Spot Scanning Proton Therapy – Treatment Planning

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Acronyms

- SFO - Single field optimization:
  - Each field is optimized to deliver the prescribed dose to target volume(s):
  - SFUD - Single field uniform dose
  - SFIB - Single field integrated boost*

- MFO - Multi-field optimization or Intensity modulated proton therapy (IMPT):
  - All spots from all fields are optimized simultaneously
  - More flexible with more degrees of freedom – more conformal dose distribution
  - Complex dose distribution for each field

*Szu et al. PTCOG50 - 2011

SFO vs. MFO

<table>
<thead>
<tr>
<th>SFO</th>
<th>MFO (IMPT)</th>
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<tbody>
<tr>
<td>&quot;Open Field&quot; for simpler volumes</td>
<td>&quot;Patch Field&quot; for complex volumes</td>
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<tr>
<td>Uniform or non-uniform dose distributions</td>
<td>More versatile to get a good plan</td>
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<tr>
<td>Less sensitive to uncertainties</td>
<td>More sensitive to uncertainties</td>
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<tr>
<td>Use SFO plan if IMPT plan is not significantly better</td>
<td>Robustness of MFO is important</td>
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SFO vs. MFO (IMPT)

Field One
- 42 yr old male
- BOS/Chordoma
- Post resection

Field Two
- 42 yr old male
- BOS/Chordoma
- Post resection

Field Three
- 42 yr old male
- BOS/Chordoma
- Post resection
SFO vs. MFO (IMPT)

- 42 yr old male
- BOS/Chordoma
- Post resection

Spot Spacing & Lateral Margins

- Current TPS limits to:
  - Rect-linear spot positions
  - Lateral spot spacing, \( s \) is constant for each beam
  - Spot spacing in depth direction, depending on available proton beam energies (\( \Delta d = 0.1 \sim 0.6 \) cm for MDACC)

  \( s' = s \)

  - Lateral spot margins:
    - Allow one spot outside the planning target volume, \( s' < s \).
    - For better penumbra, \( s' \) can be slightly < \( s \).
    - \( s' \) is equivalent to block margin

Spot spacing

- Spot spacing
  \[
  s = \alpha \times FWHM_{air}
  \]

- What \( \alpha \) should be?

\( \alpha = 0.8 \)
\( \alpha = 0.65 \)
Delivery Constraints

- Spot spacing, \( s = \alpha \times \text{FWHM} \), \( \alpha \leq 0.65 \)
- Smaller \( \alpha \) is better for penumbra
- How small \( \alpha \) can be?
- Hitachi PROBEAT – minimum MU 0.005 per spot
- Current clinical TPS optimizer does not incorporate this constraint in the optimization process – similar to early days of IMRT
- Truncation errors could significantly degrade a optimized plan when converted to a deliverable plan
- If \( \alpha \) is too small, "MU starvation" effect – too many spots to share finite numbers of MU

Impact of Spot spacing

Squares -3 mm
Triangles - 7 mm

Zhu et al. Med. Phys. 2010
Margins & Target Volumes

- There is no smearing (except spot size)
- Current TPS does not support proximal & distal margins for scanning beam
- For single or parallel opposed beam in major axis directions, an approximated bsPTV* may be used for SFO.
- For others, a conventional "PTV" is used
- bsPTV does not applicable to MFO*.
- Plan robustness should be evaluated.

*Park et al. IJRBP 2011

bsPTV & Approximated bsPTV

Approximated bsPTV for field 1

Field 1
bsPTV & Approximated bsPTV

Field 1 Field 2

Approximated bsPTV – Example

- = CTV + Margins
- Margins:
  - Lateral: Distal margin ~ 1.1 cm
  - Posterior: ~ 0.5 cm
  - Else where: ~ 0.6 cm

Margins:
- Lateral: Distal margin ~ 1.1 cm
- Posterior: ~ 0.5 cm
- Else where: ~ 0.6 cm
Two lateral fields

26-year-old male
• Right parotid
• Acinic cell carcinoma
• CTV1 64 Gy(RBE)
• CTV2 60 Gy(RBE)
• CTV3 54 Gy(RBE)

Head & Neck – SFIB

26-year-old male
• Right parotid
• Acinic cell carcinoma
• CTV1 64 Gy(RBE)
• CTV2 60 Gy(RBE)
• CTV3 54 Gy(RBE)

Head & Neck – SFIB – Field 1

26-year-old male
• Right parotid
• Acinic cell carcinoma
• CTV1 64 Gy(RBE)
• CTV2 60 Gy(RBE)
• CTV3 54 Gy(RBE)
Head & Neck – SFIB – Field 2

- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck - SFIB

- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck – SFIB DVH
Head & Neck - SFIB

- Problem
  - Larger penumbra

- Solutions
  - Smaller spot size
  - Aperture

Head & Neck – MFO (IMPT)

- 67 yo male
- Squamous cell carcinoma
- Right base of tongue
- CTV66, CTV60 & CTV54
- 3 fields: G280°/C15°, G80°/C345° & G180°/C0°

- Simultaneous spot optimization
- Spot spacing = 1 cm
- Distal & prox. margins = 0 cm
- Lateral margin = 0.8 cm
Robust evaluation

- Is the plan robust with respect to the range & setup uncertainties?

Robust Evaluation
- Assuming isocenter moved ±3 mm
- Range uncertainties: ±3.5% of the range
- Total 9 plans including the nominal plan
- DVH band for each volume
- Maximum dose or minimum dose to each volume to see the worst case scenarios

Robustness Evaluation – H&N MFO IMPT with EA

- 57 yo male
- Squamous cell carcinoma
- Right tonsil
- CTV66, CTV60 & CTV54
- 3 fields: G310°/C30°
  G170°/C340°
  G180°/C90°
Summary

- Spot scanning proton therapy is challenging, exciting, and rewarding:
  - SFO (SFUD & SFIB) & MFO (IMPT)

- Further development/improvement:
  - Robust optimization for SFO & MFO
  - Better optimizer in general
  - Implementation of bsPTV for SFO by TPS
  - Aperture (TPS modeling) for scanning
  - Moving target with scanning beam
  - Patient QA program
  - Dose algorithm

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