

# iPhone 12 MagSafe technology and cardiac implantable devices: Assessment of the actual risk

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## Abstract

**Background:** Pacemaker (PM) and implantable cardioverter defibrillators (ICD) are equipped with a magnetic sensor activated by external application of magnets to easily manage some functions of these devices. If activated inadvertently or outside a controlled environment and without the supervision of clinical personnel, this magnetic mode introduces a potential risk. In reality, the possibility of a static magnetic field affecting a PM or ICD is remote. However, the presence of the magnet in the iPhone 12 made the possibility of inadvertently activating the magnetic switch of PM and ICD less remote.

**Objective:** This study investigates the effects of magnetic interference of the iPhone 12 on a large set of cardiac implantable devices representative of the current market and proposes adequate rules of conduct.

**Methods:** We investigated the risk of the magnetic interference of the iPhone 12 and its MagSafe accessories on a comprehensive set of PMs and ICDs, including the subcutaneous ICD. For the first time, the magnetic interference phenomena were correlated with the magnetic field levels measured all around iPhone 12.

**Results:** We discovered that the magnets inside iPhone 12 trigger the magnetic mode in the 12 tested devices up to a distance of 1 cm.

**Conclusions:** Considering the implications related to the activation of the magnetic switch, to date, it is advisable to follow Apple's indications relating to the safety distance of 15 cm, which is widely compatible with the results obtained from this paper and in line with the indications provided by the implantable cardiac device manufacturers.

## KEYWORDS

implantable cardioverter defibrillator, magnetic interference, pacemaker, risk evaluation, smart-phone

## 1 | INTRODUCTION

Any electronic device is potentially susceptible to electricity, magnetic, and electromagnetic fields. The effects of electromagnetic interference depend on various physical factors such as the power, fre-

quency, and modulation of the field, as well as the distance from the source. Pacemaker (PM) and implantable cardioverter defibrillators (ICD), being critical and essential life-saving devices, are designed to be immune to most electrical, magnetic, and electromagnetic sources found in daily life.

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Additionally, PM and ICD have always been equipped with magnetic sensors activated by external application of magnets to easily manage some functions of these devices.<sup>1</sup> The magnets used in a clinical setting have a shape that allows them to act over the implantation site appropriately. Once positioned, the magnetic sensor is activated and the device enters a particular operating mode, generally called the *magnetic mode*. Activation of this mode is immediate, and deactivation occurs by simply removing the magnet. The functions associated with this mode are described in the device manuals and typically allow switching to an asynchronous pacing mode in PMs and suspension of therapy in the event of ventricular arrhythmia or detection of arrhythmias in ICDs. Old generation devices used magnetic reed switch technology, which has historically demonstrated a very low but non-zero rate of failing to open upon magnet removal. Nowadays, the magnetic reed switches have been replaced by Hall-effect sensors which are not affected by this issue.

These functions are useful in particular circumstances, such as during device programming, for emergency deactivation or in surgical interventions where there is a risk of interference caused by electro-surgical units. However, if activated inadvertently or outside a controlled environment and without the supervision of clinical personnel, these functions introduce a potential risk to the wearer of an implanted device.

In reality, the possibility of a static magnetic field affecting a PM or ICD is remote, as it is unlikely that a PM or a patient with an implantable defibrillator will unknowingly place a magnet on the implant site. However, given this characteristic of recognizing static magnetic fields above a certain intensity (typically greater than 1 mT, approximately 40 times higher than the value of the earth's magnetic field), the manuals of these devices clarify the need to not approach sources of high static magnetic fields, such as those present in the vicinity of high-power loudspeakers, electronic article surveillance and security systems, magnetic clips for bags and cases.

Recently, the introduction of the wireless charging mode (for smartphone and smartwatch recharge) has led to the use of magnets inside the charging base to ensure positioning and correct alignment between the charger and the smartphone/smartwatch.

However, regarding the iPhone 12 smartphone, the wireless charging mode (MagSafe technology) is achieved using a magnet positioned in the smartphone itself to guarantee the optimal alignment with the charger. The presence of the magnet in the smartphone made the possibility of inadvertently activating the magnetic switch of PMs and defibrillators less remote.

