The Promise and Potential Pitfalls of Deformable Image

Clinical applications in the Head&Neck: Verification using 3D dosimetry

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Disclosures

• NCI R01 funding – RPC collaboration (IROC)
• Several sponsored research agreements involving the application of 3D dosimetry

Outline

• Basics of H&N IMRT – Key challenges
• Role of 3D Dosimetry in DIR Validation

An old-school H&N treatment plan!

• Problem … – This plan is not conformal enough!

- 73Gy
- 66Gy
- 54Gy
- 45Gy
- 30Gy
Theoretical birth of IMRT

- 1988 Brahme – 1st inverse planning.

Problem …
- This plan is not conformal enough!

Solution – fluence modulation

We are now masters of fluence!

- Fluence modulation
  - IMRT, VMAT
  - Tomotherapy
  - Cyberknife, VERO

New challenges
- PTV definition
- Adaptive therapy
- Efficiency
- Optimal Plan
- Knowledge guide
- Commissioning
- Verification
The role of DIR in H&N RT

- DIR can help with .........
- Contouring: greater efficiency and accuracy?
- Dose accumulation: intra-Tx dose acceptable?
- Adaptive planning: create a more optimal plan?
- Treatment response: enable more precise assessment?

Clinical Example

- Nasopharynx, with Bilateral Necks
  - T4N3a
    - Primary - 20fx of 2Gy/day, 40Gy total
    - Boost - 15fx of 2Gy/day, 30Gy total
- H&N with substantial tumor shrinkage
  - Adaptive Planning: How to ensure adequate
    - PTV coverage
    - OAR sparing
  - Dose Warping and Dose Accumulation

Treatment timeline

Overview of the plan
Primary for 12FX, CT1

Primary-rev for 8FX, CT2

Boost for 15FX, CT2

CT1 and CT2 overlay - parotids by MD
CT1 and CT2 overlay - parotids by MD and propagated Rigid reg'n

CT1 and CT2 overlay - parotids – MD and propagated DIR reg'n

CT2 – MD and DIR contours

Substantial PTV volume changes
Adaptive re-contouring MIM

- Deformably contour replanning CTs
- Generates entire structure sets automatically
- Timesavings of 75% demonstrated
- Makes true adaptive therapy possible

Dose of the day?

CT1 CBCT (re-calc)

Primary1 12FX CT1
Primary-rev 8FX CT2
Boost 15FX CT2

Dose warping

What is the final accumulated dose?

35FX 2Gy
70Gy
**Boost dose CT2 warped to CT1**

CT2 (after 9th FX)  CT1

**Plan Sum - Primary and Boost dose warped onto CT1**

- But what have we done?
- How accurate?

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**Challenges of dose warping?**

- DIR assumes
  - Every point in one image has a corresponding point in the other
- Not valid when
  - Tissue shrinks/swells
  - Dose in deformed voxel?

**Can 3D Dosimetry help?**

- Radiochromic Plastic: Presage
- Contrast: light absorption
- Good dosimetry properties
- Flexible

Physical Dose is defined as energy per unit mass (J/kg)

Velocity (Theo Lazarkis)

Heuris Inc. www.presage3d.com
Presage-Def Deformable 3D Dosimeter

- Elastic polyurethane
- Radiochromic leuco dye
  - Linear $\Delta OD$ with dose

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Increasing Dose →
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$\Delta OD/cm = 0.0032(dose) + 0.002$
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$R^2 = 0.99$

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>0.000</th>
<th>0.005</th>
<th>0.010</th>
<th>0.015</th>
<th>0.020</th>
<th>0.025</th>
<th>0.030</th>
<th>0.035</th>
<th>0.040</th>
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<tbody>
<tr>
<td>$\Delta OD$ (cm$^{-1}$)</td>
<td>0.000</td>
<td>0.010</td>
<td>0.020</td>
<td>0.030</td>
<td>0.040</td>
<td>0.050</td>
<td>0.060</td>
<td>0.070</td>
<td>0.080</td>
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</tbody>
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DLOS : Duke Large Field-of-View Optical-CT Scanner

