

# Clinical applications of magnets on cardiac rhythm management devices

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The growing indications for permanent pacemaker and implantable cardioverter defibrillator (ICD) implantation have increased the number of patients with these cardiac rhythm management devices (CRMDs). Cardiac rhythm management devices occasionally perform inappropriately in response to electromagnetic interference (e.g. surgical electrocautery) or lead noise over-sensing (e.g. lead fracture). Temporary reprogramming of the CRMDs using device programmers can prevent these untoward device responses. However, these programmers are device manufacturer specific and require technically qualified personnel to operate. This could cause delayed patient care and increased use of resources in certain clinical situations. Alternatively, clinical magnets, when appropriately positioned over the device site, can change the pacing to an asynchronous mode in pacemakers and suspend tachycardia therapies in ICDs. Although readily available, clinical magnets have not been widely used for this purpose, perhaps due to the unfamiliarity with the variable responses of CRMDs to magnet application. This article provides a comprehensive overview of the current literature on the mechanism of action and the specific responses of various CRMDs to clinical magnets.

**Keywords** Magnet • Pacemakers • Implantable cardioverter defibrillators (ICDs) • Reed switch • Giant magnetosensitive resistors (GMRs)

## Introduction

Implantable cardioverter defibrillators (ICDs) and permanent pacemakers are encountered commonly in clinical practice. However, many healthcare providers are unfamiliar with the functions of these cardiac rhythm management devices (CRMDs). Clinical scenarios such as in operating rooms where electromagnetic interference (EMI) may interfere with the device functioning or patients presenting with inappropriate ICD shocks in the emergency rooms warrant reprogramming of CRMDs. Device reprogramming is usually performed using the corresponding manufacturer's proprietary programmers, the operation of which is relatively complex and requires technically trained personnel. Alternatively, these devices are incorporated with magnet-sensitive switches that respond to clinical magnets to perform some of the basic functions. Magnets are readily available and do not require special training to use, making them an excellent option to reprogramme CRMDs in urgent situations. In general, magnet application

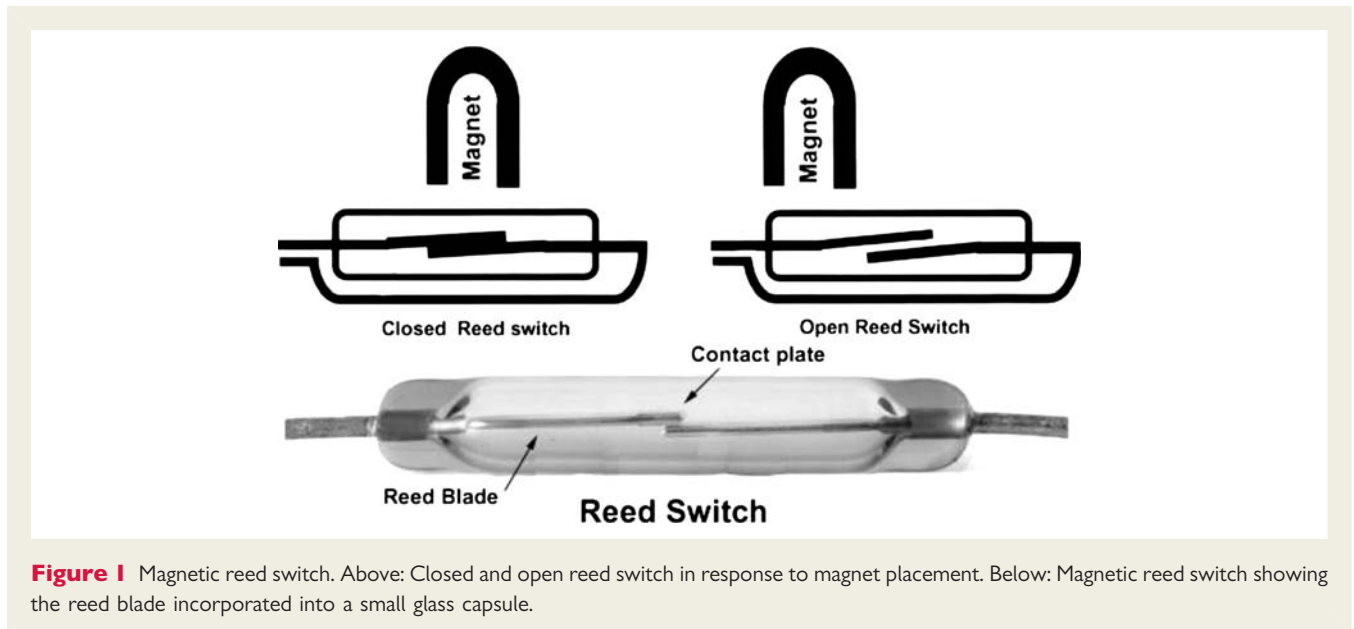
switches pacemakers to an asynchronous pacing mode and suspends all anti-tachycardia therapies of most ICDs without affecting the pacing mode. This article provides a comprehensive review of the mechanism of action and responses of currently available pacemakers and ICDs to clinical magnets.

