Safety of Radiotherapy in Patients with Cardiac Implantable Electronic Devices

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Abstract

Background: Patients with cardiac implantable electronic devices (CIEDs) usually have multiple comorbidities, and some require radiotherapy (RTx) for cancer treatment. However, the effect of RTx in patients with CIEDs is unclear. We aimed to examine the effectiveness of RTx in patients with CIEDs, and share our real-world clinical experience in this population.

Methods: We recruited patients with a pacemaker or implantable cardioverter-defibrillator who underwent RTx between April 2009 and August 2019. RTx and CIED interrogation data were collected from electronic medical records. Patients who received an RTx cardiology consultation and CIED interrogation before and after RTx were assigned to the proper consultation (PC) group. All others were enrolled in the no-consultation (NC) group.

Results: Out of 23 patients, 3 (13.0%) and 20 (87.0%) patients were assigned to the PC and NC groups, respectively. The most common RTx sites were the abdomen and pelvis (34.8%). The mean cumulative dose was 50.1 ± 11.7 Gy, and the mean beam energy was 10.3 ± 4.01 mV. The PC and NC groups showed no significant difference in cumulative dose (51.5 ± 12.1 vs. 45.3 ± 3.9 , $p=0.19$) or beam energy (10.4 ± 4.03 vs. 7.0 ± 1.41 , $p=0.08$). There was no significant between-group difference in any pre-RTx CIED parameter. Two patients died during the study period; both were in the NC group. The relationship between death and device malfunction was not clear in either case.

Conclusions: Patients with CIEDs frequently do not receive a cardiology consultation before RTx. Although radiotherapy-related CIED complications occur stochastically and are difficult to predict, cooperation between the cardiology and radiation therapy departments, and regular device follow-up are necessary for the safety of these patients.

Background

As populations have aged and the indications for implantable cardiac devices have widened, the number of patients who need cardiac implantable electronic devices (CIEDs), such as pacemakers (PMs) or implantable cardioverter-defibrillators (ICDs), has steadily increased.[1–3] Patients with CIEDs usually have multiple comorbidities that require medical attention, and some receive radiotherapy for the treatment of cancer.[4–6] Radiotherapy (RTx) has been associated with CIED dysfunction, which can potentially threaten patient safety.[7] Clinically, RTx doses less than 2 grays (Gy) and between 2 and 10 Gy are categorized as low and medium risk, respectively.[8–10] Nevertheless, CIED malfunctions related to RTx have been reported even in patients receiving safe doses.[7, 11, 12]

Although strategies for the management of RTx in patients with CIEDs have been proposed in various countries, the domestic experience in our context and researchers are still lacking.[10, 13, 14] Additionally, physicians worldwide lack information about the effects of radiation therapy in patients with CIEDs. Therefore, we aimed to examine cases of RTx treatment in patients with PMs or ICDs to share our real-world clinical experience in this population.

Materials And Methods

Study population

We recruited patients with a PM or ICD who underwent RTx between April 2009 and August 2019 in our hospital. In all consultation cases, the patient was referred to the cardiology department for an evaluation of potential RTx-related risks and to determine the RTx dose. These patients underwent CIED interrogation before and after RTx to determine whether some parameters significantly presented a potential risk of device failure or needed a CIED mode change according to RTx. Patients who did not receive a cardiology consultation still underwent RTx as scheduled by the respective departments. Although these patients did not visit the cardiology department in preparation for RTx, they underwent device interrogation during their regular cardiology follow-up.

We evaluated the safety of receiving RTx in patients with all kinds of PMs and ICDs by enrolling consecutive patients. Further, we did not exclude patients based on the device type (conventional or magnetic resonance imaging(MRI)-conditional) or manufacturer. Patients without a CIED at the time of RTx were excluded.

The institutional review board approved the study protocol(IRB number, B-2003/601 – 110), and we performed our research according to the tenets of the Declaration of Helsinki.