According to recent studies, when the iPhone 12 is placed around an ICD, the magnet present in the smartphone can activate the magnetic switch in the ICD, suspending the detection of tachyarrhythmias, only as long as it remains in place, and thus preventing anti-tachy pacing and shocks from being delivered.<sup>2,3</sup> This means that the ICD is no longer able to apply the intended therapy in an arrhythmia event.

The presence of the magnet in the smartphone, therefore, makes it possible to unintentionally activate the magnetic switch of PMs and ICDs, a normally unlikely event.

This study investigates the effects of magnetic interference of the iPhone 12 on a large set of cardiac implantable devices representative of the current market.<sup>4</sup> Given the different technologies of magnetic switches used in cardiac implantable devices and since the functions associated with the magnetic mode of PMs and ICDs may vary depending on the manufacturer,<sup>1</sup> PMs and ICDs of leading worldwide manufacturers were evaluated.

This study aims to comprehensively assess the risks for PM and ICD wearers associated with the magnets present in the iPhone 12 and its MagSafe accessories and to provide adequate rules of conduct. An additional aim is to accurately measure the magnetic field levels generated by the iPhone 12 magnets to relate the observed phenomena to the magnetic field immunity of the cardiac implantable devices.

## 2 | METHODS

### 2.1 | Representative sample of pacemakers and defibrillators

In May 2021, a measurement campaign was conducted to analyze the behavior of a representative sample of these devices. The PMs and ICD of leading worldwide manufacturers were evaluated: Abbott, Biotronik, Boston Scientific, Medico, Medtronic, Microport. Since each manufacturer implements a particular type of magnetic sensor in all its own models, the tests were conducted on one PM and one ICD for each manufacturer. The models are shown in Table 1. Furthermore, the subcutaneous ICD (s-ICD) EMBLEM by Boston Scientific (the only s-ICD currently available worldwide) was tested.

### 2.2 | Test setup

#### 2.2.1 | In vitro tests

The devices were tested in vitro using demo models provided by the manufacturers. The test setup allows the real-time display and recording of the electrical signals generated by the devices as well as the generation of a simulated heart signals, which reproduced the spontaneous activity of the heart (sinus rhythm or tachyarrhythmia) (Figure 1). Particularly, the lead was immersed in a saline solution in which two metal electrodes connected to a PC-based proprietary system for signal acquisition and generation (developed in LabView, National Instruments, USA) were also immersed. A calibrated spacer was used to position the device gradually at greater distances from the iPhone 12. With the support of the manufacturers' specialist staff, each device was programmed to make the identification of the magnetic mode trigger possible. For PMs, the asynchronous mode-pacing rate was programmed to be greater than the basic rate. Different strategies have been used for ICDs depending on the manufacturer, as each model has a peculiar magnetic mode behavior. In two cases, the activation of the magnetic mode was recognized via sound emitted by the device. In two cases, wireless communication between the device and its programmer

**TABLE 1** Models of pacemakers and implantable cardioverter defibrillators tested for each manufacturer

	Pacemaker	ICD	s-ICD
Abbott	Assurity MRI	Fortify Assura VR	-
Biotronik	Etrinsa DR	Intika Neo 7 HF-T	-
Boston Scientific	Visionist	Inogen DR	Emblem
Medico	Iris DR	-	-
Medtronic	Advisa SR	Evera MRI SVR	-
Microport	Teo	Platinum	-

**FIGURE 1** Test setup [Color figure can be viewed at wileyonlinelibrary.com]

was used. In one case, it was necessary to simulate a tachyarrhythmia to evaluate the inactivation of the antitachycardia pacing during the magnetic mode.

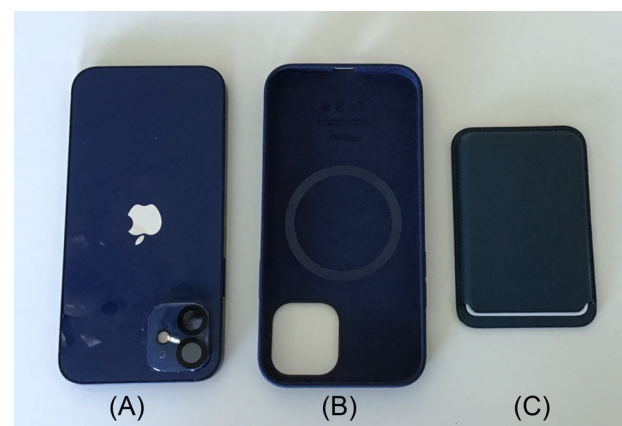
## 2.2.2 | Magnetic field mapping

The magnetic field generated by the magnets inside the iPhone was measured using ETM-1 Probe (Metrolab Instruments SA, Geneva, Switzerland) (accuracy 2% or  $\pm 3$  digits). The probe was set to acquire the magnitude of the magnetic field.

