Review of Cardiac Implantable Electronic Devices (CIEDs) and Potential Device Malfunctions due to Radiotherapy

Joann I. Prisciandaro, Ph.D.
joannp@med.umich.edu

Learning Objectives

1. Review of Implantable Cardiac Pacemaker (ICP) and Implantable Cardiac Defibrillator (ICD) devices
2. Discuss conditions in clinical use that can induce device malfunctions

Outline

- Rationale for updating AAPM Report 45 / Task Group 34
- Functionality and components of CIEDs
- Potential effects of ionizing radiation on CIEDs

Rationale for Updating AAPM Report 45 / Task Group 34

Management of radiation oncology patients with implanted cardiac pacemakers: Report of AAPM Task Group No. 34

J. R. Marbach
Cancer Therapy and Research Center, San Antonio, Texas 78229
M. R. Sontag
Duke University Medical Center, Durham, North Carolina 27710
J. Van Dyk
Ontario Cancer Institute, Toronto, Ontario M4X 1K9, Canada
A. B. Wolbarst[a)]
Environmental Protection Agency, Washington, D.C. 20460

(Received 12 May 1992; accepted for publication 4 October 1993)

Contemporary cardiac pacemakers can fail from radiation damage at doses as low as 10 gray and can exhibit functional changes at doses as low as 2 gray. A review and discussion of this potential problem is presented and a protocol is offered that suggests that radiation therapy patients with implanted pacemakers be planned so as to limit accumulated dose to the pacemaker to 2 gray. Although certain levels and types of electromagnetic interference can cause pacemaker malfunction, there is evidence that this is not a serious problem around most contemporary radiation therapy equipment.

Key words: radiation oncology, pacemakers, treatment protocol, complications

Med. Phys. 21 (1), January 1994

Rationale for Updating AAPM Report 45 / Task Group 34

Published studies show that the radiation sensitivity of contemporary cardiac pacemakers vary, depending on the manufacturer and model.[6,8,83,84] Since the problem of radiation exposure still affects relatively few (percentage-wise) pacemaker patients, it is unreasonable to propose that all pacemaker manufacturers radiation harden their devices. To do so would incur a significant expense that would eventually have to be passed on to all cardiac pacemaker patients. If necessary, a pacemaker can be moved to an area outside the radiation treatment volume in order to preclude failure from overexposure.

Med. Phys. 21 (1), January 1994

CIED Vendor Recommendations

Vendor	Device	Dose Limit (Gy) 2014	Dose Limit (Gy) 2020
Abbott (St. Jude)	ICD	No safe dose (tested to 30 Gy, few errors observed at 20 Gy)	
	ICP		
Biotronik, Inc.	ICD	No safe dose	
	ICP	10 Gy	No safe dose
Boston Scientific	ICD/ICD	No safe dose	
Medtronic	ICD	1 – 5 Gy (based on model)	5 Gy
	ICP	5 Gy	5 Gy

Rationale for Updating AAPM Report 45 / Task Group 34

- Average life expectancy of American has increased from 75 (1960 – 65) to 79 years (2015 – 20)
- Between 1993-2009 ICP utilization increased by 55.6%
- In 2014, an estimated 351,000 ICP and 60,000 ICD implant procedures were performed for inpatients in the United States

http://data.un.org/Data.aspx?q=life+expectancy&d=PopDiv&f=variableID%3a68
Greenspon *et al.*, Journal of American College of Cardiology, 2012; 60(16): 1540-1545.
https://www.acc.org/latest-in-cardiology/ten-points-to-remember/2019/02/15/14/39/aha-2019-heart-disease-and-stroke-statistics

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Management of radiotherapy patients with implanted cardiac pacemakers and defibrillators: A Report of the AAPM TG-203†