Radiotherapy data

Data on RTx treatments were collected from electronic medical records (EMRs) at our hospital. Data included information about the malignant site, RTx start and end dates, the anatomical region irradiated and cumulative tumor dose, the number of fractions and fraction dose (maximal applied during the RTx course), and beam energy (maximal applied during the RTx course). Anatomical regions were classified as the abdomen and pelvis, brain, breast, head and neck, and lung. The abdomen and pelvis classification included the bladder, prostate, inguinal lymph nodes, pelvis, and inferior pubic ramus. The head and neck classification included the tonsils and associated lymph nodes, glottis, nasopharynx, and pyriform sinus.

Pacemaker and implantable cardioverter-defibrillator data

CIED interrogation data were collected from EMRs. The data included information on device class (PM, ICD), device type (VVI, VVIR, DDD, DDDR, single-chamber ICD, dual-chamber ICD), generator manufacturer, device model, and the date of implantation and revision.

Cardiac implantable electronic device preparation for radiotherapy

We defined appropriate RTx preparation as: (1) a cardiology consultation for RTx and (2) a CIED interrogation or mode change before and after RTx. Patients who received both were assigned to the

proper consultation (PC) group. All other patients were considered to have received incomplete preparation and were assigned to the no-consultation (NC) group.

Statistical analysis

Student's t , the Wilcoxon rank, and the chi-square tests were used to compare means and proportions of baseline clinical characteristics between the groups. All statistical analyses were performed using R version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria), and $p < 0.05$ was considered statistically significant.

Results

Baseline characteristics

There were 27 consecutive cases. Four patients were excluded because they received RTx before CIED implantation. Thus, 23 patients with a PM or ICD who underwent RTx during the study period were analyzed (mean age, 72.1 ± 9.7 years [range, 54–93]; male, 17 [73.9%]; Table 1) (Fig. 1). There were 20 patients (87.0%) in the NC group and 3 (13.0%) in the PC group. RTx was mostly performed in the abdomen and pelvis (34.8%), the mean cumulative dose was 50.1 ± 11.7 Gy, and the mean beam energy was 10.3 ± 4.01 mV (Table 1). One patient received gamma knife RTx, and the rest received photon RTx. The most common indication for PM implantation was complete atrioventricular (AV) block, and the DDD type was the most frequently found. All patients with an ICD received it for primary prevention (Table 1).

Table 1
Baseline Characteristics

	Total (n = 23)	NC (n = 20)	PC (n = 3)	<i>p</i>-value
Age at RT	72.1 ± 9.7	72.2 ± 10.5	71.7 ± 5.7	0.90
Male (%)	17 (73.9)	15 (75.0)	2 (66.7)	0.76
HTN	14 (60.9)	11 (55.0)	3 (100.0)	0.14
DM	9 (39.1)	8 (40.0)	1 (33.3)	0.83
A.fib	11 (47.8)	10 (50.0)	1 (33.3)	0.59
Stroke	2 (8.7)	2 (10.0)	0 (0.0)	0.57
Anatomic region				
-Abdomen and Pelvis	8 (34.8)	8 (40.0)	0 (0.0)	0.18
-Brain	4 (17.4)	2 (10.0)	2 (66.7)	0.02
-Breast	3 (13.0)	2 (10.0)	1 (33.3)	0.26
-Head and Neck	5 (21.7)	5 (25.0)	0 (0.0)	0.33
-Lung (Rt.)	3 (13.0)	3 (15.0)	0 (0.0)	0.47
Cumulative dose (Gy)	50.1 ± 11.7	51.5 ± 12.1	45.3 ± 3.9	0.19
Beam types				
-Photon	22 (95.7)	20 (100.0)	2 (66.7)	
-Gamma Knife	1 (4.3)	0 (0.0)	1 (33.3)	
Beam energy (mV)	10.3 ± 4.01	10.4 ± 4.03	7.0 ± 1.41	0.08
Device age at RTx, Months	30.1 ± 31.6	31.1 ± 32.7	23.2 ± 27.0	0.68
Indication for CIED implantation				
Pacemaker [#]				
complete AV block	11	8	3	
sick sinus syndrome	10	10	0	
ICD and CRT-D				

