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Electromagnetic Interference of Pacemakers

Umashankar Lakshmanadoss MD[1], Priya Chinnachamy MD[2]
and James P Daubert MD[3]
[1]*Johns Hopkins Medical Institutions, Baltimore, MD, USA;*
[2]*All India Institute of Medical Sciences, New Delhi,*
[3]*Duke University Medical Centre, Durham, NC,*
[1,3]*USA*
[2]*India*

1. Introduction

With expanding indications for device therapies for management of cardiovascular diseases, the number of patients receiving pacemaker implantations are increasing every year. These cardiac electronic devices rely on complex microcircuitry and use electromagnetic waves for their communication with the programmers. Therefore, they are susceptible to interference from the surrounding electromagnetic radiation. Electromagnetic interference (EMI) can be defined as any signal, either biologic or non-biologic, that falls within a frequency spectrum that are being detected by the sensing circuitry of the pacemaker. They can interfere with the optimal function of the pacemaker and is always a concern for the patients with a pacemaker, since the risk of EMI is greatest in pacemaker dependent patients.

EMI may potentially affect a pacemaker in one of three ways: Stopping the pacemaker from delivering the stimulating pulses that regulate heart's rhythm; causing the pacemaker to deliver the irregularly; and causing the pacemaker to ignore heart's own rhythm and deliver pulses at a fixed rate. EMI with pacemakers can be very complex, not only from the technical standpoint, but also from the view of public health issues. Pacemakers may be affected by various equipments in our daily life, varying from hospital equipments to security devices. Hospital procedures like electrocautery, cardioversion, defibrillation, magnetic resonance imaging, lithotripsy, radiofrequency ablation, diathermy etc., may interfere with the normal pacemaker function. Similarly other electromagnetic equipments like cell phones, digital media players (MP3, ipod etc.,) security devices, anti - theft devices, conduction heaters, microwave ovens, welding equipments may also interfere with the pacemaker. Complete avoidance of these equipments may not be practical for most of the patients with pacemaker and this may significantly affect the quality of life too. Hence, patients with these devices should be advised to employ certain recommended changes so that they can enjoy the full benefits of the pacemaker.

It is important that the clinician taking care of a patient with implanted device be aware of these resources and to provide appropriate education and protection to the patient. In this chapter, we will discuss about the various interferences with the pacemakers in day to day activities of the patients and the methods to tackle them.

2. Electro Magnetic Interference

There are three essential elements to any electromagnetic compatibility problem. There must be an electromagnetic source, a receptor (in our case the implanted cardiac device) that cannot function properly due to the electromagnetic phenomenon, and an environment between them that allows the source to interfere with the receptor. Each of these three elements must be present, although they may not be readily identified in every situation. Identifying at least two of these elements and eliminating (or attenuating) one of them generally solves electromagnetic compatibility problems.

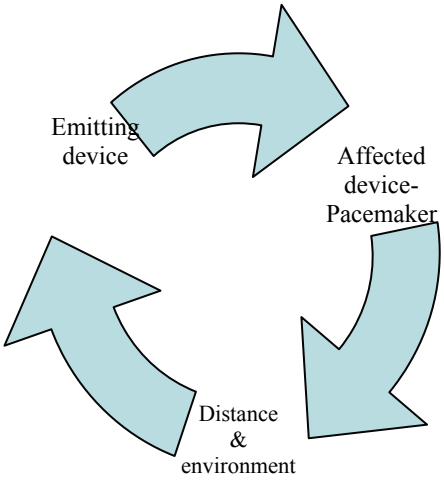

Fig. 1. Essentials of EMI.

The factors affecting EMI can be broadly classified into properties of the emitting device (i.e., frequency, which is inversely proportional to wavelength, and power of emissions); the physical relationship between the devices (i.e., distance); and the susceptibility of the affected device (i.e., electromagnetic shielding).

a. Emitting device

The frequency of electromagnetic radiation plays a role in relation to the length of various electric components in the susceptible device. These act as antennae to receive interfering signals. Long wavelengths (low frequencies) transfer minimal energy to small electronic components, and very short wavelengths (extremely high frequencies) are easily shielded. Frequencies between 10 kHz and 1 GHz are generally the most problematic. The amplitude (or power) influences the effect that the EMI has on the susceptible device. Handheld radios transmit at a constant power output of 2 to 5 W. Early analog cellular phones functioned at high power output levels, but more recent digital cellular phones can vary in their power output levels during use and function at less-problematic higher frequencies. The lowest power output occurs during standby operation, with variable power when the cellular phone is in use and maximal power when it is ringing (Shaw et al., 2004). Power output may be as low as 60 mW, with peaks to about 2 W, averaging 600 mW. Within hospitals, shielding from the base station may force cellular devices to operate at higher power. New cellular technologies introduce new variables that may affect EMI. Wireless local area

networks (802.11) and Bluetooth function at a higher frequency and lower power as compared with cellular devices and are far less likely to produce EMI.

b. Affected device

Electromagnetic compatibility (EMC) refers to the ability of electronic devices of different types to operate in an electromagnetic environment without loss of intended function. The EMC of the affected device affects the degree of malfunction that may occur. Newer devices are designed according to more stringent standards, with attention to shielding and electromagnetic immunity, and are less susceptible to EMI. Equipment manufactured before 1993 are more susceptible to EMI as compared with more modern equipment, which are now subject to International Electrotechnical Commission Standard 60601-1-2. Even more higher standards are required for critical and life-support devices.

c. Distance and environment

For electromagnetic fields, the energy level falls rapidly as the distance from the source increases (proportional to the square of the distance). Clinically relevant EMI is very uncommon at distances greater than 1 m (Lawrentschuk, N 2004). Building structures and many other environmental factors may influence the degree of EMI. Electromagnetic radiation from multiple sources in a dense hospital environment may aggregate and produce more pronounced effects than anticipated. Although many factors affecting EMI are difficult to predict, the reduction in field strength with distance is generally predictable. According to Faraday's Law (Figure 2), the induced voltage is proportional to the induction area. Two important management variables are distance of the device from the EMI source and the duration of exposure. The intensity of an electric or magnetic field decreases with the square of the distance. Thus, if a patient doubles the distance from the source, he or she is exposed to only one fourth of the original field.

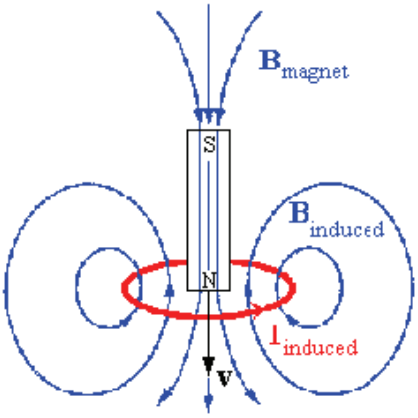

Fig. 2. Faraday's Law

EMI occurs when EM waves emitted by one electronic source or device impede the normal function of another electronic device. EM fields have both an electric field measured in volts per meter and a magnetic field measured in amperes per meter. Their sources can be broadly divided into radiofrequency waves with frequencies from 0.1 Hz to 100 MHz (eg, electric power, radio and television transmitter, electrocautery) and microwaves from 100 MHz to 12 GHz (eg, radar transmitters, cellular telephones, microwave ovens). EMI can be

galvanic, which requires direct contact with electrical current (eg, cautery), EM not requiring direct contact with the source (arc welding), or magnetic, that occurs from close contact with a strong magnetic field. eg, magnetic resonance imaging (MRI).

