Abdominal implantable cardioverter-defibrillator placement in a patient requiring bilateral chest radiation therapy

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Introduction
The prevalence of cancer in the United States in 2012 was 13.7 million.1 According to the National Cancer Institute,2 approximately one half of all patients with cancer will receive some sort of radiation therapy (RT) during the course of their treatment. In a recent single-center case series,3 nearly 1% of patients receiving RT had cardiac implantable electronic devices (CIEDs). We can therefore deduce that there are a sizable number of patients receiving RT for cancer who also have CIEDs.

Modern CIEDs use integrated circuits built with complementary metal-oxide-semiconductor technology, which make them smaller, reliable, and energy efficient but more sensitive to ionizing radiation from RT, as compared with older devices, which used nonprogrammable bipolar semiconductors.4 These effects range from mild programming corruption to power-on-reset or even total device failure and tend to increase with cumulative radiation exposure. RT machines also cause electromagnetic interference or scatter radiation of neutrons that can disrupt device function.5,6

Optimal management of patients with CIEDs undergoing RT is unknown. We present a case of a patient with an implantable cardioverter-defibrillator (ICD) with single-coil defibrillator lead who required whole chest radiation and demonstrate an innovative solution.

Case report
A 69-year-old former smoker with coronary artery disease status post–myocardial infarction in 1998 and ischemic cardiomyopathy (left ventricular ejection fraction 10%–15%) status post-ICD implantation in 2001 for inducible ventricular tachycardia was referred for evaluation by oncology, given plans for RT. His right ventricular (RV) lead was a single-coil Medtronic Sprint model 6943 (Minneapolis, MN), and his right atrial lead was a Medtronic CapSureFix model 4568, which has demonstrated progressively falling impedances since implantation. Given the lack of atrial pacing requirement, his system was programmed to VVI mode. He was on amiodarone from 2001 to 2006, which was discontinued because of reduced diffusing capacity of the lung for carbon monoxide. He has a history of appropriate ICD discharge and antitachycardia pacing for recurrent monomorphic ventricular tachycardia. He underwent ICD generator change in 2005 and 2013; his most recent generator was a Medtronic Maximo II DR model D284TRG (Figure 1).

In August 2015 he developed hoarseness with cervical lymphadenopathy. A computed tomographic scan of the chest showed a right upper lobe mass that was compressing the laryngeal nerve. He was determined to have stage IIIb adenocarcinoma of the lung. He started chemotherpay but needed external beam radiation (photon therapy) to a large bilateral thoracic field to a dose of 60 Gy in 30 fractions; therefore, the radiation oncologist requested repositioning of the ICD generator. It was anticipated that with cancer treatment his prognosis for survival would approach 3 years, but treatment was unlikely to be curative.

Electrophysiological procedure
The patient was brought to the electrophysiology laboratory in the fasting state. After informed consent was obtained, left upper extremity venography was performed, which revealed that the subclavian vein was completely occluded with bridging collaterals. This precluded ipsilateral implantation of a superior vena cava (SVC) coil or azygous lead to allow for an RV coil → RV can/SVC defibrillation option. The decision was made to relocate the ICD to the left upper quadrant and add a subcutaneous coil. A 6-cm incision was made over the ICD header, carried down to the device pocket, and the generator was removed. The
The right atrial lead was capped, given a history of falling impedances.

Next, an 8-cm incision was made in the left upper quadrant and a subcutaneous pocket was created. The chronic ICD lead IS-1 connector was attached to a 37-cm Medtronic IS-1 lead extender model 6984M, which was then tunneled to the abdominal pocket. The chronic ICD lead DF-1 connector was attached to a 25-cm Medtronic DF-1 Y-Adaptor/Extender model 6726, which was then tunneled to the abdominal pocket. A 41-cm Medtronic subcutaneous coil model 6996SQ was tunneled from the pectoral pocket to the left side of the chest. The subcutaneous coil was connected to a 25-cm Medtronic DF-1 Y-Adaptor/Extender model 6726, which was then tunneled to the abdominal pocket. A port plug was used in each DF-1 Y-adapter to convert them into a straight (non-Y) extension. DF-1 Y-adapters used as no straight DF-1 adapters of equivalent length were commercially available. The 3 lead extenders were connected to a new Medtronic Evera S VR model DVBC3D1 ICD, and the generator was placed into the abdominal pocket (Figures 2, 3A, and 3B).

Next, defibrillator threshold (DFT) testing was done; ventricular fibrillation was induced with a T-wave shock and defibrillated with a 30 J internal shock in the B > AX (RV coil → RV can/subcutaneous coil) configuration. Shock impedance was 38 Ω. Both chest and abdominal wounds were closed with 2-0 vicryl in layers, and the skin was approximated with staples.

Discussion

Management of patients with CIEDs who need RT can be challenging. Unfortunately, there are no current national or international standards or guidelines regarding CIEDs and RT exposure. The American Association of Physicists in Medicine published a consensus statement in 1994, which is now outdated, although a new task force has been created to address the issue.7,8 The complexity of RT (peak dose, total cumulative dose, dose rate, scatter radiation, and concomitant electromagnetic fields) makes it difficult to predict device function and safety.9 The generally accepted safe radiation dose is 2–10 Gy for pacemakers (PPMs) and <1 Gy for ICDs, which is well below the curative dose for breast or lung cancer (50–60 Gy); there are reports of CIED malfunction at low doses as well.9 We reviewed 2 of the largest in vivo studies of patients with CIEDs undergoing RT.

