Lack of magnet use during chest compressions leads to multiple inappropriate shocks by a subcutaneous implantable cardioverter-defibrillator

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Introduction

Subcutaneous implantable cardioverter-defibrillator (S-ICD) has been recommended as an alternative to transvenous (TV) ICD for patients with poor vascular access or high infectious risk (ie, patients on hemodialysis or with previous infection). In addition, S-ICD is increasingly implanted in primary and secondary prevention patients who do not have pacing indication, especially at young age, to obviate the long-term risk associated with intravascular leads.[1]

S-ICD was found noninferior to TV ICD in terms of device complications and inappropriate shock (IAS) rates.[2] Comparative studies demonstrated better supraventricular tachycardia ventricular tachycardia (VT) discrimination, but higher rates of IAS owing to oversensing of cardiac and extracardiac signals like T-wave oversensing (TWOS), myopotentials, and noise as well as QRS undersensing leading to sensitivity gain and IAS.[3]

Herein we report a case of IAS due to chest compressions during cardiopulmonary resuscitation (CPR) and compare it to 2 previous reports in the literature.[4,5]

KEY TEACHING POINTS

- Patients with subcutaneous implantable cardioverter-defibrillator (S-ICD) are exposed to delivery of inappropriate shocks (IAS) owing to oversensing of cardiac and extracardiac signals. Signal filtering and new sensing algorithms combined with preprocedural screening and postprocedural programming of a conditional zone and sensing vector with the higher R-to-T-wave ratio have decreased their rates.
- Chest compression during cardiopulmonary resuscitation (CPR) may cause oversensing and ultimately result in IAS delivery despite the above-mentioned measures. All sensing vectors can be susceptible to chest compression–induced oversensing.
- Use of an automated chest compression machine during patient transit may result in delivery of unnoticed multiple IAS.
- Currently, awareness for this possibility and magnet placement is the only measure to avoid IAS during CPR.

Case report

A 66-year-old man with nonischemic dilated cardiomyopathy, MitraClip implantation in the past, and history of VT underwent S-ICD implantation on March 2020 after his TV ICD was extracted owing to severe infective endocarditis associated with septic brain embolism and worsening of his kidney function that eventually required hemodialysis. The S-ICD was programmed to the secondary sensing vector, with high-pass filter on, and 2 treatment zones, conditional and shock, above the rates of 200 and 220 beats per minute (bpm), respectively. Baseline electrocardiogram and sensing electrogram are presented in Supplemental Figure 1. Of note, 6 months prior to his index event he stopped undergoing regular dialysis owing to improvement in his kidney function.

On the day of his admission, he suffered worsening dyspnea with reported central cyanosis. During a car ride (as a passenger) he lost consciousness and his family members

KEYWORDS Subcutaneous implantable cardioverter-defibrillator; Resuscitation; Inappropriate shocks; Magnet; Device sensing
(Heart Rhythm Case Reports 2022;■:1–5)

Funding Sources: None. Disclosures: S.A. is an employee of Boston Scientific. E.E.L. is an employee of Levant Technologies, a distributor of Boston Scientific products in Israel. All other authors have no conflicts to disclose that are relevant to the current manuscript. **Address reprint requests and correspondence:** Dr Yoav Michowitz, Department of Cardiology, Shaare Zedek Hospital, 12 Shmuel Beit St, Jerusalem 9103102, Israel. E-mail address: ymichowitz@gmail.com.