## Historical perspective

Before the introduction of telemetric communication with pacemakers in the 1970s, magnets were used to alter pacing behaviour to demonstrate the remaining battery life and to achieve asynchronous pacing when EMI was suspected.<sup>1</sup> The activation of a magnetic switch (magnetic coupling) was an essential feature needed for programming in earlier CRMD models and a continuous magnetic field was required in some older pacemakers to initiate a programming change.<sup>2–4</sup> Subsequent models used transmitted magnetic pulses, inductive coupling (via an antenna coil), or radio-frequency waves (current models) for communication between a

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**Figure 1** Magnetic reed switch. Above: Closed and open reed switch in response to magnet placement. Below: Magnetic reed switch showing the reed blade incorporated into a small glass capsule.

CRMD and a programmer.<sup>5</sup> Although a permanent magnet used to be part of programming wands, current programmers do not have a built-in magnet, with the exception of the Medtronic and Biotronik programming heads.

## Clinical magnets: technical considerations

Most pacemakers and ICDs have built-in magnetic reed switches that are designed to switch 'ON' or 'OFF' circuitry in response to magnets. Some of the newer devices are equipped with alternative technologies like giant magnetosensitive resistors (GMRs), Hall-effect sensors, or telemetry coils that respond to magnets.

### Magnetic reed switch

A reed switch consists of two metal strips made of magnetic material in a glass capsule (*Figure 1*).<sup>6</sup> Although several configurations are possible, the most common one involves separation of the strips (open switch) by their stiffness and a cantilever attachment to the ends of the capsule. Application of an adequate external magnetic field causes the strips to come in contact (closed switch), which leads to a sudden change in voltage sensed by a sensing amplifier. This amplifier triggers the pulse generator to switch to perform programmed functions such as the asynchronous pacing mode in pacemakers and the suspension of anti-tachycardia therapies in ICDs.<sup>7</sup> Sometimes, the reed switch may malfunction by staying in the closed or open position regardless of the external magnetic field (sticky reed switch). This is most commonly due to a cracked glass capsule of the reed switch making the metal strips stick in one position. Magnetic reed switch malfunction leading to anti-tachycardia therapy failure and accelerated battery depletion has been reported in some ICD models.<sup>8</sup>

### Giant magnetosensitive resistors

Giant magnetosensitive resistors, introduced in CRMDs by St. Jude Medical in 2006 (EPIC<sup>®</sup> II and Atlas<sup>®</sup> II models onwards), contain thin films with alternating layers of magnetic and non-magnetic materials that provide a high resistance to the flow of current. An external magnetic field, when applied to a GMR, causes the magnetic layers to line up in the same direction, which in turn lowers the resistance. This change activates the designated electronic switches to facilitate various device functions.

### Hall-effect sensor

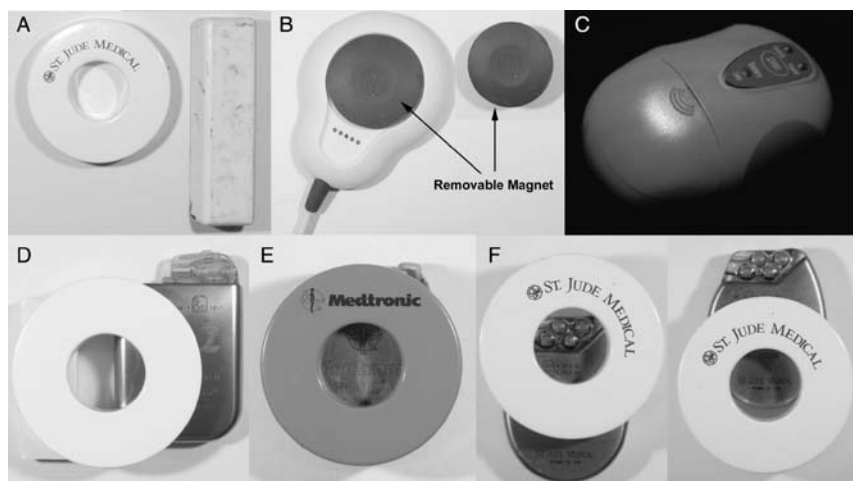
The newer magnetic resonance imaging (MRI)-safe Medtronic pacemakers are equipped with Hall-effect sensor switches, which function as a transducer to trigger an electronic switch to 'ON' or 'OFF' when activated by a magnetic field. The Hall-effect principle is based on the generation of electrical voltage across an electrical conductor, when the magnetic field is perpendicular to the direction of the current flow in the conductor.<sup>9</sup> In MRI-safe devices, it can be programmed to lock out when undergoing MRI scan.

### Telemetry coil

The Paradym<sup>®</sup> and Ovatio<sup>®</sup> ICDs from Sorin Group (Milan, Italy) use a telemetry coil for detection of a clinical magnet.

### Features and positioning of magnets

Clinical magnets, made of ferrous alloy, come in various shapes (ring or doughnut, horseshoe, and rectangle or bar) designed to be placed over the CRMD implantation site (*Figure 2*). Medtronic (Minneapolis, MN, USA) has also introduced a Smart Magnet<sup>™</sup>, with a light indicator to guide appropriate placement (*Figure 2C*). The Medtronic Smart Magnet<sup>™</sup> is produced with an external injection-moulded enclosure to withstand robust handling. Placement of the Smart Magnet<sup>™</sup> results in the expected response from all devices; however, the indicator illuminates only with



**Figure 2** Clinical magnets and their proper placement as per manufacturer (white papers) recommendations. (A) Ring/doughnut and bar magnets. (B) St. Jude Telemetry Wand magnet in position and removed from the wand. (C) Medtronic Smart Magnet™. (D) Sorin implantable cardioverter defibrillator: ring magnet placed off-centre avoiding the header on the top end of the device. (E) Medtronic, Boston Scientific, and Biotronik implantable cardioverter defibrillators: ring magnet placed directly on top of the device. (F) St. Jude implantable cardioverter defibrillator: the curve of the ring/doughnut magnet on the top or bottom end of the device.

