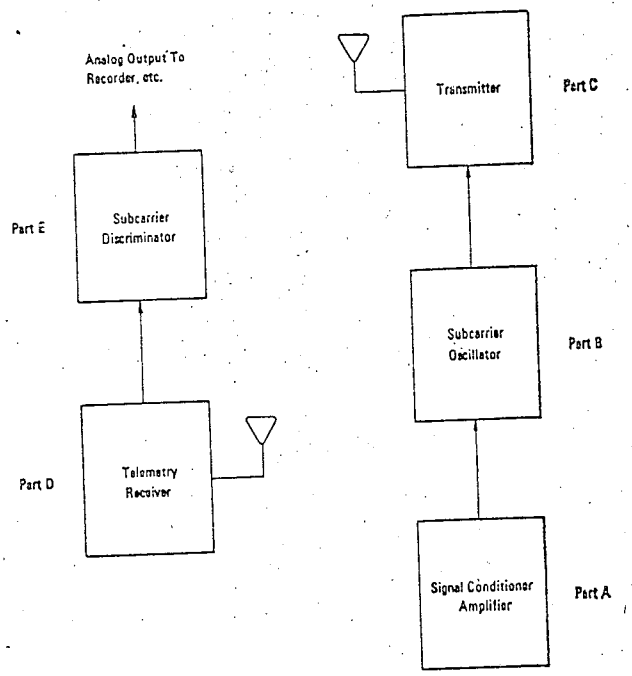

Fig. 2. Block diagram of telemetry system.

mechanism to protect against excessively fast triggered rates. In the event of loss of the triggering signal (P wave), it reverts to fixed rate pacing at its basic rate, usually 60 beats per minute.

5. *A-V Sequential* (Ectocor-Atricor) system. This is not a standard system and requires further explanation. In this system a sensitive Ectocor (129K7) is used to pace the atrium. This unit is sensitive to 1 mv for the smaller P wave, instead of the usual sensitivity of 2 mv when used for ventricular pacing. The atrial pacing signal is detected by a separate electrode in the ventricle which is connected to a modified Atricor so arranged that it senses and stimulates through a single electrode. The standard or sensitive Atricor (133A6 or 133B6) is used in this system so that the unit is sensitive to either 0.5 mv or the usual 1 mv, altered to 1 mv or 2 mv by the 20,000 ohm resistor in the modified pacer plug. Following the pacing signal to the atrium, the ventricle is paced sequentially after a 120 millisecond delay. In this system, therefore, both chambers are paced sequentially. The atrial pacer operates on the P wave stimulated standby principle; the ventricle is paced sequentially by a unit which is triggered by the electronic atrial pacing signal.[3,4] The ventricular pulse generator contains the usual 2:1 blocking mechanism when the stimulating rate exceeds twice the basic rate of the pulse generator. In the event of loss of the triggering signal, the unit reverts to fixed rate pacing at its basic rate, usually 60 beats per minute.

B. *Medtronic Pacers**

Medtronic Demand Models 5841 and 5842. These are bipolar demand (R wave inhibited) pacers with adjustable rates, and R wave sensitivity of 1.5 to 2.5 mv. Both models deliver a pulse to the heart upon sensing the absence of an R wave. Model 5842 reverts to a fixed rate, slower than the basic rate, in the presence of strong outside interference. Model 5841 differs from the other unit in that instead of reverting to a fixed rate, it ceases to deliver pulses to the heart in the presence of strong interference. Model 5841 is no longer being produced, and will disappear from use within two years.

Weapons Detector (WD-4)

The Westinghouse Weapon and Metal Detector produces a three axis, two frequency time-varying electromagnetic field within a space through which individuals

*Medtronic, Inc., Minneapolis, Minnesota.

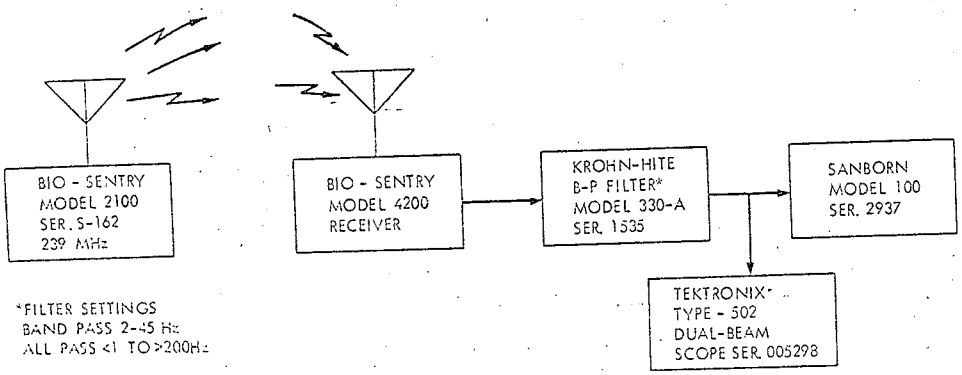

Fig. 3. Block diagram of complete data acquisition system.

