Electromagnetic interference with pacemakers caused by portable media players

Jay P. Thaker, Mehul B. Patel, MD, Krit Jongnarangsin, MD,* Valdis V. Liepa, PhD,[†]
Ranjan K. Thakur, MD, FHRS

*From the Thoracic and Cardiovascular Institute, Sparrow Health System, Michigan State University, Lansing, Michigan, and *Division of Cardiovascular Medicine and [†]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan.*

BACKGROUND Electromagnetic fields generated by electrical devices may cause interference with permanent pacemakers. Media players are becoming a common mode of portable entertainment. The most common media players used worldwide are iPods. These devices are often carried in a shirt chest pocket, which may place the devices close to an implanted pacemaker.

OBJECTIVE The purpose of this study was to determine if iPods cause interference with pacemakers.

METHOD In this prospective, single-blinded study, 100 patients who had cardiac pacemakers were tested with four types of iPods to assess for interference. Patients were monitored by a single-channel ECG monitor as well as the respective pacemaker programmer via the telemetry wand. iPods were tested by placing them 2 inches anterior to the pacemaker and wand for up to 10 seconds. To simulate actual use, standard-issue headphones were plugged into the iPods. To maintain consistency, the volume was turned up maximally, and the equalizer was turned off. A subset of 25 patients underwent testing on 2 separate days to assess for reproducibility of interference. Pacemaker interference was categorized as type I or type II telemetry interference. Type I interference was associated with atrial and/or ventricular high rates on rate histograms. Type II interference did not affect pacemaker rate counters. Electromagnetic emissions from the four iPods also were evaluated in a Faraday cage to determine the mechanism of the observed interference.

RESULTS One hundred patients (63 men and 37 women; mean age 77.1 ± 7.6 years) with 11 single-chamber pacemakers and 89 dual-chamber pacemakers underwent 800 tests. The incidence of any type of interference was 51% of patients and 20% of tests. Type I interference was seen in 19% of patients and type II in 32% of patients. Reproducibility testing confirmed that interference occurred regardless of pacing configuration (unipolar or bipolar), pacing mode (AAI, VVI, or DDD), and from one day to the next. Electromagnetic emissions testing from the iPods demonstrated maximum emissions in the pacemaker carrier frequency range when the iPod was turned "on" with the headphones attached.

CONCLUSION iPods placed within 2 inches of implanted pacemakers monitored via the telemetry wand can cause interference with pacemakers.

KEYWORDS Pacemaker; Electromagnetic interference

(Heart Rhythm 2008;5:538–544)

Introduction

Electromagnetic interference with pacemakers may result in disruption of normal device function, which may lead to serious consequences. The increasing use of electronic devices worldwide has led to a greater number of sources for electromagnetic radiation. This is a cause of concern for patients with implanted pacemakers because of the risk for electromagnetic interference.[1–6] Current pacemakers are shielded and have built-in electronic filters that diminish the probability of electromagnetic interference.[3,4] However, despite these technologic improvements, electromagnetic interference still occurs. Cellular telephones and antitheft surveillance systems are cases in point.[1,5,6]

The iPod (Apple Inc., Cupertino, CA, USA) is a widely used brand of portable media player for personal entertainment that has become quite ubiquitous. Since its introduction in 2001, it is estimated that more than 100 million iPods have been sold. Furthermore, iPods are increasingly being used in the health care setting as a teaching, training, or monitoring tool.[7–9]

Most handheld electronic devices operate at a distance from the usual pacemaker implantation site (pectoral region). Therefore, during normal use, the devices may not come close enough to an implanted pacemaker to cause electromagnetic interference. However, iPods are often carried in a shirt chest pocket or on an armband, which may place the devices in close proximity to an implanted pacemaker. Furthermore, in this new era of remote monitoring of implanted devices using a wand or wirelessly, performed in the absence of direct medical supervision, electronic devices in the near field may potentially interfere with remote

Address reprint requests and correspondence: Dr. Ranjan K. Thakur, Thoracic and Cardiovascular Institute, 405 West Greenlawn, Suite 400, Lansing, Michigan 48910. E-mail address: thakur@msu.edu. (Received December 21, 2007; accepted January 18, 2008.)

1547-5271/$ -see front matter doi:10.1016/j.hrthm.2008.01.028

monitoring. We previously reported interaction between an iPod and a pacemaker.[10] The current study was prompted by this observation. The purpose of this study was to ascertain the risk of pacemaker interference caused by iPods.