EMI signals in the 10 to 60 Hz frequency range can effect cardiac devices because they overlap the cardiac signal range. The amplitude and frequency of muscle potentials overlap the same range as the cardiac signals. Hence, oversensing of myopotential signals is common in unipolar sensing systems. (Figure 3). Myopotential signals commonly reach the 2 to 4 mV amplitude range. Bandpass filters permit only selected frequencies to pass through the sensing circuit. The typical ranges for P-waves are 20 to 40 Hz, R-waves 18 to 50 Hz, and T-waves 0 to 10 Hz (Figure 3)

Mechanical and electrical shielding designed into pacemakers and implantable cardioverter-defibrillators (ICDs), has, in most cases, enabled these medical devices to be immune to external electromagnetic interference (EMI) allowing the vast majority of patients to live their lives without the fear of EM device interactions. These device features include titanium casing, signal filtering, interference rejection circuits, feed through capacitors, noise reversion function, and programmable parameters. Bipolar leads sense less conducted and radiated interference because the electrode distance and the antenna are smaller than that of unipolar leads.

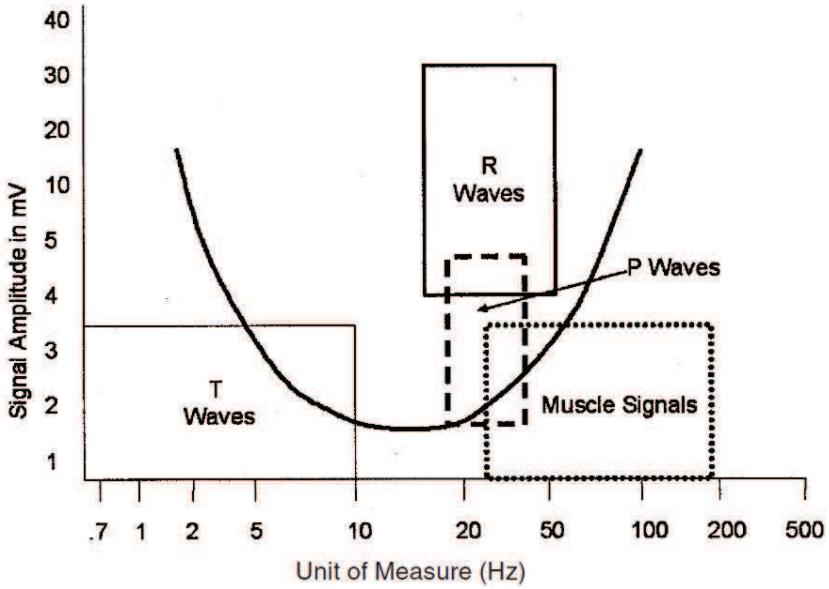

Fig. 3. Adapted from Sweesy MW et al. 2004

3. Factors influencing the response of the device

The programmed settings of the device (like sensitivity settings, polarity, mode, and refractory and blanking periods) can influence the response of the pacemaker to EMI. The more sensitive the setting, the more prone the device is to oversense the noncardiac signals. For example, an implantable cardioverter-defibrillator (ICD) and the atrial channel are most

susceptible to EMI because they usually are set at highly sensitive settings. A left-sided unipolar system is more susceptible to EMI due to a larger loop for voltage induction between the lead and pulse generator.

Rarely, a device may receive permanent damage from high-output energy (i.e., Radiofrequency ablation, external defibrillation, or high-dose radiation therapy). The type of interaction depends on the frequency, field strength of the EMI, channel (Atrial {A} or Ventricular {V}) and portion of the timing cycle in which the signal is detected. The most commonly encountered response is oversensing. In a DDD (Table 1) pacing system, oversensing of EMI noise on the atrial channel will result in ventricular-triggered pacing, most often at or near the programmed upper tracking rate. In the DDD mode, anything sensed on the atrial channel will be interpreted as a P wave, and a sensed A-V delay will be initiated.

Position I (chamber(s) paced)	Position II (chamber(s) sensed)	Position III (response to sensing)	Position IV (rate modulation)	Position V (multisite pacing)
O - None	O = None	O = None	O = None	O = None
A = Atrium	A = Atrium	T = Triggered	R = Rate modulation	A = Atrium
V = Ventricle	V = Ventricle	I = Inhibited		V = Ventricle
D = Dual (A + V)	D = Dual (A + V)	D = Dual (T + I)		D = Dual (A + V)
S* = Single (A or V)	S* = Single (A or V)			

NASPE/BPEG = North American Society of Pacing and Electrophysiology and British Pacing and Electrophysiology Group.
*Manufacturers' designation only.

Table 1. Describing the nomenclature of the Pacemaker Modes

The A-V delay clock will time-out and the ventricle will be paced because no intrinsic conduction will have actually been initiated. Oversensing of EMI on the ventricular channel will be interpreted as an intrinsic R-wave and result in ventricular inhibition whether the device is operating in the DDD or VVI mode. Noise reversion will occur if the EMI is detected during the relative refractory period, or the noise sampling portion of the ventricular refractory period. Most devices will pace asynchronously at the programmed base rate when operating in the noise reversion mode. Back-up mode or power on reset pacing is automatically activated when the pacing system is subject to high energy EMI such as electrocautery or defibrillation. The back-up behavior is typically the same as the device's elective replacement behavior (ERI). The circuitry of cardiac devices implements a zener diode, which shunts energy away from the pacemaker circuitry. On occasion, this diode can be overwhelmed by electrical interference, resulting in permanent device damage. Although rare, it may be possible to induce rapid pacing when a device detects radiofrequency signals and amplifies that output, resulting in capture at rapid rates. This rapid pacing has been reported with magnetic resonance imaging and is potentially lethal whether or not the patient is pacemaker dependent. Various factors influencing EMI are described in Table 2.

