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CLINICAL RESEARCH

High-power chargers for electric vehicles: are they safe for patients with pacemakers and defibrillators?

Carsten Lennerz [1,2]*, Claudia Schaarschmidt [1], Patrick Blažek [1], Katharina Knoll [1,2], Marc Kottmaier [1,2], Tilko Reents [1], Felix Bourier[1], Sarah Lengauer[1], Miruna Popa [1], Katharina Wimbauer [1], Fabian Bahlke [1], Hannah Krafft [1], Florian Englert [1], Lena Friedrich [1], Heribert Schunkert [2,3], Gabriele Hessling[1], Isabel Deisenhofer [1], Christof Kolb[1], and Matthew O'Connor [4]

[1]German Heart Centre Munich, Department of Electrophysiology, Technical University of Munich, Lazarettstr. 36, 80636 Munich, Germany; [2]DZHK (German Centre for Cardiovascular Research) partner site Munich Heart Alliance, Pettenkoferstr. 8a & 9, 80336 Munich, Germany; [3]German Heart Centre Munich, Technical University of Munich, Lazarettstr. 36, 80636 Munich, Germany; and [4]Cardiology Department, Auckland City Hospital, 2 Park Road, Grafton, 1023 Auckland, New Zealand

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Aims Battery electric vehicle (BEV) sales and use are rapidly expanding. Battery electric vehicles, along with their charging stations, are a potential source of electromagnetic interference (EMI) for patients with cardiac implantable electronic devices (CIEDs). The new 'high-power' charging stations have the potential to create strong electromagnetic fields and induce EMI in CIEDs, and their safety has not been evaluated.

Methods and results A total of 130 CIED patients performed 561 charges of four BEVs and a test vehicle (350 kW charge capacity) using high-power charging stations under continuous 6-lead electrocardiogram monitoring. The charging cable was placed directly over the CIED, and devices were programmed to maximize the chance of EMI detection. Cardiac implantable electronic devices were re-interrogated after patients charged all BEVs and the test vehicle for evidence of EMI. There were no incidences of EMI, specifically no over-sensing, pacing inhibition, inappropriate tachycardia detection, mode switching, or spontaneous re-programming. The risk of EMI on a patient-based analysis is 0/130 [95% confidence interval (CI) 0%–2%], and the risk of EMI on a charge-based analysis is 0/561 (95% CI 0%–0.6%). The effective magnetic field along the charging cable was 38.65 μT and at the charging station was 77.9 μT.

Conclusions The use of electric cars with high-power chargers by patients with cardiac devices appears to be safe with no evidence of clinically relevant EMI. Reasonable caution, by minimizing the time spent in close proximity with the charging cables, is still advised as the occurrence of very rare events cannot be excluded from our results.

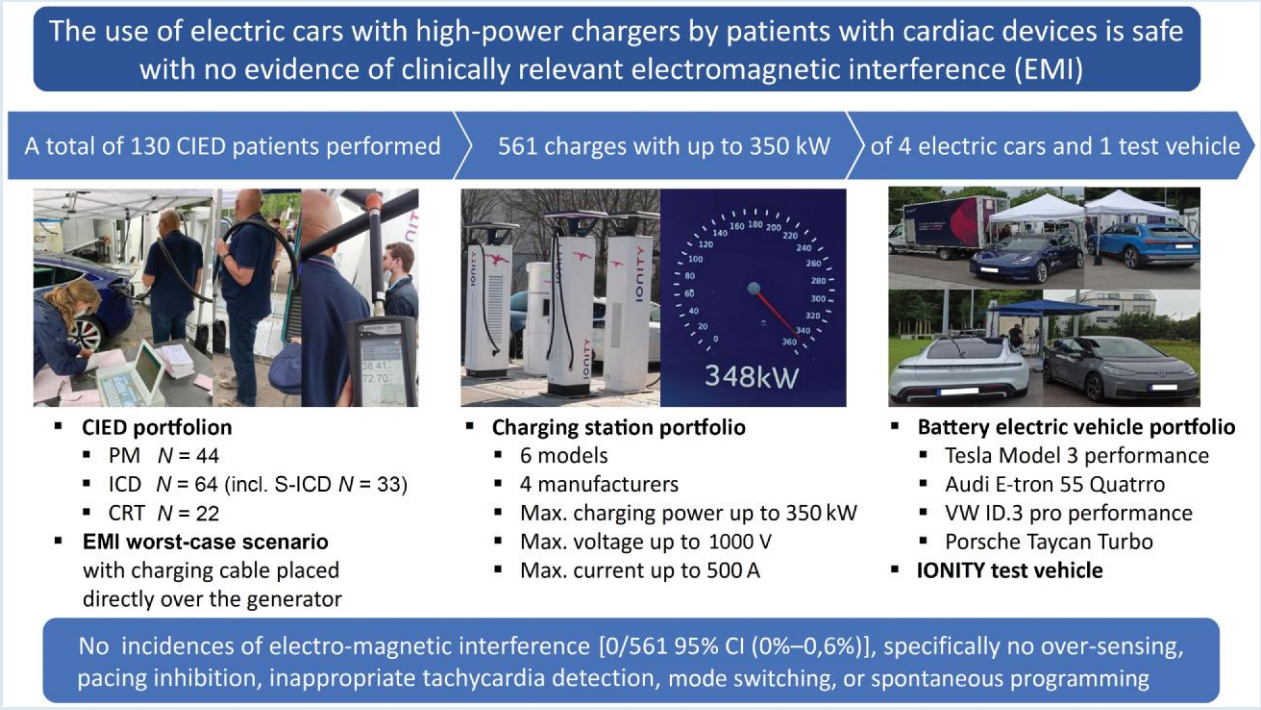
* Corresponding author. Tel: +49 (0)89 1218 2947; fax: +49 (0)89 1218 4593, *E-mail address*: lennerz@dhm.mhn.de