Methods

This prospective, single-blinded study was performed on patients in an outpatient pacemaker clinic or hospitalized patients. The study was approved by the institutional review board and followed Good Clinical Practices guidelines, including the use of standard operating procedures.[11] Written and verbal informed consent was obtained from all patients.

Four types of iPod devices were tested: Third Generation (3G), Photo, Nano, and Video. All iPod devices were manufactured prior to December 2005.

Testing protocol

Testing was performed on patients in the pacemaker clinic while sitting at 90° and on hospitalized patients supine at 30° with the pacemaker programmed to usual settings in the unipolar or bipolar configuration. Patients were constantly monitored by a single-channel ECG monitor (Codemaster XL, Hewlett Packard, Palo Alto, CA, USA) and by each pacemaker's programmer via the telemetry wand. The iPods were tested in random order. While one technician selected and handled the iPod, another technician monitored the ECG display and the pacemaker programmer screen. The monitoring technician was not aware of the pacemaker settings or the iPod device being tested.

Prior to iPod exposure, the pacemaker was interrogated, and the interrogation report was printed. All rate histograms then were cleared, and the pacemaker was exposed to the iPod. To simulate normal use, earphones were plugged into the iPod being tested, but the earbuds were left on the patient's shoulders, the volume was turned to maximum, and the equalizer was turned off. The iPod was applied 2 inches anterior to the pacemaker without touching the skin or the telemetry wand for up to 10 seconds. The iPod was turned on, played, fast forwarded, and then turned off. At the end of the test, the pacemaker was reinterrogated, and the new rate histograms were printed. If interference with an iPod was observed, the test was repeated to confirm the presence of interference. Patients were asked to report any symptoms during testing.

In 25 patients, detailed testing was performed at different pacemaker settings (AAI, VVI, and DDD mode, and unipolar/bipolar pacing configurations) on 2 different days to study the reproducibility of interference events.

