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Capacity of dental equipment to interfere with cardiac implantable electrical devices

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Patients with cardiac implantable electrical devices should take precautions when exposed to electromagnetic fields. Possible interference as a result of proximity to electromagnets or electricity flow from electronic tools employed in clinical odontology remains controversial. The objective of this study was to examine in vitro the capacity of dental equipment to provoke electromagnetic interference in pacemakers and implantable cardioverter defibrillators. Six electronic dental instruments were tested on three implantable cardioverter defibrillators and three pacemakers from different manufacturers. A simulator model, submerged in physiological saline, with elements that reproduced life-size anatomic structures was used. The instruments were analyzed at differing distances and for different time periods of application. The dental instruments studied displayed significant differences in their capacity to trigger electromagnetic interference. Significant differences in the quantity of registered interference were observed with respect to the variables manufacturer, type of cardiac implant, and application distance but not with the variable time of application. The electronic dental equipment tested at a clinical application distance (20 cm) provoked only slight interference in the pacemakers and implantable cardioverter defibrillators employed, irrespective of manufacturer.

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Cardiac implantable electrical devices (CIEDs), which include pacemakers (PMs) and implantable cardioverter defibrillators (ICDs), are electronic appliances that are capable of analyzing the heart's rhythm and regulating cardiac arrhythmia through an electrical stimulus. Cardiac implantable electrical devices are typically placed subcutaneously, through a surgical procedure, in the left infraclavicular region and are connected by flexible electrode leads via the subclavian vein.

Pacemakers monitor the electrical activity of the heart and provide stimulation and heart conduction through electrical pulses. Implantable cardioverter defibrillators permanently control heart rate, and only in the case of specific arrhythmias do they emit electrical discharges.

In spite of the fact that present-day CIEDs possess protective mechanisms that recognize and filter most interference, some electromagnetic currents could temporarily affect their function (1). Electromagnetic interference takes place when the electromagnetic field of an electromagnet, or the flow of electricity generated by an instrument, interferes with the normal working of a nearby appliance. Electromagnetic signals, if they are affecting CIEDs, can produce electrical noise or even simulate electrical activity of the heart (1–5).

Dental practice frequently involves the use of sophisticated electronic and electromagnetic equipment within the oral cavity. The proximity of the lower third of the face with the infraclavicular region, where CIEDs are usually implanted, could augment the risk of interference in their function (5).

In odontology, an ultrasonic dental scaler is principally used to eliminate hard deposits on the teeth via ultrasonic energy, which has a frequency >20 KHz (6–8). The electronic apex locator is an instrument that employs low alternating current in order to measure the length of root canals precisely (9–12). The electric pulp tester uses high-frequency, low-intensity electric currents to produce small discharges that evaluate the vitality of sensory fibers in the pulp tissue (13–15). The electrosurge is a unipolar or bipolar surgical instrument with cutting and cauterizing functions that employs alternate electrical currents. Within the field of dentistry, the most commonly used electrosurge instrument is unipolar with a low-intensity current and a frequency of 100 KHz (3, 16, 17). The osseointegration monitoring tools Osstell ISQ and Periotest M are based on differing principles. The mechanism of Osstell ISQ relies on the resonance frequency analysis of a wave applied to the implant surface (5–15 KHz and 1 V peak ampli-

tude) (18–20). Periotest M carries out measurements via an electromagnetic mechanism that requires high-frequency energy for its internal functioning; however, the external emissions are very low (19–21).

Owing to their wide clinical applications and the levels of scientific evidence associated with their therapeutic results, the use of CIEDs has spread considerably. In the USA, the number of implanted CIEDs rose from 9,000 in 1990 to 143,000 in 2005 (22). Similar increases have been observed in European countries (23). The surge of patients with CIEDs has made it necessary to establish a consensus concerning their compatibility with certain electronic instruments employed in the field of clinical dentistry. At present, there is some controversy in the literature with respect to the possible interference of these electronic instruments with PMs and/or ICDs.

The aim of the present in vitro study was to examine the behavior of CIEDs under the influence of electronic and electromagnetic equipment employed in the field of dentistry.

Material and methods

This in vitro study was jointly designed by the Odontostomatology Department at the University of Barcelona and the Arrhythmia Unit of the Cardiology Service at the Bellvitge University Hospital (University of Barcelona).