pass while being screened for excess metal and weapons. (Figure 1). The zero-to-peak electromagnetic field in the center of the passway is in the order of 0.5 gauss. The electromagnetic field is purposely kept low to minimize interaction with materials and devices such as magnetic tapes, hearing aids, and other devices which may be sensitive to electromagnetic fields. The field reaches maximum intensity near the top of one end of the passway, normally the end where the passenger leaves the unit. The highest field accessible to the implanted pacer is about 1.35 G. (0-peak). As each individual passes through, measurements are made of eddy current loss and magnetic effect (change in inductance) caused by the metal carried on the person. By making measurements of these two quantities at both a low and high frequency in the audio range, it is possible to discriminate between thick and thin metals, ferrous and nonferrous materials, and to sense the presence of metal in excess of the amount normally present. From these measurements, signatures for various materials can be obtained.

The magnetic field of the weapons detector was measured and standardized before the start of the study and re-checked during the study. Field strengths up to 1.3 G (0-Peak) at 100 Hz were detected during the study using a portable search coil.

Data Acquisition System

The decision was made to utilize a telemetry system for recording and monitoring electrocardiographic data, rather than wire cables from the patient to an ECG recorder. This allowed greater freedom for the patient to pass through the weapons detector passway, and, it eliminated the interference that may have been induced in the long leads since they would be trailing the patient as he moved.

A block diagram of the transmitter and receiver are shown in Figure 2 and a diagram of the complete system is shown in Figure 3. The technical briefs of each component are presented:

(a) *Transmitter*—An FAA radio transmitter with 50 microvolts output at 50 feet and an effective range of 200 feet. The operating frequency used was 239 MHz.

(b) *Receiver*—Conventional FM receiver with a frequency range of 215 to 260 MHz.

(c) *Signal conditioner (amplifier)*—An ECG amplifier Model 2100 with a gain of 100 and a frequency response of 0.1 Hz to 100 Hz.

(d) *Subcarrier Oscillator*—The channel used had a frequency of 10,500 Hz and a bandwidth of 160 Hz.

(e) *Subcarrier Discriminator*—Provided a single analog output signal to the recorder and oscilloscope.

(f) *Band-pass filter*—The "Filter In" condition was 2.0 Hz to 45 Hz and the "All Pass" condition was less than 1.0 Hz to greater than 200 Hz. The frequency response of the signal conditioner in the telemetry transmitter was 0.1 Hz to 100 Hz and the weapons detector had a low frequency of approximately 100 Hz. The presence of the filter allowed clearing the interference produced on the recordings by the weapon detector electromagnetic field.

The arrangement of the system immediately adjacent to the weapon detector allowed the team to observe the patients and to monitor the oscilloscope and the tracings. (Figure 4)

Patient Study Procedure

Each patient was met by one of the authors, the test explained again, and an informed consent form completed. A current medical status was determined by one of the physicians.

All preliminary studies were carried out in rooms located at a considerable distance from the weapons detector. A six lead ECG (Leads 1, 2, 3, AVR, AVL, AVF) was taken on each patient, in the erect and supine positions after a brief rest.* Appropriate parameter tests of the pacemakers were then carried out and recorded,

*Hewlett-Packard EKG: Model 1511-A or Cambridge ECG: Model 1-70B.

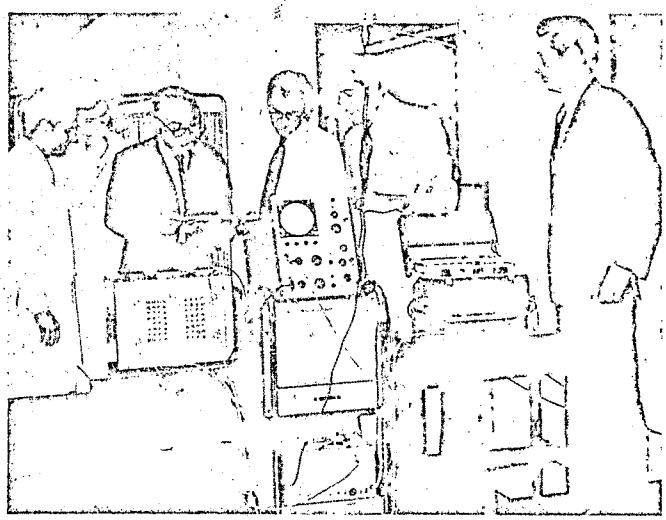

Fig. 4. The location of the data acquisition system was immediately adjacent to the weapons detection unit and allowed all investigators to observe and monitor the entire test.

