Methods and Applications of 3D Radiochromic Dosimetry

No Financial Disclosures

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3D dosimetry systems?

<table>
<thead>
<tr>
<th>Material</th>
<th>Read-out</th>
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<tbody>
<tr>
<td>Polymer gels</td>
<td>MRI</td>
</tr>
<tr>
<td>Radiochromic gels</td>
<td>X-ray-CT</td>
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<tr>
<td>– FX-orange</td>
<td></td>
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<tr>
<td>Radiochromic plastics</td>
<td>Optical-CT</td>
</tr>
<tr>
<td>– Presage</td>
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</table>

Liquid/solid scintillators
Transit dosimetry - EPIDS
Semi-3D systems - diode arrays
Radiochromic Plastic: Presage

- Contrast: light absorption
- Good dosimetry properties
- Flexible

\[
\lambda_{\text{max}} = 633 \text{ nm}
\]

PRESAGE (Heuris Inc)

- OD proportional to dose

\[
y = 0.0026x \\
R^2 = 0.9668
\]
DLOS: Duke Large Field-of-View Optical-CT Scanner

Design Specifications

<table>
<thead>
<tr>
<th>FOV</th>
<th>240 mm</th>
</tr>
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<tbody>
<tr>
<td>Resolution</td>
<td>2 - 0.2 mm</td>
</tr>
<tr>
<td>Time</td>
<td>10 - 30 mins</td>
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</tbody>
</table>

LED, diffuser filter
Dosimeter
Aquarium
CCD

Thomas et al. Med Phys, 2011

Key developmental milestones

Commissioning and benchmarking a 3D dosimetry system for clinical use

Andrew Thomas and Joseph Newton
Duke University Medical Center, Durham, North Carolina 27710

John Adamovics
Rutgers University, New Brunswick, New Jersey 08944

Mark Oldham
Duke University Medical Center, Durham, North Carolina 27710

A method to correct for stray light in telecentric optical-CT imaging of radiographic dosimeters

Andrew Thomas, Joseph Newton and Mark Oldham
Duke University Medical Center, Durham, NC, USA


A method to correct for spectral artifacts in optical-CT dosimetry

Andrew Thomas, Michael Ploquet, Kevin Jordan and Mark Oldham


A Quality Assurance Method that Utilizes 3D Dosimetry and Facilitates Clinical Interpretation

Mark Oldham, Ph.D., Andrew Thomas, Ph.D., Jennifer O’Daniel, Ph.D., Titania Jiang, B.Sc., Geoffrey Ibbott, Ph.D., John Adamovics, Ph.D., and John P. Kirkpatrick, M.D.

International Journal of Radiation Oncology Biology Physics

Aug 2012
3D Dosimeter read-out by optical-CT

DMOS-RPC Recon GUI

Duke Collaborations

<table>
<thead>
<tr>
<th>Collaboration</th>
<th>Contributors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachytherapy</td>
<td>O Craciunescu, J Chino</td>
</tr>
<tr>
<td>4D SBRT</td>
<td>F Yin, J Wu</td>
</tr>
<tr>
<td>Radiosurgery</td>
<td>Z Wang, J Chang,</td>
</tr>
<tr>
<td>Gating</td>
<td>S Yoo, A Thomas</td>
</tr>
<tr>
<td>IMRT, VMAT ...</td>
<td>J O'Daniel, J Kirkpatrick,</td>
</tr>
<tr>
<td>Deformation</td>
<td>S Das</td>
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External Collaborations

<table>
<thead>
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<tbody>
<tr>
<td>Credentialing and clinical trials.</td>
<td>Geoff Ibbott, MDACC</td>
</tr>
<tr>
<td>Protons</td>
<td>Indra Das, Indiana Univ</td>
</tr>
<tr>
<td>Neutrons</td>
<td>Anuj Kapadia</td>
</tr>
<tr>
<td>Anthropomorphic re-useable</td>
<td>John Adamovics, (Heuris)</td>
</tr>
<tr>
<td>deforming dosimeters</td>
<td></td>
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</tbody>
</table>
Accuracy of Multifocal single isocenter SRS Treatment?