Medtronic devices. The magnetic field effect of the clinical magnet is directly proportional to the strength of the magnet and inversely proportional to the distance of the magnet from the CRMD. A magnetic field effect of  $\geq 10$  Gauss aligned with the magnetic reed switch is required to activate the magnetic switch in order to alter the device function. Available clinical magnets usually have a strength of  $\geq 90$  Gauss. In obese individuals, more than one magnet may be needed to change the function of the CRMD.<sup>10</sup>

The site of magnet placement is important since a poorly positioned magnet may not produce the desired effect. Magnets are best placed directly on top of the device (Medtronic, Boston Scientific, and Biotronik) with two exceptions; in St. Jude ICDs, the position of the magnet is recommended to be placed off-centre with the curve of the magnet over the bottom or top end of the ICD<sup>11</sup>, and, in Sorin ICDs, the curve of the doughnut magnet needs to be placed directly over the device in such a fashion as to avoid the header on the top end of the device (Figure 2).

## Clinical applications of magnets

### Applications for pacemakers

#### Basic functions

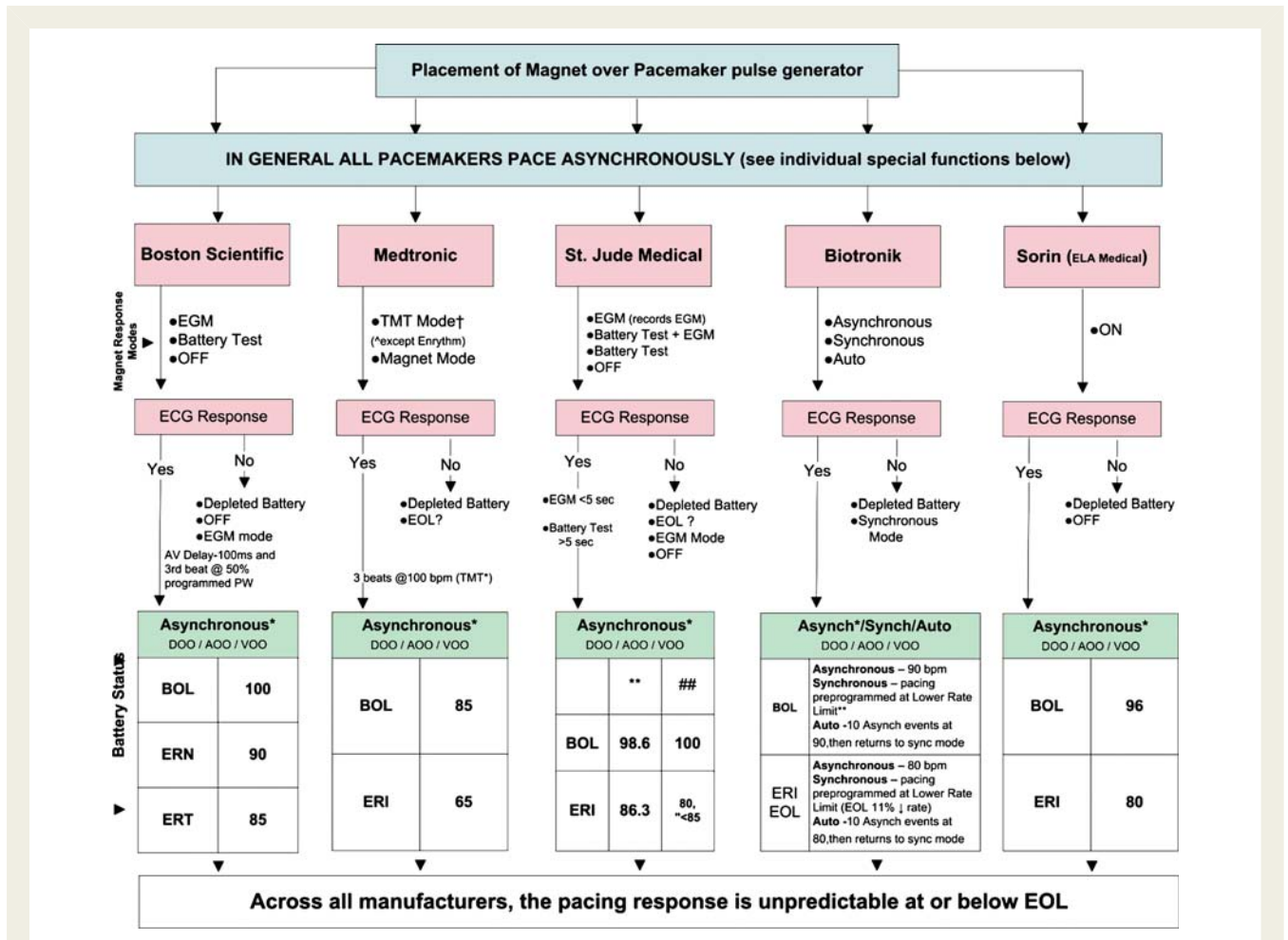
Pacemakers may sense external EMI and inhibit the pacing function. Current pacemakers, with their advanced noise-filtration techniques, are fairly resistant to common EMI sources like cell phones. The major sources of interference encountered in the medical environment causing pacing inhibition include electrocautery,<sup>12</sup> radio-frequency ablation,<sup>13</sup> radiation therapy,<sup>14</sup> electrical nerve<sup>15</sup> and muscle stimulators,<sup>16</sup> and dental instruments.<sup>17</sup> Clinical magnets can be used to temporarily switch pacemakers to an asynchronous pacing mode,<sup>18</sup> thereby preventing pacing inhibition from EMI.

