Radiation Therapy of Patients with Cardiac Implantable Devices: Dosimetric Evaluation and Clinical Management

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Are we living longer?

“Seemed more patients with pacemakers these days”
When we see this in the images...

“Is that a pacemaker?!”
“Why nobody told us?!”

“Do I have to contour this?!”
“What is the dose limit?”
“What planning technique should I use? ……”

RTT
CMD
Outline

- Introduction
  - Arrhythmia
  - Cardiac Implantable Electronic Devices (CIED)
  - Photon interactions

- CIED Errors

- Out-of-field dose
  - TG 34: no direct beam
  - TG 158

- Guidelines
  - Cumulative dose
  - Risk categories
  - Clinical management

- Policy and procedure

Q & A
Introduction

• Arrhythmia
• CIED
• Photon interactions*

*This presentation will focus mainly on MV EBRT
Arrhythmia

- Abnormal heart rhythms
- Natural pacemaker – SA node
- Causes
  - Abnormal rhythm from SA node
  - Interrupted conduction pathway
  - Impulses from other heart tissue

Cardiac Implantable Electronic Devices

- Implantable Cardiac Pacemaker (ICP)
- Implantable Cardioverter Defibrillator (ICD)
  - Newer ICDs – both pacemaker and defibrillator
CIED - components

Pulse Generator
- Capacitors
- Semiconductor Chips
- Battery

Ref: C M Costelloe et al., AJR 2012; 199:1252-1258
Photodisintegration

\[ \frac{A}{Z}X + \gamma \rightarrow \frac{A-1}{Z}X + \frac{1}{0}n \]

Photoneutron contamination when > 10 MV !!!

Ref: F Khan et al., Khan’s Lectures Handbook of the Physics of Radiation Therapy, 2011
Potential CIED errors

- By ionizing radiation
- By Electromagnetic Interference (EMI)
Potential CIED errors by ionizing radiation

- Altered stimulation (amplitude, frequency)
- Altered sensing (over-/under sensing)
- Inhibition of stimulation (pause, asystole)
- Change in operational mode (incl. asynchronous stimulation)

Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404
Potential CIED errors by ionizing radiation

- Battery depletion (ERI-exchange indicator)
- Altered electrode sensing (impedance)
- Loss of telemetry or programming capabilities
- Reset in default setting (fallback mode)
- Loss of function

Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404
Other potential errors for ICD only

• Inhibition of antitachyarrhythmia therapy
• Altered (reduced) shock energy
• Prolonged detection and charging intervals
• Inadequate (shock) therapy

Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404
Potential CIED errors by EMI

- Altered sensing (over-/under sensing)
- Inhibition of stimulation (pause, asystole)
- Reed-switch interaction (asynchronous stimulation)
- Atrial-triggered fast ventricular pacing
- ICD: Inhibition of antitachyarrhythmia therapy
- ICD: Inadequate (shock) therapy
- Reset/reprogramming of device

Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404
Out-of-field radiation doses

- AAPM TG34 recommended
  “Pacemaker not in direct beam”
- AAPM TG158

Ref: JR Marbach et al., AAPM Report No. 45, Med Phys 1994
Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429
AAPM TG-34 recommendations

- Should not be treated with a betatron
- Should not be in direct radiation beam
- Dose should be estimated before RT
- If > 2 Gy, should be checked prior to RT, and possibly at the start of each week
- Functional changes in pacemaker have been observed in the 2-10 Gy range

Ref: JR Marbach et al., AAPM Report No. 45, Med Phys 1994
Out-of-field radiation doses

- **Internal (patient) scatter**
  Dominant in close proximity to the treated volume
- **Collimator scatter**
- **Head leakage**
  Dominant at distance > ~20 cm

Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429

Figure adapted from: (Last accessed on 9/4/19) [https://www.aapm.org/meetings/amos2/pdf/49-14482-90758-54.pdf](https://www.aapm.org/meetings/amos2/pdf/49-14482-90758-54.pdf)
Out-of-field radiation doses

- Softer than primary beam energy
- Decrease with distance
- Increase with field size (when close to field edge)
- Increase with modulation due to more head leakage and collimator scatter (when farther from field)

Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429
Out-of-field radiation doses

- Beam energy > ~10 MV → Neutrons
  - Primary collimator, target, flattening filter, jaws, MLC…
  - Isotropic neutron emissions from accelerator head
  - Fluence of neutrons increases linearly with MU
  - For Varian accelerator: ~10 times from 10 MV to 15 MV
    ~2 times form 15 MV to 18 MV

Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429
Out-of-field radiation doses