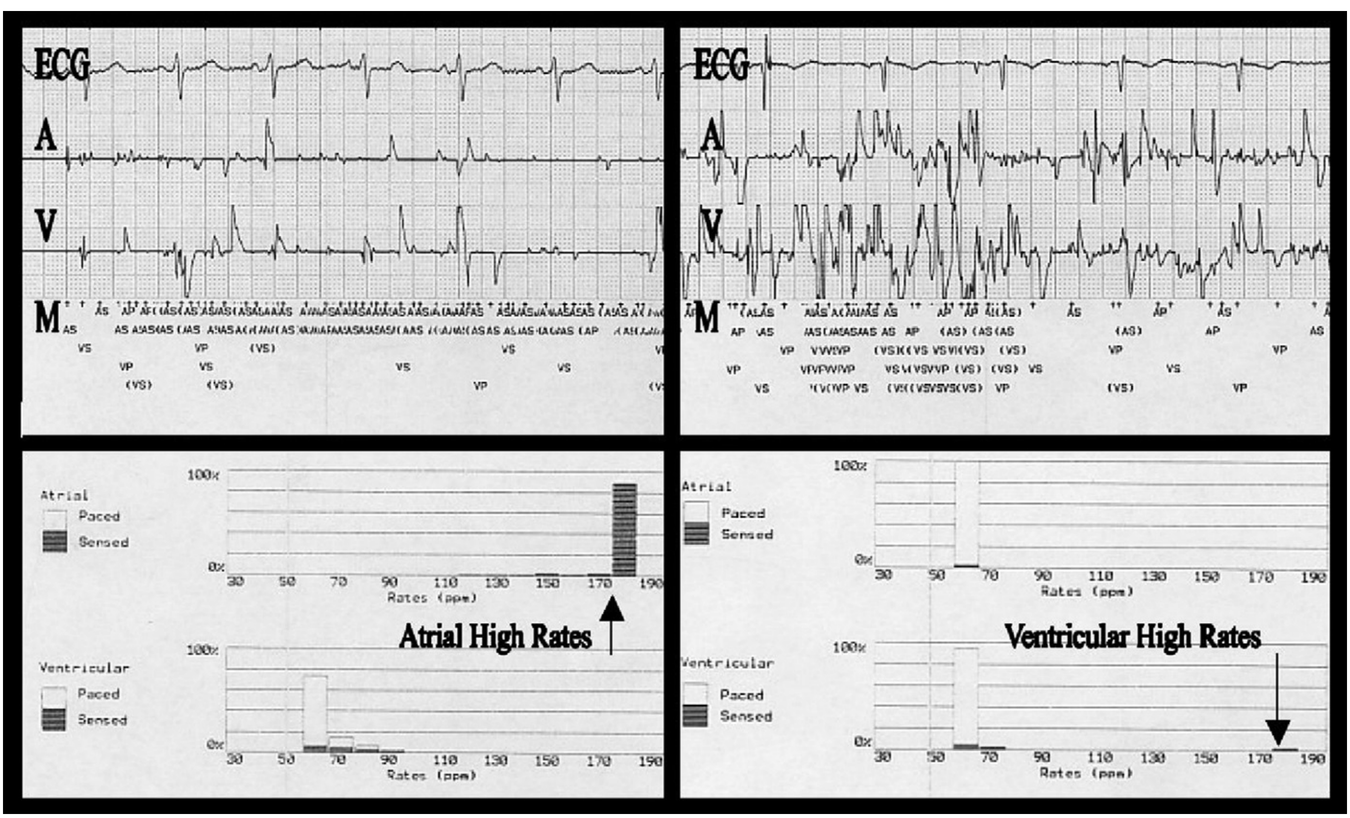

Figure 1 Two examples of type I interference. **Top left:** Interference during iPod exposure. Marker channel shows abundant atrial sensed (AS) events. **Bottom left:** Rate histograms obtained after interrogation. A large bar corresponding to rate of 180 bpm is seen in the atrial channel, and smaller bars are seen at 150 and 170 bpm. **Top right:** Another interference pattern in a different patient. Marker channel shows abundant AS and ventricular sensed (VS) events. **Bottom right:** Rate histograms obtained after interrogation. A small bar at a rate of 180 bpm is seen. ECG channels clearly show sinus rhythm in both patients.

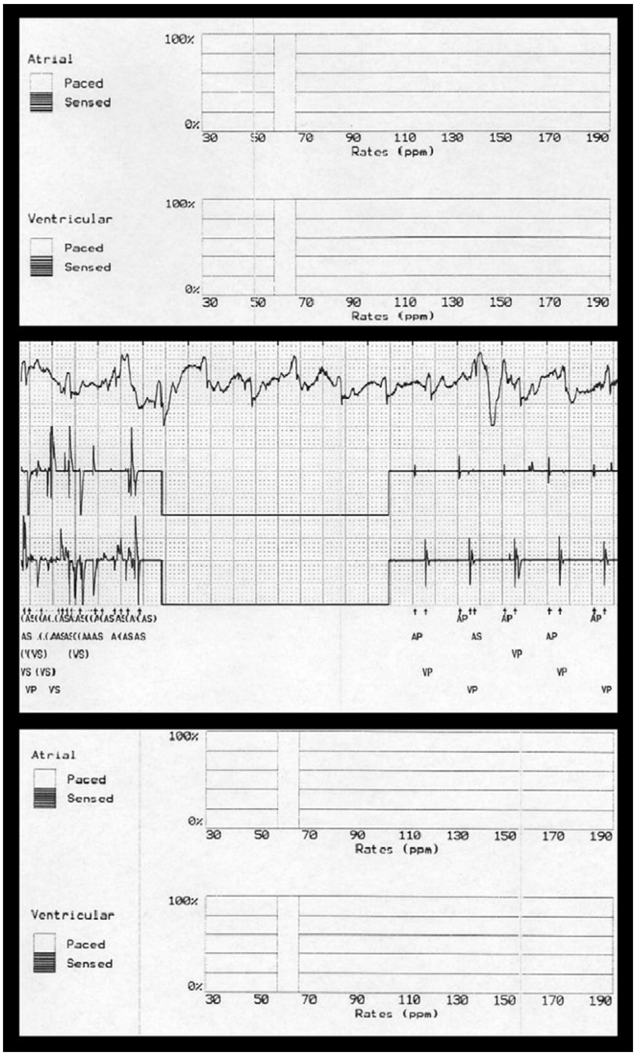

Figure 2 Type II interference. **Top:** Rate histograms before iPod exposure. The patient was AV paced at 60 bpm. Rate histogram shows large bars corresponding to atrial and ventricular pacing at 60 bpm. **Middle:** Interference seen with iPod exposure. Initially, high-density atrial sensed (AS) and ventricular sensed (VS) annotations are seen, followed by blanking of the atrial and ventricular electrogram channels. This is followed by resumption of atrial and ventricular electrograms without any interference as evidenced by appropriate annotations of atrial paced (AP) and ventricular paced (VP) events. **Bottom:** Rate histograms obtained after iPod exposure. No high rates are recorded. Because the only evidence of interference was seen in the marker channels without any alteration of the rate histograms, this was classified as a type II interference.

