Three Dimensional Dosimetry

Session Program: Therapy Education
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August 1, 2016

Learning objectives

1: 3D Dosimetry in the Clinic: Background and Motivation
   • Understand recent developments enabling clinically practical 3D dosimetry,
   • Appreciate 3D dosimetry workflow and dosimetry procedures, and
   • Observe select examples from the clinic.

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

3: 3D Dosimetry in the Clinic and Research: Special techniques

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

Over the years I have had the pleasure of working with various companies to test and develop ideas.

- **Most recently, Modus QA**
  - Testing readout systems and dosimeters under development, sharing software ideas…
  - No personal gain, but valuable in-kind research support.
3D volumetric dosimeters

- Chemical dosimeters that undergo radiation changes that can be probed by some physical technique

**Gel dosimeters**

- CCSEO
- PRESAGE
- Radiochromic plastic

**PRESAGE**

- Mark Oldham
- Duke
- Geoff Ibbott
- MDAnd
- FXG
- LCV micelle

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3D volumetric dosimeters

- Chemical dosimeters that undergo radiation changes that can be probed by some physical technique

**We are NOT considering:**

- Liquid Scintillators
- Exit/transit dosimetry – EPIDS
- Semi-3D systems – diode/ion chamber arrays

These are important systems that have their place, but are not in the scope of this session.
What typically comprises a volumetric 3D dosimeter?

Some matrix through which some stuff is dispersed

(Stuff ≡ dose reporter molecules)

Small amount stuff that changes under irradiation

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e.g., Fricke gel dosimeter

89% bulk water

5% gelatin

(in FX gels, + 0.05 mM xylenol orange)
e.g., radiochromic Leucodye micelle dosimeter

~96 % bulk water

4 % gelatin

Colour indicator trapped in micelles

(1mM Leuco crystal violet, 4mM surfactant, order 10 mM other stuff)

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e.g., polymer gel dosimeter

89 % bulk water

5 % gelatin

monomers

Large polymers

(in normoxic gels, + 5 mM tetrakis THPC)
Radiochromic Plastic: Presage

- a radiochromic Leucodye dispersed in polyurethane matrix
- Tissue equivalent
- Economical

Typical 3D Dosimeters

- records and retains spatial dose deposition information
- 3D!
- high spatial resolution
- manufactured in liquid form
- anatomical equivalence
- can be manufactures in anatomically equivalent phantoms

- absorbs dose similarly to water/tissue
- not necessary to correct for different absorption properties
- tissue equivalent
- can experiment with other types of equivalence (e.g. lung)

- dose integrating
- can record dose over entire delivery (e.g. IMRT)

(c/o Andrew Jirasek, UBC Kelowna)
Dosimeter - 3D Readout

- Polymer gels
- Radiochromic gels
  - FX-orange
  - Leucodye micelle gels
- Radiochromic plastics
  - Presage

(adapted from M Oldham, Duke)

Model dose response

Not all dosimeters show a threshold or a saturation dose.
Examples of Readout

MRI: Schieb 2001

X-ray CT: Hilts et al. 2000

CALIBRATION

vials

Our Preference
Independent volumes from same batch of dosimeter
Optical CT

Based on change of optical attenuation coefficients in irradiated dosimeter

- Fricke and Radiochromic dosimeters
  - Absorption changes

Precision and accuracy of 3D systems

In our hands using gel dosimeters we have been able to achieve:

- Relative doses (precision)
  - 2 to 3% easily, <1 or 2% with work
- Delivered dose (absolute dose) (accuracy)
  - 3 to 5% easily, 1–2% with work
3D Dosimetry (old problems/solutions)

Not yet broadly clinically adopted

- Imaging for readout not always readily available
  (MRI to optical CT or x-ray CT as available)

- Gel preparation (toxicity, oxygen contamination …)
  (some systems easily prepared, commercial vendors)

- May have better tools for applications to be tested
  (use the right tool for the right job)

- Data analysis laborious and lengthy
  (open source Slicer-RT module)

Commercial service providers for various systems and dosimeters:

- GeVero, Poland (www.polygevero.com)
- Heuris Pharma, USA (www.presage3d.com)
- MGS Research Inc., USA (www.mgsresearch.com)
- Modus QA, Canada (www.modusqa.com)
- RT Safe, Greece (www.rt-safe.com)

Apologies if this list is dated.
3D dosimetry process

Parker MSc 1997
Data analysis

We work in SLICER-RT open source environment

Percent depth-dose (PDD) method was used to calibrate (i.e. calculate optical dose sensitivity) our gel dosimeters.