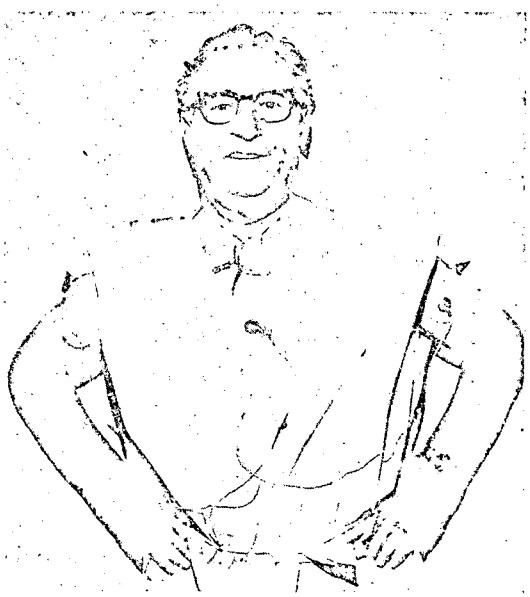

Fig. 5. Photograph of patient showing position of electrodes and transmitter.

utilizing magnetic switch operation and external overdrive of the pulse generator when appropriate.[5] Following this, disposable electrodes* were fixed to the patients right arm, left arm, and central anterior chest for use with the telemetry system.

The patient was then lead to the corridor to the weapons detector and the battery powered transmitter was connected and attached to the patient's gown or around his neck. (Figure 5) The test was not started until a clean, stable signal was obtained on both the oscilloscope and the paper recorder. If necessary, the electrode wires were taped to the patient to prevent motion artifacts. The patient was then escorted by a physician through the weapons detector and back to the starting point. (Figure 6) Transit time in the weapons detector ranged from five to 10 seconds. Continuous monitoring was carried out throughout the short walk up to the weapons detector, through it, and back to the starting point. If motion artifact continued to be a problem, the patient was taken through the test area in a wheelchair. In the few patients in whom a change in rate on passing through the weapons detector was apparent, control studies were run in which the walk was repeated with the weapons detector switched off to confirm or rule out psychological factors. (Figure 7) The maximum field strength was known to be at end of the passageway normally the end for exiting the detector. Control studies were accomplished by having the patients pass through the system in a reverse direction. (Figure 8)

The electromagnetic interference in the ECG trace was not filtered if the rate could be clearly determined. (Figure 9) In all cases, however, in which electromagnetic interference from the weapons detector made the ECG tracing difficult to interpret, duplicate tracings were made with appropriate filtration adjusted to eliminate distortion of the ECG trace. (Figure 10)

*Gel Pad Disposable Silver/Silver Chloride Electrodes, Bimetics, Inc. 3040 E. River Road, Dayton, Ohio 45439

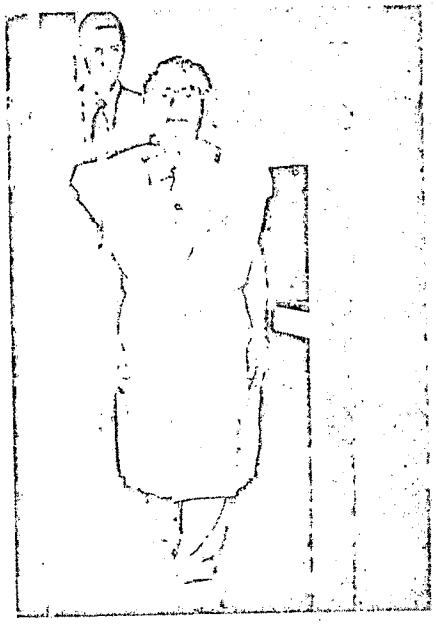

Fig. 6. One of the physicians on the team escorted each patient throughout the entire test procedure, here as they walk through the electromagnetic field.

RESULTS

A total of 53 patients with permanently implanted pacemakers were exposed to the active magnetometer field. The number and types of pacemakers studied are shown in the following chart:

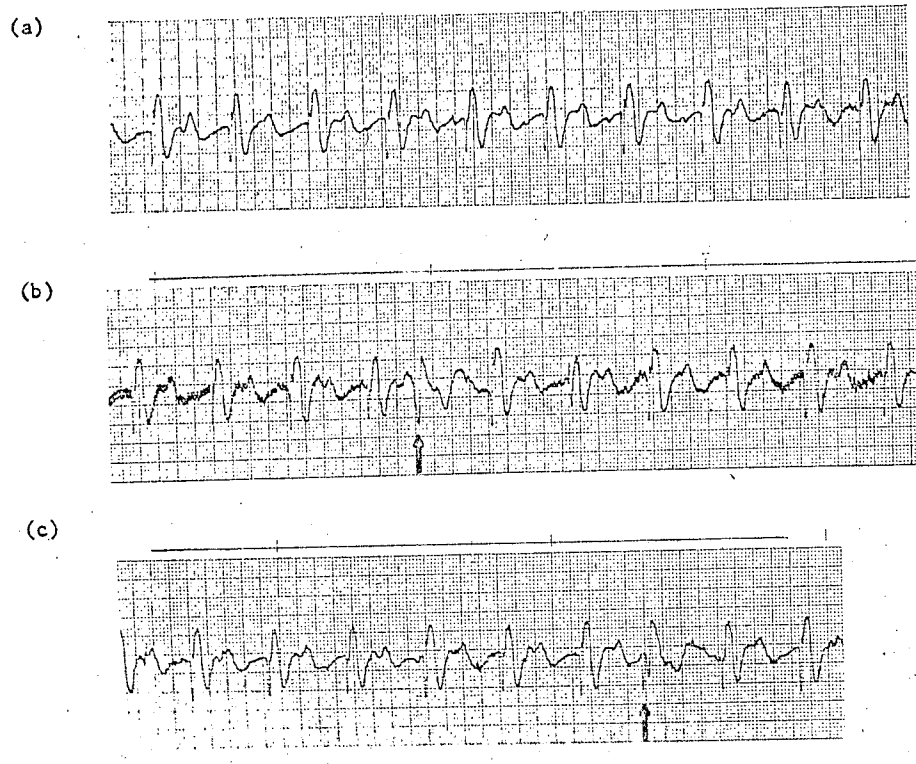

Fig. 7. ECG tracings (Ectocor, R-S standby ventricular pacing): a. Outside weapons detector. b. Inside weapon detector. Extra beat (arrow). *Line at top* indicates time *in* weapons detector. c. Same, in weapons detector, with weapon detector *switched off*. Again an extra beat is seen, suggesting other than an external electronic cause.

Type of Pacing	Type of Pacemaker	Number of Patients Tested
Unipolar Ventricular	*Cordis Ectocor* (R-S°)	17
Unipolar Ventricular	*Cordis Stanicor* (R-I°°)	17
Unipolar Ventricular	*Cordis Ventricor* (Fixed Rate)	1
Bipolar Ventricular	*Medtronic-Model 5841* (R-I°°)	1
Bipolar Ventricular	*Medtronic-Model 5842* (R-I°°)	3
Unipolar Atrial	*Cordis Ectocor* (P-S°°°) (Sensitive)	8
Unipolar A-V Synchronous	*Cordis Atricor* (Sensitive)	3
Unipolar A-V Sequential	Cordis Ectocor (P-S°°°)-*Atricor* (Sensitive)	3

°R-S R wave stimulated.
°°R-I R wave inhibited.
°°°P-S P wave stimulated.

In general (1) no patient was aware of any symptoms on passing through the weapons detector, (2) no pacer ceased to function while in the magnetometer field, (3) post-test ECG's showed no change in rate in any pacemaker, (4) no patient suffered any ill effects from the test, (5) no standard ventricular pacemaker, unipolar or bipolar, was affected by the weapons detector, i.e., Cordis fixed rate Ventricor, Stanicor, and standard sensitivity Ectocor, and Medtronic demand units Models 5841 and 5842.

