3D Dosimetry in the Clinic and Research

3D DOSIMETRY IN END-TO-END DOSIMETRY QA

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Disclosures

My institution holds Master Research Agreements with Varian, Elekta, and Philips

I will be discussing devices that are not currently available for sale, and that do not have FDA clearance.
Learning objectives

1: 3D Dosimetry in the Clinic: Background and Motivation

2: 3D Dosimetry in the Clinic: Motion interplay effects in dynamic radiotherapy

3: 3D Dosimetry in the Clinic and Research: Validating Special Techniques

4: 3D Dosimetry in end-to-end dosimetry QA

- Evidence of need for E2E dosimetry
- Benefits of 3D dosimetry for E2E testing
- Specific examples of 3D dosimetry and E2E tests

G. Ibbott, AAPM, 2016
Errors in Radiation Therapy

1. Errors in medicine occur too often
   • IOM study: ~98,000 deaths/year
   • New York Times series:
     • St. Vincent’s Hospital: IMRT error
     • Moffitt Cancer Center: Calibration error

2. QA is essential
   • Equipment is more complex
   • Techniques are more complex
   • Risk to patient from error is greater
   • Most institutions report insufficient staff
What causes things to go wrong?*

**Selected Causes/Contributing factors**

<table>
<thead>
<tr>
<th>Cause</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Therapist error</td>
<td>84%</td>
</tr>
<tr>
<td>Failure to follow policies/procedures</td>
<td>63%</td>
</tr>
<tr>
<td>Incorrect body part</td>
<td>46%</td>
</tr>
<tr>
<td>Physics/Dosimetry</td>
<td>27%</td>
</tr>
<tr>
<td>Wrong patient</td>
<td>19%</td>
</tr>
<tr>
<td>Inadequate policies/procedures</td>
<td>16%</td>
</tr>
<tr>
<td>RO error</td>
<td>12%</td>
</tr>
</tbody>
</table>

*New York State*

Courtesy Peter Dunscombe: “Safety in Radiation Therapy: A call to action”
IROC Phantoms

Pelvis (10)

Thorax (13)

Spine (4)

H&N (31)

SRS Head (4)

Liver (2)

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# IROC Phantom Results

Comparison between institution’s plan and delivered dose.

<table>
<thead>
<tr>
<th>Phantom</th>
<th>H&amp;N</th>
<th>Liver</th>
<th>Lung</th>
<th>Prostate</th>
<th>Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiations</td>
<td>1351</td>
<td>9</td>
<td>484</td>
<td>411</td>
<td>168</td>
</tr>
<tr>
<td>Pass</td>
<td>1118</td>
<td>6</td>
<td>394</td>
<td>352</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>(83%)</td>
<td>(67%)</td>
<td>(81%)</td>
<td>(86%)</td>
<td>(67%)</td>
</tr>
<tr>
<td>Fail</td>
<td>233</td>
<td>3</td>
<td>90</td>
<td>59</td>
<td>55</td>
</tr>
<tr>
<td>Criteria</td>
<td>7%/4mm</td>
<td>7%/4mm</td>
<td>5%/5mm</td>
<td>7%/4mm</td>
<td>5%/3mm</td>
</tr>
</tbody>
</table>

G. Ibbott, AAPM, 2016
H&N Phantom
Volumetric Dosimeters

• Fricke Gel
• Polymer Gel
• Radiochromic Polyurethane (Presage™)

G. Ibbott, AAPM, 2016
Measured dose vs. calculations

NDD Pass Rate = 97.6%

Eclipse
Presage

Courtesy M. Oldham, Duke Univ., 2012
The Transform Method

- Current dosimetry methods only allow for dose comparison in the phantom.
- 3D dosimetry techniques allow the phantom dose distribution to be transformed into the patient geometry, facilitating clinical interpretation.

Jackson, Juang, Adamovics and Oldham (2015) Physics in Medicine and Biology
3D Dosimetry
Gels Investigated:

- Conventional Fricke gels: Iron(II) oxidation-based radiation reporting system
  - Our Fricke type gels shown in this presentation have greater optical and MR contrast compared to the conventional formulation
  - All dosimeters shown here were prepared in gelatin

- BANG™ polymer gels
  - Standard formulation prepared by the manufacturer and poured into glass vessels of our design
Fricke gels

- Un-irradiated (Fe$^{2+}$) vs irradiated (Fe$^{3+}$) dosimeters
- Doses from 0 Gy to 100 Gy:
MR Imaging of Irradiated Gel

- Irradiated dosimeter with un-irradiated region shown below with $T_1$-weighted MR images in gray and RGB scale

TR/TE = 500/20 ms

Un-irradiated control

Irradiated region (~17 Gy)
MRI Guided Radiation Therapy

Purpose

Treat the patient while simultaneously imaging with a ‘conventional’ 1.5T diagnostic MRI

How

1. Mount the Linac on a rotatable gantry around the MRI magnet
   *The radiation isocenter is at the centre of the MRI imaging volume*

2. Modify the Linac to make it compatible with the MR environment

3. Modify the MRI system
   *Minimize material in the beam path*
   *Minimize magnetic field at the Linac*
Change in irradiated region during beam-on can be seen with $T_1$-$T_2$-weighted balanced-Fast Field Echo (b-FFE) MR images.

$TR/TE = 5/2.4$ ms

Irradiated region (~17 Gy)

1 f = 250 ms
200 fps

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MR-Linac is a research programme. It is not available for sale and its future availability cannot be guaranteed.
Field edge measured with MR-Linac at different times post-irradiation
(averaged line profiles across penumbra region)

22h post-irradiation
80/20 penumbra = 5.6 mm

22h post-irradiation
80/20 penumbra = 6.5 mm

R2 [1/s]

Position [mm]

- patient Right at 22h
- patient Right at 80 min
- patient Right at 45 min
- patient Left at 22h
- patient Left at 55 min
- patient Left at 20 min
- unirradiated

G. Ibbott, AAPM, 2016
Real-time imaging of Penumbra

- Demonstrates immediate response of BANG gel to radiation
  - (Comparable to Fricke response with dose)

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Summary

- 3D dosimetry offers benefits beyond those of conventional dosimeters
- 3D dosimeters can be optimized for conducting remote audits
- Gel dosimetry has potential in magnetic field environment

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