https://doi.org/10.1016/j.hrcr.2022.09.001

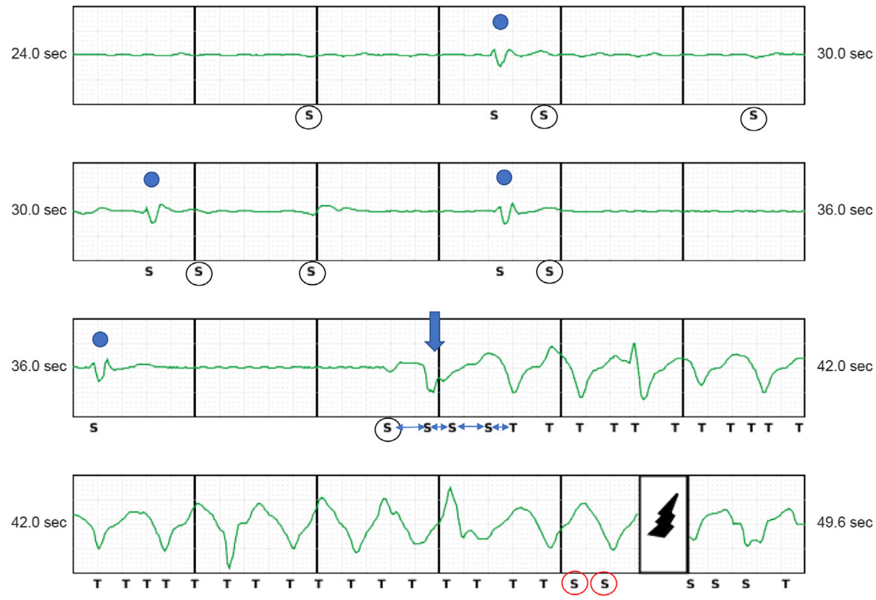

Figure 1 Extreme bradycardia is shown. Sensing during bradycardia is marked by the device with "S," appropriately sensed beats are marked by a blue circle above, and oversensed beats are encircled with black. The start of chest compressions, which causes rapid rate oversensing, is marked with the blue arrow. As heart rate calculation is based on the average of the last 4 certified beats, the first treatable ("T") marker appears after 4 rapid "R-R" intervals (marked with double-sided arrows); further oversensed beats are also marked as treatable and ultimately the device delivers a shock. Of note, the last 2 sensed beats before shock are marked with "S" (encircled with red) and not "T." This is a normal marker behavior of the device that can be seen before every shock delivery and is related to shock synchronization.

started performing CPR immediately on scene. Upon emergency medical service arrival, the first identified rhythm was asystole or extreme bradycardia. He was intubated and CPR was continued during transit, with a LUCAS device (Joife AB, Lund, Sweden), an automated chest compression machine, replacing the need for manual compressions. CPR was performed for 27 minutes, without placement of a magnet over the S-ICD. The rhythm identified with return of spontaneous circulation was idioventricular with ST-segment elevation in lead V_2. Notably, the emergency medical service team notified that the patient received multiple shocks from his S-ICD during his resuscitation, alerting the team for a possible ventricular fibrillation (VF) storm. Ischemic trigger was suspected and he was transported to the catheterization lab to undergo catheterization, which demonstrated normal coronaries. His basic lab results showed an elevated creatinine level but without hyperkalemia. The S-ICD was interrogated and showed 21 IAS during CPR while his basic rhythm was asystole / extreme bradycardia. During hospitalization, the patient did not regain full consciousness and died after 3 weeks from pneumonia.

Several examples of the device interrogation findings are presented in the figures. Figure 1 demonstrates extreme bradycardia with oversensing due to dynamic sensitivity gain. Chest compressions, which started during sensitivity gain, were oversensed and were marked as a treatable event ("T") by the device, which eventually delivered a shock. Another episode of chest compression–associated IAS is provided in Figure 2. Dynamic sensitivity gain with a change in sensing behavior (red arrow) and depiction of faster oversensed chest compression artifacts is seen. (Further explanation for tachycardia-related change in sensing behavior is included in the discussion section.) Noteworthy, the intrinsic activity is seen clearly throughout this apparent VT episode (blue dots), confirming the false perception of VT by the device. Calculated heart rate arranged on a timeline is shown in Figure 3 (these data were extracted after personal communication with the Boston Scientific research and development team). As seen, the patient's heart rate suddenly dropped from 72 bpm to 30 bpm and lower. After approximately 70 seconds of extreme bradycardia, CPR was started and caused inappropriately calculated high rates, which went above the conditional and shock zone bars and ultimately terminated with delivery of IAS.

Discussion

The current case describes CPR-induced S-ICD oversensing causing multiple IAS. The mechanism of oversensing is related to severe bradycardia that led to dynamic sensitivity gain and inappropriate sensing of chest compression artifacts. Lack of magnet placement combined with the use of a LUCAS device, in contrast to human compressions, contributed to multiple IAS that were continuously delivered and not stopped, possibly contributing to worsening of left ventricular function.[6]

Of note, similarly to TV ICD, S-ICD increased sensitivity is seen as a result of the longer interval of sensed event during bradycardia; however, it is also seen once tachycardia is declared. In order to prevent underdetection of VF or fast VT, during tachycardia ("tachy mode") the algorithm dynamically increases sensitivity by shortening the refractory period