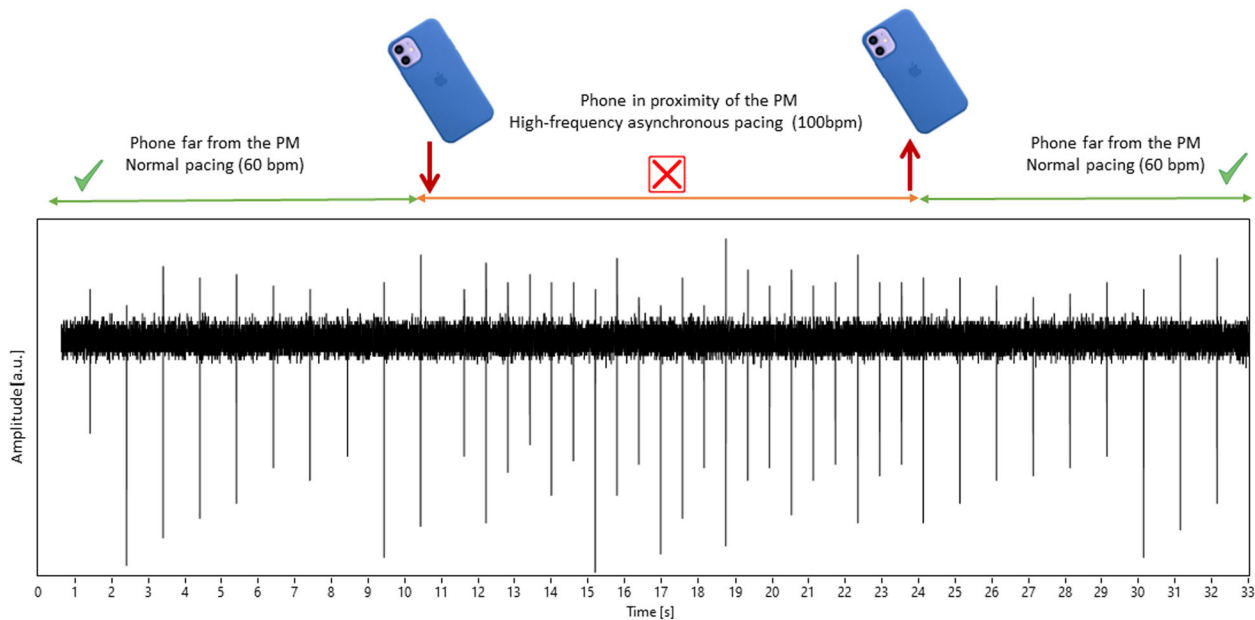
## 2.3 | Test protocol

### 2.3.1 | In vitro tests

The tests were conducted using the iPhone 12. In addition, the effect of the MagSafe case and wallet accessories were also evaluated (Figure 2): tests were conducted also with the iPhone inserted into

**FIGURE 2** iPhone (A) and MagSafe accessories (case [B] and wallet [C]) [Color figure can be viewed at wileyonlinelibrary.com]

the case, and with the iPhone inserted into the case and hooked to the wallet. Before each test session, a baseline device interrogation



**FIGURE 3** Magnet mode asynchronous pacing triggered by the iPhone on the pacemakers [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

was conducted to check the normal functioning of the device the leads and verify that the magnetic mode (i.e., the response to a magnet) was active. Then, a standard magnet was used to ensure that the magnetic mode can be triggered in all devices.

The iPhone 12 was placed at different distances from the device in steps of 1 mm using the calibrated spacer, starting from the zero distance up to the distance at which the magnetic mode was no longer activated. Both sides of the generators were tested. The iPhone was positioned so that the major surfaces of the iPhone and the device were parallel. This positioning mimics what could actually happen in the worst case.