#### Special functions

In the presence of pacemaker-mediated tachycardia or inappropriate sensing due to the presence of cross-talk inhibition or far-field sensing, a clinical magnet may be used to induce temporary asynchronous pacing<sup>19</sup> until device reprogramming can be performed. Magnets have also been used to verify pacing capture and even determine adequate pacing capture safety margins [e.g. Threshold Margin Test (TMT) explained below]. Carotid sinus massage, which has been previously employed by some to evaluate pacemaker capture by slowing the heart rate to the lower rate limit, is generally discouraged due to its potential to cause strokes.<sup>20</sup> Magnet application can also be used to identify CRMD manufacturers based on the specific magnet-induced pacing rate (Figure 3) of each model.<sup>21</sup> The use of a magnet also provides information regarding the battery status of the device, since the pacing rate on magnet application varies depending on the available battery life. The different levels of battery status reflected by rate include beginning of life (BOL), elective replacement indicator (ERI)/recommended replacement time (RRT), and end of life (EOL) (Figure 3). However, from EOL to complete depletion of the battery, the pacing response of all devices is unpredictable.

#### Patient-operated functions

Certain manufacturers (Boston Scientific, Biotronik and St. Jude Medical) have programmable modes in their devices, which allow the patient to apply a clinical magnet over their device thereby triggering electrocardiogram (ECG) storage without any effect on pacing. This feature is useful for patients who experience undiagnosed symptoms like dizziness or palpitations. The stored information can also be transmitted to the physician either automatically or in some devices by the application of a magnet (Home Monitoring<sup>®</sup>, Biotronik, Berlin, Germany) by the



**Figure 3** Response of pacemakers to magnet placement. In general, magnet application results in asynchronous pacing in all pacemakers with manufacturer-specific exceptions explained in the figure. The first step shows the different magnet response modes programmable in pacemakers and the corresponding electrocardiogram (ECG) responses (Each mode has been explained in detail in the text). If no ECG response is seen on magnet application, the pacemaker might have been programmed to ignore the magnet or might have a depleted battery or one of the different modes shown in the flowchart. Asynchronous pacing occurs at a fixed magnet rate according to the device manufacturer, individual models, and remaining battery life. Pacemaker programmed to DDD pace as DOO, VVI as VOO, and AAI as AOO. On magnet removal, all pacemakers revert to the original programmed pacing mode, except for Sorin pacemakers that undergo a ‘capture test’ with six pacing outputs at the magnet rate and 94 ms AV delay and then a ‘rate test’ with two paced outputs at a basic programmed rate and rest AV delay followed by pacing at a preprogrammed rate. Battery statuses: BOL, beginning of life; ERI, elective replacement indicator; ERT, elective replacement time; ERN, elective replacement near; EOL, end of life. The magnet rates at different battery status have been specified for each device manufacturer. At EOL and below, the response of pacemakers to magnet placement is unpredictable across all the manufacturers. bpm, beats per minute; AV, atrioventricular, Asynch, asynchronous; Sync, synchronous; †TMT, Threshold Margin Test; PW, pulse width. \*\*St. Jude Medical Pacemaker Models: Affinity®, Identity®, Integrity®, Verity®, Victory®, Zephyr®, Accent®, Anthem®. ##St. Jude Medical Pacemaker Models: Meta®, Microny®, Tempo® (Regency® 100 bpm at BOL and <85 bpm at ERI).

patient<sup>22</sup> through remote monitoring systems like CareLink® (Medtronic Inc., Minneapolis, MN, USA), Merlin® (St. Jude Medical, Sylmar, USA), and Latitude® (Boston Scientific, St Paul, USA).<sup>23,24,25</sup>

### Applications for implantable cardioverter defibrillators

#### Basic functions

Implantable cardioverter defibrillators can sometimes recognize noise from EMI as ventricular tachycardia or fibrillation and may deliver inappropriate shocks. When EMI is anticipated, as in surgical electrocautery, anti-tachycardia therapies need to be

programmed for the duration of the procedure.<sup>26</sup> Alternatively, a magnet could be applied to activate the magnetic switch to inhibit anti-tachycardia therapies in most ICDs. Similarly, in emergency situations, magnets can be used to terminate device shocks due to inappropriate arrhythmia detection in conditions such as a fractured lead, loose set screw, T-wave and myopotential over-sensing, and supraventricular tachycardias.<sup>21</sup>

#### Special functions including patient-friendly features

Identification of some of the ICD models and manufacturers can be achieved based on auditory response (Medtronic, Boston Scientific)

and pacing rate (Sorin). Additionally, magnet-activated 'alert tones', such as an 'all clear' tone, or 'low urgency' and 'high urgency' tones in Medtronic devices, give more information on the status of the device.<sup>27</sup> The alert tone feature is especially helpful for patients to evaluate/replay any alert tones indicating device malfunction. The patients (once properly trained by their physicians) can wave or place a magnet over their device and listen for the tones. A dual high–low tone is indicative of high-urgency alert while an intermittent 'ON'/'OFF' tone indicates low urgency. A continuous steady tone simply indicates an exposure to a constant magnetic field. Indeed, some implanting centres provide clinical magnets and instructions regarding their appropriate use to their patients.