Structured Graphical Abstract

Key question: New high-power charger technology has increased charge speed for electric cars; the high current has potential to cause electromagnetic interference (EMI) in cardiac implantable electronic devices (CIEDs). This study evaluates the risk associated with high-power charger use by patients with CIEDs.

Key finding: A total of 130 patients with CIEDs representative of current devices and leads performed 561 car charging events using six different charging stations, four different commercially available BEVs and a test vehicle. There were no episodes of EMI detected and no spontaneous reprogramming, pacing inhibition, or inappropriate tachycardia detection.

Take-home message: New high-power charger technology appears to be safe for patients with CIEDs to use, and no specific restrictions should be placed on their use.



Keywords Cardiac implantable electronic device • Electromagnetic interference • Electric cars • High-power chargers • Pacemaker • Implantable cardioverter defibrillator

What's new

- This is the first assessment of electromagnetic interference between high-power charging of electric cars and cardiac implantable electronic devices.
- A variety of high-power charging stations and modern battery-electric vehicles were used by monitored CIED patients.
- There were no episodes of electromagnetic interference detected and no spontaneous reprogramming, pacing inhibition, or inappropriate tachycardia detection.
- New high-power charger technology appears safe for patients with CIEDs to use, and no specific restrictions should be placed on their use.

Introduction

Cardiac implantable electronic devices (CIEDs) including pacemakers (PMs), implantable cardioverter defibrillators (ICDs), and cardiac resynchronization therapy (CRT) systems are the primary treatment or common adjuncts to treatment of arrhythmias or heart failure respectively and have an increasing prevalence.[1–3] Previous studies have demonstrated that CIEDs are vulnerable to electromagnetic interference (EMI) that can result in spontaneous device reprogramming, mode switching, pacing inhibition, or inappropriate tachycardia detection/therapy.[4–7]

The electromagnetic field created by an electrical device has the potential to cause EMI. The electromagnetic field can induce current in the CIED circuits, and this can be sensed by the CIED and erroneously attributed to intra-cardiac signals. The risk of EMI is related to the strength of the electric and the magnetic field. The magnetic field itself is proportional to the electric current source as determined by Ampere's law. Thus, with a greater charging current, there will be a stronger magnetic field there and a subsequent higher risk of EMI. The underlying principle is that the motor's rotational speed is proportional to applied voltage and torque is proportional to current drawn. Car manufacturers optimize current and voltage to maximize power, speed, and torque. Car design represents a compromise between maximal tolerated current and voltage. Electric motors used in full electric cars (eCars) are high-powered; the cars used in our study provide up to 500 kW.