With respect to the inclusion criteria, all electronic dental instruments tested in the study were required to possess the capacity to generate electrical or electromagnetic fields derived from their mechanisms of action. In addition, manufacturers had counterindicated their use in patients with CIEDs.

The following equipment was employed: an electrosurge (XO Odontosurge; XO Care, Hørsholm, Denmark); an electric pulp tester (Denlux B 1000 Pulppen; Dental Electronic, Ballerup, Denmark); an ultrasonic piezoelectric dental scaler (Satelec Suprasson P5 Booster; Acteon Group, Merignac Cedex, France); an electronic apex locator (Morita Root ZX; Morita, Irvine, CA, USA); and the osseointegration monitoring tools, Periotest M (Medizintechnik Gulden, Modautal, Germany) and Osstell ISQ (Osstell AB, Göteborg, Sweden).

All the CIEDs fulfilled the following inclusion criteria: the generator was new, and, during a previous function test, presented no errors or structural defects.

Three different types and manufacturers of PM [Medtronic Adapta DR ADDR01 (Medtronic, Minneapolis, MN, USA), Boston Scientific Insignia I Ultra (Boston Scientific, Natick, MA, USA), and Biotronik Estella SR-T (Biotronik SE, Berlin, Germany)], and three different types and manufacturers of ICD [Medtronic Secura DR (Medtronic), Boston Scientific Teligen 100 (Boston Scientific), and Biotronik Lumax 540 VR-T DX (Biotronik SE), were included in the study (Fig. 1). The new electrode leads with normal insulation were Capsure Fix MRI 5086 (Medtronic) for the PMs and Sprint 6932 (Medtronic) for the ICDs. The electrode leads with deteriorated insulation were 5038 VDD (Medtronic) for the PMs and Sprint Fidelis 6949 (Medtronic) for the ICDs. Bipolar electrode leads were employed in all the experiments.

The study was performed with a simulated model made of Forex (Airex AG, Sins, Switzerland), a plastic derived from expanded polyvinyl chloride (PVC). The model reproduced a number of life-size anatomic structures of reference, such as the thorax, neck, and lower jaw. It was filled with a solution of 0.4% saline in order to obtain an electrical impedance similar to that in the human body. The CIEDs were placed with their electrode leads in positions corresponding to where these leads would be placed in vivo (Fig. 1A,B).

The following variables were taken into consideration: application distance (*dA*) and application time (*tA*) of the instruments; dental equipment type; the type and manufacturer of the CIEDs; and the state of the insulation of the electrode leads of the CIEDs: normal (*nI*) vs. deteriorated (*dI*). Insulation abrasion has been reported as a common problem affecting the leads of silicone cardiac implantable devices. Abrasions may occur when a lead is in contact with the pulse generator in the pocket (can abrasion), other leads (lead-to-lead abrasion), other devices (annuloplasty ring), and anatomic structures (clavicle, rib). The implantation procedure through the jugular veins increases the risk of electrode lead bends along the way to the generator and may also eventually induce breaks in its insulation (24, 25).

The dental equipment was set at pulse mode – on/off – in the tests with the variable *dA* in order to test the most critical phases of the CIEDs that occur when these devices are switched on and off. In the tests with the variable *tA*, the instruments were continuously set at the 'on' mode. In all testing the dental equipment was set at maximum potency and the CIEDs were programmed to maximum sensitivity mode.

A positive control – direct contact of an electrosurge with a CIED – which always induced electromagnetic interference, was established. The negative control corresponded to the normal functioning of the CIEDs, as reflected in their corresponding electrocardiography register.

The experiments with the variable *dA* were performed with electrode lead insulation in normal (*dAnI*) and deteriorated (*dAdI*) conditions. The tests for *dAnI* were carried out at 20 cm from the PM/ICD, at 1 cm from the PM/ICD, and at 1 cm from the electrode tip (1 cm ET). The tests for the *dAdI* were the same as for the *dAnI* with an additional test at 1 cm from the deteriorated insulation region (1 cm Fx). The experiments with the variable *tA* were also performed with the electrode lead insulation in normal (*tAnI*) and deteriorated (*tAdI*) conditions. In both cases there was continuous application of the instrument for 10 s at 20 cm from the PM/ICD. In the tests where electromagnetic interference was observed, the time period of application was increased to 60 s. All tests were carried out three times for each of the dental instruments studied, in agreement with the principles of Repeatability for the Validation for Analytical Procedures (26), providing a final total of 972 tests/observations.