In the group of patients with a sensitive (1 mv) Ecto-

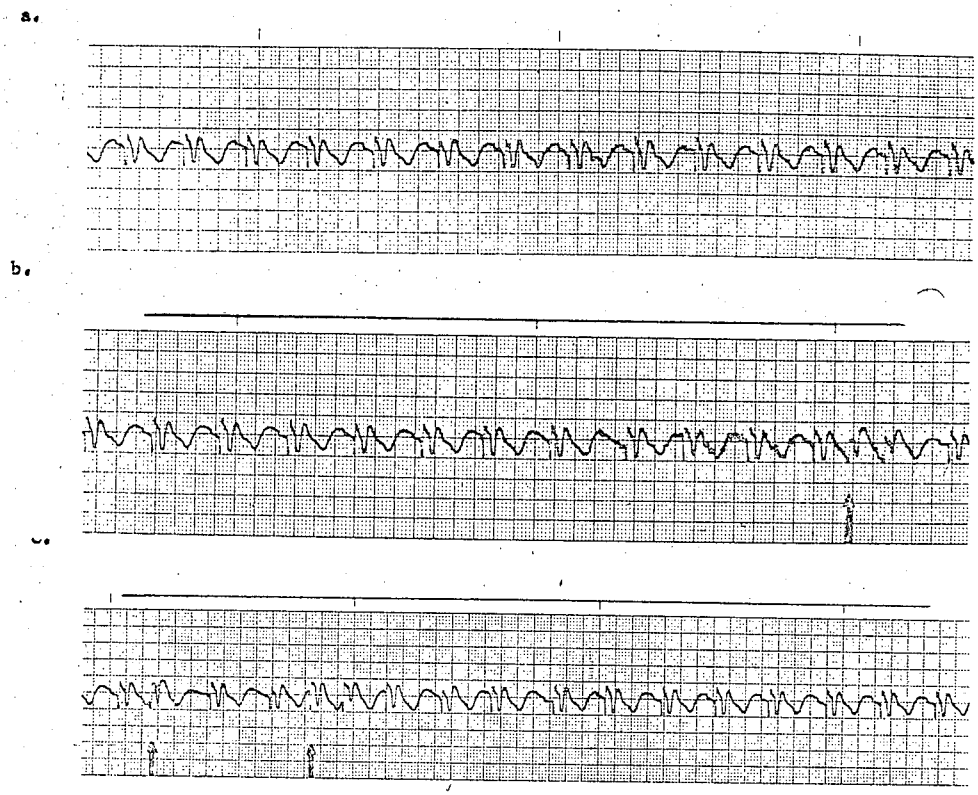

Fig. 8. Some patients were studied as they passed in each direction through the detector. ECG tracings (Sensitive Atricor, A-V synchronous pacing): a. Outside weapons detector. b. Line indicates time in weapons detector. Note increase in rate at right (arrow), just before leaving unit in the area of maximum field strength. c. Reverse direction. Note two brief episodes of increased rate on entering passway (arrows) in the area of maximum field strength.

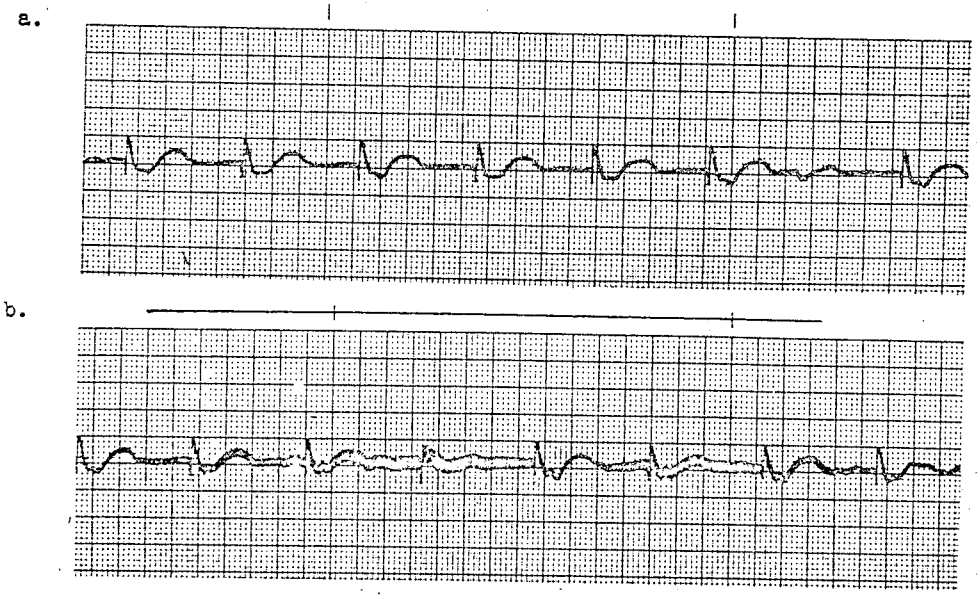

Fig. 9. ECG tracings (Stanicor, R-I demand ventricular pacing): a. Outside weapons detector. b. In weapons detector, Rate is easily measured in spite of interference.

cor, pacing the atrium, one patient out of eight showed a slight increase of rate for one beat only. This may well have been a spontaneous extra beat. The effect was not seen with the weapons detector switched off, nor was it seen in a repeat test with the unit switched on again. (Figure 11) No effect of any kind was seen in the other seven.