## Precautions against clinical magnet use

In certain clinical scenarios, programming should be preferred over the use of magnets. These include surgeries to be performed in a non-supine position making magnet position over the CRMD unstable or when the magnet response mode has been deactivated by the manufacturer or clinician for any reason. Since a bradycardia pacing mode is unaffected by magnets in ICDs, pacemaker-dependent patients should have their ICD reprogrammed to an asynchronous mode to prevent pacing inhibition from electrocautery-related EMI. Clinical magnets do not alter rate-adaptive functions in ICDs and reprogramming is necessary when this function needs to be inhibited. This is in contrast to those pacemakers wherein magnet application disables any rate responsiveness.

Although magnet application is anticipated to result only in temporary alteration of CRMDs, some of the Boston Scientific ICD models with specific programmable modes (Table 1) may not revert to original programming after removal of the magnet. If a magnet is used to alter such CRMD function, it should be interrogated at the earliest opportunity<sup>29</sup> to detect any programming changes that may have occurred. This will avoid any unprotected time of possible suspended therapy and correction of any potential device-related problems.<sup>30</sup> Additionally, unusual responses to magnet application have also been reported previously, like switching of the ICD to an EOL battery status.<sup>31</sup> Moreover, irrespective of the type of reprogramming technique used, electrocautery

closer than 15 cm (6 inches) to the CRMD can cause permanent damage to the internal circuitry of the device and the CRMD should be interrogated following such an event.<sup>32</sup> Furthermore, when an ICD is deactivated using a magnet, ready availability of external defibrillation should be ensured.<sup>29</sup>

## Magnet effects on pacemakers

Figure 3 details the various pacemaker responses to clinical magnet application. All pacemakers respond to a magnet by switching to an asynchronous pacing mode at a programmed atrioventricular (AV) delay and a fixed magnet rate depending on the manufacturer, device model, and the status of the battery. The programmed mode DDD switches to DOO, VVI switches to VOO, and AAI switches to AOO. The rate response feature is switched to 'OFF' on magnet application in pacemakers. In biventricular pacemakers, both the right and left ventricles continue to be paced in the above modes with magnet application so long as the device is at or above ERI. However, from below ERI voltage, this response is unpredictable.

If magnet application on a pacemaker site does not produce any response on the surface ECG pacing rate or mode, the magnet may be repositioned. If no change is still observed, the following reasons may apply: (i) a depleted pacemaker battery; (ii) the pacemaker is programmed to ignore the magnet (St. Jude, Boston Scientific, and Biotronik synchronous mode); (iii) the magnetic field does not reach the device, as in the case of those with deeper (abdominal or submuscular) implants or in very obese patients; (iv) EOL or lower battery life. Additionally, with Biotronik pacemakers in a synchronous mode (Figure 3), if the patient's intrinsic heart rate is higher than the lower rate limit (LRL) programmed, there will be no ECG response. In almost all pacemakers, removal of the magnet causes the device to revert to pacing at the normal preprogrammed rate with the exception of Sorin pacemakers as described below.

## Boston Scientific

Boston Scientific pacemakers are designed to switch to an asynchronous pacing mode on magnet application if the device is not programmed to a magnet 'OFF' mode. It also has a battery test mode

**Table 1** Guidant/Boston Scientific implantable cardioverter defibrillator models with and without the 'change tachy mode with magnet' feature<sup>a</sup>

Devices with the 'change tachy mode with magnet' feature	PRIZM <sup>®</sup> 1 - 1850, 1851, 1852, 1853, 1857, 1858 PRIZM <sup>®</sup> 2 - 1860, 1861 VITALITY <sup>®</sup> 1 - T125, T127, T135
Devices without the 'change tachy mode with magnet' feature	VITALITY <sup>®</sup> 2 - T165, T167, T175, T177, T180, A135, A155 CONFIENT <sup>®</sup> - E030 TELIGEN <sup>®</sup> - E110 LIVIAN <sup>®</sup> - H220, H225 (LV-1), H227, H229 (LV-1) COGNIS <sup>®</sup> - N118 (LV-1), N119
Devices with a 'software patch' <sup>b</sup> to inactivate the 'change tachy mode with magnet' feature	CONTAK <sup>®</sup> RENEWAL 1 - H135 CONTAK <sup>®</sup> RENEWAL 3 & 4 - H170, H175 (LV-1), H177, H179 (LV-1) CONTAK <sup>®</sup> RENEWAL 3RF - H210, H215 (LV-1), H217, H219 (LV-1)

<sup>a</sup>This feature determines the response of the implantable cardioverter defibrillator to magnet placement as explained in the text and in Figure 4.

<sup>b</sup>The 'software patch' refers to the software upgrade released by Boston Scientific for the mentioned implantable cardioverter defibrillator models, which allowed inactivation of the 'change tachy mode with magnet' feature in these devices.<sup>28</sup>

and an electrogram (EGM) mode to initiate ECG storage without any effect on pacing.

In the magnet response mode, Boston Scientific pacemakers are paced at a magnet rate of 100 bpm at EOL with an AV delay of 100 ms. The third pulse during the magnet test is issued at 50% of the programmed pulse width to allow the clinician to evaluate the safety margin. The magnet rate is 100, 95, and 85 beats per minute (bpm) at EOL, elective replacement near (ERN), and ERT, respectively, in Boston Scientific pacemakers.