For each distance, the relative position of the iPhone with respect to the device was varied until the one or those that determined the activation of the magnetic mode was found. The tests were repeated for the MagSafe case and the wallet with the iPhone 12 inserted into the MagSafe case and inserted into the MagSafe case and hooked to the MagSafe wallet.

### 2.3.2 | Magnetic field mapping

The magnetic field was mapped over three planes parallel to the plane of the iPhone 12 at distances 0, 1, and 2 cm. For each plane, measurements were collected with a spatial resolution of 1 cm in both directions.

## 3 | RESULTS

### 3.1 | In vitro tests

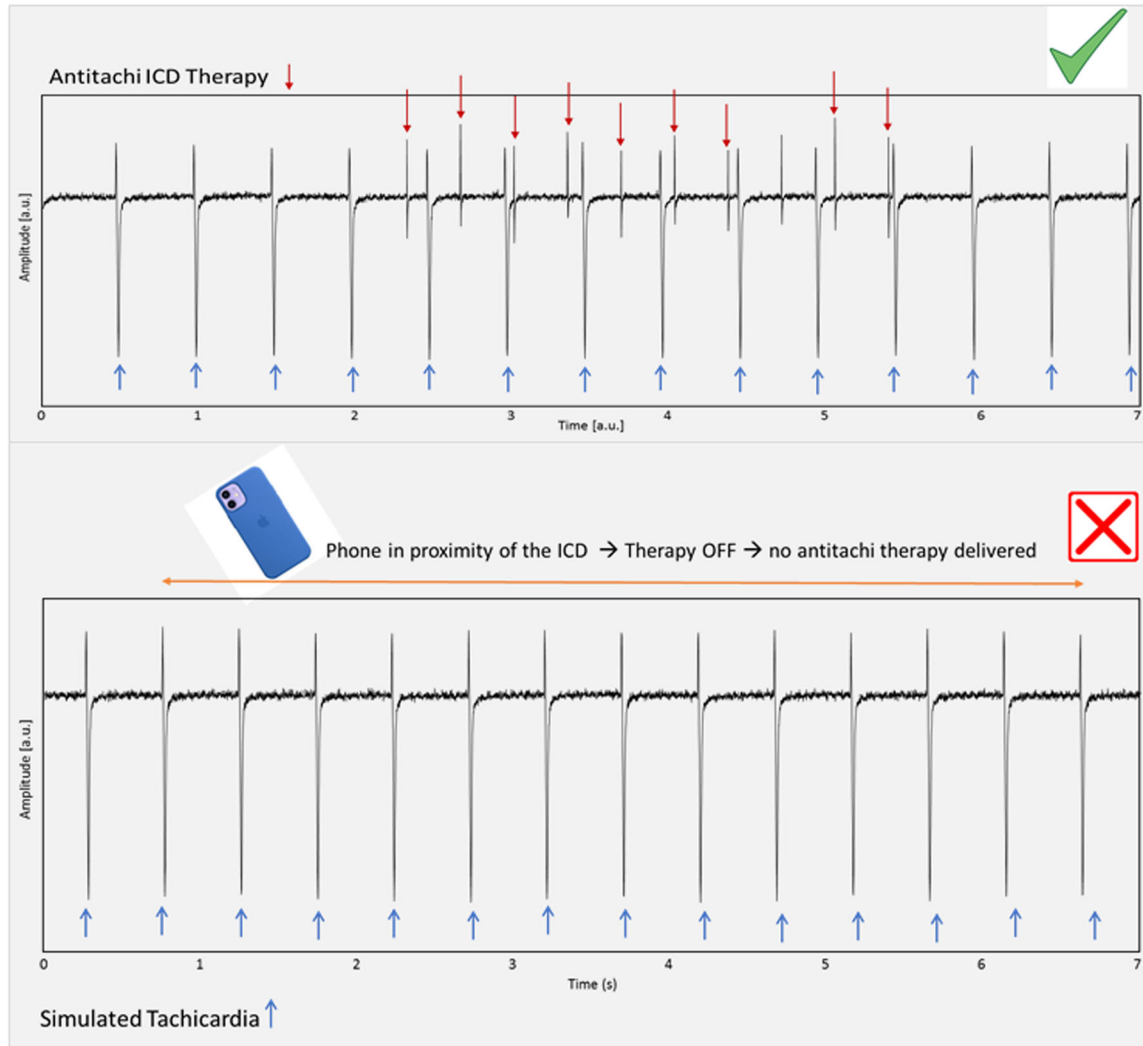
In all PMs and ICDs devices, it was possible to trigger the activation of the magnetic mode using the iPhone 12 placed at zero distance.