A.fib, atrial fibrillation; AV, atrioventricular; CIED, cardiac implantable electronic device; CRT-D, cardiac resynchronization therapy with defibrillator; DM, diabetes mellitus; HTN, hypertension; ICD, implantable cardioverter-defibrillator; NC, no-consultation group; PC, proper-consultation group; RTx, radiotherapy; Rt, right

	Total (n = 23)	NC (n = 20)	PC (n = 3)	<i>p</i> -value
primary prevention	2	2	0	
Device Type				
-DDD	15	12	3	
-VVI	6	2	0	
-ICD	2	0	0	
A.fib, atrial fibrillation; AV, atrioventricular; CIED, cardiac implantable electronic device; CRT-D, cardiac resynchronization therapy with defibrillator; DM, diabetes mellitus; HTN, hypertension; ICD, implantable cardioverter-defibrillator; NC, no-consultation group; PC, proper-consultation group; RTx, radiotherapy; Rt, right				

The baseline characteristics were not statistically different between the two groups, except for the frequency of brain RTx. The cumulative dose and beam energy showed no statistical between-group differences (51.5 ± 12.1 vs. 45.3 ± 3.9 , $p = 0.19$) (Table 1).

Cardiac implantable electronic device parameters and complications

All pre-RTx CIED parameters showed no significant difference between the two groups. Additionally, the post-RTx parameters were not different between the two groups (Table 2).

Table 2
Changes in the atrial and ventricular impedance, sensing, and captured threshold before and after radiotherapy

	NC (n = 20)	PC (n = 3)	p-value
Impedance (ohms)			
Atrial			
Pre	499.2 ± 91.2	518.3 ± 105	0.79
Post	433.4 ± 109	485.7 ± 56.7	0.31
Ventricular			
Pre	619.9 ± 168	568.3 ± 84.3	0.44
Post	562.4 ± 107	542.7 ± 86.4	0.75
Sensing (mV)			
Atrial			
Pre	3.180 ± 0.9	3.23 ± 2.1	0.97
Post	3.35 ± 1.28	3.03 ± 1.95	0.81
Ventricular			
Pre	13.0 ± 5.12	12.5 ± 4.82	0.88
Post	13.1 ± 3.85	12.7 ± 8.20	0.96
Capture threshold (V)			
Atrial			
Pre	0.58 ± 0.34	0.58 ± 0.14	0.98
Post	0.68 ± 0.47	0.63 ± 0.13	0.76
Ventricular			
Pre	0.69 ± 0.37	0.75 ± 0.13	0.60
Post	0.68 ± 0.42	0.75 ± 0.13	0.61
NC, non-consultation group; PC, proper-consultation group			

No malfunction (0/3, 0%) occurred after RTx in the PC group, and two malfunctions (2/20, 10%) occurred in the NC group. In one of the two malfunctions, the atrial lead impedance decreased from 435 to 171 ohms (S1 Fig). One month after radiation therapy, the patient's PM program was changed from DDD to

VVI because of the failure of the former to sense P waves. In the other malfunction, atrial and ventricular lead capture failures were observed. The patient had undergone a DDD PM implantation to treat complete atrioventricular block 5 years before RTx, and she was PM dependent (S2 Fig). She was dead on arrival at the emergency room four months after the radiation therapy, and only a pacing “blip” was observed on the electrocardiogram (ECG) at that time (S2 Fig). However, as the patient was receiving only palliative therapy for terminal breast cancer and did not undergo an appropriate PM assessment before and after RTx, it is difficult to distinguish between death secondary to disease progression and death resulting from capture failure.