Definitions

Interference events were classified as type I or type II telemetry interference. *Type I interference* was defined as spurious atrial or ventricular sensing seen on the pacemaker programmer's marker channel during exposure to the iPod and evidence of this being detected in the pacemaker by high atrial/ventricular rates on rate histograms (Figure 1). *Type II interference* was defined as any interference with the monitor screen that did not affect pacemaker function and was not detectable by pacemaker interrogation (Figure 2). Interaction events were further characterized as *transient* if the interference lasted ≤50% of the application time and *persistent* if interference lasted >50% of the application time.

Detailed testing

Twenty-five patients with dual-chamber pacemakers who were not pacemaker dependent underwent detailed testing on 2 days to assess reproducibility of interference (1) in unipolar and bipolar pacing configurations, (2) in AAI, VVI, and DDD pacing modes, and (3) variability from day to day. Pacemaker sensitivity in either atrial or ventricular channel was left as programmed; only the pacing mode and pacing polarity were altered for testing. Tests for polarity (unipolar vs bipolar) were performed in the patient's programmed mode, and tests for different pacing modes were performed in the bipolar configuration.

Electromagnetic emissions testing of iPods

All four iPods were evaluated for electromagnetic emissions in a Faraday cage using a standard bicone antenna at a distance of 12 inches. The antenna was placed on top of the iPod with earphones and then connected to an 80-dB gain amplifier. The output was displayed on a spectrum analyzer (Hewlett Packard 8753E) from 0 to 1,000 MHz. To assess electromagnetic emissions in the lower-frequency range (0–500 kHz), the iPod was placed in the middle of a loop antenna, and the output was displayed on the same spectrum analyzer. Outputs from the spectrum analyzer were recorded in a computer, displayed, and printed.

Data collection and statistical analysis

Standardized data collection forms were used to collect information on demographics, implantation details, pacemaker lead(s) and generator, pacemaker programmed parameters, and test results. All data were maintained in a Microsoft Excel database and analyzed using SPSS statistical software (SPSS, Inc., Chicago, IL, USA). Data are presented as mean ± 1 SD. Event rates were compared using the two-proportion Z-test. $P \leq .05$ was considered significant.

Results

Routine testing

A total of 100 patients were tested. All patients were tested using four different iPods with pacemakers in both bipolar

Table 1 Permanent pacemaker– iPod interactions

	No. of interference events (%)	No. of patients (%)
Interference		
Type I	63 (7.88%)	19 (19%)
Type II	94 (11.75%)	32 (32%)
iPod	**Type I**	**Type II**
3G	22 (2.75%)	59 (7.4%)
Photo	28 (3.5%)	31 (3.9%)
Video	10 (1.25%)	3 (0.4%)
Nano	3 (0.4%)	1 (0.13%)

One hundred patients underwent evaluation in the unipolar and bipolar pacing configurations, with four different iPods, resulting in 800 tests.

Table 2 Effect of pacing configuration on interference

Interference	Unipolar	Bipolar	*P* value
Type I	48 (4.0%)	60 (5.0%)	.226
Type II	146 (12.2%)	150 (12.5%)	.788

To determine the reproducibility of type I and type II interference events, 25 nonpacemaker dependent patients with dual-chamber pacemakers underwent evaluation in unipolar and bipolar configurations, in AAI, VVI, and DDD modes, on 2 separate days, using four different iPods, resulting in 1,200 tests.

Table 4 Day-to-day variability of interference

Interference	Day 1	Day 2	*P* value
Type I	46 (3.83%)	62 (5.2%)	.106
Type II	161 (13.4%)	135 (11.25%)	.08

Day-to-day variability of interference events on 2 separate days was evaluated in 25 patients who underwent 1,200 tests (see legend for Table 2). Data represent the number of type I and type II interference events on two separate days; these events may not have occurred in the same patients.

and unipolar configurations, resulting in 800 tests. The study population consisted of 100 patients (63 men and 37 women; mean age of 77.1 ± 7.6 years). The patients had 89 dual-chamber pacemakers and 11 single-chamber pacemakers. Pacemakers were implanted for sick sinus syndrome in 36 patients, symptomatic bradycardia in 24, syncope in 12, heart block in 11, post-atrioventricular nodal ablation in 9, and other reasons in 8. The distribution of pacemakers by manufacturer were 60 Guidant Inc., 13 Medtronic Inc., and 27 St. Jude Medical Inc.. At the time of testing, mean population parameters were P waves 2.67 ± 1.37 mV, R waves 10.5 ± 4.75 mV, atrial sensitivity 0.67 ± 0.52 mV, and ventricular sensitivity 2.31 ± 0.61 mV. Table 1 lists the main results. Sixty-three type I interference events (out of 800 [7.88%]) were seen in 19 (19%) patients, and 98 type II interference events (11.75%) were seen in 32 patients (32%). None of the patients reported any symptoms.