Moyed Miften[a),‡]
Task Group 203, Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO 80045, USA
Dimitris Mihailidis[a),‡]
Task Group 203, University of Pennsylvania Perelman Center for Advanced Medicine, Philadelphia, PA 19104, USA
Stephen F. Kry
Department of Radiation Physics, UT MD Anderson Cancer Center, Houston, TX 77030, USA
Chester Reft
Department of Radiation Oncology, University of Chicago, Chicago, IL 60637, USA
Carlos Esquivel
Department of Radiation Oncology, UT Health Sciences Center, San Antonio, TX 78229, USA
Jonathan Farr
Division of Radiological Sciences, St. Jude Children's Research Hospital, Memphis, TN 38105, USA
David Followill
Department of Radiation Physics, UT MD Anderson Cancer Center, Houston, TX 77030, USA
Coen Hurkmans
Department of Radiotherapy, Catharina Hospital, Eindhoven, the Netherlands
Arthur Liu
Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO 80045, USA
Olivier Gayou
Department of Radiation Oncology, Allegheny General Hospital, Pittsburg, PA 15212, USA
Michael Gossman
Department of Radiation Oncology, Tri-State Regional Cancer Center, Ashland, KY 41101, USA
Mahadevappa Mahesh
Department of Radiology, Johns Hopkins University School of Medicine, Baltimore, MD 21287, USA
Richard Popple
Department of Radiation Oncology, University of Alabama, Birmingham, AL 35249, USA
Joann Prisciandaro
Department of Radiation Oncology, University of Michigan, Ann Arbor, MI 48109, USA
Jeffrey Wilkinson
Consultant, Medtronic Inc., Mounds View, MN55112, USA

Med Phys, 2019; 46(12): e757-e788.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Role of CIEDs

- Correct for cardiac arrhythmia
  - Bradycardia (heart rate is too slow, < 60 beats per min)
  - Tachycardia (heart rate is too fast, > 100 beats per min)
  - Fibrillation (irregular rhythm)
- If the arrhythmia is serious or of concern, a CIED, such as an ICP or ICD, may be implanted

RADIATION ONCOLOGY | MICHIGAN MEDICINE

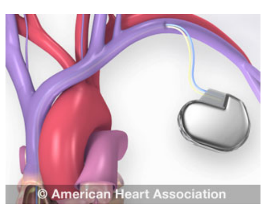
Purpose of ICPs

- Sense heart rhythms
- Record
- Therapy
  - Sends an electrical pulses to the heart when arrhythmias are detected to pace the heart → Pacing
  - Some designs – coordinate the chambers of the heart (i.e., ventricles)

RADIATION ONCOLOGY | MICHIGAN MEDICINE

ICP Components

- Leads/electrodes
  - Senses and transmits electrical impulses
- Pulse generator
  - Records heart rhythms
  - Controls therapies
  - Generates pulses to correct for arrthythmia
- Battery
  - Powers the generator



RADIATION ONCOLOGY | MICHIGAN MEDICINE

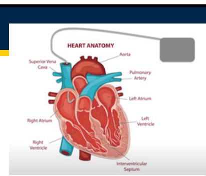
ICP Designs

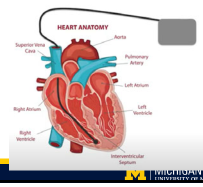
- Single chamber ICPs
- Dual-chamber ICPs
- Biventricular ICPs

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Single Chamber ICP

- Right atrium
  - Sinus node not working adequately, but rest of heart functioning normally
- Right ventricle
  - Normal pulses from the right atrium do not reach the ventricle



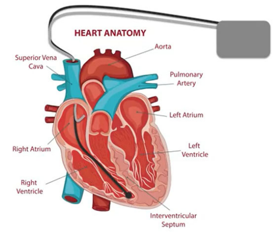


https://www.youtube.com/watch?v=GIMOa0HvLE0

RADIATION ONCOLOGY MICHIGAN MEDICINE

Dual-Chamber ICP

- One lead is placed in the right atrium and a second in the right ventricle
- Coordinates atrial and ventricular contraction, by sequentially pacing atria then ventricle to maximize the heart's pumping ability.

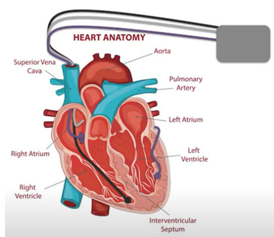


https://www.youtube.com/watch?v=GIMOa0HvLE0

RADIATION ONCOLOGY MICHIGAN MEDICINE

Biventricular ICP

- Leads are placed in the right and left ventricles, and typically a third lead is added to the right atrium.
- The addition of the lead in the left ventricle works to contract the left and right ventricle simultaneously.



https://www.youtube.com/watch?v=GIMOa0HvLE0

RADIATION ONCOLOGY MICHIGAN MEDICINE

Leadless ICPs

- First approved by FDA in 2016
- Advantages of these CIEDs include a reduction in lead and subcutaneous pocket complications, and hospitalization
- Offered by several leading ICP vendors (e.g., Medtronic, Boston Scientific, Abbott [St. Jude])

http://www.implantable-device.com/2019/05/13/my-take-from-hrs-leadless-pacemakers-are-entering-the-mainstream/
Bhatia and El-Chami, J Geriatr Cardiol, 2018; 15(4): 249-253.