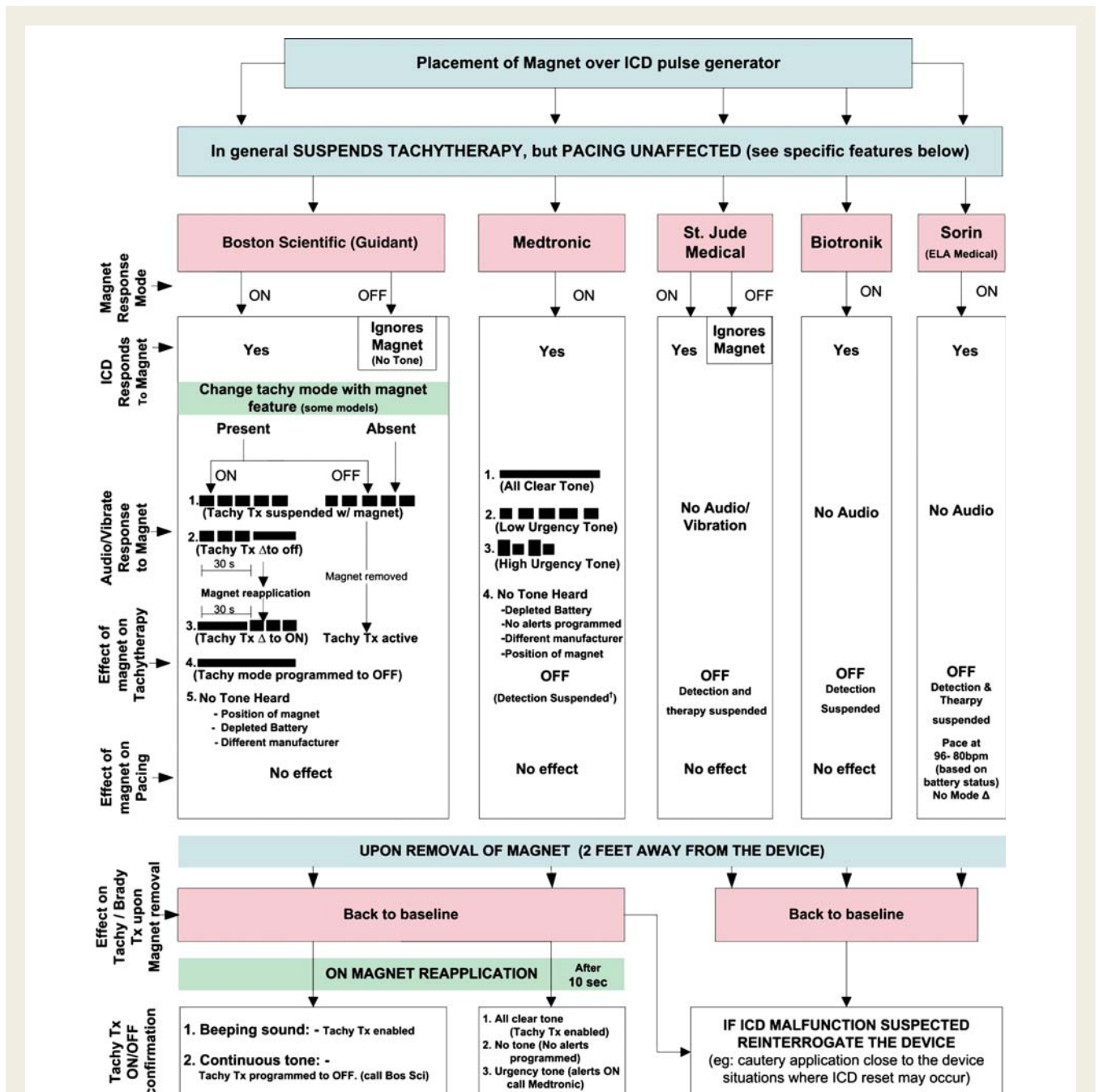
### Medtronic

Medtronic pacemakers do not have a magnet 'OFF' mode and asynchronous pacing can always be expected on magnet application.

With the exception of EnRhythm® (Medtronic, Minneapolis, MN, USA), asynchronous pacing is preceded by three paced pulses at 100 bpm, with the pulse width of the last pacing reduced by 20%. This is known as the TMT and is used to ascertain adequate pacing capture safety margin. In Medtronic devices, the magnet rates are 85 and 65 bpm at EOL and ERI, respectively. A rate of 65 bpm is specifically reserved for providing information about battery life (ERI) with magnet application. Thus, Medtronic pacemakers cannot be programmed to pace at a rate of 65 bpm.

### St. Jude Medical

St. Jude Medical pacemakers may be programmed to ignore the magnet ('OFF' mode) or have one of the following three



manufacturer-programmed modes: (i) Battery test mode, in which there is a switch to asynchronous pacing immediately on magnet application; (ii) Battery test + EGM mode, in which an ECG is stored if the magnet is held over the device for less than 5 s and a switch is made to asynchronous pacing if held for >5 s; and (iii) EGM mode, in which an ECG is stored without any effect on pacing.

An additional VARIO mode is present in some older models (Microny<sup>®</sup> and Regency<sup>®</sup>, St. Jude Medical Inc., St. Paul, MN, USA). This feature was available in some Pacesetter devices, which are currently under St. Jude Medical but are being phased out. This mode is to check battery life and adequate pacing capture safety margin. It involves a repetitive cycle of 32 asynchronous events on magnet application with the first 16 paced events at 100 bpm (85 bpm at ERI) followed by 15 events at 119 bpm with successive reduction in pacing voltage and the last paced event at no output.