All interference events were persistent. The majority of interference events occurred with the iPod 3G and Photo; very few occurred with the Nano and Video.

Detailed testing

In order to evaluate the reproducibility of interference in different pacing modes (AAI, VVI, DDD), pacing configurations (unipolar vs bipolar), and from day to day, a subset of 25 patients with dual-chamber pacemakers who were not pacemaker dependent underwent detailed testing with all four iPods on 2 different days, resulting in an additional 1,200 tests.

With respect to unipolar and bipolar pacing configurations, no difference was seen in the event rates for type I or type II interference (Table 2). Effect of pacing mode on pacemaker interference is shown in Table 3. Type I interference was independent of pacing mode, but type II interference was less common during AAI pacing. Results of testing on 2 different days are shown in Table 4. Event rates for type I and type II interference were similar on the 2 days.

Electromagnetic emissions from iPods

Electromagnetic emissions from iPods are shown in Figures 3 and 4. Figure 3 shows the output from a standard bicone antenna (0–1,000 MHz). Figure 4 shows the output from a loop antenna (0–0.5 MHz). Outputs from both antennas are displayed on a scale from 0 to 80 dB. Because the antennas used were calibrated at 3 m, we cannot ascribe any absolute amplitude values to these recordings. The left-hand column shows the baseline state while the iPod was off; the middle column displays the emission output with the iPod turned on but without the earphones, and the right-hand column shows the emission output with the earphones plugged in. At high frequencies (Figure 3), emissions are present when the iPod was turned on and even more so when the earphones were plugged in. At low frequencies (Figure 4), the effect of earphones was less prominent.

Discussion

We live in a world surrounded by electrical devices, all of which emit electromagnetic radiation. The most common household devices with which the general population comes in contact emit low-amplitude electromagnetic signals. The amplitude of these signals falls with the square of the distance, resulting in a relatively low incidence of electromagnetic interference. However, electromagnetic radiation may cause interference with pacemakers. This effect has been shown with a variety of electrical devices, the most prominent being cellular telephones.[5,6] iPods are a form of portable media player (music, photo, and video) that is quite ubiquitous worldwide. iPods are the most popular type of MP3 player and therefore were selected for this study.

iPods are often carried in a shirt chest pocket, a location that may put the devices close to an ipsilaterally implanted

Table 3 Effect of pacing mode on interference

Interference	AAI	VVI	DDD	*P* value)
Type I	33 (2.75%)	37 (3.1%)	38 (3.2%)	.617 (AAI-VVI) .534 (AAI-DDD) .903 (VVI-DDD)
Type II	75 (6.25%)	102 (8.5%)	119 (9.92%)	.021 (AAI-VVI) .001 (AAI-DDD) .179 (VVI-DDD)

Distribution of interference events by pacing mode in 25 patients who underwent 1,200 tests (see legend for Table 2).