Electromagnetic interference detection algorithms and device shielding reduce the risk of clinical EMI, but events do still occur and it is important to identify and evaluate new potential sources of EMI.[8,9] The recent study on the risk associated with the Apple iPhone 12 (and other products that contain magnets) highlights that new technologies can pose such a risk to patients and that this is a significant source of anxiety or uncertainty for CIED patients.[10,11]

The use of eCars, also known as battery electric vehicles (BEVs), has grown exponentially over the last 5 years, and they represent a potential source of EMI. One of the limitations in the uptake of BEVs was the long charge time required; however, this has been addressed with the development of high-power charger stations facilitating higher current delivery to rapidly charge a BEV battery. Our group has previously studied BEV use by CIED patients and found no incidence of EMI in 108 patients.[12] During this study, the strongest magnetic field was detected along the charging cable. At the time of that study, the fastest charging car (with the largest current flow and thus electromagnetic field) was a Tesla Model S P85 utilizing 22 kW. Newer high-power chargers are capable of more rapidly charging BEVs; they utilize DC power and can deliver 300–350 kW. As the charging current is directly proportional to the magnetic field, the high-power chargers have the potential to cause clinically relevant EMI.[12,13]

The purpose of our study was to evaluate the potential EMI risk posed by these high-power chargers.

Methods

Consecutive patients attending for routine device follow up between January 2020 and June 2021 were asked for general interest in the study. All transvenous devices including PMs, CRT devices, and ICDs including subcutaneous ICDs (S-ICDs) were eligible for inclusion. Exclusion criteria included leadless PM, suspected lead malfunction, estimated battery longevity <3 months, or intrinsic heart rate >120 bpm. Volunteers were invited to the IONITY test site and taking part in the study from June 2021 till July 2021.

Four BEVs, capable of high-power charging, were used during the study (Porsche Taycan Turbo, VW ID3 pro performance, Tesla Model 3 Performance and Audi E-tron 55 Quattro). In addition, an IONITY test vehicle that can facilitate a 350 kW charge was also used. These BEVs were chosen as they are fully electric and compatible with use of high-power chargers. The performance and charging details of the test cars are detailed in *Table 1*. Six common high-power charging stations were used capable of delivering 300–350 kW. As the current delivered is inversely proportional to the state of charge of the battery at the end of each test day, each BEV was driven until the battery charge was <20%. The actual current delivered during each charge was measured for each BEV during each charge (see Supplementary material online, *Table S1*). Measurement of the electric and magnetic fields were undertaken along the charging cable and at the charging column and are presented as root mean square (RMS). Details of the charging columns and probes used are in *Appendix 1*.

A complete device interrogation was undertaken before reprogramming to maximize the chance of EMI detection as previously published.[12] In short, ventricular pacing was ensured by shortening AV delays and increasing the base rate. Tachycardia detection algorithms were set to the minimal number of intervals, and anti-tachycardia therapies were disabled. During the study, patients were continuously monitored with 6-lead electrocardiogram (ECG), and two cardiologists independently evaluated the recordings for any evidence of EMI such as inappropriate pacing inhibition, upper rate tracking, loss of capture, or spontaneous mode switching.

Table 1 Technical specification of the tested BEV

Battery electric car	Porsche Taycan Turbo	Tesla Model 3 performance	Audi E-tron 55 Quattro	VW ID.3 pro performance	Test vehicle
Power unit					
Maximum power (KW)	500	413	300	150	—
Maximum power (PS)	680	562	408	204	—
Maximum torque (Nm)	850	660	664	310	—
Range[a] (km)	452	567	417	427	—
Charging					
Battery capacity (gross) (kWh)	93.4	82.0	95.0	62.0	—
Battery capacity (net) (kWh)	83.7	76.0	86.5	58.0	—
Maximum charging power (kW)	262	250	155	130	350
Charging time[b]					
from 10% to 80% (min)	19	25	26	30	—
Performance					
top speed (km/h)	260	261	200	160	—
acceleration 0–100 km/h (s)	3.2	3.3	5.7	7.3	—
Consumption[c]					
Electrical consumption combined (kWh/100 km)	23.9–17.8	19.5–13.9	27.5–21–1	19.7–14.5	—
Electrical consumption city (kWh/100 km)	20.9–14.4	17.1–11.2	23.7–16.6	17.1–11.3	—

Source: https://ev-database.de
[a]WLTP Worldwide harmonized Light vehicles Test Procedure.
[b]CCS (350 kW DC).
[c]Winter—summer.

Figure 1 Illustration of the charging procedure, as a worst-case scenario the participants positioned the charging cable in close proximity to the CIED. Charging of four representative full battery electric cars: (*A*) Porsche Taycan Turbo, (*B*) Tesla Model 3 performance, (*C*) VW ID.3 pro performance, and (*D*) Audi E-tron 55 Quattro. CIED, cardiac implantable electronic device.

