Using Multiple CT Images to Aid Robust IMPT Optimization

Mingyao Zhu
University of Maryland School of Medicine
Maryland Proton Treatment Center

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Disclosure

• None

Learning Objectives

• Understand the unique sensitivity of proton doses to anatomic changes;
• Review recent progress on multiple CT (mCT) robust optimization (RO) for intensity modulated proton therapy (IMPT):
  • Methods for mCT IMPT optimization;
  • mCT RO for thoracic, sinonasal, and pelvic IMPT;
  • Benefits and challenges of mCT IMPT optimization
Introduction

• More interests in proton therapy (PT);

Proton Facilities

<table>
<thead>
<tr>
<th>Facility Status</th>
<th>Total</th>
<th>USA</th>
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</thead>
<tbody>
<tr>
<td>In operation</td>
<td>67</td>
<td>27</td>
</tr>
<tr>
<td>Under construction</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>In planning stage</td>
<td>20</td>
<td>4</td>
</tr>
</tbody>
</table>

* as of July 19, 2018

Introduction

• More interests in proton therapy (PT);
  • Uncertainties in PT:
    - Patient Setup
    - Proton Range
    - RBE
    - Anatomy variation
    - Margin
    - Multi-beam RBE opt.
    - Motion
    - ITV + margin
    - RBE + margin
    - Re-painting
    - Etc.

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    - Adaptive RT
    - Beam angle

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    - Re-painting
    - Adaptive RT
    - Beam angle
    - Robust optimization setup and range
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  - RBE
  - Anatomy variation
  - Margin
  - Multi-beam RBE-opt.
  - ITV + margin for moving etc.
  - Adaptive RT beam angle

Proton is sensitive to anatomy changes

- Lower density proximal to target:
  - Dose "over-shooting"
  - Over-dosing to distal OAR
  - Under-dosing to proximal Target
Proton dose is sensitive to anatomy changes

Higher density proximal to target:
- Dose "pulling back"
- Under-dosing to distal Target
- Over-dosing to proximal OAR

Patient Anatomy changes
- Thoracic
  - Tumor shrinkage
  - Patient weight change
  - Pulmonary fluid
- Sinonasal
  - Cavity filling
- Pelvic
  - Bowel filling
Lung IMPT: anatomy changes dramatically


30% re-planning
Between PCT and ACT:
- Negligible variation of CTV volume
- Large difference of Range and SOBP
Dosimetric consequence


Re-plan is required

Head and neck IMPT

Pelvic nodes irradiation with IMPT
Field dose

Weekly re-scan (QA) during treatment

Hot spots on re-scans
Hot spots on re-scan

- Hot spots up to 144% can be seen on re-scan CTs;
- Usually small and random;
- Hasn’t trigger re-planning;
- However it is a concern

Global maximum doses

<table>
<thead>
<tr>
<th>Pt #</th>
<th># of QA CTs</th>
<th>Nominal plan Dmax</th>
<th>QA plan Dmax Range</th>
<th>QA plan Dmax</th>
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<tbody>
<tr>
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<td>3</td>
<td>105.8%</td>
<td>121.2%</td>
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<tr>
<td>10</td>
<td>4</td>
<td>108.3%</td>
<td>120.5%</td>
<td></td>
</tr>
</tbody>
</table>

IMPT is uniquely sensitive to patient anatomy change

- Undesired dosimetric consequence
- Unpredictable dosimetric consequence

- Mitigation strategy: frequent re-scan and re-plan
  - Resource intensive
  - Suboptimal treatment

- Question: Is it possible/how to proactively take it into account in plan optimization?
Multiple CT optimization

Robust optimization

Setup: 5mm

Range: 3.5%

Anatomy

Isocenter offset

SPR scaling

Multiple CT images

Types of multiple CTs

Planning CT + Adaptive CT + Synthetic CT

mCT for lung IMPT

Planning CT + Adaptive CT

- 8 patients with 4D scans,
- PCT: planning CT
- ACT: adaptive CT
- IGTV+8mm → CTV
- CTV+5mm → PTV