One of the important features made by the manufacturers made over the past few decades to reduce the EMI is the change in lead polarity. In a unipolar system, the tip of the electrode acts as the negatively charged, current emitting cathode. The surface of the pulse generator

Factors influencing EMI
Controllable factors
1. Programmed parameters
Sensitivity settings
Sensing polarity
Pacing mode
Refractory periods
Blanking periods
Committed crosstalk detection window
Sensor settings
2. Distance and position of the patient
3. Duration of the exposure
Less Controllable Factors
1. Intensity of the EMI field
2. Nonprogrammable device characteristics and settings
3. Frequency of the signals
4. Zener diode
5. Lead configuration
6. Access codes, parity links, and reed switch closure

Table 2. Factors influencing EMI.

acts as the positively charged anode, to which electrons flow to complete the circuit. The case of the pulse generator must maintain contact with tissue and be at least partially uninsulated or else pacing cannot occur. This concept is important to consider during pulse generator implant or replacement. In these situations, pacing will not occur where the lead may be connected but the pulse generator may not be in contact in contact with the patient's skin or subcutaneous tissue. A bipolar lead places both electrodes within the heart, where the cathode is at the tip of the lead. The anode is a ring electrode that is located about 1–2 cm proximal to the tip. Bipolar leads are slightly thicker and may draw slightly more current than unipolar leads. Nevertheless, they offer a number of advantages including fewer incidences of EMI and are more commonly used in the United States. Because the electrodes in a bipolar system are close to each other and within the heart, there is less likelihood of extraneous signals being sensed as a cardiac event. This reduces the incidence of inappropriate pacemaker inhibition due to sensing of skeletal myopotentials. Bipolar sensing effectively has eliminated myopotential inhibition and crosstalk as pacemaker problems. Astridge PS et al., (1996) had shown that with bipolar sensing, there is considerably less sensing of external electric fields and less effect from electrocautery during surgery.

4. Pacemaker responses to EMI

4.1 Pacing Inhibition

This function normally allows the sensing of the electrical potential that is given off by the heart when it contracts. Sensing of the heart contractions causes the pacemaker to withhold the electrical stimulus (inhibit/standby). This response is limited to a heart rate range up to approximately 300 pulses per minute or 5 Hertz (Pinski et al. 2002). Radiated magnetic fields or conducted currents that are detected by the pacemaker in this rate range also cause the

output of the pacemaker to erroneously withhold the electrical stimulus (inhibit/standby). Pacemaker will withhold pacing pulses, if electrical potentials are detected within the heart rate range. Sustained pacing inhibition is potentially catastrophic in pacemaker dependent patients. Depending on the duration of inhibition and emergence of escape rhythms, lightheadedness, syncope, or death could result. Prolonged inhibition is uncommon because of the protective algorithms available in pacemakers. The majority of patients currently undergoing pacemaker implantation are not completely dependent on pacemaker.

4.2 Triggering of rapid or premature pacing

Very strong electromagnetic fields could induce voltage in the lead(s) that may directly capture the myocardium. For example, 58-kHz acoustomagnetic Electronic article surveillance systems are capable of inducing 3.7 V in pacemaker leads leading to isolated premature paced beats (but no sustained rapid pacing) as observed by McIvor et al., (1998). Oversensing of EMI by the atrial channel of a pacemaker programmed to a tracking mode (DDD, VDD) can trigger ventricular pacing at or near the upper tracking rate limit. Alternatively, automatic mode switching may occur if this function is enabled. In some pacemakers, detection of noise in the atrial channel can trigger a noise reversion mode. Preferential detection of EMI is not uncommon because atrial sensitivity is usually programmed higher (more sensitive) than ventricular sensitivity. It is possible to observe rapid pacing due to atrial oversensing as the patient approaches an electromagnetic field, followed by a period of ventricular oversensing (inhibition or mode reversion) as the field becomes stronger. Patients who experience this problem are typically symptomatic and complain of rapid palpitations. If sustained, inappropriate pacemaker acceleration induced by atrial oversensing may cause palpitation, hypotension, or angina. Very rapid pacing could induce ventricular fibrillation.

4.3 Noise reversion mode

Pacemakers incorporate protective algorithms against prolonged inhibition from spurious signals. A common response is transient reversion to *asynchronous pacing*. These algorithms are based on the fact that rapid frequencies are unlikely to represent myocardial activation. In most pacemakers, a noise sampling or noise interrogation window (also known as relative refractory period) occupies the second part of the ventricular refractory period. Pacemakers do not respond to signals during the initial portion of the ventricular refractory period (i.e., ventricular blanking), which is usually nonprogrammable and fixed or adjusted automatically by the generator based on the strength and duration of the ventricular event. Signals recognized during the noise sampling window cannot reset the lower rate timer (therefore preventing inhibition), but can affect other timing intervals, most importantly, the ventricular refractory period. The pacemaker has a safety feature that identifies/classifies strong continuous radiated electromagnetic fields or conducted currents that occur outside of the cardiac rate range (i.e. > or = 300 Pulses per minute or 5 Hertz. Once a field or current is identified / classified, this safety feature allows a pacemaker to deliver pacing stimuli to the heart when sensing strong continuous radiated electromagnetic fields or conducted currents. Pacemaker reversion minimizes the types of continuous electromagnetic fields or conducted currents that can cause the pacemaker to be inhibited. Pacemaker will continuously pace the heart at the programmed low rate of the pacemaker in the presence of a strong continuous alternating magnetic field.

4.4 Electric (Power–On) reset

Momentary strong EMI, by inducing very high voltage within device circuits, or triggering special microprocessor timers, may cause reset of DDD and VVIR pacemakers to the VVI or VOO mode, a condition called power-on or electric reset. Electrosurgery and external or internal defibrillation are the most common causes of the reset phenomenon. In the reset mode, the pulse generator functions only with basic factory preset instructions (pacing mode and parameters) stored in the nonvolatile read-only memory, as communication between the random access memory (containing the programmable settings) and the microprocessor has been interrupted. In some pacemakers, the pacing mode and rate are similar during electrical reset and elective replacement indicator. In devices with different replacement and reset parameters, strong EMI may activate either one. In some pacemakers, two levels of electrical reset (partial and full) exist. Partial reset tends to occur with less intense interference, generally preserving the programmed pacing mode and rates. In some pulse generators, there will be no response to magnet application in the reset mode. The reset mode does not revert back when EMI is discontinued. A DDD(R) device reset to the VOO or VVI mode might cause hypotension, particularly in patients with pacemaker syndrome. Resolution of the problem requires a specific programmer command. Electric reset can be differentiated from battery depletion by telemetry of battery voltage and impedance. When reset is due to EMI, the battery voltage should be normal (approximately 2.8 V) and battery impedance normal or slightly rose according to battery age.

4.5 Damage to the generator or to the electrode-myocardial interface

In the overwhelming majority of cases, the effects of EMI are temporary, lasting only as long as the device is within range of the source. However, strong EMI (e.g., electrosurgery and external defibrillation) can cause permanent damage to an implanted device. Circuitry damage, (resulting in output failure, pacemaker runaway, and other malfunctions) can occur, requiring generator replacement (at times emergent). Increases in pacing thresholds secondary to local heat related injury at the myocardium lead interface are also possible.

