Treatment Planning Considerations for Adaptive Radiotherapy

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Key Elements Of ART

Tx Planning Considerations for ART

- Complicated & Resource-Intensive: When to Adapt
- Goal of Adaptation not Well Defined: How to Adapt
- Current QA Protocol Time Intensive: How to Verify

When to Adapt?

- Efficient & Effective
  - High Efficiency: use when sufficient
  - Less Effective: use when necessary

ART == A(adaptive) (IG)RT

If multiple found, select the one with the smallest PTV

- Treatment Using the Plan from Database
  - Yes
  - No

- Treatment Using New Plan from Re-Optimization

Li et al., Physics in Medicine and Biology 56:1243-1258, 2011
Benefits: Target (CTV) Coverage

Ranges and Means of D99 (Minimal Dose to 99% CTV)

25/180 Re-Positioning plans has large target underdose

ART can substantially improve target coverage.

Li et al, Phys Med Biol. 2011 Mar 7;56(5):1243-58

Results: OAR Sparing

Histogram of Difference from the "Gold Standard"

Better Controlled OAR Irradiation than Re-Positioning

Benefits: Efficiency Improvement

Reduction: 43% avg.
Delivered Plans: No QA needed

Substantially reduced re-optimization necessity
½ Re-Optimizations, Same Quality

- Improved OAR Spacing Compared to Re-Positioning
- Uncompromised daily CTV Coverage (D99 > 98%)
- Reduced Re-Optimization Frequency by 43%

From Challenges to Tools

- When to Adapt
  - Daily Evidence-Based Decision Making
- How to Adapt
  - Motion Management
- How to Verify
  - Online Quality Assurance

Addressing Inter-fractional Change

- Fluence-map Deformation Based on BEV Mohan et al. 2005
- Direct-Aperture-Def. Based on BEV Feng et al. 2006
- LP Fluence Opt. Based on Structures Wu et al. 2008
- MLC Position Shift Based on BEV Court & Dong et al. 2005
- Aperture morphing Based on BEV Ahunbay et al. 2008
Knowledge-Guided Plan Adaptation
• Step 1. Deformable registration of Daily and Planning CT images
  ➢ Warping planned dose to changed anatomy
  ➢ Known Goal dose

• Step 2. Auto-optimization
  ➢ Known optimization parameter settings

• Step 3. Knowledge based plan quality QA
  ➢ known plan quality parameters

Li et al, Med Phys 40, 111711, 2013

Step 1. Deform the Original Dose for New Anatomy

Dose Atlas Guiding Optimization
• Features of all cases covered by only 5 atlas
• New anatomy matched to nearest atlas
• Deformable Registration used to apply atlas dose to new anatomy
• Goal dose guides optimization

Knowledge-Guided Plan Adaptation

- Step 1. Deformable registration of Daily and Planning CT images
  - Warping planned dose to changed anatomy
  - Known Goal dose

- Step 2. Auto-optimization
  - Known optimization parameter settings

- Step 3. Knowledge based plan quality QA
  - Known plan quality parameters


Step 2. Optimization Objective from Daily Imaging

Original Objectives vs Daily Objectives

Li et al, Med Phys 40, 111711, 2013

Step 2. Re-optimization

CT Objectives vs Deformed-CT Objectives
Knowledge-Guided Plan Adaptation

- **Step 1.** Deformable registration of Daily and Planning CT images
  - Warping planned dose to changed anatomy
  - Known Goal dose

- **Step 2.** Auto-optimization
  - Known optimization parameter settings

- **Step 3.** Knowledge based plan quality QA
  - Known plan quality parameters

**Step 3. Plan Quality QA**

Planned vs. Modeled


**Addressing Intra-fractional Change**

- **Online Adaptation = 0 Margin?**
  - Inter-fractional motion can be managed with plan adaptation
  - Intra-fractional motion requires tracking or additional margin

- **SV motion as example**
  - Prostate tracking: simple with fiducial markers
  - SV tracking: difficult & requires margin
Inter-fractional SV Motion

Quantifying Intra-fractional Motion

Motion Definition

Sheng et al. JROBP June 2017
Margin: 5 mm for SV Alone

<table>
<thead>
<tr>
<th>Isotropic margin (mm)</th>
<th>95% post-tx SV coverage (% fractions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
</tr>
<tr>
<td>3</td>
<td>86</td>
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<tr>
<td>4</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>6</td>
<td>97</td>
</tr>
</tbody>
</table>

5mm: selected as minimal margin for sufficient coverage

Margin: Surrogate Underestimates

- Margin determined from surrogates
  - Using popular Van Herk’s recipe
  - Based on motion estimated from COM and Border

<table>
<thead>
<tr>
<th>Van Herk Margin</th>
<th>LR</th>
<th>AP</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of Mass</td>
<td>0 mm</td>
<td>0.5 mm</td>
<td>0.8 mm</td>
</tr>
<tr>
<td>Border</td>
<td>1.2 mm</td>
<td>3.9 mm</td>
<td>2.5 mm</td>
</tr>
</tbody>
</table>

Predicting SV Coverage via IGRT

- SV Coverage Prediction via Regression
  - Based on fractional coverage data
  - Established in a way for simple clinical implementation during IGRT

Using COM

\[ P_1(x) = 1.003 - 0.002x^{0.56} \]

Threshold: 4.5mm

Max COM Shift (mm)

Using border

\[ P_2(x) = 1.003 - 0.002e^{0.56}x \]

Threshold: 7.0mm

Max Border Shift (mm)
From Challenges to Tools

- **When to Adapt**
  - Daily Evidence-Based Decision Making

- **How to Adapt**
  - Knowledge-Guided Re-Plan Margin based on Intra-fx Motion

- **How to Verify**
  - Quality Assurance

**Dr. Dan Low’s Presentation**

**Daily Evidence-Based Decision Making**

**Knowledge-Guided Re-Plan Margin based on Intra-fx Motion**

**Quality Assurance**

**Thank you**