RADIATION ONCOLOGY MICHIGAN MEDICINE

Purpose of ICDs

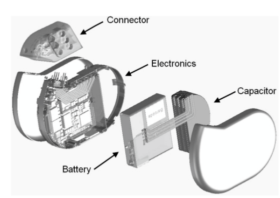
- Sense heart rhythms
- Record
- Therapy
  - Sends an electrical pulses to the heart when arrhythmias are detected to pace the heart → Pacing
  - Some designs – coordinate the chambers of the heart (i.e., ventricles)
  - Delivers high voltage pulse (~800V) to the heart when life-threatening arrhythmias are detected

Same functionality as ICPs

RADIATION ONCOLOGY MICHIGAN MEDICINE

ICD Components

- Leads/electrodes
  - Senses and transmits electrical impulses
  - Provides defibrillation
- Pulse generator
  - Records heart rhythms
  - Controls therapies
  - Generates pulses to correct for arrthythmia
- Capacitor
  - Stores and deliver high-voltage shocks
- Battery
  - Powers the generator



Van Welsenes *et al.*, Neth Heart J, 2011; 19(1): 24-30.

RADIATION ONCOLOGY MICHIGAN MEDICINE

ICD Designs

- Single chamber ICDs
  - Lead placed in right ventricle
- Dual-chamber ICDs
  - Leads placed in the right atrium and right ventricle
- Biventricular ICDs
  - Leads placed in the right atrium and ventricle, and the coronary sinus which is adjacent to left ventricle

https://www.webmd.com/heart-disease/atrial-fibrillation/abnormal-rhythms-icd

Effects of Ionizing Radiation on CIEDs

- Modern CIED circuits use complementary metal oxide semiconductors (CMOS)
- Pro - CMOS circuits have led to smaller, more energy efficient and reliable CIEDs
- Con - CMOS is known to be susceptible to ionizing and electromagnetic radiation, which may result in transient or permanent device defects

Effects of Ionizing Radiation on CIEDs

- Ionizing radiation creates excess electron-hole pairs in the SiO_2 layer of the CMOS
- Holes trapped in band gap form aberrant electrical pathways in the insulator
- May result in minor or significant malfunctions

Miften *et al.*, Med Phys, 2019; 46(12): e757-e788.

Potential Risk Factors

- Clinical conditions
  - Cumulative dose effects
  - Neutron-induced upsets
  - Dose-rate effects
  - Magnetic field effects
  - Electromagnetic interference

Cumulative dose effects

- Most commonly cited interaction between CIED and radiotherapy

TABLE III. CIEDs *in vitro* studies in recent literature.

Author	Year	Device (ICP or ICD)	Outcome
Souliman[42]	1994	18 ICPs (dual- and single-chamber models, various manufacturers)	11 ICPs failed with no recovery, first compete failure at accumulated dose of 16.8 Gy
Mouton[4]	2002	96 ICPs (various manufacturers and models)	66% amplitude change >10%, 50% permanent silence, 48% slowed down rate, 41% silence longer than 10 s. 30% accelerated rate, 27% missing impulses at start of irradiation, 23% signal compatible modification, 17% shape deformation.NB. 5% of all pacemakers were concerned with multiple short silences, which are considered to be harmful.
Hurkmans[48]	2005	19 ICPs (4 manufacturers)	All ICPs showed a point of failure at or above 90 Gy, except of one at 20 Gy; 5 of 19 ICPs showed a battery replacement warning. Loss of output was the most commonly observed point of failure. ICPs showed a large variation in their sensitivity to radiation.
Hurkmans[6]	2005	11 ICDs (4 manufacturers)	First malfunction observed at 0.5 Gy. Sensing threshold changes were often seen as first malfunction. 4 ICDs failed ≤2.5 Gy, 4 ICDs showed VT or VF, which would have resulted in delivery of a shock. No significant changes in pulse amplitude or pulse frequency were observed. No telemetry problems recorded.
Uiterwaal[49]	2006	11 ICDs	Interference detection observed for all ICDs irradiated in the treatment field, noted from the first radiation fraction. 4 ICDs showed VF or VT detection.
Kapa[123]	2008	12 ICDs (3 manufacturers)	No malfunctions observed.
Hashimoto[128]	2012	4 ICDs (same manufacturer)	Proton beam with secondary neutrons-29 Soft Error (SEU) were noted, 1event/15 Gy approx.
Hashii[108]	2013	8 ICDs (2 models same manufacturer)	10- and 18-MV photon beams, no hard errors observed, soft error more frequently observed at 18 MV.
Zaremba[34]	2013	10 ICPs and 2 ICDs (various manufacturers)	6 and 18 MV to 150 Gy (2 Gy fraction) dose.6-MV group: One ICP malfunction; 18-MV group: 14 ICP malfunctions at lower dose. No ICD malfunctions were noted at any dose level.