5 PTV targets
15 Gy central, 20-24 Gy outer
iplan and Eclipse
CBCT set-up

Objectives

• Evaluate accuracy and reproducibility
  – Novalis Tx delivery
    • 2D kV and CBCT IGRT set-up

• Method/strategy
  – 4 independent deliveries
  – 4 Presage dosimeters
  – Ion-chamber normalised
Treatment Delivery

- 4 dosimeters
- 2D KV and CBCT image guidance
- One dosimeter – ion chamber

5 lesion VMAT single-iso Radiosurgery

<table>
<thead>
<tr>
<th>Eclipse</th>
<th>Tra</th>
<th>Sag</th>
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<tbody>
<tr>
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<td>4</td>
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<td>3</td>
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<table>
<thead>
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<th>Presage</th>
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<td>2</td>
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<tr>
<td>5</td>
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</table>

Target 1: 15 Gy
Target 2: 24 Gy
Target 3: 24 Gy
Target 4: 20 Gy
Target 5: 24 Gy
5 VMAT single-iso SRS: accurate and reproducible

Average (solid lines)
1 StdDev (dashed lines)


AAPM 2015:

Crockett E, Ren L, Oldham M, AAPM 2015
DVH based Comparison Of True 3D Measurements And Delta4 system
**Micro-irradiator:**
Lung SBRT

- MC planning
- 2-40mm fields
- Lung SBRT

XRAD225Cx from Precision X-Ray Inc.

---

**3D micro-dosimetry:**
3D Printing:

Can SmartAdapt/Velocity enable next generation gynecological treatments combining IG brachytherapy with RT

Presage-Def (15.7 cm)  
High Z Rigid Insert (2.8 cm)  
Air Cavity (4.0 cm)  
Complex, Non-Uniform Deformation

“On the need for validation of deformable dose accumulation (DIR) with a novel 3D dosimeter.”

Juang et al.  IJROBP, 2013

Control  
(No Deformation)  
Deformed  
(27% Lateral Compression)
Measured Velocity Difference

Non-deformed

Deformed

Results

No Deformation Deformed VelocityAI

MEASURED CALCULATED
Brachytherapy

$^{137}$Cs source in shielded bucket

0.5mm$^3$ voxels!

Adamson J et al, Med Phys 2012

Micro-radiation therapy (MRT - UNC)

- 3 parallel beams
  - 300-400 µm width
  - 909 µm spacing
- 32 Gy entrance dose
Optical-CT Dosimetry

Scanned in Optical-CT Scanner
Reconstructed at 50 µm isotropic resolution

20 mm 400 px

Magnetic Resonance Imaging guided Radiation Therapy (MRigRT

• Remote 3D dosimetry protocol
• Duke and WashU
• Advantages
  – MR independent

• Stage I
  – TG119 irradiations
Magnetic Resonance Imaging guided Radiation Therapy (MRIgRT)

- Remote 3D dosimetry protocol
- Duke and WashU
- Advantages
  - MR independent

- Stage I
  - TG119 irradiations

**FINAL RESULTS: EXAMPLE**

**MULTI-TARGET (TG119)**

Passing Rate (3%/3mm):

Raw  Corrected
91.6%  →  98.5%

TH-CD-BRA-11
Conclusions so far!

- Hi-res 3D dosimetry is feasible
- Remaining challenges
  - Dosimeter development
    - Re-usability, remote, Deformable
    - Optical-CT developments
    - Increased practicility
  - Applications: Many
    - Advanced Tx
    - Pre-clinical
    - Deformable, IG procedures
    - New devices and techniques

Radiochromic Dosimetry at CCSEO

Based on change of optical attenuation coefficients in irradiated dosimeter

- Fricke and Radiochromic dosimeters
  - Absorption changes

Modus QA

Fricke Gels

Leucodye MicelleGels
Data analysis

We work in SLICER-RT open source environment

(Alexander, IUPESM World Congress, Toronto, 2015)
Non-diffusing leuco crystal violet gelatin hydrogel (see IC3DDose16)
~20 Gy per beam, jaw size=3x3, 2x2, 1x1 & 0.6x0.6 cm
AP, 6 MV, 400 MU/min,
“POP bottle vessel”, 11 cm diameter

Reconstruction

- 512 projections, 0.25mm voxels, 10 minute scan time, FDK reconstruction, hamming filter (Modus VistaRecon.exe)
- Vista optical CBCT scanner, custom source (Fresnel lens + LED)
• diffusion is not a problem over ~14h

Background-Corrected, Depth Dose Curves

K Jordan, London Regional Cancer Program
Background-Corrected Beam Profiles

Resources for future reading

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

Schreiner 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)

Chapter 30
Gel Dosimetry
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Cancer Centre of Southeastern Ontario at Kingston General Hospital
and Queen’s University, Kingston, ON, Canada

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Acknowledgements

Collaborators:
   John Adamovics
   Geoff Ibbott,
   Harold Li
   Daniel Letourneau
   Leith Rankine

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   Junzho Chino,
   John Kirkpatrick
   Christy Cramer

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