Table 2 Patient and device characteristics

Patient	
Total number	130
Men	103 (79%)
Age (years)	59 ± 18
Indication	
Indication for anti-bradycardia therapy (PM)	45 (35%)
Sinus-node dysfunction	13 (10%)
Atrioventricular block[a]	32 (25%)
Indication for anti-tachycardia therapy (ICD)	85 (65%)
Primary prevention of SCD	35 (27%)
Secondary prevention of SCD	50 (38%)
Pacing mode	
AAI	2 (2%)
VVI or VVIR	23 (18%)
VVIRV	1 (1%)
DDD or DDDR	49 (38%)
DDD0V or DDDRV	20 (12%)
VDD	1 (1%)
VDD0V	1 (1%)
0D0	33 (25%)

Values are given as number with percentage in parentheses except age.
ICD, implantable cardioverter defibrillator; PM, pacemaker; SCD, sudden cardiac death.
[a]Including patients with combined sinus node and atrioventricular node dysfunction.

Every patient plugged in the charging cable and commenced charging of each of the four test BEVs and the IONITY test vehicle. The charging cable was placed over CIED to mimic a 'worst-case scenario' and maximize the chance of EMI occurrence (*Figure 1*). After charging all four BEVs and the IONITY test vehicle, the CIED was interrogated to ascertain if there had been any spurious tachycardia detection or mode switching. At conclusion of the study, the CIED programming was returned to pre-study settings.

This study was approved by the local ethics committee and complies with the declaration of Helsinki. The study was registered at ClinicalTrials.gov with the identifier NCT05361681.

Statistical analysis

Based on our previous work, we estimated the prevalence of EMI could be up to 3.4%. Hence, we calculated 120 patients were required to observe at least one EMI event with a probability of 95% if the EMI event rate was 2.5%. With an estimated drop-out rate of 7.5%, the target sample size was 130 patients.

Data are presented as numbers and percentage and mean ± standard deviation (SD). Continuous variables are presented as mean and SD with 95% confidence interval (CI). Categorical data are presented in absolute numbers and percentage; percentages may not add up to 100% due to rounding. Comparisons between continuous data were performed using Student's *t*-test. Comparisons between categorical data were performed using the chi-squared test.

Results

A total of 130 patients with a mean age of 59 ± 18 years (79% male) performed 561 charges. The CIEDs tested included 45 PM (35%) and 85 ICDs (65%) of which 33 were S-ICDs representing 25% of the ICDs (*Table 2*). Device indication was primary prevention of sudden cardiac death (SCD) in 38%, secondary prevention of SCD in 27%,

Table 3 CIEDs tested for EMI from charging BEV

Manufacturer	Device	Type of device	Number of devices
Biotronik	Enitra 6 DR	PM-DR	7
	Enitra 8 DR-T	PM-DR	3
	Iforia 5 VR-T DX	ICD-VR	1
	Inlexa 3 DR-T	ICD-VR	1
	Inlexa 3 HF-T	ICD-CRT	2
	Intica 5 HF-T QP	ICD-CRT	1
	Intica 7 HF-T QP	ICD-CRT	1
	Itrevia 5 VR-T	ICD-VR	1
	Lumax 340 VR-T XL	ICD-VR	1
	Lumax 640 VR-T	ICD-VR	1
	Rivacor 3 DR-T ProMRI	ICD-DR	1
	Rivacor 5 HF-T QP ProMRI	ICD-CRT	1
	Altrua 60	PM-DR	1
Boston Scientific	Autogen CRT-D	ICD-CRT	1
	Dynagen VR	ICD-VR	1
	Emblem A209	S-ICD	33
	Essentio MRI EL	PM-DR	1
	Incepta F162	ICD-DR	1
	Ingenio	PM-DR	1
	Inogen CRT-D	ICD-CRT	2
	Inogen VR	ICD-VR	2
	Proponent MRI EL DR	PM-DR	2
	Teligen 100	ICD-DR	1
Medtronic	Adapta L ADDRL1	PM-SR	1
	Amplia MRI Quad	ICD-CRT	1
	Attesta ATDR01	PM-DR	2
	Compia MRI CRT-D	ICD-CRT	1
	Ensura SR MRI	PM-SR	1
	Evera MRI S DR	ICD -DR	6
	Evera MRI S VR	ICD-VR	5
	Primo MRI DR DF4	ICD -DR	3
	Protecta VR	ICD-VR	4
	Sensia SEDRL1	PM-DR	3
	Viva XT CRT-D	ICD-CRT	1
Microport/Sorin	Kora 100 DR	PM-DR	1
	Kora 250 DR	PM-DR	1
	Paradym DR	ICD-DR	1
	Paradym RF CRT	ICD-CRT	1
	Platinium CRT-D	ICD-CRT	1
	Platinium VR	ICD-VR	1
	Reply CRT-P	PM-CRT	1
	Reply DR	PM-DR	3
	Teo DR	PM-DR	1
Abbott/SJM	Accent DR	PM-DR	1
	Accent MRI	PM-VR	1
	Allure MP	PM-CRT	1
	Endurity Core DR	PM-DR	7
	Fortify VR	ICD-VR	2
	Quadra Assura	ICD-CRT	3
	Sustain^{TM} XL DR PM2136	PM-DR	3
	Unify Assura	ICD-CRT	3
	Verity^{TM} ADx XL DR 5357	PM-DR	1
Vitatron	C20 SR	PM-VR	2