Discussion

In this study, we documented the real-world clinical courses of CIED recipients undergoing RTx, such as gamma knife and photon RTx, and we noticed that clinicians still lack recognition and preparation regarding RTx-related CIED malfunction. Although the number of subjects was small during the study period, we found that 82.6% of patients with a CIED did not receive proper cardiology consultation for RTx from 2009 to 2019. This study documented that the pre- and post-RTx CIED parameters were not significantly different in patients with or without an appropriate cardiology consultation. However, it is not clear whether the post-RTx parameters in the NC group guaranteed the safety of the CIEDs even if the patients did not report a CIED malfunction after RTx. Although the device parameters of most NC group patients were in the normal range, they could not reflect the circumstances at the time RTx ended because these patients did not receive appropriate device interrogation.

Patients undergoing CIED implantation could have several comorbidities.[15] Accordingly, magnetic resonance imaging (MRI) or RTx could be indicated in a CIED recipient and can affect a CIED.[7, 16–19] The effects of MRI on CIEDs have been documented, and recommendations, including guidelines and prevention protocols, have been reported and used in the clinical field.[2, 20–23] We previously reported that, given appropriate precautions and consultations, MRI, even 3 Tesla MRI, can be performed safely in patients with a CIED.[24] Based on our experience, we developed an automatic consultation system that improved the pre-MRI consultation rate and the safety and quality of care in patients with a CIED.[25] CIED malfunctions related to RTx are easier to miss than those occurring secondary to MRI. One of our patients complained of dizziness after RTx for left breast cancer. She had a DDD-type PM on the right side and received RTx at 43 Gy (S3A Fig). At that time, the ECG revealed non-sustained ventricular fibrillation (S3B Fig). She was assigned to the PC group in this study. This case demonstrated that CIED dysfunction is difficult to identify and rarely reported. Moreover, RTx-related CIED malfunctions occur stochastically and are difficult to predict.[26, 27]

Reports indicate that CIEDs can be affected by direct ionizing radiation and photoneutrons leading to device malfunction.[26, 28] Grant et al. investigated RTx factors that caused CIED malfunctions and recommended non-neutron-producing RTx rather than neutron-producing RTx.[28] However, the mechanism and effects of radiation exposure are not clear. Several studies have demonstrated that safe radiation doses in the presence of a PM or ICD are 2–10 Gy and < 1 Gy, respectively. These levels are

under the curative doses for breast and lung cancer (up to 50–60 Gy).[8–10, 29, 30] In addition to recommendations for appropriate radiation dosage, cooperation between cardiology and radiation therapy departments is necessary for the prevention and proper monitoring of RTx-related complications; however, this multidisciplinary approach seems to be rare in actual practice. Zaremba et al. reported a 3.1% CIED malfunction rate in 453 RTx courses, and 22.6–27.9% of participants underwent device interrogation before and after RTx.[6] Only 21.7% of our study participants underwent appropriate pre- and post-CIED interrogation. Although almost all CIED recipients have a risk of RTx-related device dysfunction, there is no adequate preventive management. Further, clinicians are insufficiently aware of the fact that RTx poses a risk in patients with a CIED. The 2017 Heart Rhythm Society (HRS) consensus statement recommends device relocation if there is a possibility that it could interfere with RTx. Additionally, weekly CIED evaluations are recommended for patients undergoing neutron-producing treatment.[31] Thus, the 2017 HRS consensus statement reinforces the importance of cooperation between radiation and cardiology departments when a patient with a CIED requires RTx (Fig. 2).

