3D Dosimetry with Polymer Gel

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Outline

I. Basics of polymer gel dosimetry
II. OCT Application - IMRT
III. MRI Applications
   - Gamma Knife
   - heterogeneity
Polymer Gel Dosimetry

- Ferrous sulphate (Fricke) doped gel: Gore, Kang, Schulz (Yale) 1984.
- BANANA: Maryanski, Gore, Schulz (Yale) 1993.
- BANG, BANG2, BANG3.
- MAGIC: Gore et al. (Yale) 2001.
- VIPAR, MAGAS, MAGAT, and many more.
BANG3 Polymer Gel Dosimeter

MGS Research Inc., Guilford, CT, USA

- **Water** (~80%): source of radicals, which initiate polymerization process.
- **Gelatin** (~14%): provides mechanical integrity.
- **Monomers**, Methacrylic acid (~6%): form polymers.
- Sensitivity modifier: CuSO$_4$ (~0.5mM).
BANG Kit

• Users can create polymer gel with desired sensitivity when needed.
• The dose response is modified by changing the amount of CuSO₄.
• Oxygen is removed by adding ascorbic acid.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Ascorbic acid (mMol)</th>
<th>CuSO₄ (mMol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CC05</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>CC15</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>CC210</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>CC315</td>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

Y.Murakami and T.Nakashima (2005)
Radiation Effect

Before

After
Dose estimation methods

- Magnetic Resonance Imaging (MRI)
- Optical CT (OCT)
- X-ray computed tomography (XCT)
- Ultrasound (US)
Optical Computed Tomography

He-Ne laser

Detector (photodiode)

Mirror

Mirror

OCTOPUS, MGS Research Inc.
OCT Scanning Principle

Light Beam

Gel

Optical Detector: photodiode

Gel rotates in medium

Reconstruction by Filtered back projection

Courtesy: C-S Wuu, Columbia University
OCT calibration

<table>
<thead>
<tr>
<th>Dose (Gy), 6 MV x-rays</th>
<th>A(1/cm), 633nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Gy/min</td>
<td></td>
</tr>
<tr>
<td>4Gy/min</td>
<td></td>
</tr>
<tr>
<td>6Gy/min</td>
<td></td>
</tr>
</tbody>
</table>

Courtesy: C-S Wuu, Columbia University
Irradiated Gel with IMRT Plan

Courtesy: C-S Wuu, Columbia University
Comparison of Transverse Dose Distributions
Red: Plan  Blue: Gel  Green: Film
MRI-based polymer gel dosimetry

✓ Measure spin-spin relaxation time, T2 (R2).

✓ MRI pulse sequences:
  
  • Hahn spin-echo sequence:
    » TR=2 s, TE=20 ms and 100 ms.
    » 24x24 FOV, 256x256 pixels, 2-5 mm slice.
    » NEX=2 to 3
  
  • CPMG (Carr-Purcell-Meiboom-Gill)
R2 vs. Absorbed dose

\[ y = -4E-05x^2 + 0.0353x + 3.9301 \]

\[ R^2 = 0.9977 \]

\[ y = 0.0259x + 4.3041 \]

\[ R^2 = 0.9859 \]
Gamma Knife
Phantom

- BANG polymer gel dosimeter
- 16-cm diameter spherical vessel.
- Radiation changes magnetic property of polymer gel => MRI to estimate dose.
Experimental Procedure

1) A phantom was placed in the Leksell frame.
2) Depth of the phantom is measured.
3) The phantom was irradiated. 25 Gy to 50%.
4) Phantoms were scanned with Philips 1.0T Gyroscan MRI scanner with Hahn spin-echo pulse sequence.

Experiments closely simulate actual treatment.
One-D profile along z-axis
8 mm collimator and $\gamma = 110^\circ$. 

![Graph showing one-dimensional profile along z-axis with different collimation and gamma angles.](image-url)
Orthogonal Planes

14-mm collimator (HU Exp 14)
Slice-by-slice Comparison
14-mm collimator (HU Exp 14)
Dose Difference: 14-mm

HU Exp 14

Mean dose difference vs dose

Histogram of dose difference

Mean = 0.02 Gy
Std = 2.0 Gy
Dose Difference: 4-mm

HU Exp 8

Mean dose difference vs dose

Histogram of dose difference

Mean = 0.2 Gy
Std = 5.1 Gy
Dose Difference: HU Exp 13 and 6

- 8-mm
- 18-mm
Radiobiological Comparison:
Method

- Goitein-Lyman Model for TCP and NTCP
- Spherical tumor
- Normal brain tissue outside the tumor
- Maximum dose: 100 Gy

- $TCD_{50} = 50 \text{ Gy}$
- $\gamma_{50} = 2$
- $TD_{50/5} = 60 \text{ Gy}$
- $n=0.25$
- $m=0.15$
### Radiobiological Comparison: Result

<table>
<thead>
<tr>
<th>Coll. [mm]</th>
<th>Tumor Diameter* [mm]</th>
<th>TCP</th>
<th>NTCP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GP</td>
<td>BANG</td>
</tr>
<tr>
<td>4</td>
<td>5.0</td>
<td>69.8</td>
<td>44.1</td>
</tr>
<tr>
<td>8</td>
<td>10.0</td>
<td>68.0</td>
<td>66.1</td>
</tr>
<tr>
<td>14</td>
<td>16.0</td>
<td>77.3</td>
<td>76.5</td>
</tr>
<tr>
<td>18</td>
<td>25.0</td>
<td>57.9</td>
<td>56.0</td>
</tr>
</tbody>
</table>

(*) corresponds to the size of 50% isodose surface.
Air and Bone in Tissue
Heterogeneity Phantom

- A 6 cm diameter and 6 cm deep cylindrical cavity on one of the flat ends.
- 3 cm thick cylindrical inserts.
- Simulate air and bone.
Homogeneous phantom: 6 MV X
Phantom with bone: 6 MV X

Photons

Tissue

Bone
6 MV X, bone
Phantom with bone: 18 MV X

Photons

Tissue

Bone
18 MV X, bone
Phantom with air: 6 MV X

Photons

Tissue

Air
6 MV X, air
Phantom with air: 18 MV X

[Diagram showing the path of photons through tissue and air.]
18 MV X, air
Phantom with air: 18 MV X, FS4x4
Polymer gel dosimetry can give 3D dose distributions in one irradiation with the least dose perturbation.

OCT and MRI are dose reading tools.

Polymer gel dosimetry is evolving technology.

For wider acceptance, we need easy-to-use and inexpensive polymer gel and fast and accurate reading tools.
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