Electron beam irradiations to the surface of a Fricke xylenol orange gel dosimeter were performed for a range of energies (9, 12, 16 MeV).

Gel response has previously been shown to be independent of photon or electron energy.

Gel dosimeter batch calibration

- Percent depth-dose (PDD) method was used to calibrate (i.e. calculate optical dose sensitivity) our gel dosimeters.
- Electron beam irradiations to the surface of a Fricke xylenol orange gel dosimeter were performed for a range of energies (9, 12, 16 MeV).
- Gel response has previously been shown to be independent of photon or electron energy.

6 x 6 cm² applicator

12 MeV electron beam irradiation
• Calibration procedure was performed by a single user five times for each gel, and dose sensitivities were averaged.

<table>
<thead>
<tr>
<th>Gel Batch</th>
<th>Electron Beam Energy (MeV)</th>
<th>Mean Sensitivity (cm$^2$ Gy$^{-1}$) ± Relative Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9</td>
<td>0.0848 ± 0.1%</td>
</tr>
<tr>
<td>A</td>
<td>12</td>
<td>0.0830 ± 0.1%</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>0.0849 ± 0.1%</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>0.0872 ± 0.1%</td>
</tr>
</tbody>
</table>

Validation of VMAT FSRT calculated doses using a multi-configurational phantom

- Ion chamber:
  - Capintec PR-05P (volume=0.07 cm$^3$)
  - Point dose measurements at isocenter
- EBT3 Gafchromic film
  - Coronal mid-plane orientation
  - Analyzed with CCSEO radiochromic film imaging system
- Fricke xylenol orange gel
  - Vista optical CT scanner
  - Analyzed with Gel Dosimetry Analysis Application in 3D Slicer

(Lalonde, IUPESM World Congress, Toronto, 2015)
Technique Validation CCSEO (prior to first treatment)

- 4 PTV\(_{40}\) plans
  - Dose profiles
    - Eclipse
    - Film
    - Gel

Peak PTV doses agree with calculated doses within:
- 3% for gel
- 5% for film

Technique Validation CCSEO (prior to first treatment)

- Gel Results: 4PTV plan (3 to 6 mm diam.):
  - Gamma agreement (3%/3 mm) = 95.8%
Conclusions

- Full 3D dosimeters have attractive features desirable for modern dose delivery validation
- Many of the problems that have kept 3D dosimetry out of the clinic have been corrected
- My colleagues will now illustrate this further

Resources for future reading

2 reviews lightly cited:

Oldham M 2014
in: Advances in Medical Physics
Godfrey D et al (ed)
(Medical Physics Publishing, Madison WI)

Schréiner LJ and Olding T 2009 Gel dosimetry
in: Clinical Dosimetry Measurements in Radiotherapy
(AAPM Medical Physics Monograph No. 34)
Rogers D and Cygler J (ed.),
(Medical Physics Publishing, Madison WI)
Resources for future reading (2)

6 Volumes of the open journal J. Phys: Conf. Series

Volume 573 2015
8th International Conference on 3D Radiation Dosimetry (IC3DDose)
4-7 September 2014, Ystad, Sweden

Volume 444 2013
7th International Conference on 3D Radiation Dosimetry (IC3DDose)
4-8 December 2012, Sydney, Australia

Volume 250 2010
IC3DDose: The 6th International Conference on 3D Radiation Dosimetry
22-26 August, 2010, South Carolina, USA

Volume 164 2008
Volume 56 2006
Volume 3 2004
DosGel (International Conferences on Radiotherapy Gel Dosimetry)

9th International Conference on 3D Radiation Dosimetry

MD Anderson Cancer Center

9th International Conference on 3D Radiation Dosimetry

The San Luis Resort
Spa and Conference Center

INTERNATIONAL CONFERENCE
SAVE THE DATE
Nov. 7 - 10, 2016
GALVESTON, TEXAS
Questions: time is short today, feel free to contact us

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