All tests were monitored with specific telemetry connections for each CIED: Carelink Programmer – Model 2090 (Medtronic), Zoom Latitude 3120 (Boston Scientific), and Renamic (Biotronik SE). The electrocardiography results were printed and evaluated with the assistance of an electrophysiologist (Fig. 1C). Data from each test were registered as binary, according to whether or not interference was produced, the class of electromagnetic interference, and its category (degree of severity). For the PMs/ICDs, the electromagnetic interference categories were: electrical noise, electrical reset, deprogramming, and short- and

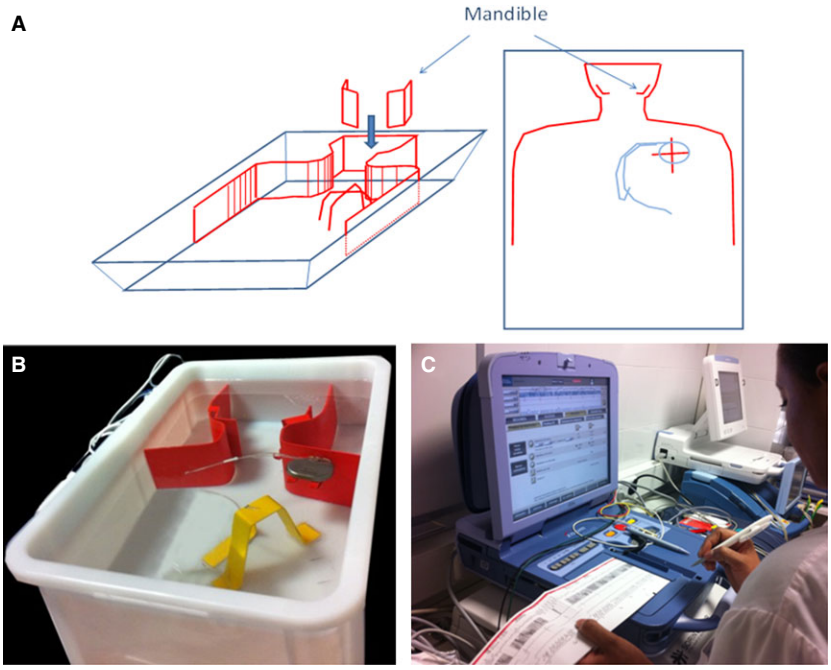

Fig. 1. (A) Diagram showing the simulated model in which the implants with cardiac activity were positioned for the in vitro experiments. (B) Simulated model with the cardiac implantable electrical device (CIED) and its corresponding electrode lead positioned to reproduce the situation in vivo. (C) Programmers with telemetry connections used to monitor the behavior of each CIED model during the study.

long-lasting stimulation inhibition. Inappropriate discharge was considered as electromagnetic interference exclusively for the ICDs and was a consequence of a false signal incorrectly interpreted as an arrhythmia. Classification of the severity of the observed interference was determined by an electrophysiologist with respect to possible clinical repercussions: *absence*, no interference; *light*, electrical noise or reset; *moderate*, deprogramming; *severe*, short-lasting stimulation inhibition (≤3 pacings); and *very severe*, inappropriate discharge and long-lasting stimulation inhibition (>3 pacings).

Statistical analysis was performed using the chi-square test or Fisher's exact test, as appropriate. The level of statistical significance for all the tests was $P < 0.05$. In the case of double interference, only the most severe one was taken into consideration, in order to avoid errors and redundant data.

Results

Dental equipment variable

During analysis of the dental instruments, all, at some time, showed the capacity to induce electromagnetic interference in the CIEDs. With respect to the severity of the interference, significant differences were observed among the different instruments tested ($P < 0.001$). In the *light* and *moderate* categories the greatest amount of electromagnetic interference was triggered by the electrosurge. In the *severe* category, however, it was the electric pulp tester that caused the most electromagnetic interference (Table 1).