4.6 Pacemaker magnet response

In the past, patients with a pacemaker in whom EMI was likely were frequently managed by placing a magnet over their device to produce asynchronous pacing. As device technology has expanded, it has become less clear how each individual device will respond to a magnet, and there appears to be no universal effect, even between two otherwise identical devices (Table 5). The response will depend largely on how the device has been programmed. For many pacemakers, the presence of a magnet will indeed induce continuous asynchronous pacing. For others, however, a very short period of asynchronous pacing might occur or there may be no effect at all. A static magnetic field of 10 Gauss or more will cause the pacemaker to deliver a continuous sequence of stimuli at 85 beats per minute for current pacemaker or other normal low rates specific to the older model pacemakers. Pacemaker will continuously pace the heart at the magnet rate (85 bpm for current pacemakers) while in the presence of a strong static magnetic field associated with either a permanent magnet or an electro-magnet. With the ICD, approximately 99% of them are programmed to have their anti-tachycardia function disabled in the presence of a magnet without affecting their bradycardia pacing. In the event of a magnet ever being applied to an implantable device, its function and programming should be checked at the earliest opportunity.

5. Sources of EMI:

Most of the common home and workplace items that can generate EMI typically do not interfere with normal operation of implantable medical devices.
Common electromagnetic sources are described in Table 3.

Electromagnetic fields
Daily life: 1. Cellular telephones 2. Electronic article surveillance devices 3. Metal detectors 4. Some home appliances (e.g., electric razor, toy remote controls)
Work and industrial environment: 1. High voltage power lines 2. Transformers 3. Welders 4. Electric motors
Medical environment: 1. Magnetic resonance image scanners 2. Electrosurgery 3. Defibrillation 4. Neurostimulators 5. TENS units 6. Therapeutic diathermy 7. Ionizing radiation 8. Radiotherapy 9. Lithotripsy

Table 3. Sources of EMI

6. EMI in daily life:

6.1 Household related exposures

6.1.1 Portable headphones

Portable headphones such as those used with portable digital music players (MP3 players) like iPods, generate powerful magnetic fields that have the potential to cause clinically relevant magnetic interference in pacemaker patients. Placement of portable headphones in a front shirt pocket in close proximity to a patient's pacemaker could temporarily deactivate the device and inhibit the delivery of a required therapy. Because magnetic field strength falls off quickly with distance, keeping the portable headphones even a short distance from the chest wall can effectively eliminate the potential for magnetic interference. Lee et al., (2009) noted that clinically significant magnetic interference can occur when portable headphones are placed in close proximity to implanted pacemakers (in 30% of study group). Patients are advised to keep portable the headphones at least 3 cm from their device.

Item	Low risk	Pacemaker Reversion	Pacemaker Inhibition	Remarks
Bingo Wand	X	X		Maintain 15cm distance
Casino slot machines	X			Low risk
Electric Guitars	X	X		Maintain 15cm distance
Electric Speakers	X	X		Maintain 15cm distance
Electric Toy Trains	X	X		Maintain 15cm distance
Electric Golf Cart	X	X		Maintain 15cm distance
Laser Tag	X	X		Maintain 15cm distance
Radio Controlled Model cars, Airplanes, Boats etc.,	X	X	X	Maintain 15cm distance
Rifle / Shot Guns	X			Low risk
Tatoo Machine	X	X		Maintain 15cm distance

Table 4. Electromagnetic Compatibility of devices involved in Hobbies

6.1.2 Cellular telephones and other wireless devices

Interference between pacemaker and cellular telephones were addressed by Hayes et al., (1997) They have investigated 980 device patients and 5533 cell phone exposures and found that interactions were highly variable by phone type, pacemaker manufacturer, and pacemaker model. Most interference was oversensing and occurred when the phone was placed directly over the implanted device. Modern digital cell phones generate strong, amplitude modulated fields with pulse repetition rates near the physiologic sensing range. Device manufacturers are advising to maintain a 10-15cm distance between the antenna of the cell phone and the implanted device. If using powerful cell phone, which is using greater than 3 watts, it is advisable to maintain a 30cm distance from the device.

Recently, third-generation mobile phones, UMTS (Universal Mobile Telecommunication System), were introduced in Europe. Ismail et al., 2010 conducted a study which included 100 patients, 23 with single-chamber and 77 with dual-chamber pacemakers. Two UMTS cellular phones (T-Mobile, Vodafone) were tested in the standby, dialing, and operating mode in this cohort of patients. Regardless of atrial and ventricular sensitivity settings, both UMTS mobile phones (Nokia 6650 and Motorola A835) did not show any interference with all tested pacemakers. In addition, both cellular phones did not interfere with the marker channels and the intracardiac ECGs of the pacemakers. Ismail et al. concluded that third-generation mobile phones are safe for patients with pacemaker. This is due to the high frequency band for this system (1,800–2,200 MHz) and the low power output between 0.01 and 0.25 W.

6.1.3 Hearing aids

Cochlear implant type of hearing aids is with low risk of having EMI with the pacemakers. Hearing Aids with transmitting necklace loops coupled into the ear piece Telcoil (T-coil) of the hearing aid emit magnetic fields. The transmitting antenna associated with this type of hearing aid system is incorporated into the necklace loop. This antenna radiates a magnetic field that is coupled into the T-coil in the earpiece of the hearing aid. Maintain a 6" (15cm) distance between the pacemaker and the portion of the hearing aid necklace radiating the magnetic field. If the transmitting antenna is closer than the noted distance, there is a potential for pacemaker reversion or inhibition. Individuals may want to reposition the loop so that it is located on the opposite shoulder from the implant site or look for an alternate transmitting antenna system that can also be worn in such a way to maintain the recommended distance of greater than 6" (15cm).

6.2 Work / environment related exposures

6.2.1 Electric shock

EMI from electric power can occur if patients come in proximity to high voltage overhead power lines (accidentally or by occupation) or it may be caused by electrical appliances held close or in direct contact with the chest. Implanted devices are susceptible to interference signals of 50–60 Hz, frequencies that lie within the bandwidth sampled for detection of intracardiac signals. A momentary shock from an electrical outlet (110 / 220 volts) or higher voltages, if in a commercial or industrial setting, will cause pacemaker inhibition or inhibition of the pacemaker portion of the ICD. A memorable momentary shock may cause some of the parameters of the pacemaker or ICD to be reset to nominal values. If any parameter changed, the physician can restore the original parameters in the office. Permanent damage to the pacemaker or ICD is unlikely to occur unless the shock is very severe. Prolonged external shocks greater than 2 seconds can cause reversion in the pacemaker. Prolonged external shocks greater than 8 seconds can cause inhibition in the pacemaker portion of the ICD and/or a shock therapy. As with momentary shocks, there is a low risk of permanent damage to the pacemaker or ICD from prolonged shocks associated with a 110 / 220 volt source. Bipolar sensing protects from EMI in all but the most extreme environmental conditions, like power generating stations, while with unipolar sensing inappropriate pacemaker behavior can occur during routine daily exposures. EMI from household appliances is more likely with improper grounding.