Figure 3 exhibits the results obtained from the PMs: the iPhone can trigger the magnetic mode inducing the asynchronous mode of stimulation.

Figure 4 shows the inactivation of the antitachycardia pacing caused by the magnetic mode triggered via the iPhone on ICDs. The upper panel shows the correct behavior of antitachycardia pacing activation in the presence of tachycardia. After the high-frequency pulses generated by the PC-based system, the ICD started delivering the antitachycardia pacing. According to the lower panel, the magnetic mode triggered by the iPhone inactivates the antitachycardia pacing.

These phenomena were observed up to a maximum distance of 1 cm, with differences among the manufacturers ranging from 0.2 to 1 cm. In all cases but one, the side of the device that was more sensitive to the static field was the one with the manufacturer's logo. Notably, most manufacturers indicate to implant the device with this side toward the skin. Regarding the device, the activation of the magnetic mode was observed only in a few specific relative positions of the iPhone. In all cases, the search for the positions of the iPhone that determined the activation of the magnetic mode required several attempts. Once the position was detected and the magnetic mode was activated, moving the iPhone 12 a few millimeters apart in any direction likely caused the device's normal operating mode to be restored.

Similar results were obtained with the iPhone 12 inserted in the MagSafe case. However, instead, the maximum activation distances were shorter with the iPhone inserted into the MagSafe case and hooked to the MagSafe wallet. Indeed, in this case, we reported the distance between the device and the wallet and thus the distance from the iPhone magnet can be obtained by adding the wallet thickness to this shorter distance (approximately 0.5 cm).



**FIGURE 4** Inactivation of the antitachycardia pacing caused by the magnetic mode triggered by the iPhone. Upper panel: correct behavior of antitachycardia pacing activation in the presence of a tachycardia; lower panel: the magnetic mode triggered by the iPhone inactivated by the antitachycardia pacing [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

### 3.2 | Magnetic field mapping

Figure 5 shows the colormap of the magnetic field generated by the iPhone 12. The magnetic field's magnitude resulted in being as high as 5 mT when the probe was placed in contact with the iPhone's backside. The magnetic field decreased as the distance increased; at 1 cm the magnetic field was below 2 mT, and at 2 cm, it hardly exceeded 1 mT.

## 4 | DISCUSSION

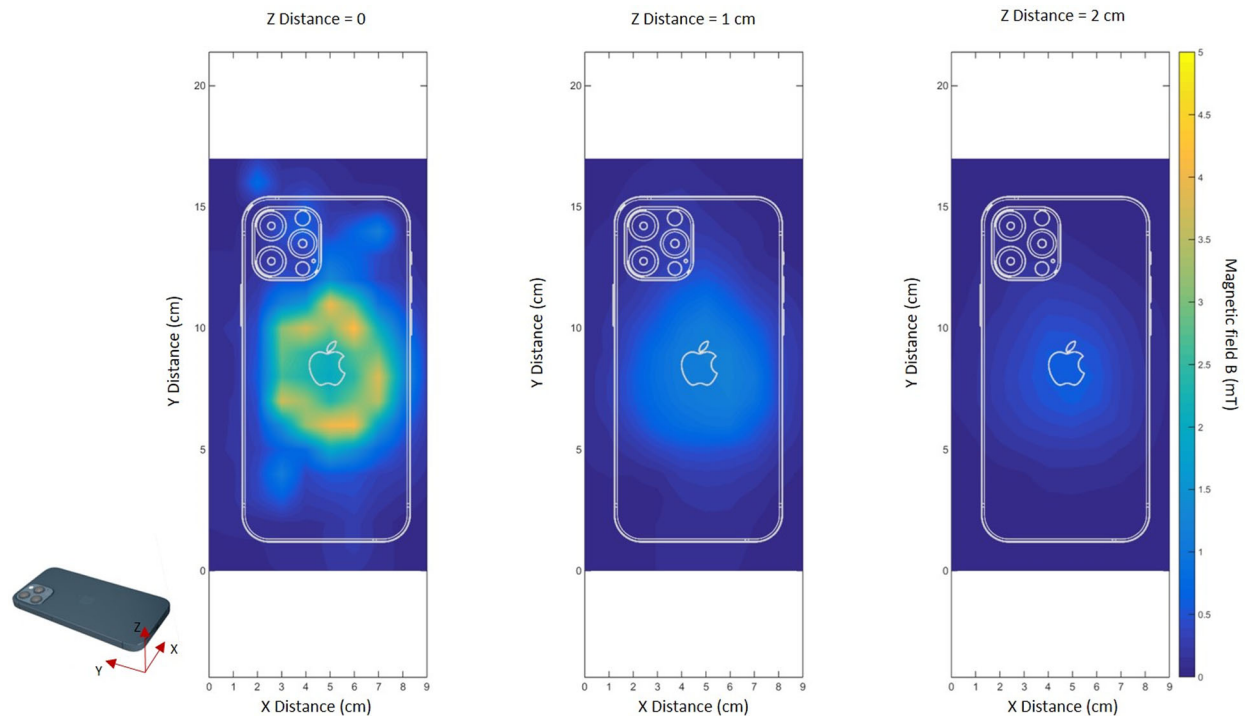
Recently, Greenberg et al. and Nadeem et al. reported potential risk arising from the static magnetic field due to iPhone 12 MagSafe technology based on ex vivo and in vivo testing on some ICD models.<sup>2,3</sup> Particularly, it was shown that the magnetic mode may be triggered