Distance of application variable (*dA*)

With respect to the *dA*, the quantity of interference induced in the CIEDs was statistically significant for all the dental equipment ($P < 0.001$).

For the ICDs, the electric pulp tester and ultrasonic piezoelectric dental scaler displayed significant differences in the amount of electromagnetic interference induced according to the distance of application ($P < 0.001$) and ($P = 0.002$), respectively. The electronic apex locator, electrosurge, Osstell ISQ, and Periotest M did not, however, present significant differences for this variable ($P > 0.05$). The greatest amount of electromagnetic interference was produced 1 cm from the area where the electrode lead insulation had deteriorated (1 cm Fx) ($P < 0.001$) (Table 2).

In the case of PMs, the electric pulp tester ($P < 0.001$), Osstell ISQ ($P = 0.001$), Periotest M ($P = 0.003$), and ultrasonic piezoelectric dental scaler ($P = 0.005$) displayed significant differences in the amount of electromagnetic interference induced, according to the distance of application. However, the electronic apex locator and electrosurge did not ($P > 0.05$). A significantly greater quantity of electromagnetic interference was associated with a distance of 1 cm from the electrode tip (1 cm ET) ($P < 0.001$) (Table 2).

The distance between the CIED, located in the infraclavicular region, and the oral cavity is generally about 20 cm. At this distance only two electric noises (electromagnetic interference *light* category), which

Table 1

Electromagnetic interference category of severity adjusted according to the dental equipment tested

	Degree of severity													
	Light			Moderate			Severe			Very severe			Total		
Dental equipment	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**
EPT	18	12.4		0	0.0		33	49.25		0	0.0		51	23.7	
EAL	15	10.3		0	0.0		0	0.0		0	0.0		15	6.97	
OT	33	22.8		0	0.0		6	8.96		0	0.0		39	18.14	
ES	37	25.5	<0.001	3	100.0	<0.001	16	23.88	<0.001	0	0.0	<0.001	56	26.04	<0.001
PT	18	12.4		0	0.0		6	8.96		0	0.0		24	11.2	
UDS	24	16.6		0	0.0		6	8.96		0	0.0		30	13.95	
Total	145	100.0		3	100.0		67	100.0		0	0.0		215	100.0	

EAL, electronic apex locator; EPT, electric pulp tester; ES, electrosurge; OT, Osstell ISQ; PT, Periotest M; UDS, ultrasonic dental scaler.
**P* value (Fisher's exact test).
†% total interference according to degree of severity

were induced by electrosurge, were reported in PMs. For the ICDs, 24 electric noises were observed (electromagnetic interference *light* category), which were induced by various dental instruments (Table 2).

Time of application variable (*tA*)

In the analysis of *tA*, it was observed that lengthening the time from 10 s to 60 s did not modify the amount of electromagnetic interference for any of the CIEDs ($P = 1.000$), a result that was reported for both normal ($P = 1.000$) and deteriorated ($P = 1.000$) electrode lead insulation.

Type of CIED variable (PM vs. ICD)

In the analysis of the type of CIED variable with respect to interference and its degree of severity, overall the ICDs presented the greatest amount ($P < 0.001$) and the largest number of electromagnetic interference in the category *light* ($P < 0.001$). The PMs, however, displayed the greatest amount of *moderate* and *severe* interference ($P < 0.001$) (Table 3).

Manufacturer of CIED variable

In the analysis of the different manufacturers of CIEDs, significant differences were observed for electromagnetic interference ($P < 0.001$). In the PMs the number of interferences were 75 for Boston Scientic, 38 for Biotronik, and 24 for Medtronic, and, in the ICDs, were 114 for Boston Scientic, 18 for Medtronic, and 15 for Biotronik ($P < 0.001$) (Table 4).

Electrode lead insulation integrity (*nI* vs. *dI*) variable

In the analysis of the electrode lead insulation integrity variation (normal vs. deteriorated) statistical significance was globally observed in the number of interferences ($P < 0.001$), with higher electromagnetic interference values when the insulation was deteriorated. Significant differences were also reported when the variable *nI* vs. *dI* was evaluated with respect to *dA* ($P < 0.001$) and *tA* ($P = 0.032$), again with higher electromagnetic interference values for deteriorated insulation.