Dosimetric comparison


Dosimetric comparison


DVH comparison

mCT plan:
Slightly higher CTV dose
Slightly higher Lung V20

DVH comparison

Solid: P-PCT
Dashed: M-PCT

Solid: A-ACT
Dashed: M-ACT
Dotted: P-ACT

Robustness comparison

PCT
mCT

mCT RO for lung IMPT

• Using 2 patient scans: PCT and ACT
• Include both CTs in optimization
• On PCT:
  • Similar coverage
  • Slightly higher lung dose
  • Similar robustness
  • No statistically difference in heart or spinal cord dose

mCT for lung IMPT

- Using 2 patient scans: PCT and ACT
- Include both CTs in optimization
- On ACT:
  - Reduced cold spot—improve tumor control
  - Could potentially reduce re-planning frequency

mCT RO for lung IMPT is feasible


mCT for sinonasal IMPT

- 5 patients
- 25 synthetic CT images per patient
- Each with a different density override in cavities
- Compared with SFUD and adaptive plans

**mCT for sinonasal**  

![Image](image1.png)  


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**mCT RO for sinonasal cancer**  

- Better target coverage than SFUD (+ margin);  
- Lower OAR dose than SFUD (+ margin);  
- Online adaptation is the best, but implementation is not realistic;  
- mCT RO plans are anatomically robust under conditions of large cavity filling variation, therefore can be an alternative to the online adaptation;

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**IMPT for pelvic nodal targets**  

<table>
<thead>
<tr>
<th>Pt.</th>
<th># of QA CTs</th>
<th>Nominal plan Dmax</th>
<th>QA plan Dmax Range</th>
<th>Solution: Robust optimization with different density variation</th>
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<td>4</td>
<td>108.3%</td>
<td>108.3% to 120.5%</td>
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mCT for Pelvic IMPT

- 10 previously treated patients
- Used the same planning CT
- Two copies of the planning CT are created
- RO optimization with all 3 CTs
- Evaluate on the QA CTs

Zhu, et al, ASTRO 2017

Bowel filling variation simulation

Patient position:
- 0.5 cm
- 7 scenarios
Range Uncertainty:
- 3.5%
- 3 scenarios
Image sets:
- 3 CTs
Total: 63 scenarios

mCT RO for pelvic IMPT
Plan quality comparison

Without RO

Bowel override to AIR

Bowel override to tissue

Plan quality comparison

mCT

RO

Without RO

CTV

Bladder

Rectum

Plan quality comparison

Large Bowel

Small Bowel
## CTV robustness comparison

### Doses on re-scan CT1

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<th>Pt.</th>
<th>mCT RO</th>
<th>Without RO</th>
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<th>Max</th>
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### Global maximum dose on re-scan CTs

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</table>
Clinically implementation

• All prostate patients are planned with this method;
• The frequency of re-scan reduced by 50%:
  • From weekly scans to every other week;
• Haven’t observe concerning hot spots on the re-scan CTs so far;
• This method can be used for other disease sites
  • GYN
  • Bladder
  • Anal/rectal
  • Head and neck
  • etc...

Summary

• Anatomy changes during treatment
  • Under cover target
  • Over dosing OAR
  • Require frequent adaptive scan/planning
• mCT robust optimization
  • Additional CT (re-scan or synthetic)
  • Include anatomy variation in optimization
    • Improve target coverage
    • May also reduce dose to normal tissue

Questions?
mCT for sinonasal

MPTC method—previously

- Without Robustness Optimization
  - Feb. 2016 – June 2017

- 3 fields:
  - Left lateral
  - Right lateral
  - PA

- Split field target to better spare OARs

- Multiple field optimization;
Plan robustness evaluation

12 scenarios
- ±5mm (6 scenarios)
- ±3.5% (2 scenarios)

CTV External

WCS: D95 > 95%
Hot spots on re-scan

Using OAR margin to split field

CT image preparation

• Once all the contours are completed, export the planning CT with RT structure, anonymized to the same Patient ID and Name;
CT image preparation

- Once all the contours are completed, export the planning CT with RT structure, anonymized to the same Patient ID and Name;
- Import the anonymized CT+RT structure to the same patient/case;
- Co-register the two CTs by manually “set identity”
- Contour the material override structure only on the copied CT;
- Assign material accordingly

Robustness evaluation
Optimization objective functions

Dmax on QA CTs