Miften *et al.*, Med Phys, 2019; 46(12): e757-e788.

Cumulative Dose Effects

- 18 ICPs from five manufacturers
- Irradiation conditions
  - 8 MV photons
  - 10x10 cm^2 field
  - 100 cm SSD
  - 2 cm depth
  - 2.8 Gy/fx to 70 Gy or point of failure
- 11 of 18 ICPs experienced permanent failures
- First failure observed at 16.8 Gy

Souliman and Christie, PACE, 1994; 17:270-273

Cumulative Dose Effects

- 96 explanted ICPs (varying ages)
- Irradiation conditions:
  - 18 MV photons
  - 15x15 cm^2 field
  - 100 cm SSD
  - 10 cm polystyrene depth (10.2 cm equivalent depth in H2O)
  - Up to 200 Gy or point of failure
  - Dose rates: 0.05 – 8 Gy/min
- Spread of total dose failures – as low as 0.15 Gy, but 10 ICPs withstood > 140 Gy without failure

Mouton *et al.*, Phys Med Biol, 2002; 47: 2789-2893.

Cumulative Dose Effects

- 19 new ICPs from four manufacturers
- Irradiation conditions
  - 6 MV photons
  - 10x10 cm^2 field
  - 100 cm SSD
  - 1.6 cm depth
  - Up to 120 Gy or point of failure
- All devices experienced point of failure at ≥ 90 Gy
  - Complete loss of signal (pacing pulse) - 7 ICPs
  - Lost telemetry capabilities - 3 ICPs

Hurkman *et al.*, Radiother Oncol, 2005; 76(1):93-98.

Cumulative dose effects

- Potential effects of high cumulative dose
  - Changes in pacing pulse
  - Changes in sensing threshold
  - Temporary or permanent loss of telemetry capabilities
  - Changes in pacing frequency
  - Battery depletion
  - Changes in lead impedance
  - Complete loss of signal

Miften *et al.*, Med Phys, 2019; 46(12): e757-e788.

Neutron-Induced Upsets

TABLE III. CIEDs *in vitro* studies in recent literature.

Author	Year	Device (ICP or ICD)	Outcome
Hashimoto[128]	2012	4 ICDs (same manufacturer)	Proton beam with secondary neutrons-29 Soft Error (SEU) were noted, 1event/15 Gy approx.
Hashii[108]	2013	8 ICDs (2 models same manufacturer)	10- and 18-MV photon beams, no hard errors observed, soft error more frequently observed at 18 MV.
Zaremba[34]	2013	10 ICPs and 2 ICDs (various manufacturers)	6 and 18 MV to 150 Gy (2 Gy fraction) dose.6-MV group: One ICP malfunction; 18-MV group: 14 ICP malfunctions at lower dose. No ICD malfunctions were noted at any dose level.

Miften *et al.*, Med Phys, 2019; 46(12): e757-e788.