In the two groups in which the sensitive (0.5 mv) Atricor pulse generator was used, namely the A-V Synchronous pacing group and the A-V Sequential pacing group, some *change in rate* occurred in all three patients in each group. In the A-V Synchronous group (Atricor), in two of the three patients, there was an increase in rate over a two- to three-beat period followed by either a 2:1 blocking mechanism or a loss of P wave sensing causing the pacer to revert to a slower rate. This lasted for one, two, or three beats only; normal pacing then resumed. (See Figure 8) In one patient there was no increase in rate but a *drop* in rate occurred from 100 beats per minute to 60 beats per minute for one or two beats and then reversion to normal pacing occurred. This suggested that loss of P wave synchrony rather than a 2:1 blocking mechanism had occurred. (Figure 12) In the sequential group minimal changes in atrial pacing occurred, usually restricted to an increase in rate limited to one beat only, as was seen in the one patient with an atrial pacer. However, the more sensitive pulse generator pacing the ventricle (modified Atricor) showed an independent increase in rate lasting for several beats with loss of A-V synchrony. (Figure 13). The

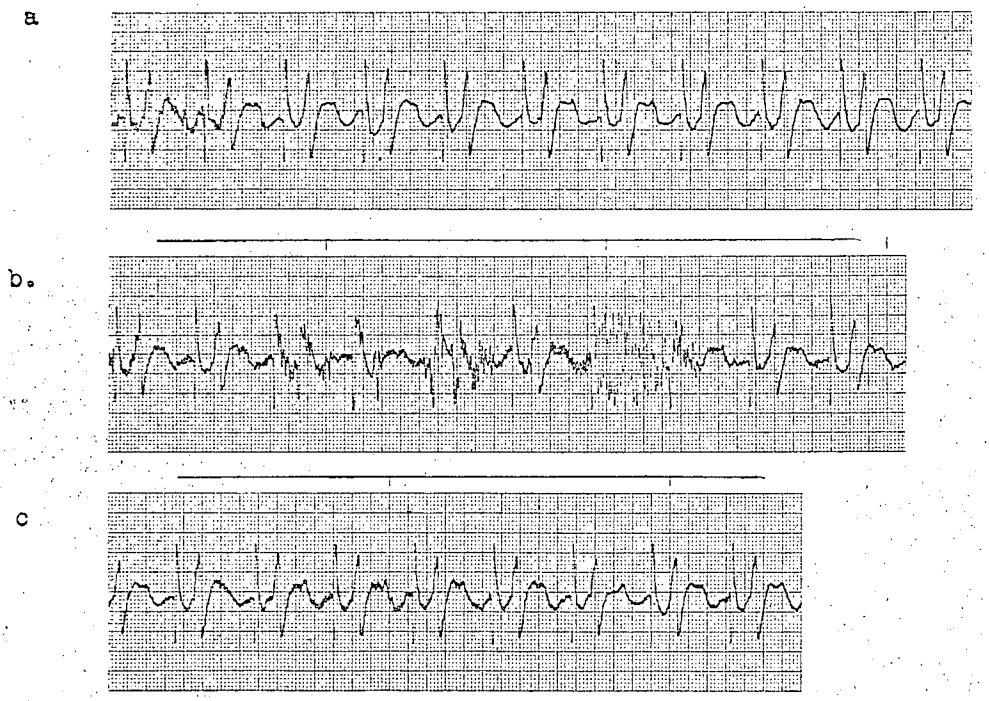

Fig. 10. ECG tracings (Sensitive Ectocor, P-S standby atrial pacing): a. Outside weapons detector. b. In weapons detector—"All Pass"—(No filter). c. In weapons detector—"Filter In." No rate change is noted on clear tracing.

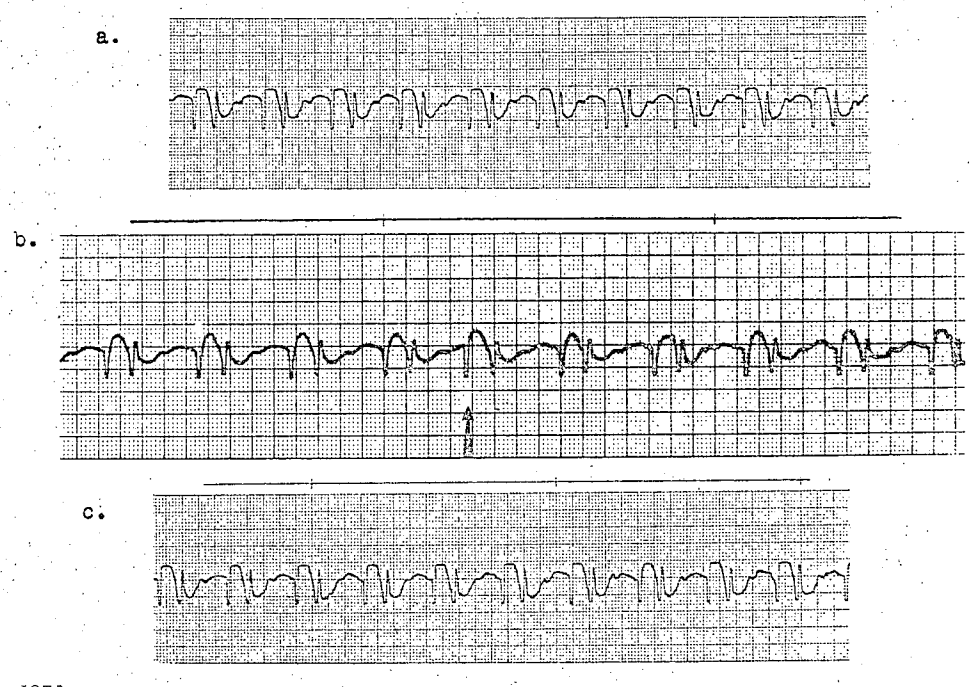

Fig. 11. ECG tracings (Sensitive Ectocor, P-S standby atrial pacing): a. Outside weapons detector. b. In weapons detector. Note one faster beat (arrow). c. In weapons detector for second test—no effect.