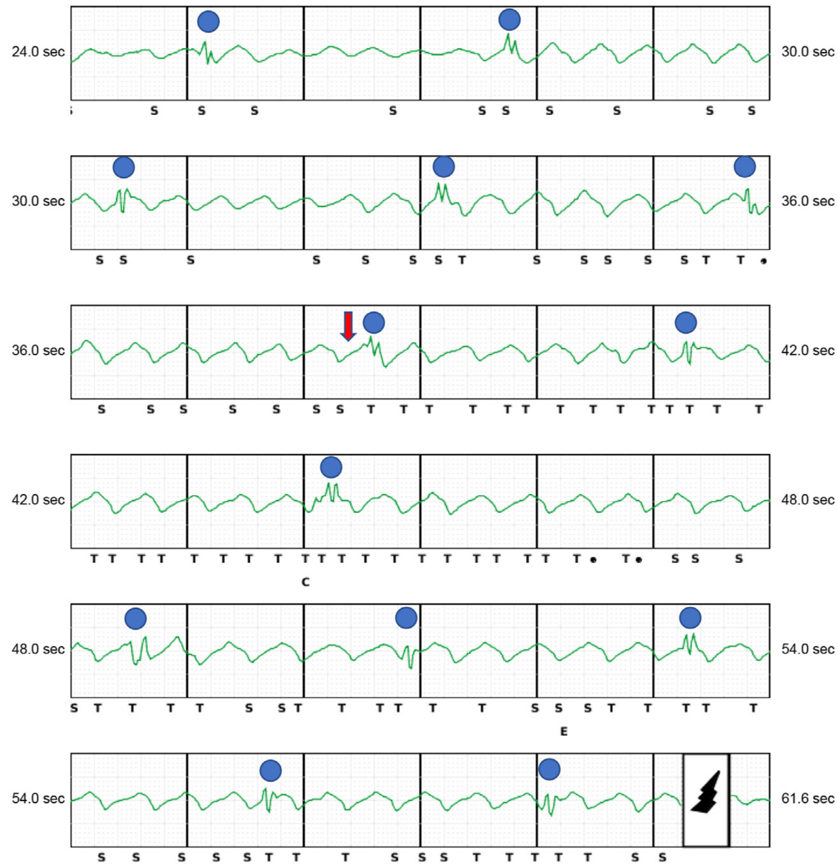

Figure 2 Cardiopulmonary resuscitation (CPR) during bradycardia is shown. The patient's intrinsic QRS complexes are marked by a blue circle, confirming that the apparent "wide complex" in between these beats represents oversensing secondary to CPR, rather than true wide complex tachycardia. Chest compression artifacts cause oversensing, while oversensed complexes with calculated heart rate (HR) below the conditional zone cutoff are marked by the device with "S," those above the shock zone cutoff are marked as treatable "T," and those with calculated HR within the conditional zone are further analyzed by several algorithms before an "S" or "T" marker is generated. A dot (".") signifies a double-detection events, which are discarded (see Supplemental Figure 2). The red arrow signifies increased sensitivity behavior that is related to tachycardia oversensing (see text for further explanation). At the end of the episode inappropriate shock is delivered.

and by more rapidly decaying to the sensitivity floor.[4,7] This change in sensitivity behavior is demonstrated in Figure 2, where similar CPR movements recorded before this dynamic sensitivity gain increase were suddenly recorded as much higher ventricular activity rate after its increase.

The S-ICD sensing capabilities from the extracardiac subcutaneous tissue differ from TV ICD, which senses an intracardiac bipolar signal. The S-ICD sensed signal resembles the surface QRS, a quality that enables it to have better supraventricular tachycardia VT discrimination compared to TV ICD.[8] However, it is exposed to higher rates of oversensing of intracardiac and extracardiac signals. Therefore, sensing algorithm features were designed to avoid oversensing while at the same time assure proper detection of ventricular arrhythmia. Some of these features manifest in the current case. S-ICD sensing involves 3 phases: detection, certification, and therapy decision. During the detection phase signals are filtered, while usage of a high-pass filter, known as the SMART Pass filter,[9] further stresses the QRS compared to other signals. Furthermore, according to rate and variation of detection amplitudes, 1 of 5 unique signal detection profiles may be used. The detection profile includes a refractory period followed by 2 constant threshold periods (used to avoid TWOS, particularly when successive detection amplitudes vary by 20% or more) and a decay profile to the sensing floor. As mentioned above, examples of these rate-related different sensing profiles reaching highest sensitivity, and as a result oversensing, are demonstrated in the current case (Figures 1 and 2). During the certification phase, 4 algorithms to avoid QRS double counting and TWOS are used. Operation of 1 of these algorithms, interval analysis algorithm, is presented in Supplemental Figure 2. Finally, during therapy decision, QRS morphology discriminators are used at the conditional zone while only heart rate calculation is used at the shock zone.[8,10,11] In the current case, inappropriate heart rate calculation was above the shock zone level. Nevertheless, even with miscalculated rates only at the conditional zone, the use of QRS morphology discriminators would result in the delivery of IAS.