6.2.2 Magnets and pacemakers

Magnet responses vary widely among manufacturers and even among various models of a single manufacturer (Table 5). For example, magnet application in single-chamber systems may result in asynchronous pacing at the standard rate or the programmed rate, ventricular demand pacing at a fast rate, or ventricular triggered pacing. Magnet application in dual-chamber systems may result in dual-chamber asynchronous pacing at the programmed rate or at a standard rate, or at the programmed rate plus a fixed percent increment; or it may even result in asynchronous single-chamber ventricular pacing at a standard rate. Elective replacement indicators in some models may be elicited only in the magnet mode. In such instances, routine magnet application may be especially important for determining the need for replacement of a depleting pacer generator. The application of a magnet over the generator is rarely associated with adverse effects. On occasion ventricular ectopy may result from asynchronous ventricular pacing, but this is seldom sustained. Caution is

warranted if the patient has both a pacer and an implantable cardioverter-defibrillator; some implanted defibrillators may have tachycardia therapy inactivated by prolonged magnet exposure. Because most devices respond to magnet application by asynchronous pacing, magnets may also be employed, both diagnostically and therapeutically, in cases where potential pacer malfunction is attributed to sensing problems. Magnet application can be therapeutic to terminate pacemaker mediated tachycardia or to restore pacing in cases of oversensing. In cases of pacemaker dependence, rapid magnet conversion to asynchronous pacing may be critical in preventing asystole due to oversensing or crosstalk inhibition (particularly if the appropriate pacemaker programmer is unavailable). In some contemporary pacemakers, however, magnet application may trigger specialized pacemaker functions such as threshold search or electrogram storage rather than asynchronous pacing.

Possible Responses to Magnet Application
1. Asynchronous pacing
2. Triggered Mode
3. Rate Change 4. Programmed rate 5. Faster rate than programmed
6. Threshold determination - Fixed percentage amplitude reduction over first few paced complexes
7. Trigger Electrogram storage
8. No change in pacer function - Programmable magnet response

Table 5. Responses to Magnet application

6.2.3 Electronic Article Surveillance Devices (EAS)

These are the scanners located on the the counter used to identify the items to be purchased and deactivate the anti-theft tags at checkout counters in stores. The transmitter in these devices emits an electromagnetic field designed to interact with a "tag" in a store item. As a result of the interaction, the tag emits back a signal that is then detected by the receiver. Customers are exposed to an electromagnetic field as they walk through the gate that consists of a pair of transmitter and receiver pedestals. EAS systems differ greatly in the frequency and strength of emitted fields. Electromagnetic fields from these devices have the potential to induce interference signals in the sensing circuit of implanted cardiac devices. McIvor et al. studied the effects of six EAS systems in 50 patients with pacemakers from seven different manufacturers. One exposure protocol mimicked the most common real-life situation, walking at a normal pace midway between the gates. A "worst-case scenario" protocol required the patients to lean against the transmitter gate with the body parallel and then perpendicular to the transmitter.

Interactions occurred with 48 pacemakers, almost exclusively with acoustomagnetic systems. No pacemaker reacted to the swept radiofrequency systems. Only two patients presented transient asynchronous pacing while exposed to an electromagnetic system. The frequency of interactions with the acoustomagnetic system increased with the duration and closeness of the exposure. It was 16% when walking through the gates and 96% when leaning against the pedestal. Transient asynchronous pacing was the most common response, followed by atrial oversensing with tracking, ventricular oversensing with inhibition, and "voltage-induced" paced beats.

Item	Low risk	Pacemaker Reversion	Pacemaker Inhibition	Remarks
Ab Stimulator			X	Not recommended to use
Badge with electronic circuit	X	X		Maintain 15cms from the wall unit
Bagde with magnetic clasp	X	X		Maintain 15cm distance
Body fat scale (Electronic)		X	X	Not recommended
Electric Blanket	X			Low Risk
Electric Fences	X		X	Momentary shock may change the settings
Elecric Tooth brush	X	X	X	Maintain 15cm distance
Electric grocery cart / personal sccoters	X	X		Maintain 15cm distance
Electric Shocks	X	X	X	A momentary shock will cause PM inhibition
Hair Dryer	X	X		Maintain 15cm distance
Home security System	X			Low risk
Home security system – Microwave	X	X		Maintain 15cm distance
Hot tub	X			Low Risk
Induction Stove Top	X	X		Maintain 60cm distance
Ionized air filter	X	X		Maintain 15cm distance
Magnetic back brace	X	X		Maintain 15cm distance
Massage Chair	X			Low Risk
Massager – handheld	X	X		Maintain 15cm distance
Medical alert Necklace / bacelet	X			Low risk
Microwave ovens	X			Low risk
Motor Cycle	X	X	X	Maintain 30cms distance from the ignition system
Pest control – Ultrasonic only	X	X		Maintain 15cm distance
Pest control – radiofrequency	X	X		Maintain 15cm distance
Sewing Machines	X	X		Maintain 15cm distance
Shaver with electrical cord	X	X		Maintain 15cm distance
Speakers	X	X		Maintain 15cm distance
TV Audio Headset	X	X		Maintain 15cm distance
TV Remote Infrared	X			Low risk

Table 6. Electromagnetic Compatibility of devices involved in daily Home Use.

Available evidence suggests that although severe interactions between EAS systems and implanted cardiac devices can occur, they are unlikely when patients walk through the gates at a normal pace. However, interactions are likely with prolonged, close exposure to acoustomagnetic or electromagnetic systems. Prolonged exposure may result in pacemaker reversion or inhibition. When scanning wands with deactivators are used, patients are advised to maintain a 60 cm distance between the wand and the implanted device.

6.2.4 House arrest anklets and bracelets:

House arrest anklets, worn by the individual, emit low level radio frequency signals at specific time intervals. These radio frequency signals are detected by a receiving unit connected to the telephone. The telephone periodically communicates with a central monitoring facility. As it is associated with low power transmission, the risk of affecting the pacemaker is very low. Patients with pacemaker should maintain a 6" (15cm) distance between pacemaker and the bracelet. If the device is closer than 6" (15cm), then, there can be a potential for pacemaker reversion or inhibition. The response is specific to the time interval and duration of the radio frequency transmission of the bracelet.

6.2.5 Metal detectors:

Metal Detectors or magnetometers are used in airports, government buildings and some schools. Metal detector archways or hand held wands in compliance with federal regulations are unlikely to affect Pacemaker. Walk through the archway metal detector is also considered as a low risk. If the archway detects metal in the device, patients should request a hand search. If hand held metal detector wand is to be used, patients should request that the wand not be placed directly over the device. If the security personnel insist on using the wand over the pacemaker, patients should be advised to request that the exposure of pacemaker to the magnetic field of the wand be limited to 1- 2 seconds every 10 seconds. X-ray radiation is also used in some airports for security check. Conpass-X-1280® is an X-ray body scanner that provides the detection of all dangerous objects within 10 seconds. (Detects metal & non metal weapons, explosives, dangerous liquids, diamonds, gold and illicit drugs (including swallowed). The amount of radiation used is lesser than the one used in diagnostic radiation. Other companies with similar systems are American Science & Engineering, Inc. & Rapiscan's Secure 1000®. These detection systems do not utilize an alternating magnetic field to detect metal as does the archway and wand metal detectors. Millimeter Wave Imaging Scanners are used in airports, courthouses and jails. They are otherwise called as 3D scanner, whole body imaging, or RF / Microwave scanner. These devices can emit a low magnetic radiation. Patients should keep their implanted heart device 6"(15cm) away from the walls of the scanner. If closer than 6"(15cm), there are chances for pacemaker reversion.