- Decrease with Flattening filter-free (FFF)
- Increase with physical wedges

- Larger errors in dose calculation by treatment planning systems (TPS) when > 3 cm from field edge or < 5% isodose line

- Measurement and Monte Carlo Simulation

Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429
Published guidelines

- Cumulative dose
- Risk categories
- Clinical management
Cumulative dose guidelines

• AAPM TG-34 (1994): 2 Gy limit
  – Does not include current technology and ICD
• Different among manufacturers and some do not provide a safe dose limit
• *HRS consensus statement: < 5 Gy
• **DSRO: Risk categories
• ***Upcoming AAPM TG-203: Risk categories

*Ref: JH Indik et al., Heart Rhythm 2017; 14:e97-e153
**Ref: CW Hurkmans et al. Radiat Oncol 2012; 7:198
## Recommendations from Manufacturers

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Biotronik</th>
<th>Boston Scientific</th>
<th>Medtronic</th>
<th>St. Jude Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device checks</td>
<td><strong>Before</strong> and <strong>after</strong> RT</td>
<td>Specific to patient</td>
<td><strong>After</strong> RT, If exceeds safe dose during RT</td>
<td><strong>During</strong> and <strong>after</strong> RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitor <strong>after</strong> RT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max ICP dose</td>
<td>2 Gy</td>
<td>No safe dose</td>
<td>5 Gy</td>
<td>No safe dose</td>
</tr>
<tr>
<td>Max ICD dose</td>
<td>2 Gy</td>
<td>No safe dose</td>
<td>1-5 Gy dep. on model</td>
<td>No safe dose</td>
</tr>
<tr>
<td>Max energy</td>
<td>&lt;10 MV</td>
<td>Not stated</td>
<td>≤10 MV</td>
<td>Not stated</td>
</tr>
<tr>
<td>Inactivation of antitachycardia</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pb shielding</td>
<td>Yes</td>
<td>All available shielding</td>
<td>No (ineffective against neutrons)</td>
<td>Not stated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>options</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rhythm monitoring</td>
<td>Yes, during RT</td>
<td>Determine by physician team</td>
<td>Not stated</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Ref: T Zaremba et al., PACE 2015; 38:343-356*
Risk categories – Dutch Society of Radiotherapy and Oncology

Table 2 Patient risk categories: cumulative dose to the CIED and pacing independent versus pacing dependent

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>&lt; 2 Gy</th>
<th>2-10 Gy</th>
<th>&gt; 10 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacing-independent</td>
<td>Low risk</td>
<td>Medium risk</td>
<td>High risk</td>
</tr>
<tr>
<td>Pacing dependent</td>
<td>Medium risk</td>
<td>Medium risk</td>
<td>High risk</td>
</tr>
</tbody>
</table>

Risk defined from the patients' perspective; how high is the risk for the patient? The patient's risk is not equal to the risk of a CIED defect.

**Upcoming TG-203***: will adopt similar risk category approach but will likely define 2-5 Gy as medium risk and > 5 Gy as high risk

Ref: CW Hurkmans et al. Radiat Oncol 2012; 7:198
# Pacemaker dependency

The risk of serious injury or death from pacemaker failure

<table>
<thead>
<tr>
<th></th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms</td>
<td>Bradycardia</td>
<td>Asymptomatic</td>
<td>Asymptomatic</td>
</tr>
<tr>
<td>Ventricular rate</td>
<td>No intrinsic activity</td>
<td>Ventricular rate &lt; 30 beats per minute</td>
<td>Ventricular rate &gt; 30 beats per minute</td>
</tr>
<tr>
<td>Abrupt cessation of pacing</td>
<td>Fatal</td>
<td>Not fatal</td>
<td>Not fatal</td>
</tr>
<tr>
<td>Emergent/urgent situation</td>
<td>Expected</td>
<td>Not expected</td>
<td>Not expected</td>
</tr>
<tr>
<td>Level of cardiac monitoring</td>
<td>Intense and active, before, during and after radiotherapy: cardiac arrest team on call</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Previous untoward</td>
<td>Highely dependent</td>
<td>Not present</td>
<td>Not present</td>
</tr>
<tr>
<td>cardiac history</td>
<td></td>
<td>Intermediately dependent</td>
<td>Non dependent</td>
</tr>
<tr>
<td>Pacemaker dependency</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref: T Wadasadawala et al., Clin Oncol 2011; 23:79-85
Guidelines by Dutch Society of Radiotherapy and Oncology

Patient with CIED and indicated radiotherapy

- Inform treating cardiologist and inform patient
- Determine patients’ pacing-dependency
  - If ICD, inform if anti-tachycardia therapy can be switched off by magnet
  - If CIED check-up > 3 months ago, plan check-up prior to start of radiotherapy