Discussion

Pacemakers and ICDs are sensitive to external electromagnetic interference. In spite of the fact that the smaller, present-day CIEDs have better protective characteristics, their normal function can be affected by some electronic dental instruments that emit electromagnetic waves (5).

To the best of our knowledge, no previous studies have evaluated the electromagnetic interferences induced by either the Osstell ISQ or the Periotest M. Most dental research has been focused on electronic apex locators, ultrasonic dental scalers, electrosurge instruments, and electric pulp testers (8, 11, 12, 27–36). In reference to the electric pulp tester, the first in vivo study, performed by Woolley *et al.* (27), reported that this instrument provoked electromagnetic interference in PMs. Some authors observed that electric pulp testers did not induce electromagnetic interference in PMs (28, 30). More recently, Wilson *et al.* (34) stated that electric pulp testers did not induce any kind of interference in vivo in the ICDs and PMs studied. In our work, the electric pulp tester was the instrument that triggered the greatest number of interferences in PMs and ICDs, and was also the device that caused the most *severe* electromagnetic interferences. After analyzing the discrepancies in these published studies we are of the opinion that they could be because an in vivo model was used in contrast to an in vitro one. It can be difficult with in vivo studies to carry out certain specific situations that are easily reproducible in an in vitro experimental model. Therefore, the model chosen for our in vitro study could explain the increased electromagnetic interference in the CIEDs.

The capacity of ultrasonic dental scalers to interfere with CIEDs has been widely studied by several authors.

Table 2

Electromagnetic interference adjusted according to application distance and dental equipment

Device and distance	Dental equipment															
	EPT			EAL			OT			ES			PT			UDS			Total		
	n	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**
ICD																					
20 cm ICD	3	9.1	<0.001	3	25.0	0.773	6	28.6	1.000	6	22.2	0.068	3	25.0	0.725	3	16.6	0.002	24	19.51	<0.001
1 cm ICD	6	18.2		3	25.0		6	28.6		6	22.2		3	25.0		3	16.6		27	21.95	
1 cm Fx‡	15	45.4		3	25.0		3	14.3		9	33.3		3	25.0		9	50.0		42	34.14	
1 cm ET§	9	27.3		3	25.0		6	28.6		6	22.2		3	25.0		3	16.6		30	24.40	
PM																					
20 cm PM	0	0.0	<0.001	0	0.0	nc	0	0.0	0.001	2	5.0	0.766	0	0.0	0.003	0	0.0	0.005	2	1	<0.001
1 cm PM	12	25.0		0	0.0		12	66.6		15	37.5		6	40.0		3	20.0		48	35.30	
1 cm Fx‡	18	37.5		0	0.0		3	16.6		6	15.0		6	40.0		3	20.0		36	26.47	
1 cm ET§	18	37.5		0	0.0		3	16.6		17	42.5		3	20.0		9	60.0		50	36.76	

EAL, electronic apex locator; EPT, electric pulp tester; ES, electrosurge; ICD, implantable cardioverter defibrillator; nc, not calculated; OT, Osstell; PM, pacemaker; PT, Periotest M; UDS, ultrasonic dental scaler.

**P* value (Fisher's exact test).

†Percentage total interference for the dental instrument and ICD/PM.

‡1 cm from the area of the electrode insulation fracture.

§1 cm from the electrode tip.

Zappa *et al.* (30) did not report in vivo interference from an ultrasonic dental scaler on PMs. Patel *et al.* (33) concluded that an ultrasonic dental scaler could be employed with the patients fitted with a PM included in their study. In agreement with this finding, our research showed that, at a clinical distance of application (20 cm), no electromagnetic interference was recorded for the ultrasonic dental scaler with the tested PMs. In contrast, Miller *et al.* (31) reported in vitro the presence of electromagnetic interference with the use of an ultrasonic dental scaler in uni- and bipolar PM groups. Adams *et al.* (29) specified that they had detected interference only when the ultrasonic dental scaler handpiece was at a distance of 6 cm or less from the PM electrode leads. We also observed electromagnetic interference when the ultrasonic dental scaler application distance was up to 1 cm from the PM, and up to 1 cm from the area where the electrode lead insulation had deteriorated.