Neutron-Induced Upsets

TABLE IV. CIED *in vivo* studies in recent literature

Author	Year	Tumor site (Device)	Prescribed dose (Beam Energy)	Dose to device	Outcome
Lau[118]	2008	Pelvis irradiation (ICD)	74 Gy (23-MV photons)	<0.1 Gy	Electrical reset potentially by secondary neutrons.
Ng[180]	2008	Esophagus, Prostate	45 Gy72 Gy	Unreported	Power-on reset/pulse width change noted.
Gelblum[10]	2009	33 patients treated at various sites including prostate (ICD)	0.6–81 Gy (6/15-MV photons)	0.01–2.9 Gy	Reprogramming of device in one case. Photon beams <10 MV was recommended
Tondato[52]	2009	Thyroid, Nose, Lung (ICP)	28–63 Gy (6-MV photons — possibly)	Unreported	Most cases had minor parameter changes (over/under sensing). Some were more serious that required re-programming.
Wadasadawala[165]	2011	Various sites (ICP)	45–70 Gy (6-MV photons)	0.06–60 Gy	No malfunction after 5 months of median follow-up.
Ferrara[68]	2010	37 patients with ICPs and 8 with ICDs	8–79.2 Gy (6- and 18-MV photons, electrons)	0.3–5.6 Gy	No malfunctions reported.
Soejima[20]	2011	Prospective survey: 60 patients with ICPs and 2 with ICDs	20–74 Gy (6/15-MV photons, Cyberknife, IMRT)	0.48-2.1 Gy (6 patients >2 Gy reported)	No malfunction for >2 Gy reported, 1 ICP prostate IMRT 15 MV memory initialized.
Makkar[181] Prisciandaro[70]	20122015	69 patients devices placed 1.5–10 cm from treatment field (ICPs and ICDs)	4–77.7 Gy (electrons, photons, IMRT, SRS, SBRT)	ICP: 5 Gy (max); ICD: 1.7 Gy (max)Mean dose: <2 Gy to all devices	Soft Errors in two ICD patients irradiated with 16 MV.
Elders[29]	2013	15 patient treated in various sites (ICD)	Doses ranged from 16–70 Gy depending on the site (6/10/18-MV photons)	<1 Gy in most cases.	Soft Errors noted in 29% of treatments with higher energy beams-secondary neutrons suspected as reason.
Gomez[43,182]	2013	42 patients treated in various sites (ICPs and ICDs)	Median prescribed dose 74 GyE (protons)	Median estimated: 0.8-Gyproton 346-mSv neutron	2 ICDs reset, 2 ICPs reset
Grant[57]	2015	215 patients treated in various sites (ICPs&ICDs)	Dose ranged by site. Primarily 6 and 18 MV.	Median 0.50 Gy; range: 0–30.2 Gy	15 SEU events (attributed to neutrons), 2 unrecoverable.3 transient noise events.

Miften *et al.*, M

Neutron-Induced Upsets

- Prospective survey of 62 patients (60 with ICPs and 2 with ICDs) from 29 institutions
- Device was outside of the txmt field in all patients, but inside of imaging field in 21 patients
- Patients received a total dose of 20 – 74 Gy, median 50 Gy
- Device was evaluated for 52 patients (before, during, or after RT)
- One ICP malfunction was noted – patient treated with 15 MV beam, IMRT to prostate, total dose 74 Gy in 37 fx. Device re-initialized between 46 – 56 Gy.

Soejima *et al.*, J Radiat Res, 2011; 52(4): 516-521.

Neutron-Induced Upsets

- Retrospective survey of 69 patients (50 with ICPs and 19 with ICDs)
- Device was outside of the txmt field in all patients, 1.5 cm to > 40 cm
- Patients received a total dose of 4 – 77.7 Gy
- Two ICP malfunctions were noted for patients treated with at least one 16 MV photon beam – partial resets of device, one device < 2.5 cm from txmt field

Makkar *et al.*, Heart Rhythm, 2012; 9(12): 1964-1968.
Prisciandaro *et al.*, JACMP, 2015; 16(1): 254-263

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Neutron-Induced Upsets

- Retrospective study of 215 patients (123 with ICPs and 92 with ICDs)
- Patients received a median dose of 33 Gy
- 15 devices (4 ICPs and 11 ICDs) experienced single-event upsets in patients treated with high energy photon beams (15 or 18 MV)

Grant *et al.*, JAMA Oncol, 2015; 1(5): 624-632.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Neutron-Induced Upsets