6.3 Hospital environment

Although patients with pacemakers usually spend less time in the hospital than in the outside environment, the hospital, ironically, is where the majority of patient encounters with EMI occur. Some interference sources, such as magnetic resonance imaging (MRI) and

electrocautery devices, are encountered more frequently, whereas others, such as transcutaneous electrical nerve stimulation (TENS) units and dental equipment, although encountered frequently, are not routinely recognized as sources of electromagnetic radiation.

6.3.1 Direct Current Cardioversion (CV) and defibrillation in patients with pacemaker:

The use of CV in patients with implanted devices has long been a cause for concern with regard to the potential for adverse effects on the generator and/or leads, with the result that this simple and effective therapy may have been delayed or even denied to some patients. These concerns were largely fuelled by a number of reports in the 1970s and 1980s suggesting the potential for device interference or lead failure. Devices implanted within the last decade, however, are considerably more sophisticated, more likely to use bipolar lead configurations, and better protected against external interference than those of the period from which these reports arose, leaving the question of safety in patients with modern implantable devices open. In addition, CV has evolved over recent years with the development of equipment able to deliver biphasic shocks resulting in an increased efficacy and lower energy requirements. Manegold et al., 2007 studied 29 patients with pacemaker undergoing elective external cardioversion for atrial fibrillation, using an anterior–posterior shock electrode orientation with a distance to the implanted device ≥ 8 cm. He noted that there is reduction of the pacing impedance immediately after the cardioversion. However there was no device or lead dysfunction noted in any of those patients. Waller et al., recommended that the defibrillator paddles be placed ≥15cm from the pulse generator and be oriented in an anterior–lateral, anterior–posterior or left pectoral–right hypochondrial (for right sided generators) positions in order to place the electric field perpendicular and not parallel to the course of the leads. Some manufacturers recommend use of VOO or AOO modes during cardioversion in order to switch off the amplifier. Additionally, the time between two successive shocks ought to be about ≥ 5 min in order to allow cooling of the diodes. After defibrillation, the pacemaker should be interrogated and the program confirmed. Expected pacing threshold rise should be managed by increasing the output and any change in sensing threshold should similarly be corrected by reprogramming.

6.3.2 Electro Convulsion Therapy (ECT):

ECT is used to treat depression, anxiety and other mental disorders. ECT usually delivers measured electrical stimuli over a brief period of time (1-2 seconds). These briefly applied electrical stimuli induce a seizure that may last for several minutes. As a result the pacemaker may respond by either pausing (inhibiting) or delivering 1-2 pacemaker stimuli. The pacemaker portion of the ICD will be inhibited for as long as the current is present (1-2 beats). If ECT is used for longer than 8 seconds, there may be a potential for pacemaker reversion. The activity detected during the seizure period may affect the rate response circuit. If the rate response circuit is programmed "on", there is the potential to elevate the rate of the pacemaker portion of the ICD or the pacemaker rate. It is recommended that individuals considering this procedure consult the cardiologist to evaluate any possible risks associated with these responses in conjunction with their medical condition.

6.3.3 Electrocautery

Electrocautery is used in surgeries to cut tissue and stop the bleeding of blood vessels. Several electrosurgical techniques can generate EMI. During electrosurgery in monopolar modes, the electric current spreads out and penetrates the entire body of the patient. This stray current may be interpreted by an implanted device as an intracardiac signal. Casavant D et al., 1998, described that pacing inhibition, pacing triggering, automatic mode switching, noise reversion or spurious tachyarrhythmia detection can occur, depending on the type of device, the programmed settings, the duration of EMI, and the channel in which the current is oversensed. It is recommended to apply the magnet over the pacemaker during the surgical procedure. When cautery performed less than 6" (15cm) or grounding electrode is placed less than 6"(15cm) from device, damage can occur and/or the output of the device can be affected even when the magnet is applied. Damage may occur to the tissue at the lead tissue interface. Currents induced into the lead system may initiate an arrhythmia. Magnet application in the pacemaker causes the pacemaker to deliver a sequence of stimuli at a normal low rate (usually 85 bpm magnet rate). If magnet is not placed over the pacemaker, application of electrosurgery should be limited to 1-2 seconds every 10 seconds. If these timing intervals are restrictive, reprogramming of the pacemaker should be considered, especially for individuals that are dependent on the pacemaker.

6.3.4 Extracorporeal Shock Wave Lithotripsy

Extracorporeal shock wave lithotripsy (ESWL) is a noninvasive technique that uses electrohydraulic waves to disintegrate renal calculi. An underwater electrical spark causes rapid expansion of water vapor, which generates an electrohydraulic wave directed toward a semielliptical housing that diverts the wave toward a focal point in the bath. The patient is positioned in the bath so that the renal calculi are at the focal point. Potential causes of pacemaker dysfunction inherent in the use of this technique include EMI and mechanical disruption of the pulse generator and its casing. In vivo and in vitro studies have evaluated the extent of EMI and the mechanical disruption of pacemakers, when the pacemakers were placed at various distances from the electrohydraulic wave source. The extracorporeal shock wave is capable of producing extrasystoles and therefore is delivered a few milliseconds after the R-wave. The extracorporeal shock wave is delivered after the atrial spike in patients with dual-chamber pacemakers who are atrially paced. The number of chambers paced and/or sensed and the pacemaker settings largely influence the effect that ESWL has on pacemakers. ESWL, triggered synchronously after the ventricular pacing spike, exhibited no interference on single chamber pacemaker function. Rate-responsive pacemakers increased their pacing rate to the upper pacing limit when exposed to synchronous ESWL. Dual-chamber pacemakers programmed to DDD settings exhibited inhibition because they oversensed the electromagnetic ESWL wave. Reprogramming the pacemaker to VVI or VOO mode resulted in normal pacemaker function. Piezoelectric crystals in rate responsive pacemakers may shatter, when placed at the electrohydraulic wave focal point but remain intact when placed 5 centimeters from the focal point. Patients with a rate-responsive pacemaker that contains piezoelectric crystals should not undergo ESWL if the device is implanted in the abdomen, but this procedure may safely be performed in such a patient if the device is located in the thorax. Careful pacemaker follow-up monitoring should continue for at least several months after the procedure to ensure that no damage was sustained to the reed switch. In addition to continuous electrocardiographic monitoring, the

following guidelines should be followed in treating patients with pacemakers who have ESWL (Cooper et al., 1988):

1. Single-chamber pacemakers generally do not require sensing and/or pacing changes.
2. Reprogram dual-chamber devices to VVI mode.
3. The piezoelectric activity-sensing, rate-responsive, and single-chamber function should be turned off.