In contrast, electromagnetic *slight* interferences were reported for ICDs, even at clinical application distances (20 cm). Roedig *et al.* (36) evaluated in vitro the effects of various dental instruments on PMs and ICDs and observed that ultrasonic dental scaler induced interference in all the CIEDs studied. They also reported that interference generally occurred close to the generator, especially when near the electrode leads. In our in vitro study no differences between applications at 1 cm from the generator vs. 1 cm from the electrode tip were observed. Recent in vivo research, conducted by Maiorana *et al.* (8), led to the conclusion that ultrasonic dental scaler did not interfere with the ICDs tested. In our study, this equipment triggered interference in the PMs and ICDs, particularly when applied near the deteriorated areas of the electrode lead insulation or the electrode tip. In 2000, the American Academy of Periodontology established clinical guidelines for ultrasonic dental scalers, recommending that they should not be employed in patients with PMs (37). However, these criteria were revoked in 2007 and, at present, there are no guidelines concerning their use in patients with a PM. Scientific evidence suggests that normal clinical use of this dental ultrasonic equipment has no effect on CIEDs (8, 29, 32, 33, 35, 38). In our study, the ultrasonic dental scalers, at a clinical distance of application (20 cm), only produced *light* electromagnetic interference in the ICDs.

The electrosurge has been tested in several studies. Woolley *et al.* (27) reported that electrosurge provoked electromagnetic interference in PMs in vivo. In contrast, Brand *et al.* (35), in an in vitro study with electromagnetic equipment, including the electrosurge, concluded that the instruments tested did not emit any electromagnetic interferences of risk for the CIEDs analyzed. Other authors confirm these results (30). It should be recognized that, in our study, the electrosurge triggered electromagnetic interference in both types of CIEDs, particularly in the PMs, and above all when applied at 1 cm from the generator or 1 cm from the electrode tip. Indeed, the manufac-

Table 3

Electromagnetic interference severity categories adjusted according to the type of cardiac implantable electrical device (CIED) analyzed

	Degree of severity														
	Light			Moderate			Severe			Very severe			Total		
CIED	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**
PM	28	19.3		3	100.0		52	77.6		0	0.0		83	38.6	
ICD	117	80.7	<0.001	0	0.0	<0.001	15	22.4	<0.001	0	0.0	<0.001	132	61.4	<0.001
Total	145	100.0		3	100.0		67	100.0		0	0.0		215	100.0	

CIED, cardiac implantable electrical device; ICD, implantable cardioverter defibrillator; PM, pacemaker.
**P* value (Fisher's exact test).
†% total of interference according to degree of severity.

turer, Boston Scientific, does warn that certain precautions must be taken during the use of an electrosurge in order to minimize the risk of interference (39).

There are various publications which make reference to the possible effects of the electronic apex locator on PMs and ICDs. Garofalo *et al*. (32), in their in vitro study, concluded that electronic apex locator could be used without risk in patients with PMs. Patel *et al*. (33) concluded that electronic apex locator could be employed with patients fitted with a PM who were included in their study. In similar manner, Wilson *et al*. (34) observed in vivo that electronic apex locator did not induce any kind of interference on the PMs and ICDs studied. More recently, Gomez *et al*. (11) reported that electromagnetic interference only occurs in vitro when the electronic apex locators are applied close to the electrode tip, and occasionally near PMs. Idzahi *et al*. (12), in their in vitro research, did not find any interference from the electronic apex locators on the ICDs studied. According to our results, the electronic apex locator is also considered to be a safe instrument when used at a clinical application distance (20 cm).

Publications comparing PM and ICD behavior with respect to electronic dental equipment are scarce (36). In our in vitro study, the ICDs displayed a greater quantity of *light* electromagnetic interference, whereas that presented by the PMs was *moderate* and *severe*. In this respect, Pinski *et al*. (40) affirmed that the ICDs have greater sensitivity as they are designed for early detection of ventricular tachyarrhythmia, which would account for the higher electromagnetic interference in our findings.

Regarding classification of interference, some authors agreed to categorize the severity of each stimulation inhibition according to the PM dependence and the duration of this induced inhibition on CIEDs (1, 41). In our study, short-lasting stimulation inhibitions (≤ 3 pacings) were classified in the *severe* category. On the other hand, long-lasting stimulation inhibitions (>3 pacings) were classified in the *very severe* category.