In the present case, 21 IAS were delivered. Of note, the high-pass filter, which is programmed off when the sensed QRS amplitude is <0.5 mV and in the presence of ≥ 2 long R-R intervals,[9] was enabled during the first 5 IAS and programmed off thereafter. Initially, chest compression oversensing was perceived as an intrinsic activity that did not fulfill the criteria for turning off this filter (Supplemental Figure 3). After

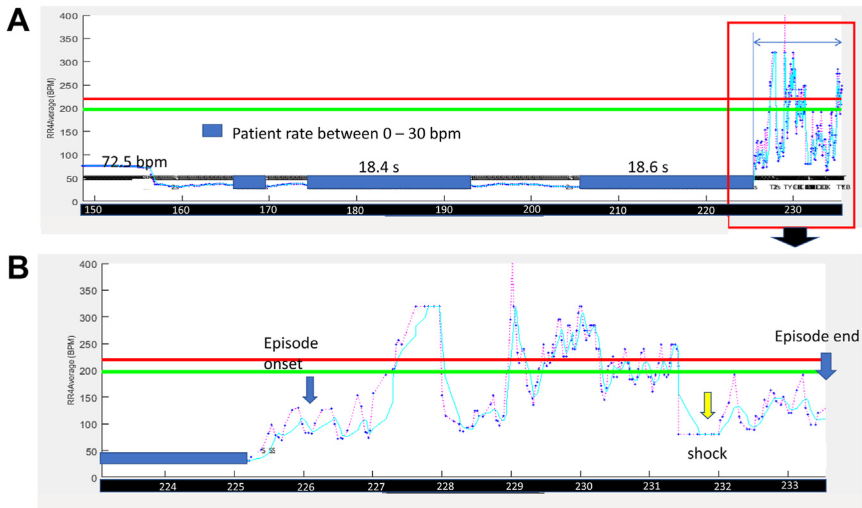

Figure 3 An episode of chest compression oversensing and inappropriate shock delivery is presented in faster (**A**) and slower speeds (**B**). The green and red bars represent the conditional and shock zones cutoffs, respectively. Real-time heart rate (HR) is presented by pink line and an average of 4 "R-R" intervals is presented in light blue line. **A:** The patient's HR suddenly dropped from 72.5 beats/min to below 30 beats/min; a rise in calculated HR after approximately 70 seconds was related to the start of chest compression (encircled by the red rectangle). **B:** Magnification of the episode part encircled by a red rectangle in panel A. The blue arrows denote episode onset and end as recorded by the device, and time of inappropriate shock delivery is marked with a yellow arrow.

the fifth IAS, severe bradycardia without oversensing resulted in S-ICD pacing accompanied by high-pass filter deactivation (Supplemental Figure 4). In the 2 previous case reports[4,5] the high-pass filter was automatically programmed off before the IAS owing to prolonged asystole. Also, uniquely for the current case, the multiple IAS received by the patient is related to the use of a LUCAS device during patient transfer, which causes larger, more uniform artifacts and does not sense shock delivery, as compared to a personal-delivered CPR. In comparison, Cmorej and colleagues[5] reported that a bystander CPR was stopped after the first IAS.

Interestingly, in this report sensing was programmed to the secondary vector, while it was the alternate and primary vectors in the other 2 reported cases describing CPR-induced oversensing and IAS.[4,5] Therefore, at least with the current accumulated knowledge, all vectors can be susceptible to chest compression–induced interference.

Currently, magnet placement over the device is the only way to emergently withhold therapies in the field settings. The magnet should be applied over the device header or lower edge. A beeping tone, verifying that therapy is withheld, should be heard and lasts for 1 minute. Thereafter therapy is continuously withheld as long as the magnet is not moved. If the magnet is removed and placed again, a beeping tone will be heard again. In case of deeply implanted devices, use of a stethoscope may aid in recognizing the beeping and sometimes multiple magnets are needed. Of note, during magnet placements, episodes will not be stored in device memory, programmer commanded shocks are aborted, and postshock pacing is withheld.

Avoiding IAS during CPR in patients with S-ICD is not trivial. The S-ICD may not be recognized by the personnel performing the CPR; in addition, placing and securing a magnet over the device may be difficult during CPR. Moreover, only powerful magnets are suitable for disabling S-ICD therapies. Cmorej and colleagues[5] described CPR-induced IAS despite magnet placement, emphasizing the need to hear a beeping sound in order to verify appropriate placement. At this time, with the current technology, awareness and appropriate magnet placement are the only options to avoid unnecessary CPR-induced IAS, which are misleading and could potentially lead to R-on-T induction of true VF.

Conclusion

In summary, a case of CPR-induced IAS is presented; awareness to this possibility and appropriate magnet placement may prevent IAS. Future S-ICD technological developments should be directed at solutions that will automatically detect chest compression–avoiding IAS.

Acknowledgments

We thank Hannah Rayz for her help in preparing the manuscript.

Appendix

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2022.09.001

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