CRT, cardiac resynchronization therapy; ICD, implantable cardioverter defibrillator; PM, pacemaker; SCD = sudden cardiac death.

AV block in 25%, and sinus node dysfunction in 10%. A wide range of devices were represented in our study including 53 distinct devices from six different manufactures (*Table 3*). Similarly, a wide variety of leads were included in the study (*Table 4*). Lead location and sensing programming are detailed in *Appendix 2*. Details of the number of charges performed on each BEV with each high-power charger are shown in *Table 5*.

The maximal magnetic field (H-field) along the charging cable and at the charging system connector (connection to the BEV) was 38.65 μT RMS and at the charging station (at the point at which the charging cable leaves the charging user unit) was 77.9 μT (*Figure 2*). The maximal electric field (E-field) along the charging cable was 74.33 V/m RMS and 281.7 V/m peak. The charge delivered for each car varied depending on the battery's state of charge; for the Porsche Taycan, Tesla Model 3, and VW ID3, the charge delivered was inversely related to the state of charge, but for the Audi E-tron and the IONITY test vehicle, the charge delivered was independent of the state of charge (*Figure 3* and Supplementary material online, *Table S1*). The charge delivered was greatest with the IONITY test vehicle at 350 kW followed by the Tesla at 190 kW with a state of charge <20%.

There were no episodes of EMI detected; specifically, there were no episodes of pacing inhibition, over-sensing, spurious tachycardia detection, or spontaneous device reprogramming. Thus, the risk of EMI on a patient-based analysis is 0/130 (95% CI 0%–2%), and the risk of EMI on a charge-based analysis is 0/561 (95% CI 0%–0.6%).

Discussion

To our knowledge, this is the first study to evaluate the risk of EMI for patients with CIEDs during the use of high-power charging stations for BEV. Our data did not show any evidence of EMI during plugging in or charging of BEV. A wide range of device and lead models were represented, which allows for generalization of our results. However, the number of any specific device investigated was low, and thus we cannot

Table 4 Leads tested for EMI from charging BEV

Manufacturer	Lead	Position	Number of leads
Biotronik	Corox ProMRI OTW-S BP	LV	1
	Linox Smart ProMRI S 65	RV	4
	Plexa ProMRI S 65	RV	3
	Plexa S DX 65/17	RV	2
	Plexa SD 65/16	RV	1
	Protego ProMRI S65	RV	2
	Sentus ProMRI OTW QP	LV	2
	Sentus ProMRI OTW QP	LV	1
	Setrox S 60	RV	2
	Siello S 53	RA	9
	Siello S 60	RV	2
	Solia S 53	RA	12
	Solia S 60	RV	7
Boston Scientific	3401	subcutaneous	13
	3501	subcutaneous	16
	Acuity × 4 4671	LV	1
	Easytrak II 4518	LV	1
	Endotak Reliance 0138	RV	1
	Endotak Reliance 0148	RV	1
	Endotak Reliance 0175	RV	2
	Endotak Reliance 0181	RV	1
	Endotak Reliance 0293	RV	1
	FineLine II Sterox MRI 4459	RV	1
	FineLine II Sterox MRI 4473	RA	1
	Flextend II 4096	RA	1
	Ingevity MRI 7741	RA	2
	Ingevity MRI 7742	RV	1
	Q-TRAK 3010	subcutaneous	4
	Reliance 4-Front 0692	RV	1
	Reliance 4-Front 0693	RV	2
Medtronic	4057	RV	1
	4024 CapSure SP	RV	1
	4074 CapSure Sense	RV	2
	4076 CapSureFix Novus	RA	3
	4092 Capsure SP Novus	RV	5
	4194 Attain OTW	LV	1
	4195 Attain StarFix	LV	1
	4196 Attain Ability	LV	1
	4296 Attain Ability Plus	LV	1
	4298 Attain Performa	LV	1
	5076 CapsureFix Novus MRI	RA + RV	13
	5086 CapsureFix Novus MRI	RA + RV	2
	6931 Sprint Fidelis	RV	1
	6935 Sprint Quattro Secure S	RV	3
	6935 M Sprint Quattro Secure S MRI	RV	9
	6943 Sprint	RV	1
	6944 Sprint Quattro	RV	2