**Design Specifications**
- FOV: 240 mm
- Resolution: 2 - 0.2 mm
- Time: 10 - 30 mins

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LED, diffuser filter
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Dosimeter Aquarium
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"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)
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1Juang. IJROBP 2013;87(2): 414-421
```
Results

No Deformation | Deformed | Velocity AI

3D Gamma Calculations: 3%/3mm Deformed vs control

96.4% passing

60.0% passing (B spline)

Biomechanical model?

MorfeusSurfProj: Guided node-to-surface projection
- Automated surface correspondence
- Practical for most clinical data

MorfeusPlates: Model compression between plates
- Mimics physical experiment, forces*
- Feasible for simple dosimeter data


Biomechanical or B-spline?

<table>
<thead>
<tr>
<th>Dose distribution</th>
<th>Cross section</th>
<th>3D accuracy</th>
<th>73%/3mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Optical CT</td>
<td>Coronal</td>
<td>Axial</td>
<td>Sagittal</td>
</tr>
<tr>
<td>Predicted Commercial DIR</td>
<td>60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted MorfeusSurfProj</td>
<td>91%</td>
<td></td>
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</table>
3D deformable phantoms containing bony and cavity inserts.

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

Compatible with optical-CT 3D dosimetry – 1mm³ voxels

- Optical-CT projection
- Un-irradiated dosimeter

• 3D print anatomically accurate dosimeters
• ProtoGen (plastic)
  - 0.23mm x 0.23mm x 0.1 mm
• Optical-CT projection
• Un-irradiated dosimeter

3D Printed Presage dosimeter

Optical-CT unirradiated
X-ray-CBCT showing spinal
Recent developments

- New Presage-Def formulation
  - Improved dose sensitivity and response stability
  - Higher durometer (30-50A versus 10-20A)

Dose Response

\[ \text{Dose Response (AOD/cm)} \]

\[ \text{ Response Change} \]

\[ \begin{array}{c}
\text{Time Elapsed (h)} \\
\end{array} \]

Temporal Stability

\[ \text{3.7x INCREASE} \]

\[ \text{-9.4%} \]

New Presage-Def

Original Presage-Def

Can we measure dose in a deformed dosimeter?

- Integral dose within 75% isodose line consistent with planned dose in both DIR and control

<table>
<thead>
<tr>
<th></th>
<th>Control Integral Dose (Gy-cm²)</th>
<th>Deformation Integral Dose (Gy-cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse</td>
<td>558.5</td>
<td>549.4</td>
</tr>
<tr>
<td>Presage-Def</td>
<td>537.0</td>
<td>527.5</td>
</tr>
<tr>
<td>% Difference</td>
<td>3.9%</td>
<td>4.0%</td>
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Presage-Def 4-field box dosimetry

Eclipse Calculated Dose

Presage-Def Measured Dose

Lateral Line Profile Comparison

Experimental (21% Compression)

Control

(No Deformation)

3D H&N Deformable Phantom

For DIR Performance Evaluation

The phantom splits along the sagittal plane to reveal optical markers that are used to measure the ground truth deformation between the undeformed and deformed phantom.

This enables the ground-truth deformed dose to be known, which is the basis for checking the accuracy of any DIR algorithm.


Jean Pouliot, University of California San Francisco
Deformed
Undeformed
Phantom CT Images

Use your favorite DIR on the two phantom images and compare predicted deformation with measured deformation (ground truth)

### The Ground Truth

### Conclusions

- **Promise**
  - Efficiency – contouring
    - ATLAS’s
    - Contour propagation
  - Efficacy - accuracy
    - Improve adaptive therapy
    - Dose accumulation

- **Pitfalls ?**
  - Contour accuracy
    - Physician approval essential
  - Dose accumulation
    - Extreme caution
    - Validate/commission your algorithm TG132
  - Know your algorithm ?!