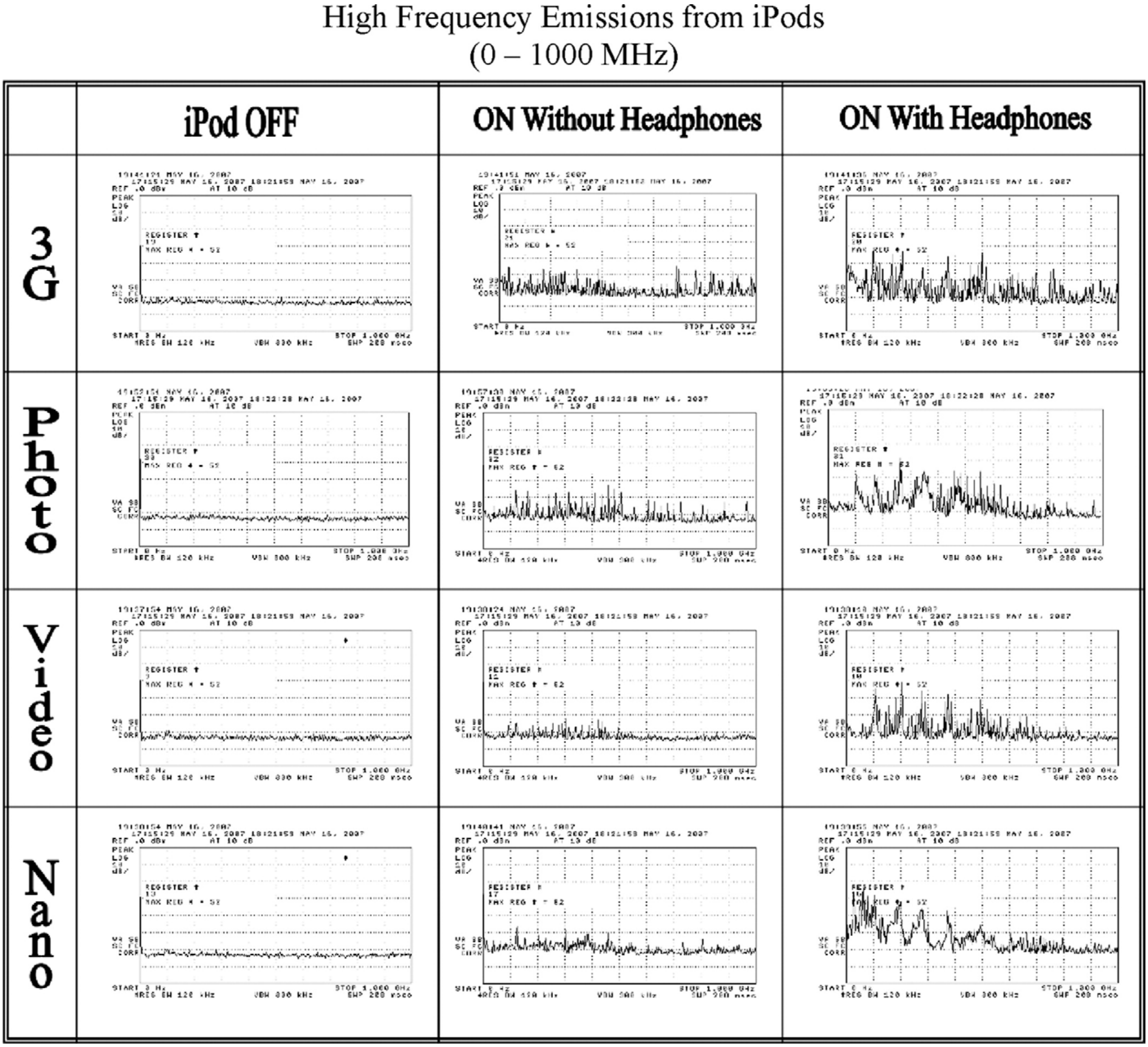

Figure 3 Relative electromagnetic emissions from the four iPods measured in the "OFF," "ON without headphones," and "ON with headphones" states. These are relative measure because the bicone antennas were calibrated at 3 m but were used at 18 inches. The ordinate in each graph corresponds to 0 to 1,000 MHz. The abscissa corresponds to 0 to 80 dB. For each iPod, no electromagnetic emissions were detected when the device was in the "OFF" state. Emissions increased when the iPod was turned "ON without headphones" and increased further when the iPod was "ON with headphones."

pacemaker and potentially create interference with the pacemaker. This study found that iPods cause type I interference in 19% of patients and type II interference in 32% of patients. None of the patients reported any symptoms.

Telemetry interference may be clinically significant, especially as these devices move toward remote monitoring and possibly remote programming. High atrial rates on rate histograms may be misinterpreted as atrial fibrillation, atrial lead fracture, or a loose set screw and lead to unnecessary interventions. Similarly, high rates in the ventricular channel may raise concern about ventricular tachycardia or ventricular lead problems. We did not observe any mode switch episodes, which may be related to the short duration of iPod exposure. iPods were generally applied for less than 10 seconds. High atrial rates would have to be sensed continuously long enough for a mode switch to occur. We also did not see any evidence of type I interference causing inhibition of pacing. This may be due to the fact that most patients had a native rhythm at the time of iPod testing and they were not paced; thus, pacing inhibition would not have been seen.

Detailed testing to evaluate the reproducibility of these observations was performed in 25 nonpacemaker-dependent patients with dual-chamber pacemakers. We did not find any difference in interference rates regardless of whether the pacemaker was in the unipolar or bipolar configuration. This finding was somewhat surprising because electromag-