Brambatti et al3 performed a single-center prospective study of 261 patients with CIEDs undergoing RT. They were classified as low risk (not PPM dependent, no chest radiation, or cumulative dose <20 Gy), acute high risk (PPM dependent), or chronic high risk (chest radiation and/or cumulative dose >20 Gy). CIED relocation was recommended only if cumulative dose >20 Gy or PPM dependent with a cumulative dose of 2–20 Gy. Forty-one patients received chest radiation contralateral to the CIED, 25 received chest radiation ipsilateral to the CIED, and 15 received bilateral chest radiation. Of the study cohort, 4 had inappropriate device function. Three of these had radiation to the central chest with total radiation dose <2 Gy. Of those 3, 1 (ICD) had a power-on-reset and 2 (PPM) had maximum sensory pacing. Therefore, it appears that with chest exposure, even smaller doses of RT can affect CIEDs.

Zaremba et al9 performed a population-based multicenter cohort study of 560 patients with CIEDs undergoing RT. Of the 14 patients with device malfunctions, 4 received chest RT, 7 received abdomen and pelvis RT, and the remaining received RT to the head and neck, spine, or lower extremity.
The median cumulative radiation dose associated with device malfunctions was 46.5 Gy. Eleven of the device malfunctions were power resets or minor software errors; 2 required a software update; and 1 had elevated atrial thresholds. These errors occurred in 2.5% of patients with PPMs and 6.8% of patients with ICDs.

Where and how to relocate CIEDs, when indicated, is not well expounded upon in the literature. If unilateral chest RT

![Diagram of implantable cardioverter-defibrillator (ICD) system with subcutaneous coil, DF-1 connectors, and IS-1 lead extenders.](image)

**Figure 2** Schematic of implantable cardioverter-defibrillator (ICD) system with subcutaneous coil, DF-1 connectors, and IS-1 lead extenders. DF = Defibrillator cathode; DF + = Defibrillator anode; RA = right atrial; RV = right ventricular.

![Radiographic images of the repositioned implantable cardioverter-defibrillator system with a subcutaneous coil and right ventricular lead tunneled to the left upper quadrant in anterior-posterior (A) and lateral (B) projections. The Y-adapters are bracketed.](image)

**Figure 3** Radiographic images of the repositioned implantable cardioverter-defibrillator system with a subcutaneous coil and right ventricular lead tunneled to the left upper quadrant in anterior-posterior (A) and lateral (B) projections. The Y-adapters are bracketed.
is needed, moving the generator to the contralateral pectoral side is reasonable. Our patient required bilateral chest radiation, so this was not a possibility. For this patient, the following options were considered:

1. Extract the entire ICD system while maintaining venous access and implant a 100-cm Medtronic Sprint Quattro dual-coil defibrillator lead and tunnel to the left upper quadrant. Given the patient’s comorbidities and limited expected life span, this was felt to be too invasive with significant potential risk.

2. Cap current system and implant a new right-sided 100-cm Medtronic Sprint Quattro dual-coil defibrillator lead and tunnel to the right upper quadrant. However, this would have required more transvenous hardware in the body and required an additional incision with subsequent radiation that may affect wound healing and infectious risk. Also, radiation-induced venous stenosis and deep venous thrombosis have been reported and recent endovascular disruption on both sides may enhance this risk.

3. Extend current lead to the left upper quadrant abdomen without additional hardware. However, this would have limited defibrillation vectors to RV coil → RV can and vice versa. There are limited data on the adequacy of DFTs in single-coil systems with active abdominal generators. Solomon et al studied 10 patients with left abdominal ICDs with either dual-coil endocardial leads or anterior and posterior epicardial patches undergoing generator change. For the endocardial lead group (n = 3), they tested 3 defibrillation vector configurations:
   (i) passive can with RV → SVC; (ii) active can → RV;
   (iii) active can → SVC. The last 2 configurations used a Medtronic 5425 active can ICD emulator and excluded 1 electrode to simulate lead failure, that is, making it a single-coil system. DFTs were 14.0 ± 10.5 J for the passive can configuration, 14.0 ± 9.2 J for the active can → RV configuration, and 19.7 ± 9.7 J for the active can → SVC configuration. Given the paucity of data available, and since the pocket was already open and 2 lead extenders had to be tunneled, we felt that adding the subcutaneous coil had potential benefit (RV coil → RV can/subcutaneous coil defibrillation vector) without much additional risk (see option 5 below).

4. Extend the current lead to the left upper quadrant and add a subcutaneous coil via separate DF-1 connectors, given occluded left subclavian vein. This is the option we chose. To reduce hardware bulk we could have connected both the subcutaneous and DF-1 leads to 1 Y-adapter, but this would have limited defibrillation vectors. A right-sided SVC or azygous coil could have been placed and tunneled to the left-sided abdominal generator via an extender, but this would have required an additional incision (see option 3 above) and transabdominal lead positioning.

6. A totally subcutaneous ICD was not an option, as it would still be in the thoracic cavity and therefore subject to RT exposure as well as potentially restricting RT portal access.

**Conclusion**

Much uncertainty exists about optimal management of patients with CIEDs undergoing RT, given the lack of current guidelines. ICDs appear to be particularly susceptible to device damage from ionizing radiation and electromagnetic interference during these treatments, not necessarily in a dose-dependent manner. Device relocation is an option, but no guidance is given in the literature. We present a solution in a patient with a single-coil ICD lead who required whole chest radiation, which consisted of placing a subcutaneous coil with reimplantation of the generator in the upper abdomen. We also present other potential configurations and their downsides; ultimately an individualized approach is essential.

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