when the iPhone 12 Pro Max is placed directly on the skin over an implantable cardiac device from all three major device manufacturers, and thus, it can inhibit life-saving therapies.<sup>3</sup>

Prompted by these early findings, we conducted a systematic in vitro test on a set of PM and ICD representatives of the current market to assess the actual risk and provide useful elements for reducing risk through appropriate rules of conduct.

Our measures were conducted in vitro on six transvenous PMs, five transvenous ICDs, and one subcutaneous ICD. Compared to previously published papers,<sup>2,3</sup> we tested devices by all the major manufacturers of PMs and ICDs worldwide, including the subcutaneous ICD. Since each manufacturer has stated that they will implement a single type of magnetic sensor in all owned PM and ICD models, having tested one PM and ICD of each manufacturer makes the results obtained in this study more generalizable than previously published data. An additional difference regarding the previously published papers is that the iPhone 12 MagSafe accessories (i.e., case and wallet) were also evaluated.





**FIGURE 5** Colormap of the magnetic field generated by the iPhone 12 over three planes parallel to the iPhone, at distances 0, 1, and 2 cm [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.com)]

In all devices, the magnetic mode was activated by the iPhone placed in contact with the device and it always deactivated upon iPhone removal. Activation occurred only in a few specific relative positions of the iPhone with respect to the devices, which varied from device to device depending on the technology, sensitive area, and position of the magnetic switch.

Magnetic interference occurred at a maximum distance of 1 cm. In all cases but one, the most sensitive side was the one showing the manufacturer's logo. This is the side facing the skin, according to the manufacturers' implant procedure indications. These results in terms of maximum distance and iPhone positioning that trigger the magnet mode exhibit that magnetic interference occurs in a small area around the iPhone 12 magnet.

As for the accessories, the results showed that with the iPhone inserted in the case, the distances of activation of the magnetic mode are comparable to those observed with the iPhone alone.

When the wallet was hooked to the iPhone instead, the results showed that the magnetic interference phenomena were obtained at shorter distances, where the distance in this case is that between the device and the wallet. This is due to the fact that the wallet has its own thickness, acting as a spacer to the iPhone magnet. This distance is therefore shorter since the thickness of the wallet must be taken into account.

An essential added value of this paper is that, for the first time, the magnetic field generated by magnets inside the iPhone 12 has been mapped. Our results show that the magnetic field can be as high as 5 mT, when the probe was placed in contact with the backside of the

iPhone 12. This result is consistent with the single spot value of 50 G reported by Nadeem et al.<sup>3</sup>

According to the international standards that regulate cardiac implantable stimulators' design and manufacturing,<sup>5-7</sup> these devices must be immune to static magnetic fields below 1 mT. Thus, for magnetic field levels above 1 mT, activation of the magnetic mode may occur (rather, there will be a magnetic field level for which it will occur, given the need to implement the magnetic mode for these devices). This is consistent with what was observed in our testing for a distance up to 1 cm, where the magnetic field was as high as 2 mT, according to our magnetic field measurements. Indeed, for a distance greater than 1 cm, we found that the magnetic field generated by the iPhone hardly exceeded 1 mT.