- Photon beam energy $\leq 10$MV
  - Estimate dose on CIED (seed rawing for indication)
  - Minimize dose on CIED with treatment plan optimisation

Ref: CW Hurkmans et al. Radiat Oncol 2012; 7:198
DSRO guidelines

When the tumour is within this zone it is likely that the CIED dose is:

- **LOW RISK**
  - Audiovisual monitoring of patient
  - In case ICD: program tachycardia therapy off or use magnet
  - Letter to cardiologist
  - ICDs: weekly check-ups

- **INTERMEDIATE RISK**
  See LOW RISK plus:
  - Crashcart present during RT
  - Weekly check-up CIED
  - Possibility of external pacing
  - Trained staff with cardiology expertise can be present within 10 minutes (if not, patients should be referred to another institute)

- **HIGH RISK**
  - In exceptional cases a decision to start RT can be made
  - Safety measures which are atleast those used for intermediate risk patients
  - ECG-monitoring during every fraction
  - CIED checked within 24 hours by pacemaker technician

Ref: CW Hurkmans et al. Radiat Oncol 2012; 7:198
Policy and Procedure

ROSWELL PARK COMPREHENSIVE CANCER CENTER
CIED management P&P

- Identify patients who have CIED
- Alert and documentation in patient chart
- Multidisciplinary team clinical management
- Published guidelines and manufacture safe dose limit if provided
Identify patients with CIED

Clinical Center Associates Medical review form with a CIED question

Nursing Staff Verify medical form If CIED, document in EHR, obtain CIED card

Physician Care Team Review device info Activate an alert in chart Request physics consult

CT Simulation Time Out
- Verify the presence or absence of CIED
- If CIED presents and no device info in chart, ask for device card
- If CIED presents and no alert in patient chart, activate the alert
# CIED document and Alert

## Medical Device ID

**Patient:** Patient Name  
**Physician:** Following Physician/Clinic Name  
**Physician Telephone:** Following Phone

<table>
<thead>
<tr>
<th>MFG</th>
<th>Product</th>
<th>Model/Serial</th>
<th>Implant Dt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston Sci</td>
<td>CRT-D</td>
<td>1234 968765</td>
<td>12-OCT-2015</td>
</tr>
<tr>
<td>Boston Sci</td>
<td>Lead</td>
<td>7654 123456</td>
<td>12-OCT-2015</td>
</tr>
<tr>
<td>Boston Sci</td>
<td>Lead</td>
<td>6789 234567</td>
<td>12-OCT-2015</td>
</tr>
<tr>
<td>Boston Sci</td>
<td>Lead</td>
<td>4321 345678</td>
<td>12-OCT-2015</td>
</tr>
</tbody>
</table>

## Implant Cardiac Rhythm Management Patient

Contact physician for medical questions or emergency  
www.bostonscientific.com

### For Patients

- **For Patients**  
  866.494.3268 (USA)  
  001.651.582.4000 (Outside USA)  
  www.lifebeatonline.com

### For Medical Personnel

- **1.800.227.3422** or 651.582.4000

### MRI

- For questions regarding MRI device compatibility, see the  
  Boston Scientific website at www.bostonscientific.com/imageready

CRM-64301-AB OCT2015

### Patient Log and Chart Activity - ID: 007 Test, Word

| Notifications:  
| Pace Maker: ICD |
Dosimetry procedure

- No primary radiation beam
- Photon beam energy $\leq 10$ MV
- Contour CIED in CT images and report TPS computed maximum dose
- If no manufacture dose limit, $<2$ Gy (TG34)
- If $>2$ Gy, notify physicist and physician for further evaluation
Physicist procedure

- Review patient chart for CIED information
- Verify alert in patient chart
- Verify treatment plan and CIED doses according to guidelines and P&P
- Notify and discuss with relevant parties if problem detected
Avoid direct beam at verification imaging

In this example, Y1 jaw was closed during double exposure MV imaging.
Physician and care team

• Schedule interrogation of the CIED by a manufacturer-representative. Frequency is at discretion of attending physician.
• Document interrogation report in EMR
• At least should interrogate CIED at completion
• If cumulative dose guidelines cannot be met, make decision to choose other options, e.g. CIED relocation, magnet, etc.
Summary

- Risk categories - cumulative dose limit, type of CIED and patient’s CIED dependency
- Limitations in TPS out-of-field dose computation
- No direct radiation
- No high-energy photon
- Multidisciplinary clinical management - develop a **Standard Policy and Procedure**!!!
CIED in radiation therapy

Thank you!

Questions?


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