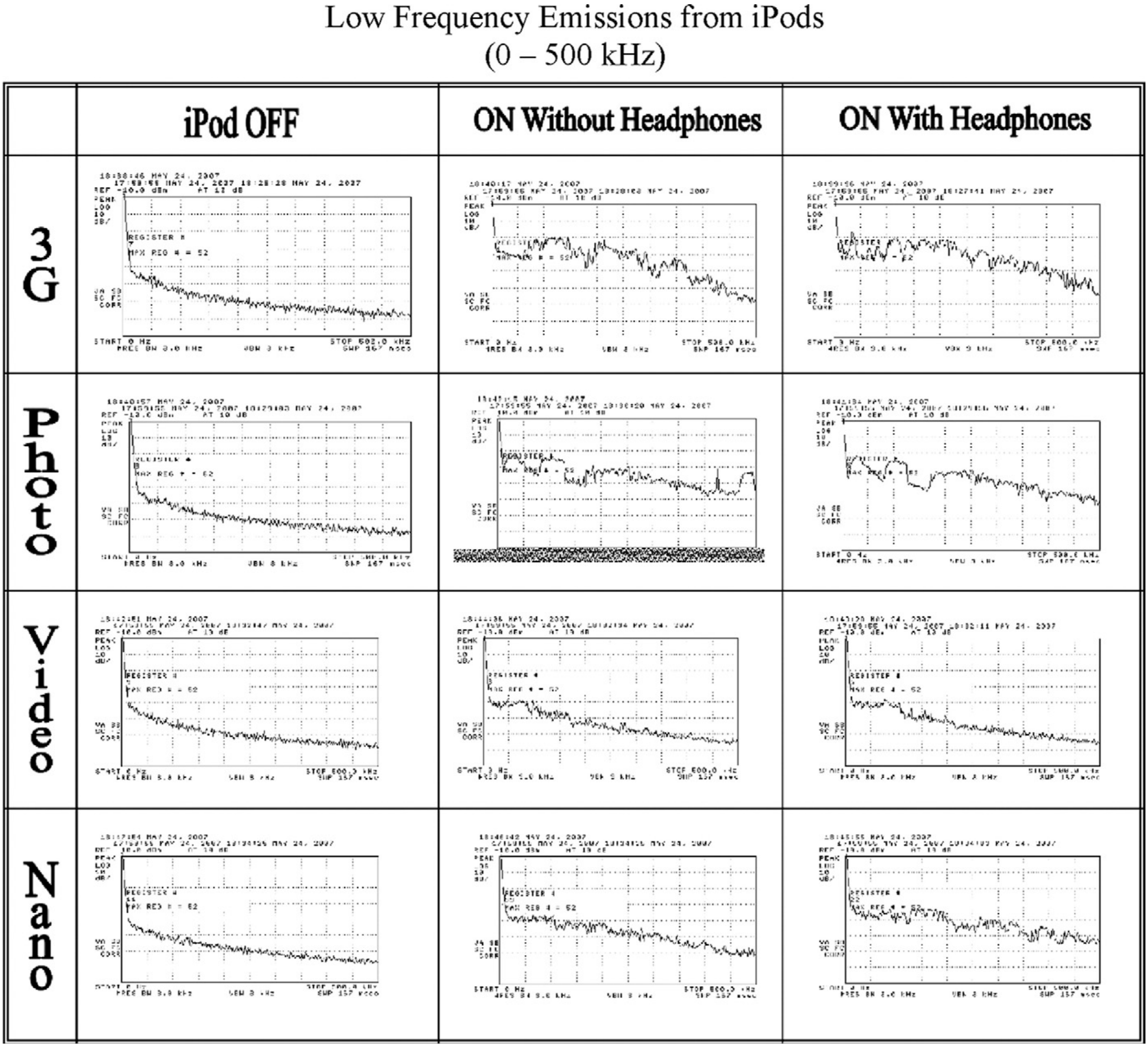

Figure 4 Relative electromagnetic emissions from the four iPods in the frequency range from 0 to 500 kHz. These are relative measures. A loop antenna was used. Emissions are seen in the range from 100 to 200 kHz, especially for 3G and Photo iPods.

netic interference is reportedly more common in the unipolar configuration because of a larger antenna between the lead tip and the pacemaker generator. However, considering that iPod signals are gaining entry into the pacemaker through the telemetry channel (rather than the leads), this may explain why polarity did not affect interference rates. Also, we found fewer episodes of type II interference in the AAI mode compared with the VVI or DDD mode. This may be related to low-amplitude signals from iPods not being sensed in the atrial channel.

To ascertain the mechanism of interference caused by iPods, we examined the emissions from these devices in an isolated Faraday cage. We used a bicone antenna to study high-frequency electric fields (0–1,000 MHz) and a loop antenna to study lower-frequency magnetic fields (0–500 kHz). We found evidence of emissions from these devices in the lower-frequency range (100–200 kHz). Pacemakers communicate with their respective programmers via the wand, at the carrier frequency. Carrier frequencies for the three manufacturers tested in this study vary from 100 to 175 kHz, with a bandwidth range of 0 to 250 kHz. iPod emissions at the carrier frequency may suggest a mechanism for how iPod emissions gain entry into pacemakers.