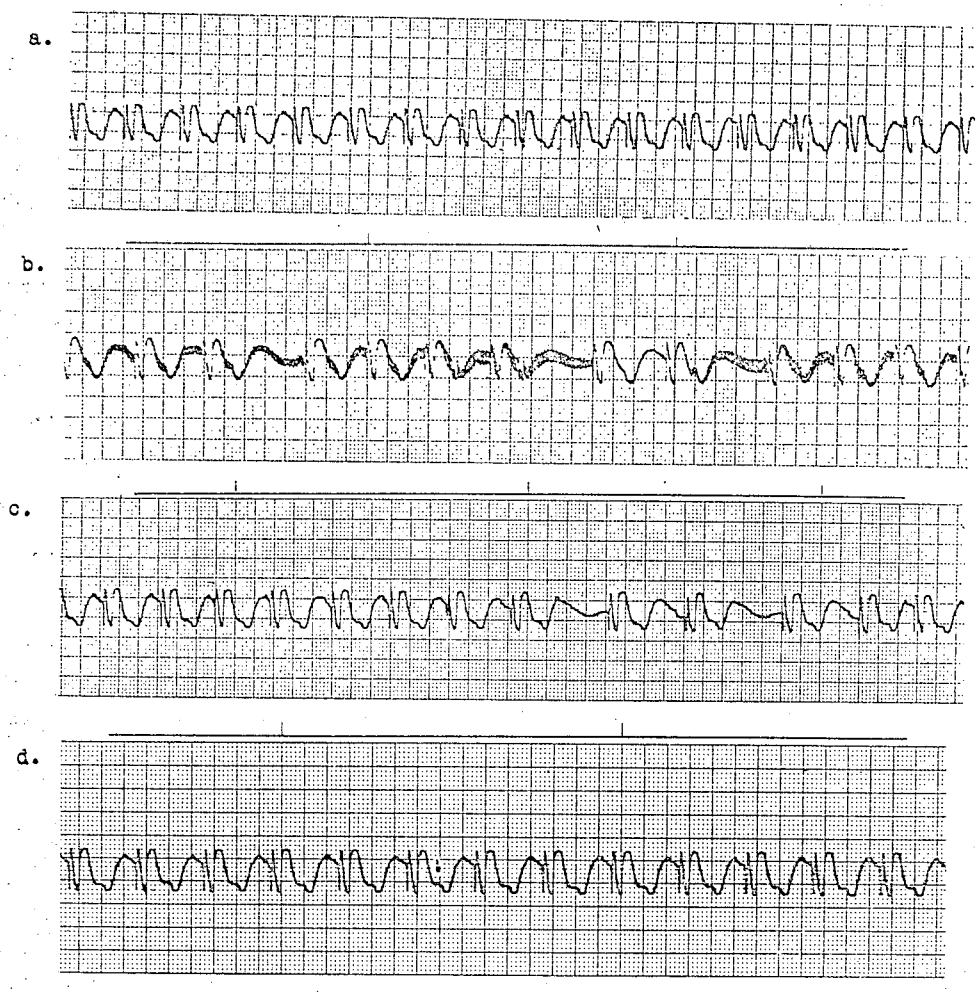

Fig. 12. ECG tracings (Sensitive Atricor, A-V synchronous pacing: a. Outside weapons detector rate 95-180 beats per minute. b. In weapons detector—"All Pass." Note periodic slowing to rate of 60 beats per minute for one beat without prior increase in rate c. "Filter In"—same effect. d. In weapons detector with unit switched off—no effect.