Table 4

Electromagnetic interference adjusted according to the cardiac implantable electrical device (CIED) manufacturers analyzed

	Electromagnetic interference variable																	
	Elec. noise			Elec. reset			Deprogram.			Sti. inhibition			Inap. disc‡			Total		
Manufacturer	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**	*n*	%†	*P**
Global																		
Biotronik	28	9.9	<0.001	0	0.0	nc	3	11	0.110	22	7.7	0.401	0	0.0	nc	53	18.7	<0.001
Boston	162	57.0		0	0.0		0	0.0		27	9.5		0	0.0		189	66.5	
Medtronic	24	8.5		0	0.0		0	0.0		18	6.3		0	0.0		42	14.8	
PM																		
Biotronik	19	6.7	<0.001	0	0	nc	3	1.1	0.110	16	5.6	<0.005	–	–	–	38	13.4	<0.001
Boston	48	16.9		0	0		0	0		27	9.5		–	–		75	26.4	
Medtronic	15	5.3		0	0		0	0		9	3.2		–	–		24	8.5	
ICD																		
Biotronik	9	3.2	<0.001	0	0	nc	0	0	nc	6	2.1	<0.004	0	0	nc	15	5.3	<0.001
Boston	114	40.1		0	0		0	0		0	0		0	0		114	40.1	
Medtronic	9	3.2		0	0		0	0		9	3.2		0	0		18	6.4	

Deprogram., deprogramming; Elec., electrical; EMI, electromagnetic interference; ICD, implantable cardioverter defibrillator; Inap. disc, inappropriate discharge; nc, not calculated; PM, pacemaker; Sti. inhibition, stimuation inhibition.
**P* value (Fisher's exact test).
†% according to total EMI ($n = 284$).
‡EMI inappropriate discharge was found only in the ICDs.

It has been reported, by some researchers, that insulation abrasion is a common problem affecting the silicone electrode leads of CIEDs (24, 25). According to our results, the state of insulation of the electrode lead was a variable that had a considerable effect on the amount of electromagnetic interference registered; deterioration increased the quantity of electromagnetic interference.

For in vitro experimental protocols, a bucket filled with a saline solution that has had its impedance adjusted to human body values is generally used (11, 12, 31, 35, 36). In our study, however, in order to achieve conditions close to those found in vivo, a simulated model was designed. Moreover, material that reproduced some life-size anatomic structures of reference (thorax, heart, neck, and mandible) was employed, which permitted the correct positioning of the CIEDs and their electrode leads.

With reference to the effective in vivo reproducibility of in vitro results, some authors have stated that, first and foremost, electric and magnetic fields decrease inversely with the square of the distance from the source (2). Moreover, the surrounding body tissues further shield the device from electromagnetic interference (38). In our study we reproduced human body features; nevertheless, in vivo tissues, such as skin, fat, muscle, bone, and teeth, may additionally hinder the conduction of electromagnetic currents. It is therefore probable that under in vivo conditions there is less electromagnetic interference induced by electric pulp tester, electronic apex locator, ultrasonic dental scaler, unipolar electrosurge, Osstell ISQ and Periotest M, particularly in heavily built patients or in those with a high body mass.

Roedig *et al*. (36) acknowledged that a limitation of their research was to have studied only one PM/ICD manufacturer. Dodinot *et al*. (42) observed differences between PMs produced by different manufacturers and concluded that the PM produced by Medtronic was the most resistant with respect to electromagnetic interference. In our study, differences in electromagnetic interference were observed in the CIEDs according to their manufacturer; those with the lowest electromagnetic interference were the PMs and ICDs produced by Medtronic and Biotronik, respectively.

In summary, our in vitro model permitted a precise reproduction of in vivo conditions for the experiments performed. The possibility of carrying out extreme tests near the CIEDs and the electrode tips demonstrated that under certain conditions some dental equipment can trigger electromagnetic interference in PMs and/or ICDs. Our results show that at a clinical application distance (20 cm), the electronic dental equipment tested only provoked *light* interference (electric noise) in the CIED examined, irrespective of manufacturer. Therefore, we can conclude that the dental instruments analyzed in our study may be used in clinical dentistry for patients with PMs and ICDs. This study could be of help in redefining standards and guidelines concerning the use of electronic dental equipment in patients with cardiac implanted electrical devices.

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