In our study, two malfunctions occurred in the NC group. One patient received pelvic RTx (cumulative dose, 60 Gy) for prostate cancer. He complained of orthopnea caused by lung metastasis. When the patient visited the cardiology department for a post-RTx device evaluation, we found that the lead impedance had changed from 435 to 171 ohms (S1 Fig). The other patient received left breast RTx (cumulative dose, 45 Gy). She complained of severe diarrhea after chemotherapy and died after receiving supportive care without any curative cancer treatment. A normal paced rhythm was identified on the patient's ECG 3 months after RTx (S2 Fig). However, when the patient arrived dead at the emergency department 4 months after RTx, her ECG showed no paced rhythm (S2 Fig). Although neither ECG detected any abnormal event related to the device at that time, we could not rule out device dysfunction definitively. In another case, a 64-year-old woman scheduled to receive left breast RTx was referred to the cardiology department for PM implantation due to AV block. The cardiologist decided that the PM should be inserted in the right chest to avoid interfering with her RTx according to the guidelines (S3 Fig).

Study limitations

Our study has some limitations. First, although we enrolled all patients with PMs or ICDs who underwent RTx, our cohort was small. Thus, it was difficult to compare values between patients. We attempted to overcome this limitation by analyzing the changes in all data and comparing the differences between groups based on consultation status. However, some data, particularly post-RTx interrogation values, were missing, making it difficult to compare the two groups directly. Second, due to the retrospective nature of the study, we could only assess the device function by interrogation, which indirectly reflects potential device dysfunction. Therefore, it was difficult to accurately determine the device condition at the time of death in patients who died. Despite these limitations, our retrospective single-center review included diverse RTx target cases reflecting real-world practice. Furthermore, we believe our study provides important clinical information about the potential for CIED complications associated with RTx.

Conclusion

In conclusion, the number of patients with a CIED referred for RTx consultations was low. Although RTx-related complications are difficult to predict, cooperation between the cardiology and radiation therapy departments and regular follow-up may be necessary to identify device dysfunction and for the safety of the patients. Furthermore, our results may support the establishment of guidelines for the safe management of CIED recipients who require RTx and could provide evidence to guide future research.

List Of Abbreviations

AV block: atrioventricular block,

CIEDs: cardiac implantable electronic devices

ECG: electrocardiogram

EMRs: electronic medical records

Gy: grays

ICDs: implantable cardioverter-defibrillators

MRI: magnetic resonance imaging

NC group: no-consultation group

PC group: proper consultation group

PMs: pacemakers

RTx: Radiotherapy

Declarations

Ethics approval

The Seoul National University Bundang Hospital institutional review board approved the study protocol (IRB number, B-2003/601-110), and we performed our research according to the tenets of the Declaration of Helsinki.

Consent to participate

Not applicable

Availability of Data and materials

Data are available. Please contact corresponding author.

Competing interests

None.

Authors' contributions

IYO conceptualized this study. DH collected the data. DH and IYO wrote the initial draft. DH analyzed the data. DH and IYO reviewed the data analysis. JHL, YJC, and IYO reviewed the manuscript and interpreted the findings.

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References

1. Roguin A, Zviman MM, Meininger GR, Rodrigues ER, Dickfeld TM, Bluemke DA, Lardo A, Berger RD, Calkins H and Halperin HR. Modern pacemaker and implantable cardioverter/defibrillator systems can be magnetic resonance imaging safe: in vitro and in vivo assessment of safety and function at 1.5 T. *Circulation*. 2004;110:475-82.
2. Nazarian S, Beinart R and Halperin HR. Magnetic resonance imaging and implantable devices. *Circ Arrhythm Electrophysiol*. 2013;6:419-28.
3. Khamooshian A and Mahmood F. Non-infectious lead extractions: enemy of good? *J Cardiothorac Vasc Anesth*. 2017;31:629-30.
4. Niehaus M and Tebbenjohanns J. Electromagnetic interference in patients with implanted pacemakers or cardioverter-defibrillators. *Heart*. 2001;86:246-8.
5. Quint DJ. Indications for emergent MRI of the central nervous system. *JAMA*. 2000;283:853-5.
6. Zaremba T, Jakobsen AR, Sogaard M, Thøgersen AM, Johansen MB, Madsen LB and Riahi S. Risk of device malfunction in cancer patients with implantable cardiac device undergoing radiotherapy: a population-based cohort study. *Pacing Clin Electrophysiol*. 2015;38:343-56.
7. Zweng A, Schuster R, Hawlicek R and Weber HS. Life-threatening pacemaker dysfunction associated with therapeutic radiation: a case report. *Angiology*. 2009;60:509-12.
8. Sundar S, Symonds RP and Deehan C. Radiotherapy to patients with artificial cardiac pacemakers. *Cancer Treat Rev*. 2005;31:474-86.