At the present time, remote monitoring is performed via the wand or wirelessly. Because the patient is not medically supervised during remote monitoring, it is critical that precautions be taken to prevent any telemetry interference, some of which may lead to corruption of stored data (type I interference). It is imperative that the telemetry link between the device and the “base station” (wanded or wireless) be encrypted and robust so that any environmental electromagnetic radiation does not disrupt this communication and data transfer.

Study limitations

Our study design entailed continuous monitoring of the patient with an ECG monitor and the pacemaker via the respective programmer using the telemetry wand. It is possible that electromagnetic emissions from the iPod corrupt telemetry communication between the pacemaker and the programmer and result in telemetry interference. The mechanism of type I interference in which stored pacemaker histograms are affected is not known and presently is the subject of investigation in several laboratories. Whether iPods can cause interference with pacemakers in the absence of a telemetry wand is not known and requires investigation. This study exposed the pacemakers at a fixed distance of 2 inches. The effect of distance from the iPod to the pacemaker was not studied.

Clinical implications

Although several potential causes of pacemaker interference have been reported, clinically significant interference events have been rare.[1–6] This may be attributable to two factors: (1) improvement in design of electronic products and better noise filtering mechanisms in pacemakers so that interference does not occur, and (2) patient's avoidance behavior. In the case of cellular telephone causing interference, use of bandpass and feed-through filters, improvement in pacemaker software, changes in cell phone technology, and patient's avoidance of cell phone use on the ipsilateral side all probably have contributed to the lack of significant adverse events in spite of the exponential increase in cell phone use over the last decade. Based on this observation, it may be reasonable to reiterate the "don't lean, don't linger" policy advocated by the Food and Drug Administration and device manufacturers and recommend that pacemaker patients avoid putting a portable media player in an ipsilateral shirt pocket.

In the Important Product Information Guide issued with the newest iPod Touch, Apple has issued recommendations for pacemaker patients.[12] Apple recommends that pacemaker patients always keep the iPod Touch more than 6 inches away from their pacemaker when the iPod is turned on and not to carry the iPod in a shirt chest pocket.

Conclusion

iPods may cause interference if they are brought very close to an implanted pacemaker monitored through the telemetry wand. Interference is independent of pacemaker polarity or pacing mode and is reproducible from day to day. This may be an important clinical issue as devices are being followed remotely.

References

1. McIvor ME, Sridhar S. Interactions between cardiac pacemakers and antishoplifting security systems. N Eng J Med 1998;339:1394–1395.
2. Furrer M, Naegeli B, Bertel O. Hazards of an alternative medicine device in a patient with a pacemaker. N Eng J Med 2004;350:1688–1690.
3. Okan E. Electromagnetic interference in pacemakers. Indian Pacing Electrophysiol J 2002;2:74.
4. Trigano A, Blandeau O, Dale C, et al. Reliability of electromagnetic filters of cardiac pacemakers tested by cellular telephone ringing. Heart Rhythm 2005;2: 842–843.
5. Hayes DL, Wang PL, Reynolds DW, et al. Interference with cardiac pacemakers by cellular telephones. N Eng J Med 1997;336:1473–1479.
6. Calcagnini G, Censi F, Floris M, et al. Evaluation of electromagnetic interference of GSM mobile phones with pacemakers featuring remote monitoring functions. Pacing Clin Electrophysiol 2006;29:380–385.
7. Spiher B. iPod another tool in the future doctor's medical bag. The University Record Online, University of Michigan. Available at: http://www.ur.umich.edu/0607/Jun25_07/25.shtml.
8. Save a life with an Ipod (First Aid Podcasts). Available at: http://www.friedbeef.com/2006/05/04/save-a-life-with-an-ipod-first-aid-podcasts/.
9. iPod Helps Radiologists Manage Medical Images. Radiological Society of North America News. Available at: http://www.rsna.org/publications/rsnanews/dec04/ipod-1.html.
10. Patel MB, Thaker JP, Punnam S, et al. Pacemaker interference with an iPod. Heart Rhythm 2006;4:781–784.
11. Applications for FDA approval to market a new drug or an antibiotic drug. 21CFR314.126, 1992.
12. Important Product Information Guide for iPod Touch. Available at: http://manuals.info.apple.com/en/iPod_touch_Product_Info_Guide.pdf.