Continued

Table 4 *Continued*

Manufacturer	Lead	Position	Number of leads
	6947 Sprint Quattro Secure	RV	3
	unkown	RV	1
Microport/Sorin Group	Beflex RF45D	RA	3
	Beflex RF46D	RV	2
	Celerity 3D 85	LV	1
	Solia S60	RV	1
	Tilda R53	RA	2
	Vega R52	RA	2
	Vega R58	RV	2
	Vigila 1CR	RV	2
	Vigila 2CR	RV	1
	Volta 1CR	RV	1
St. Jude Medical/Abbott	Durata 7120	RV	1
	Durata 7122	RV	2
	Durata 7122Q	RV	2
	EnPath 1084T	epicardial	2
	IsoFlex Optim 1948	RV	1
	Optisure 210Q	RV	1
	Optisure 220Q	RV	1
	Quartet 1456Q	LV	2
	Quartet 1458QL	LV	2
	QuickFlex 1258T	LV	4
	QuickSite XL 1058T	LV	1
	Riata 1582	RV	1
	Tendril DX 1388T	RA	10
	Tendril MRI LPA1200M	RV	1
	Tendril SDX 1688T	RA	1
	Tendril STS 2088TC	RA + RV	21
Telectronics Encor	n/a	RA + RV	2

LV, left ventricle; n/a, not applicable; RA, right atrium; RV, right ventricle.

Table 5 Overview of charging stations at the test site and number of charging procedures per charging station and electric car

Charging station		Output value			Input value	Charging procedures					
Manufacturer	Model	Max. charging power (kW)	Max. voltage (V) (DC)	Max. current (A)	Supply voltage (V) (AC)	Porsche ($n = 130$)	Tesla ($n = 130$)	Audi ($n = 130$)	VW ($n = 130$)	Dummy ($n = 41$)	Total ($n = 561$)
ABB	Gen2	350	150–920	500	400	42		8			50
ABB	Gen3	350	150–920	500	400	6	78				84
Tritium	Veefil PK	350	200–920	500	480		5	9		41	55
Tritium	ISD	350	200–920	500	480			47			47
PES	HPC 350	350	150–950	500	480	51	5	66	130		252
Alpitroniq	HYC-300	300	1000	500	400	31	42				73

AC, alternating current; DC, direct current; max., maximal.

Figure 2 Illustration of the magnetic field strength at various locations along the charger components [including charging station, charging cable, and CCS connector and the location of the maximum (as RMS values)] for the magnetic field strength. CCS, combined charging system; RMS, root mean square.

exclude very rare events of EMI or that any specific device is at high risk for EMI.

Furthermore, we did not employ real-time wireless EGM monitoring meaning sub-clinical EMI may not have been identified. In a study by Thaker *et al.*,[14] EMI affecting the wireless monitoring itself was found to be common. Thus, the use of real-time EGM monitoring would likely result in an overstatement of the true EMI risk.

The high-power chargers utilize direct current (DC) as opposed to previous low-power chargers that utilized alternating current (AC). Conventional (household) AC chargers thus induced a magnetic field that alternates at 50/60 Hz depending on the country; this can induce discrete electrical signals (harmonics) in electrical wires/devices at specific frequencies.