## Biotronik

Biotronik devices respond differently to magnets depending on manufacturer-programmed modes that could be (i) asynchronous, (ii) synchronous (which demands pacing in programmed mode at LRL), or (iii) auto (i.e. 10 asynchronous events followed by reversion to synchronous mode). A synchronous mode is also used for a patient-triggered recording. The magnet rates for different modes vary according to the available battery life (Figure 3).

## Sorin

Sorin pacemakers also switch to asynchronous pacing in response to magnet application with a pulse width of 0.5 ms and rest AV delay (original programmed sensed AV delay). When the magnet is removed, the 'capture test' is initiated comprising six asynchronous pulses at magnet rate, programmed amplitude, and pulse width with an AV delay of 94 ms. This is used to verify adequate capture with programmed pulse width and amplitude. This is followed by the 'rate test' comprising two asynchronous pulses at

programmed rate and AV delay to demonstrate sufficient capture at these values. Capture and rate tests are followed by pacing at the original programmed rate.

## Magnet effects on implantable cardioverter defibrillators

Figure 4 shows various ICD responses to clinical magnet application. In general, magnet application suspends anti-tachycardia therapy without any effect on the pacing mode. Implantable cardioverter defibrillator models from St. Jude Medical and Boston Scientific, however, have additional programmable features to ignore the magnet or respond differently to a magnet. All biventricular ICDs behave like any other ICDs of the corresponding manufacturer. In most cases, anti-tachycardia therapy resumes with removal of the magnet. However, in some instances, magnet removal may or may not re-enable anti-tachycardia therapy. Specific care should be exercised in Guidant/Boston Scientific ICDs since some of the older models (Table 1) are equipped with circuitry that enables the magnet to permanently programme the anti-tachycardia therapy to 'OFF'. In addition, magnet application on Sorin ICDs changes the pacing rate without altering the pacing mode (discussed below). Rate response of ICDs is not influenced by magnet application.

Implantable cardioverter defibrillators have either an auditory or a vibratory alert feature; only Medtronic and Boston Scientific ICDs provide an auditory confirmation of the suspension of anti-tachycardia therapy on magnet application. If a tone is not heard, a stethoscope may be used to identify auditory response, particularly in obese patients and in those with submuscular implantations. No tones are heard in St. Jude Medical, Biotronik, and Sorin ICDs on magnet application. In Medtronic or Boston Scientific devices, if no tone is heard even after repositioning the magnet, the following reasons may apply: (i) a depleted battery; (ii) all the alerts are programmed to remain 'OFF', as in Medtronic devices; (iii) the device is programmed to ignore the magnet, as in Boston Scientific

**Figure 4** Response of implantable cardioverter defibrillators (ICDs) to magnet placement. In general, on magnet application, tachycardia detection is suspended in all ICDs and hence no anti-tachycardia therapy (Tachy Tx) occurs. The first step shows the programmed response of the ICD to the magnet. The ICD may be programmed to ignore the magnet only in Boston Scientific and St. Jude devices. There is no effect on bradycardia therapy (Brady Tx) function of ICDs, except in Sorin ICDs [pace at 96 beats per minute (bpm) at BOL to 80 bpm at ERI, without any pacing mode change ( $\Delta$ )]. Removal of the magnet re-enables anti-tachycardia therapy in most of ICDs (except Guidant older devices that have been programmed to 'change tachy mode with magnet'). Note the various audio responses seen in ICDs upon inhibition/suspension of anti-tachycardia therapy (featured only in Boston Scientific and Medtronic ICDs). In Boston Scientific ICDs: Long line, long constant tone: tachy mode is programmed to 'OFF'. Dotted line, initial beeping tones: anti-tachycardia therapy is inhibited for as long as magnet is secured over the ICD; these beeps correspond to the R waves on the electrocardiogram or in newer devices, and beep once per second (each beep is 100 ms long). Dotted line plus long line, initial beeping tones change to long constant tone after 30 s: anti-tachycardia therapy is disabled ('tachy mode' is now programmed to 'OFF') and the magnet can be removed. If the anti-tachycardia therapy had been permanently disabled (i.e. 'tachy mode' had been programmed to 'OFF'), the magnet will have to be re-applied for 30 s or more until the long constant tone reverts to beeping tones. Long line plus dotted line, long constant tone changes to beeping tones after 30 s: 'tachy mode' is programmed to 'ON' (anti-tachycardia therapy will be re-enabled once the magnet is removed). In Medtronic ICDs: Audio tones are heard only if the 'alert tone' (last for 10 s) feature is programmed 'ON'. Long line, long constant tone (all clear tone; all programmed alert parameters are within normal limits). Dotted line, low-urgency tone: 0.5 s 'ON' and 0.5 s 'OFF' for a total of 10 s (one or more of the low-urgency alert parameter needs attention). Dotted line plus long line, high-urgency tone: 0.5 s high-frequency tone followed by 0.5 s lower-frequency tone for a total of 10 s (one or more of the high-urgency alert parameter needs attention). If a low- or high-urgency tone is heard, device interrogation is warranted for possible electrical reset. St. Jude ICDs from Atlas<sup>®</sup> and Epic<sup>®</sup> II models have a vibration alert feature that warrants possible device interrogation. However, there is no vibration in response to a magnet in these devices.

devices, and/or (iv), the magnetic field does not reach the device due to sheer depth, as in the case of those with deeper (abdominal or submuscular) implants or in very obese patients.