6.3.5 Radiofrequency catheter ablation

Radiofrequency catheter ablation is first-line therapy for a variety of supraventricular and ventricular arrhythmias. The interaction between radiofrequency current and implantable devices has been studied most thoroughly during palliative ablation of the atrioventricular junction for drug-refractory atrial fibrillation. Patients with atrial fibrillation often receive pacemakers for associated spontaneous (i.e., bradycardia-tachycardia syndrome) or drug-induced bradycardia. Radiofrequency current (delivered as an unmodulated sine wave at 500 to 1000 kHz) is an intense source of pulsed interference that interacts unpredictably with permanent pacemakers. Energy delivery may result in asynchronous pacing, rapid tracking, electric reset, and premature triggering of the elective replacement indicator. It is impossible to predict (with the exception of some device-specific effects) the type of interaction that will be seen. Different interactions may be seen (in the same patient) during consecutive energy applications. Most of the interactions are transient and terminate with cessation of energy delivery.

Chang et al (1994) studied 19 pulse generators implanted in 12 dogs. They found that interactions depended on proximity of current application to the pacing leads. Interactions were frequent at 1 cm and absent at greater than 4 cm. The most dangerous interaction was *runaway* pacing with possible induction of ventricular fibrillation. Ellenbogen et al reported on the acute effects of radiofrequency ablation on pacemakers in 35 patients. They observed normal function in 14 patients. The most common interaction was asynchronous pacing because of noise reversion, followed by oversensing resulting in refractory period extension and *functional undersensing* of pacemaker. The clinical incidence of acute interaction between radiofrequency current application and permanent pacemakers has ranged from 7% to 100%. (Chang et al., 1994)

6.3.6 Radiotherapy

Radiotherapy can induce different responses in implanted devices. EMI produced by the radiotherapy machine can result in pacing inhibition, tracking, noise reversion, or inappropriate ICD discharges. Usually, the effects are mild and observed only while the machine is switched on or off. Interference may be more severe with betatrons or with linear accelerators that misfire and hence best avoided. Maintain a 6" (15cm) distance from electronic cabinetry associated with radiating device. If the device is closer than 6" (15cm) to the cabinetry, there may be a potential for pacemaker reversion or ICD shock. In 1991, Rodriguez and colleagues showed severe malfunctions of pacemakers and ICDs: of the 17 pacemakers exposed to photon radiation eight failed before 50 Gy, whereas four of the six pacemakers exposed to electron radiation failed before 70 Gy. Direct radiation of pacemakers or ICDs at therapeutic levels should be strictly avoided. Furthermore, pacemaker and ICDs have to be controlled in short periods during and after radiation

therapy, and pacemakers or ICDs should be exchanged after the radiotherapy when the accumulative dose on the pacemaker exceeds 5 Gy.

6.3.7 Transcutaneous Electrical Nerve Stimulation (TENS)

TENS units are external, noninvasive devices that are used for the treatment of patients with chronic pain. A TENS unit consists of electrodes placed on the skin and connected to a generator that applies 20 ms rectangular pulses of up to 60 mA at a frequency of 20–110 Hz. Although they are deceptively harmless in appearance, when used with the pacemaker-dependent patient, the patient may experience clinically significant ventricular pacing inhibition caused by EMI. Chen et al., 1990 published a case report documenting EMI from TENS devices in pacemakers. The resultant inappropriate ventricular inhibition was corrected by reprogramming the pacemaker's sensitivity setting. In situations in which substantial clinical benefit of using a TENS unit may exist, prolonged telemetry monitoring is required, and sensitivity settings may require adjustment. TENS can be used safely in patients with modern implanted bipolar pacemakers and in patients with unipolar pacemakers if sensitivity is reduced. It has been recommended that TENS electrodes not be placed parallel to the lead vector.

6.3.8 Transurethral Resection of the Prostate (TURP)

This procedure introduces electrical current into the body that may affect the implanted devices of individuals. Currents induced into the lead system may initiate an arrhythmia. If the grounding electrode is placed less than 6" (15cm) from device, damage can occur and/or the output of the device can be affected even when the magnet is applied. Magnet application in the pacemaker causes the pacemaker to deliver a sequence of stimuli at a normal low rate (usually 85 bpm magnet rate). If no magnet is present over the pacemaker, limiting the application of TURP electrosurgery to 1-2 seconds every 10 seconds may reduce the risk of symptoms in individuals who are dependent on the pacemaker. If these timing intervals are restrictive, reprogramming of the pacemaker should be done.

6.3.9 Dental devices

The modern dental office comprises a variety of electromagnetic devices that can interfere with pacemaker function. Miller et al., (1998) evaluated cardiac pacemaker function in proximity to contemporary electric dental equipment. A dual-chamber pacemaker with bipolar leads programmed to DDD mode and a single-chamber pacemaker with a unipolar lead programmed to VVI mode were set to maximum sensitivity, and then their function while in proximity to dental equipment was evaluated. Pacemaker inhibition was noted while the pacemaker was near an electrosurgical unit, the ultrasonic bath cleaner, and the ultrasonic scaler. EMI was absent with standard operations of the amalgamator, the electric pulp tester, a composite curing light, dental hand pieces and/or drills, the electric toothbrush, the dental chair and light, ultrasonic instruments, a radiography unit, and a sonic scaler. The non-pacemaker-dependent patient who has a dental procedure should not experience clinical symptoms from pacemaker inhibition. If the pacemaker-dependent patient cannot avoid interaction with interference-causing dental equipment, the patient's pacemaker should be programmed to asynchronous pacing mode before the dental procedure is initiated.

6.3.10 Medical procedures

Item	Low risk	PM Reversion	PM Inhibition	Remarks
Acupuncture - No electrical stimulus	X			Low risk
Acupuncture AC - Alternating Current	X	X	X	For use on torso - AC can cause pacemaker reversion. Lower risk of device detecting AC when used on extremities.
Acupuncture DC – Direct Current	X			Low risk
Diathermy		X		Diathermy is NOT recommended.
EEG Electroencephalography	X			Scan brain wave activity. Low risk of affecting PM
EMG Electromyography	X		X	Low risk If the stimuli are separated by more than 10 seconds. If it is necessary to apply stimuli at a rate faster than once every 10 seconds, magnet application is recommended.
Laser Surgery	X			Low risk
Lasik Eye Surgery	X			Low risk
Lie Detector Test	X			Lie detector tests introduce only direct current into the body. This direct current poses a low risk of affecting a pacemaker. If pacemaker or pacemaker portion of ICD is delivering stimuli, the heart rate variation parameters of the test may not be valid.
Magnetic therapy	X	X		Maintain a 6" (15cm) distance between all therapy magnets and an implanted device.
Mammogram	X			Low risk

Medical Helicopter	X			Low risk of affecting pacemaker. The vibration may increase pacing rate if the rate response function is programmed "on". Recommended to put patient on extra padding.
Radiation Therapy (External X-ray or Gamma knife)	X	X		Maintain a 6" (15cm) distance from electronic cabinetry associated with radiating device. **The Maximum cumulative gamma exposure levels for pacemaker is 500 rads**

Table 6. Electromagnetic Compatibility of devices involved in Medical Procedures.