Table IV. CIED *in vivo* studies in recent literature

Author	Year	Tumor site (Device)	Prescribed dose (Beam Energy)	Dose to device	Outcome
Lau[118]	2008	Pelvis irradiation (ICD)	74 Gy (23-MV photons)	<0.1 Gy	Electrical reset potentially by secondary neutrons.
Ng[180]	2008	Esophagus, Prostate	45 Gy72 Gy	Unreported	Power-on reset/pulse width change noted.
Gelblum[10]	2009	33 patients treated at various sites including prostate (ICD)	0.6–81 Gy (6/15-MV photons)	0.01–2.9 Gy	Reprogramming of device in one case. Photon beams <10 MV was recommended
Tondato[52]	2009	Thyroid, Nose, Lung (ICP)	28–63 Gy (6-MV photons — possibly)	Unreported	Most cases had minor parameter changes (over/under sensing). Some were more serious that required re-programming.
Wadasadawala[165]	2011	Various sites (ICP)	45–70 Gy (6-MV photons)	0.06–60 Gy	No malfunction after 5 months of median follow-up.
Ferrara[68]	2010	37 patients with ICPs and 8 with ICDs	8–79.2 Gy (6- and 18-MV photons, electrons)	0.3–5.6 Gy	No malfunctions reported.
Soejima[20]	2011	Prospective survey: 60 patients with ICPs and 2 with ICDs	20–74 Gy (6/15-MV photons, Cyberknife, IMRT)	0.48-2.1 Gy (6 patients >2 Gy reported)	No malfunction for >2 Gy reported, 1 ICP prostate IMRT 15 MV memory initialized.
Makkar[181] Prisciandaro[70]	20122015	69 patients devices placed 1.5–10 cm from treatment field (ICPs and ICDs)	4–77.7 Gy (electrons, photons, IMRT, SRS, SBRT)	ICP: 5 Gy (max); ICD: 1.7 Gy (max)Mean dose: <2 Gy to all devices	Soft Errors in two ICD patients irradiated with 16 MV.
Elders[29]	2013	15 patient treated in various sites (ICD)	Doses ranged from 16–70 Gy depending on the site (6/10/18-MV photons)	<1 Gy in most cases.	Soft Errors noted in 29% of treatments with higher energy beams-secondary neutrons suspected as reason.
Gomez[43,182]	2013	42 patients treated in various sites (ICPs and ICDs)	Median prescribed dose 74 GyE (protons)	Median estimated: 0.8-Gyproton 346-mSv neutron	2 ICDs reset, 2 ICPs reset
Grant[57]	2015	215 patients treated in various sites (ICPs&ICDs)	Dose ranged by site. Primarily 6 and 18 MV.	Median 0.50 Gy; range: 0–30.2 Gy	15 SEU events (attributed to neutrons), 2 unrecoverable.3 transient noise events.

RADIATION ONCOLOGY Miften *et al.*, Med Phys, 2019; 46(12): e757-e788. | MICHIGAN MEDICINE

Dose-Rate Effects

- 96 explanted ICPs (varying ages) were studied
- Dose rates: 0.05 – 8 Gy/min
- 70% of ICPs failed at dose rates of 8 Gy/min
- No failures observed at or below 0.2 Gy/min
- Reported failures
  - Amplitude decrease of electrical signal > 10%
  - Silences of electrical signal ≥ 10 s
  - Permanent silence

Mouton *et al.*, Phys Med Biol, 2002; 47: 2789-2893.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Dose-Rate Effects

- Confounding factors:
  - Cumulative dose: up to a total dose of 200 Gy
  - Devices irradiated in direct beam with 18MV photons

Mouton *et al.*, Phys Med Biol, 2002; 47: 2789-2893.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Magnetic Field Effects

- Heating at lead tip and tissue interface
- Force and torque on device
- Alteration of device programming
- Inappropriate function and therapies
- Electrical reset
- Component damage
- Death

Santini *et al.*, Pacing Clin Electrophysiol, 2013; 36(3): 270-278.
Indik *et al.*, Heart Rhythm, 2017; 14(7): e97-e153.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Electromagnetic Interference

- EM noise around modern linacs is minimal
- Potential sources in current practice
  - EMI guidance systems
  - Gating technologies
- Potential effects
  - Inhibit therapies
  - Shut-off of reed switch – result in fixed pacing rate
  - Trigger unnecessary therapy
  - Permanent silence

Mouton *et al.*, Phys Med Biol, 2002; 47: 2789-2893.

Recommendations

- Cumulative dose < 5 Gy
- Generator should be kept 5 cm from field edge, whenever feasible
- Avoid high energy photons (>10MV) and irradiation with proton or neutron beams
- Maintain low dose-rates to the device (< 0.01 Gy/min)
  - Soft recommendation, there are uncertainties associated with this effect
- Use precautions when MR imaging patients
  - Ensure device is MR conditional and be familiar with conditions in which the device was tested

Miften *et al.*, Med Phys, 2019; 46(12): e757-e788.

RADIATION ONCOLOGY | MICHIGAN MEDICINE

Summary

- As the average lifespan of Americans increase, the number of patients with CIEDs presenting for radiotherapy will continue to increase
- Be familiar with the different types of CIED that are used, and how the device functions
- Understand the potential clinical conditions that can induce CIED malfunctions
- With the proper precautions and patient monitoring, patients may safely receive RT

RADIATION ONCOLOGY | MICHIGAN MEDICINE