9. Hudson F, Coulshed D, D'Souza E and Baker C. Effect of radiation therapy on the latest generation of pacemakers and implantable cardioverter defibrillators: a systematic review. *J Med Imaging Radiat Oncol.* 2010;54:53-61.
10. Hurkmans CW, Kneijens JL, Oei BS, Maas AJJ, Uiterwaal GJ, van der Borden AJ, Ploegmakers MMJ and van Erven L; Dutch Society of Radiotherapy and Oncology (NvRO). Management of radiation oncology patients with a pacemaker or ICD: a new comprehensive practical guideline in The Netherlands. Dutch Society of Radiotherapy and Oncology (NvRO). *Radiat Oncol.* 2012;7:198.
11. Gelblum DY and Amols H. Implanted cardiac defibrillator care in radiation oncology patient population. *Int J Radiat Oncol Biol Phys.* 2009;73:1525-31.
12. Soejima T, Yoden E, Nishimura Y, Ono S, Yoshida A, Fukuda H, Fukuhara N, Sasaki R, Tsujino K and Norihisa Y. Radiation therapy in patients with implanted cardiac pacemakers and implantable cardioverter defibrillators: a prospective survey in Japan. *J Radiat Res.* 2011;52:516-21.
13. Marbach JR, Sontag MR, Van Dyk J and Wolbarst AB. Management of radiation oncology patients with implanted cardiac pacemakers: report of AAPM Task Group No. 34. American Association of Physicists in Medicine. *Med Phys.* 1994;21:85-90.
14. Lambert P, Da Costa A, Marcy PY, Kreps S, Angellier G, Marcié S, Bondiau PY, Briand-Amoros C and Thariat J. [Pacemaker, implanted cardiac defibrillator and irradiation: management proposal in 2010 depending on the type of cardiac stimulator and prognosis and location of cancer]. *Cancer Radiother.* 2011;15:238-49; quiz 257. [Article in French]
15. Kalin R and Stanton MS. Current clinical issues for MRI scanning of pacemaker and defibrillator patients. *Pacing Clin Electrophysiol.* 2005;28:326-8.
16. Hayes DL, Holmes DR Jr and Gray JE. Effect of 1.5 tesla nuclear magnetic resonance image scanner on permanent pacemakers. *J Am Coll Cardiol.* 1987;10:782-6.
17. Shellock FG, Tkach JA, Ruggieri PM and Masaryk TJ. Cardiac pacemakers, ICDs, and loop recorder: evaluation of translational attraction using conventional ("long-bore") and "short-bore" 1.5- and 3.0-tesla MR systems. *J Cardiovasc Magn Reson.* 2003;5:387-97.
18. Luechinger R, Zeijlemaker VA, Pedersen EM, Mortensen P, Falk E, Duru F, Candinas R and Boesiger P. In vivo heating of pacemaker leads during magnetic resonance imaging. *Eur Heart J.* 2005;26:376-83; discussion 325-7.
19. Nemec J. Runaway implantable defibrillator—a rare complication of radiation therapy. *Pacing Clin Electrophysiol.* 2007;30:716-8.
20. Nazarian S, Roguin A, Zviman MM, Lardo AC, Dickfeld TL, Calkins H, Weiss RG, Berger RD, Bluemke DA and Halperin HR. Clinical utility and safety of a protocol for noncardiac and cardiac magnetic resonance imaging of patients with permanent pacemakers and implantable-cardioverter defibrillators at 1.5 tesla. *Circulation.* 2006;114:1277-84.
21. Nazarian S and Halperin HR. How to perform magnetic resonance imaging on patients with implantable cardiac arrhythmia devices. *Heart Rhythm.* 2009;6:138-43.