6.3.11 MRI in patients with pacemaker

It has been estimated that each patient with a pacemaker or ICD has a 50% to 75% likelihood of having a clinical indication for MRI over the lifetime of their device. MRI tests have long been considered a contraindication for cardiac device patients.

In vitro analysis of modern permanent pacemakers (manufactured after 1996) revealed that maximal force acting upon devices was less than 100 g in a 1.5-T MRI scanner (Roguin A et al., 2004). This amount of force is unlikely to dislodge a chronic device that is anchored to the surrounding tissue. Pacemakers have the potential for receiving electromagnetic interference in the MRI environment, resulting in radiofrequency noise tracking, asynchronous pacing, inhibition of demand pacing, programming changes, or loss of function. The static magnetic field of the MRI scanner can alter device function by inducing unexpected reed switch opening or closure. Such potential risks have led to concerns from device manufacturers and MRI authorities regarding the performance of MRI procedures in cardiac implantable device recipients. However, several studies have assessed techniques to safely perform MRI in recipients of implanted cardiac devices.

Nazarian et al., (2009) from our institution (author UL), after a extensive research, recommended avoiding MRI in patients with less than 6 weeks' time since device implant or patients with no fixation (superior vena cava coil) leads. To reduce the risk of inappropriate inhibition of pacing due to detection of radiofrequency pulses, Nazarian et al., also recommended device programming to an asynchronous, dedicated pacing mode in pacemaker-dependent patients. To avoid inappropriate activation of pacing due to tracking of radiofrequency pulses, they suggest device programming in patients without pacemaker dependence to a nontracking ventricular or dualchamber inhibited pacing mode. In our institution, we typically deactivate tachyarrhythmia monitoring to avoid battery drainage that results from recording of multiple radiofrequency pulse sequences as arrhythmic episodes.

Potential Effects of Magnetic Resonance Imaging on Pacemakers
1. Strong Static magnetic field
Reed switch closure resulting in asynchronous pacing
2. Radiofrequency field
Alterations of pacing rate (leads detecting the RF signals and pace the heart in rapid rates)
Spurious tachyarrhythmia detection
Heating
3. Time-varying magnetic gradient field
Induction voltage (resulting in pacing)
Heating
Reed switch closure

Table 7. Effects of MRI on Pacemakers. (Pinski et al., 2002)

Finally, to reduce the risk of thermal injury and changes in lead threshold and impedance, the estimated whole-body averaged specific absorption rate of MRI sequences should be limited to <2.0 W/kg when possible. At the end of the examination, all device parameters should be checked, and programming should be restored to pre-MRI settings. MRI of pacemaker-dependent patients should not be performed unless there are highly compelling circumstances and when the benefits clearly outweigh the risks.

Recommendations for the Performance of MRI in Patients With Pacemakers
1. Only be performed at extremely experienced centers
2. Obtain written and verbal informed consent. specifically list risks, including (1) pacemaker dysfunction (2) Pacemaker damage (3) Arrhythmia (4) Death.
3. A physician with ACLS and pacemaker/ICD expertise should decide whether it is necessary to reprogram the pacemaker before the MRI and should be in.
4. A person with expertise in MR physics and safety should be involved (use lowest RF power levels, weakest/slowest necessary gradient magnetic fields)
5. Appropriate personnel and a "crash cart," including defibrillator, must be available throughout the procedure to address an adverse event.
6. Maintain visual and voice contact with the patient throughout the procedure.
7. After MRI, interrogate the pacemaker function reprogram as needed

Table 8. Recommendations for the Performance of MRI in Patients With Pacemakers (Adapted from Lavine et al., 2007)

7. Discussion with the patients

Most of the patients can be reassured that they can conduct their regular lives normally without fear of EMI, especially if their device utilizes bipolar sensing. In almost all cases in the home and daily living environment, the device reverts back to normal function as soon

as the patient increases distance from the EMI source. Extra precaution with EMI should be exercised with pacemaker- dependent patients. It may be necessary to test the questionable EMI source in a medical facility while the patient is being monitored. Stored electrograms provide a useful tool for verifying EMI interference. To minimize EMI interactions or reduce the chance of a serious device response in the medical environment, one should assess the need for the procedure or test, the dependency status of the patient, and optimal device reprogramming (such as temporarily reprogramming to asynchronous mode). Cardiac device function should be evaluated once the procedure is complete, especially if EMI interactions were noted. Patients in specialized industrial environments should be assessed individually, and the manufacturers too are usually willing to offer specific guidelines or recommendations for device patients in that environment. Emerging technologies continue to create new challenges and raise new questions concerning EMI and patients with implantable cardiac devices.

8. Conclusions

Clear instructions and guidance are required to ensure that an EMI safe area is identified before proceeding with remote device handling. Advances in electronic technology, including hermetic shielding, filtering, bipolar sensing, and algorithms designed to reject sources of EMI have been of great help in returning patients with pacemakers to active lives in their communities after pacemaker implantation. New technologies have increased concern about interference with pacemaker function. It is important for physicians to remain vigilant about the potential risks of EMI from external sources with regard to pacemaker function.

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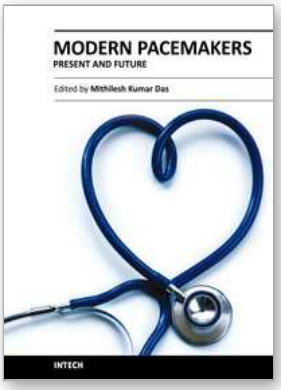

Modern Pacemakers - Present and Future

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The book focuses upon clinical as well as engineering aspects of modern cardiac pacemakers. Modern pacemaker functions, implant techniques, various complications related to implant and complications during follow-up are covered. The issue of interaction between magnetic resonance imaging and pacemakers are well discussed. Chapters are also included discussing the role of pacemakers in congenital and acquired conduction disease. Apart from pacing for bradycardia, the role of pacemakers in cardiac resynchronization therapy has been an important aspect of management of advanced heart failure. The book provides an excellent overview of implantation techniques as well as benefits and limitations of cardiac resynchronization therapy. Pacemaker follow-up with remote monitoring is getting more and more acceptance in clinical practice; therefore, chapters related to various aspects of remote monitoring are also incorporated in the book. The current aspect of cardiac pacemaker physiology and role of cardiac ion channels, as well as the present and future of biopacemakers are included to glimpse into the future management of conductions system diseases. We have also included chapters regarding gut pacemakers as well as pacemaker mechanisms of neural networks. Therefore, the book covers the entire spectrum of modern pacemaker therapy including implant techniques, device related complications, interactions, limitations, and benefits (including the role of pacing role in heart failure), as well as future prospects of cardiac pacing.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821