In our previous work, we demonstrated that the use of conventional AC chargers did not result in clinical EMI; in part, this is likely due to the relatively low-power and magnetic field strength (peak 116.5 μT along the charging cable at the charging station).[12] The high-power chargers operate with 15–100 times higher power. We measured an RMS field strength of 38.65 μT at the charging system connector (a component the driver cannot avoid coming into contact with while connecting the cable to the BEV), resulting in a calculated max peak value of from 50.25 to 137.2 μT. Previously, it has been demonstrated that EMI in PM can occur when the magnetic field strength is only 130 μT with sensitized settings or 300 μT with nominal settings. Despite this, we did not observe any EMI during this current study. Potentially, this can be explained by the high-power chargers using DC and better shielding and different structure of the charging cable (increased thickness and the presence of internal cooling systems). Incidence of spontaneous reprogramming, mode switching, and power on reset could potentially still occur with a DC-induced magnetic field, but we saw no evidence of such EMI in this study.

Home charging of BEV should be considered separately from the high-power charging technology considered here. It uses a far smaller current but utilizes AC rather than DC that has a different risk profile and so generates a different magnetic field. We believe home charging is likely 'safe' with sensible precautions such as not remaining next to the charging cable for extended periods of time.

The BEVs tested are those publicly available that can draw the highest current from the high-power chargers; despite this, they cannot operate at the maximal 350 kW. It is almost certain that future BEV will be able to do so; to address, this we included the use of a test vehicle that can draw 350 kW from the high-power chargers. Unfortunately, only 41 charge tests were able to be performed with the test vehicle before it suffered a fault and could not be used further (see Supplementary material online, *Table S2*). It is highly likely that battery and charging technology will continue to evolve and significant, disruptive changes in this technological sphere will warrant repeat evaluation of the safety for patients with CIEDs.

At the end of each day, the BEVs were driven to reduce their state of charge and facilitate maximal power draw, but during the test days, the state of charge increased between each patient (the IONITY test vehicle maintains its 350 kW and 500 A at all times). Though this resulted in a difference in current drawn during the charge, we believe it is unlikely to have resulted in a clinically relevant difference.

The strongest determinant of the strength of an electromagnetic field is the distance from its source; thus, leadless PM would be exposed to a weaker electromagnetic field than their transvenous counterparts. It is likely that the incidence of EMI would be lower with leadless PM, but as they were excluded from our study, our data cannot be extrapolated to confirm their safety.

Conclusion

The use of eCars with high-power chargers by patients with cardiac devices appears to be safe with no evidence of clinically relevant EMI.