22. Nazarian S, Hansford R, Roguin A, Goldsher D, Zviman MM, Lardo AC, Caffo BS, Frick KD, Kraut MA, Kamel IR, Calkins H, Berger RD, Bluemke DA and Halperin HR. A prospective evaluation of a protocol for magnetic resonance imaging of patients with implanted cardiac devices. *Ann Intern Med*. 2011;155:415-24.
23. Nazarian S, Reynolds M, Ryan M, Hunter T, Wolff S, Mollenkopf S and Turakhia M. Estimating the likelihood of MRI in patients after ICD implantation: a 10-year prediction model. *J Am Coll Cardiol*. 2015;65:A1090.
24. Han D, Kang SH, Cho Y and Oh IY. Experiences of magnetic resonance imaging scanning in patients with pacemakers or implantable cardioverter-defibrillators. *Korean J Intern Med*. 2019;34:99-107.
25. Han D, Lee JH, Oh IY, Chae IH, Lee HY and Cho Y. Automatic consultation system for patients with cardiac implantable electronic devices undergoing magnetic resonance imaging. *Int J Arrhythm*. 2020;21:2.
26. Miften M, Mihailidis D, Kry SF, Reft C, Esquivel C, Farr J, Followill D, Hurkmans C, Liu A, Gayou O, Gossman M, Mahesh M, Popple R, Prisciandaro J and Wilkinson J. Management of radiotherapy patients with implanted cardiac pacemakers and defibrillators: a report of the AAPM TG-203[†]. *Med Phys*. 2019;46:e757-88.
27. Bradley PD and Normand E. Single event upsets in implantable cardioverter defibrillators. *IEEE Trans Nucl Sci*. 1998;45:2929-40.
28. Grant JD, Jensen GL, Tang C, Pollard JM, Kry SF, Krishnan S, Dougherty AH, Gomez DR and Rozner MA. Radiotherapy-induced malfunction in contemporary cardiovascular implantable electronic devices: clinical incidence and predictors. *JAMA Oncol*. 2015;1:624-32.
29. Last A. Radiotherapy in patients with cardiac pacemakers. *Br J Radiol*. 1998;71:4-10.
30. Solan AN, Solan MJ, Bednarz G and Goodkin MB. Treatment of patients with cardiac pacemakers and implantable cardioverter-defibrillators during radiotherapy. *Int J Radiat Oncol Biol Phys*. 2004;59:897-904.
31. Indik JH, Gimbel JR, Abe H, Alkmim-Teixeira R, Birgersdotter-Green U, Clarke GD, Dickfeld TL, Froelich JW, Grant J, Hayes DL, Heidbuchel H, Idriss SF, Kanal E, Lampert R, Machado CE, Mandrola JM, Nazarian S, Patton KK, Rozner MA, Russo RJ, Shen WK, Shinbane JS, Teo WS, Uribe W, Verma A, Wilkoff BL and Woodard PK. 2017 HRS expert consensus statement on magnetic resonance imaging and radiation exposure in patients with cardiovascular implantable electronic devices. *Heart Rhythm*. 2017;14:e97-153.

Figures

Figure 1.

Figure 1

Study flow chart

Figure 2. **CIED management for radiation therapy**

2017 HRS expert consensus statement on MR imaging and radiation exposure in patients with CIEDs

Figure 2

2017 Heart Rhythm Society expert consensus statement on radiation exposure in patients with cardiovascular implantable electronic devices

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