Methods and Applications of 3D Radiochromic Dosimetry

No Financial Disclosures

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3D dosimetry systems?

Material

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

Read-out

- MRI
- X-ray-CT
- Optical-CT

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

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
Rider University, Lawrenceville, New Jersey 08648
Mark Oldham
Duke University Medical Center, Durham, North Carolina 27710


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

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


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 Juang, B.Sc., Geoffrey Ibbott, Ph.D., John Adamovics, Ph.D., and John P. Kirkpatrick, M.D.

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

DMOS-RPC Recon GUI

Duke 3D Dosimetry Lab, March 2011
Contact mark.oldham@duke.edu
<table>
<thead>
<tr>
<th>Duke Collaborations</th>
<th>External Collaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachytherapy</td>
<td>Geoff Ibbott, MDACC</td>
</tr>
<tr>
<td>O Craciunescu, J Chino</td>
<td></td>
</tr>
<tr>
<td>4D SBRT</td>
<td>Protons</td>
</tr>
<tr>
<td>F Yin, J Wu</td>
<td>Indra Das Indiana Univ</td>
</tr>
<tr>
<td>Radiosurgery</td>
<td>Neutrons</td>
</tr>
<tr>
<td>Z Wang, J Chang,</td>
<td>Anuj Kapadia</td>
</tr>
<tr>
<td>Gating.</td>
<td>Anthropomorphic re-useable</td>
</tr>
<tr>
<td>S Yoo, A Thomas</td>
<td>John Adamovics. (Heuris)</td>
</tr>
<tr>
<td>IMRT, VMAT ...</td>
<td>Deforming dosimeters</td>
</tr>
<tr>
<td>J O’Daniel, J Kirkpatrick,</td>
<td></td>
</tr>
<tr>
<td>Deformation</td>
<td></td>
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<td>S Das</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

Eclipse

Cor

Tra

Sag

Target 1: 15 Gy
Target 2: 24 Gy
Target 3: 24 Gy
Target 4: 20 Gy
Target 5: 24 Gy

Presage
5 VMAT single-iso SRS: accurate and reproducible

Average (solid lines)
1 StdDev (dashed lines)

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

Juang et al. IJROBP, 2013
Results

No Deformation  Deformed  Velocity AI

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

Qiongge Li
Optical-CT Dosimetry

Scanned in Optical-CT Scanner
Reconstructed at 50 μm isotropic resolution
Magnetic Resonance Imaging guided Radiation Therapy (MRIgRT)

- Remote 3D dosimetry protocol
- Duke and WashU
- Advantages
  - MR independent
- Stage I
  - TG119 irradiations
MULTI-TARGET (TG119)

Passing Rate (3%/3mm):

Raw: 91.6% → Corrected: 98.5%

TH-CD-BRA-11
Conclusions so far!

• Hi-res 3D dosimetry is feasible
• Remaining challenges
  – Dosimeter development
  – Scanner Development
  – 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

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

K Jordan, London Regional Cancer Program
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

0.6cm x 0.6cm, 5cm depth, 90SSD

Dose (normalized to maximum) vs position off beam axis (cm)

1cm x 1cm, 5cm depth, 90SSD

Dose (normalized to maximum) vs position off beam axis (cm)

2cm x 2cm, 5cm depth, 90SSD

Dose (normalized to maximum) vs position off beam axis (cm)

3cm x 3cm, 5cm depth, 90SSD

Dose (normalized to maximum) vs position off beam axis (cm)
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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INTERNATIONAL CONFERENCE
SAVE THE DATE
Nov. 7 - 10, 2016
GALVESTON, TEXAS

9th International Conference on 3D Radiation Dosimetry

IC3DDose

The San Luis Resort Spa and Conference Center
Acknowledgements

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

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  David Kirsch,
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Duke Faculty and 3D Dosimetry Lab Members
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