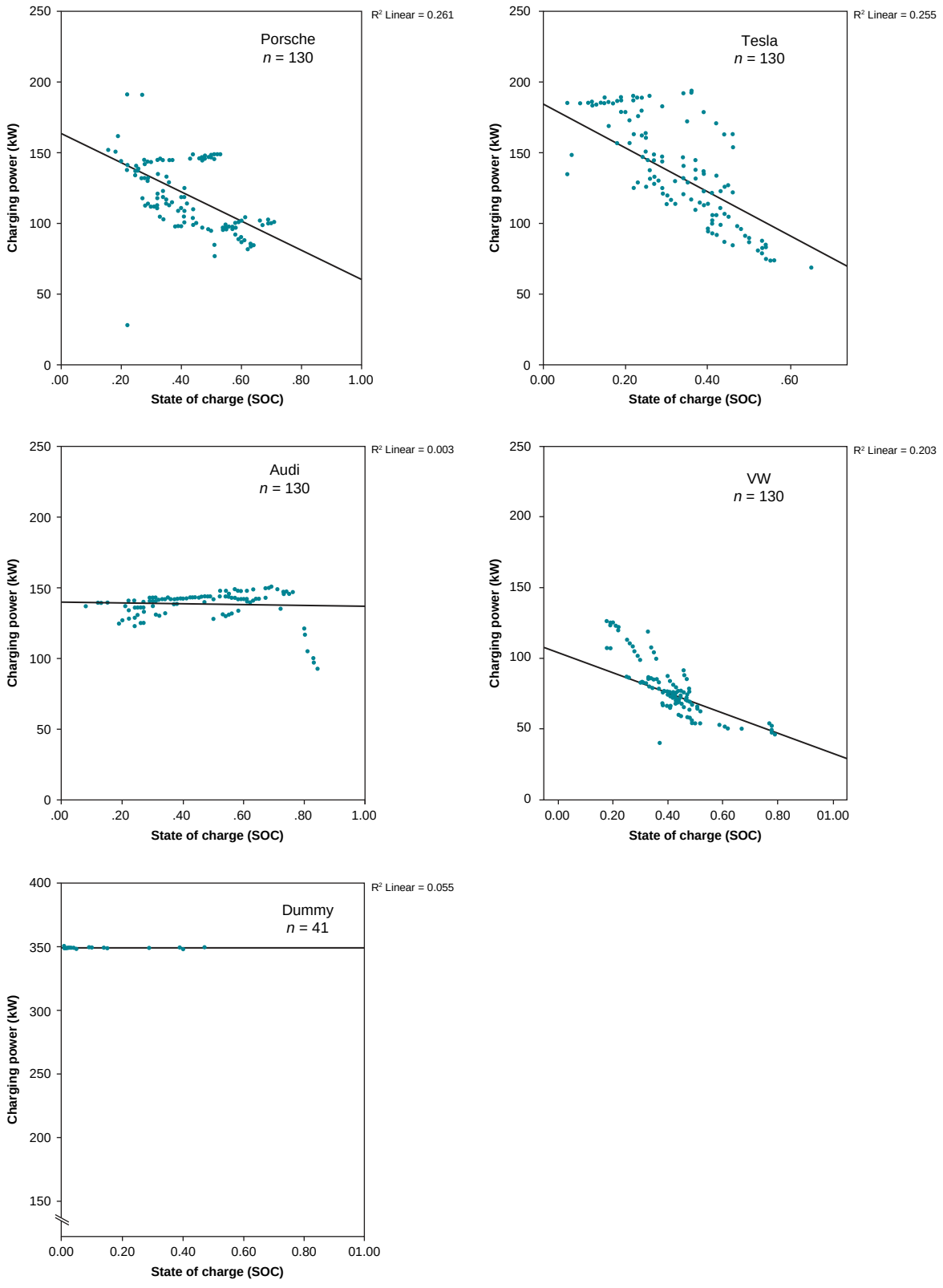


Figure 3 Charging behaviour relative to the SOC of each tested BEV. SOC, state of charge; BEV, battery electric vehicle.

Reasonable caution, by minimizing the time spent in close proximity with the charging cables, is still advised as the occurrence of very rare events cannot be excluded from our results.

Supplementary material

Supplementary material is available at *Europace* online.

Funding

This study was supported by the German Foundation of Heart Research. IONITY provided access to their test site and test vehicle; they did not have input into the design or conduction of the study. The German Social Accident Insurance (Deutsche Gesetzliche Unfallversicherung) performed the measurement of the electromagnetic fields.

Conflict of interest: C.L. has received travel and/or lecture honorary support from Biotronik. P.B. has received travel and/or lecture honorary support from Abbott Medical and Biotronik. C.K. has received travel support and/or lecture honorary from Biotronik, Microport, has participated in clinical studies supported by Abbott Medical, Biotronik, Boston Scientific, Mircoport and has served as advisor to Microport. All other authors have no conflicts of interest to declare.

Data availability

The full data set is available upon reasonable request.

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Appendix 1 Probe details for the measurement of the electric and magnetic fields

Measurements were performed by the Institute for Occupational Safety and Health (IFA) of the German Social Accident Insurance (Deutsche Gesetzliche Unfallversicherung, DGUV)

Probes used:

(1) Wavecontrol SMP2 EMI-probe, ready for spectrum analysis of electric and magnetic field
(2) Probe WP 400 (electric and magnetic field, 1Hz-400kHz, sensor surface 100 cm^2)
(3) Probe WP 400-3 (electric and magnetic field, 1Hz-400kHz, sensor surface 3 cm^2)
(4) Wavecontrol WaveMon LF-400, H-field Isotropic Sensors DC and 10 Hz to 400 kHz

Inspection guidelines:
DIN EN 61000 6-4 (EMC Electromagnetic compatibility)
EMI EU-directive 2013
DGUV directive 15

Appendix 2 Type of leads and sensing configuration

	Lead and sensing configuration					
Lead location	**Unipolar**	**Bipolar**	**Sensitivity**	**Primary**	**Secondary**	**Alternative**
RA	1	72	0.46 ± 0.27			
RV HV		52	0.57 ± 0.17			
RV LV	4	39	2.51 ± 1.11			
LV		22	n/a			
Subcutanreous				21	11	1

HV, high voltage; LV, left ventricle; LV, low voltage; RA, right atrium; RV, right ventricle.