Our findings are consistent with those by Nadeem et al.,<sup>3</sup> who reported a maximum distance of 1.5 cm. The slight difference can be due to the different approach of the *ex vivo* using the iPhone 12 Pro Max over still-packaged new devices with respect to our *in vitro* tests. The main advantages of *in vitro* testing/measurements are that they are safe, since the direct involvement of the patient is not needed. In addition, they allow provocative testing, under not only in realistic exposure conditions but also in worst-case scenarios. On the contrary, *in vivo* studies may be useful to better characterize the role played by the actual human body anatomy (body habitus) and the effects of different implant configuration that can be adopted in clinical practice (e.g., subcutaneous vs. sub-pectoral placement).

Asynchronous pacing and ICD therapy inactivation can also be instigated in other common-life situations. Indeed, cardiac devices can

be affected if patients are close enough to some objects capable of generating magnetic fields, as reported in the literature. Electronic cigarettes, fitness sports bands, wireless chargers, headphones, and tablet speakers were found to cause inadvertent trigger of the magnetic mode.<sup>8-14</sup>

With respect to other situations, given the large diffusion of iPhone 12, and the possibility that people can put their smartphones in a breast pocket or fall asleep with an iPhone immediately over the device, the unintentional activation of the magnet mode caused by iPhone 12 cannot be excluded.

## 5 | CONCLUSIONS

To our knowledge, our study is the first to test the magnetic interference of the iPhone 12 and its MagSafe accessories on a comprehensive set of PMs and ICDs from all major manufacturers, including the subcutaneous ICD. Since each manufacturer states to implement a single type of magnetic sensor in all owned PM and ICD models, the results obtained in this study can be generalized. For the first time, the magnetic interference phenomena accurately correlated to the magnetic field levels measured around the iPhone 12.

We found that the magnet present in iPhone 12 triggers the magnetic mode in a representative sample of PMs and ICDs. The phenomenon was observed up to a distance of 1 cm. Thus, the presence of the magnet on the smartphone makes it possible to unintentionally activate the magnetic switch of PM and ICDs. However, it should be emphasized that the activation of the magnetic mode was observed only in a few specific relative positions of the iPhone with respect to the device and that in most positions, the phenomenon does not get triggered.

Given the criticality of unwanted activation of the magnetic mode, it is very important to follow the information provided by the manufacturers of medical devices according to which a distance of 15 cm must be kept between a cellular phone and the device. These indications, even if not explicitly thought to reduce the risks due to exposure to a static magnetic field, are, in light of the data collected, valid for reducing the risk of accidental activation of the magnetic mode.

Apple also found it appropriate to emphasize in the instructions for use that “Medical devices such as implanted pacemakers and defibrillators may contain sensors capable of reacting to magnets and radio frequencies when in close contact. To avoid potential interactions with these devices, keep your iPhone and MagSafe accessories at a safe distance from the device (more than 15 centimeters away, or more than 30 centimeters if wireless charging is activated).<sup>15</sup>”

Considering the implications related to the activation of the magnetic switch of cardiac implantable devices, as a rule of conduct, to date, it is advisable to follow Apple’s indications relating to the safety distance of 15 cm, which are widely compatible with the results obtained from this paper and in line with the indications provided by the manufacturers of the implantable cardiac devices. However, since in real-life scenarios such distance is not always respected, it would be advisable to alert the patient about this specific iPhone 12 concern. Also, it would

be important to investigate this question further for the new iPhone models, as long as they still remain MagSafe compatible.

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## CONFLICT OF INTEREST


None.

## AUTHOR CONTRIBUTIONS

FC: Concept/design, Data collection, Data analysis/interpretation, Drafting article. EM: Data collection, Data analysis/interpretation, Critical revision of article. GO: Critical revision of article, Approval of article. GC: Data collection, Critical revision of article

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