## Boston Scientific

Boston Scientific ICDs (if not programmed to ignore the magnet) respond to clinical magnets in a complex fashion, which depends on the presence of another specific programmable mode called 'change tachy mode with magnet' found only in certain models (Table 1). If this feature is programmed 'ON', magnet placement can permanently disable tachycardia detection and anti-tachycardia therapy. This may be useful in surgical situations in which magnet placement interferes with the sterility of the surgical field (e.g. upper-torso surgery), but the tachycardia therapies must be reprogrammed to 'ON' after the procedure. The anti-tachycardia therapy can be re-enabled by re-applying the magnet for  $\geq 30$  s. However, if the 'change tachy mode with magnet' feature is absent, as in more recent models, magnet placement only inhibits anti-tachycardia therapy for as long as the magnet is placed over the device and anti-tachycardia therapy resumes with removal of the magnet.

Specific tones (Figure 4) indicate temporary or permanent suspension of anti-tachycardia therapy.<sup>33</sup> A long constant tone on initial magnet placement is a warning that the device's 'tachy mode' is programmed to 'OFF' (and the anti-tachycardia therapy had been suspended irrespective of magnet placement in this device), the reason for which needs to be ascertained before proceeding further. If a beeping tone is heard for more than 30 s, it is indicative of anti-tachycardia therapy inhibition that persists only for as long as the magnet is held over the device. These beeps correspond to the R waves on the ECG or, in some cases, simply beep once per second. If the beeping tones change to a long constant tone after the magnet has been held over the patient's device for 30 s, it indicates that the 'change tachy mode with magnet' feature is present in that device model. In this case, if the magnet is then removed the anti-tachycardia therapy remains disabled. In order to re-enable the anti-tachycardia therapy, the magnet must be re-applied over the device for  $\geq 30$  s until the constant tone reverts to beeping tones.

## Medtronic

All Medtronic ICDs suspend anti-tachycardia therapy on magnet application since the magnet 'OFF' mode is absent in these devices. The anti-tachycardia therapy remains suspended as long as the magnet is secured over the device site. Audio confirmation of therapy suspension is only heard if the 'device alert' functions are programmed to 'ON'.

Generally, anti-tachycardia therapy resumes after the magnet is removed. However, it should be confirmed by re-applying the magnet to ascertain any electrical reset that might have occurred as a result of external interference. Absence of electrical reset is indicated by the presence of a long constant tone. A high–low alternating tone, on the contrary, is a high-urgency alert indicating conditions such as electrical reset or ERI battery voltage.

## St. Jude Medical, Biotronik, and Sorin

All ICDs from these companies suspend their anti-tachycardia therapy, with the exception of St. Jude Medical ICDs that can be

programmed to ignore the magnet. The bradycardia pacing function remains unaffected during external magnet application except in Sorin ICDs. On magnet application, Sorin ICDs are designed to pace at 96 bpm at BOL to 80 bpm at ERI without any change in the programmed mode and AV delay. AV delay may be auto (Paradym<sup>®</sup>/Ovatio<sup>®</sup>) or at rest (all other models). Removal of the magnet re-enables anti-tachycardia therapy. ICDs from Biotronik and Sorin also have audible tones (these, however, are not altered by the presence of an external magnet) to alert the patient towards possible device interrogation. The St. Jude ICDs have an alternative vibratory alert mechanism in the models from Atlas<sup>®</sup> and Epic<sup>®</sup> II. In Lumax<sup>®</sup> ICDs from (Biotronik Inc., Oregon, USA) the anti-tachycardia therapy is disabled only for 8 h on constant magnet application, after which the ICD automatically resumes anti-tachycardia therapy. Therefore, to disable anti-tachycardia therapy for  $>8$  h, the device needs to be reprogrammed or one may simply remove and re-apply the magnet for an additional 8 h of disabled anti-tachycardia therapy.

## Future considerations

Simplifying the use of magnets may lead to a wider acceptability of their use. This may be achieved by providing an indicator to the user that the CRMD has recognized the magnet and by maintaining uniformity in the magnet response mode of CRMDs from different manufacturers. Collaboration among CRMD manufactures and various regulatory bodies is pivotal in achieving this goal. Although the Smart Magnet<sup>TM</sup> was a novel idea, it has not been widely used due to its manufacturer specificity. Future clinical magnets should not only be 'smarter' but also be 'universal', making possible their use on all CRMDs. This can be facilitated by introducing universal microchips in the CRMDs, capable of communicating with the magnet. Additionally, the magnet should also be able to provide simple warnings (auditory or visual) when electrical reset of the CRMD occurs.

## Summary

Clinical magnets can expedite care of patients with CRMDs. Although CRMDs vary in their responses to magnets, some important generalizations can be made. All pacemakers change to an asynchronous pacing mode with magnet application and revert to the original programming when the magnet is removed. Some pacemakers do have a programmable mode to ignore magnet application, but this feature is almost never used in clinical practice. No change in the pacing mode occurs in ICDs with magnet application. Although the general response of ICDs to magnet application is suspension of all anti-tachycardia therapies, this response is programmable depending on the model. If the user is unfamiliar with the specific models and their responses, or if any device reset or malfunction is suspected, use of a programmer is more appropriate.

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