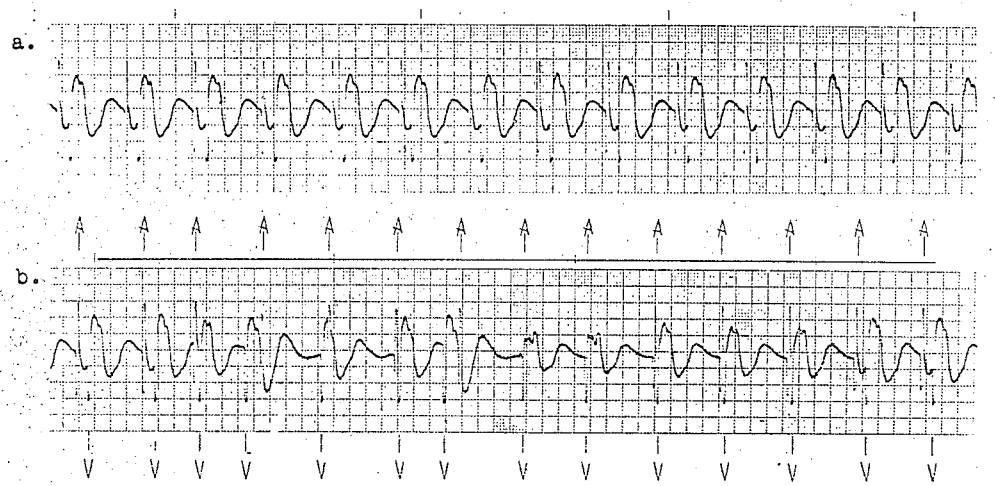

Fig. 13. ECG tracings (Sensitive Ectocor—Sensitive Atricor, A-V sequential pacing: a. Outside weapons detector. Note separate spike potentials "A" for atrial and "V" for ventricular pacing. Rate is 72 beats per minute. There is a constant short P-R interval (120 ms). b. In the weapons detector, the third beat shows the atrial pacer increasing to 93 beats per minute and the ventricular pacer to 114 beats per minute. The atrial pacer then reverts to 72 beats per minute but the ventricular pacer increases its rate—firing before the atrial spike. It then blocks to a slower rate, speeds up and slows again completely independent of the atrial pacer. In the eighth and ninth beats in the tracing the ventricular pacer fires at its basic fixed rate of 60 beats per minute, and triggers the atrial pacer to fire a zero delay impulse so that both spikes are fused. Both pacers then fire separately, the atrial before the ventricular, with a lengthening P-R interval until the normal sequence is restored in the last complex shown.

effect was immediately eliminated on leaving the magnetic field. All patients were quite unaware of these changes.

DISCUSSION

It is apparent that in the standard unipolar or bipolar ventricular pacemakers used for the vast majority of patients, no effect is produced by the weapons detector. It is probable that 95% or more of patients wearing pacemakers will fall into one of these groups having fixed rate ventricular, R wave inhibited demand, or R wave stimulated standby ventricular pacers. However, it was felt that the more unusual systems such as atrial, A-V Synchronous, and A-V Sequential pacing systems, using more sensitive pulse generators should be included in this study, as the use of this type of unit may increase in the future.

It should be pointed out that all the pacemakers tested, both standard and non-standard except the obsolete Medtronic 5841, have built-in mechanisms designed to protect the patient against extrinsic electromagnetic interference.

In all cases in which the rate increased or slowed, clinically safe rates were maintained. In the sequential group, although A-V synchrony was lost, significant competition did not occur because each pulse generator paced a different chamber. No potentially dangerous competitive ventricular pacing was observed in any case.

It is apparent that while these sensitive unipolar units are more affected by the weapons detector, in direct proportion to their sensitivity and related to their unipolarity, the resulting brief transitory arrhythmia is not clinically significant.

CONCLUSIONS

An external electromagnetic field used in a weapon detector system (WD-4) may produce minor changes in the rate of certain pacemakers, specially the sensitive unipolar atrial or the atrial or atrio-ventricular pacing systems. These changes were clinically insignificant to the patient and to the pacing system. Other systems, such as unipolar fixed rate, and unipolar and bipolar ventricular pacemakers were totally unaffected.

The weapons detector studied (WD-4) was determined to be safe for use in the public environment of an airport. Recommendation for its use was made to FAA Research & Development officials.

The WD-4 may now be implemented as another method for detecting objects that could be used in the hijacking of aircraft.

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Lymphocytopenia Appears Related to Cancer

An apparent relationship exists between lymphocytopenia and malignancy, but its significance is not known. Among 178 patients with both relative (less than 15%) and absolute (less than 1,000 per cubic millimeter) lymphocytopenia, malignancy was the most frequent diagnosis and occurred in 76. No disease was found in 40 of the patients. One hundred twenty-one of the patients had not received cytotoxic drugs, irradiation, or corticosteroids in the preceding year. In another study, absolute lymphocytopenia was found in 6% of 510 healthy subjects and 22.4% of 227 patients with untreated gastrointestinal malignancies. The incidence of malignancy in an additional 5,325 patients was about 10% in those with lymphocyte counts over 1,500 per cubic millimeter and about 29% in patients having counts less than 1,000 per cubic millimeter.

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