Spot Scanning Proton Therapy – Treatment Planning

X. Ronald Zhu, PhD
Professor
Deputy Chief Clinical Physics, Proton
Department of Radiation Physics
MD Anderson Cancer Center
Houston, TX

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Proton Treatment Planning Issues
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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

*Zhu *et al*. PTCOG50 - 2011

SFO vs. MFO

SFO	MFO (IMPT)
"Open Field" for simpler volumes	"Patch Field" for complex volumes
Uniform or non-uniform dose distributions	More versatile to get a good plan
Less sensitive to uncertainties	More sensitive to uncertainties
Use SFO plan if IMPT plan is not significantly better	Robustness of MFO is important

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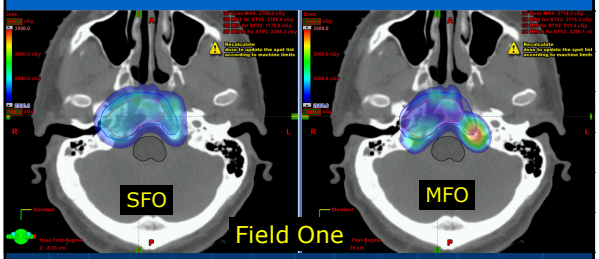
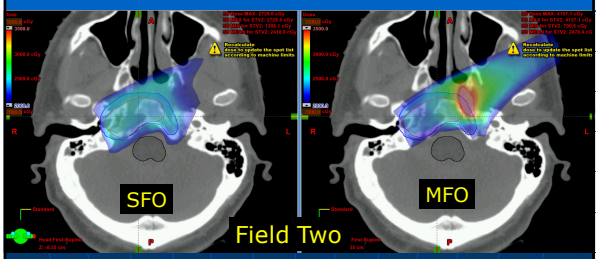
SFO vs. MFO (IMPT)



Field One

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

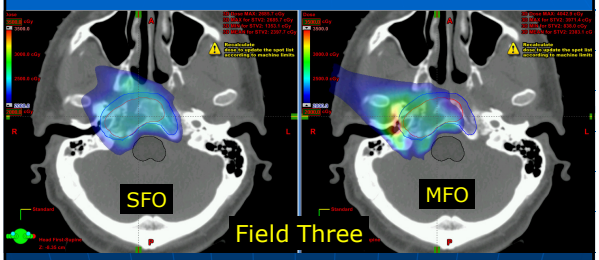
SFO vs. MFO (IMPT)



Field Two

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

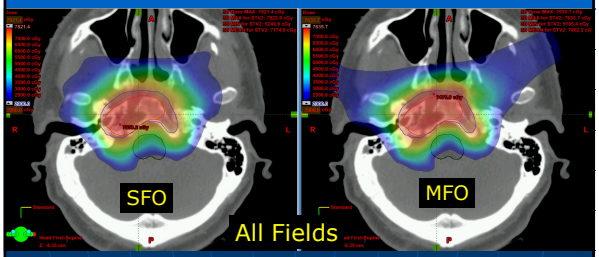
SFO vs. MFO (IMPT)



Field Three

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

SFO vs. MFO (IMPT)

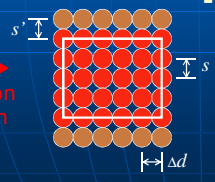


All Fields

- 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 (Δd = 0.1 ~ 0.6 cm for MDACC)



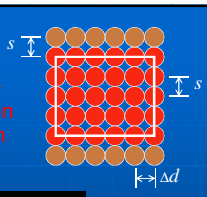
- Lateral spot margins:
  - Allow one spot outside the planning target volume, $s' = s$.
  - For better penumbra, s' can be slightly < s.
  - s' is equivalent to block margin

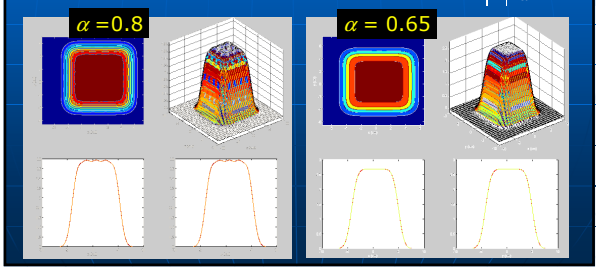
Spot spacing

- Spot spacing

$$s = \alpha \times FWHM_{air}$$

- What α should be?





Delivery Constraints

- Spot spacing, $s = \alpha \times FWHM$, α **<= 0.65**
- Smaller α is better for penumbra
- How small α 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 α is too small, "MU starvation" effect – too many spots to share finite numbers of MU

Zhu *et al*. Med. Phys. 2010

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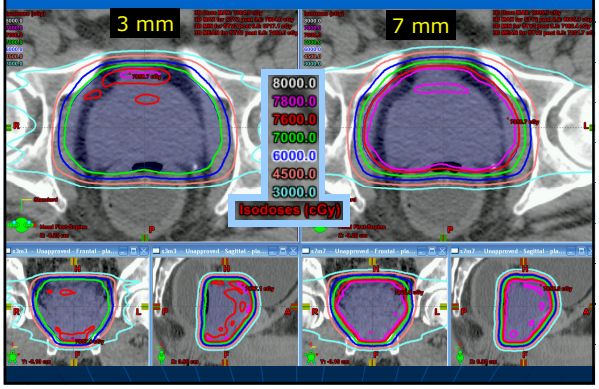
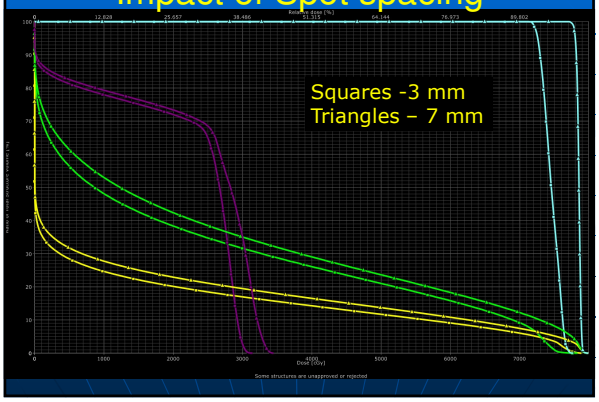
Impact of Spot spacing



Impact of Spot spacing



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

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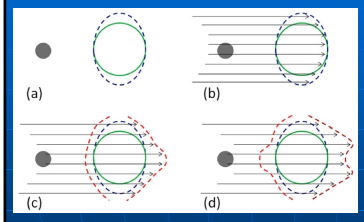
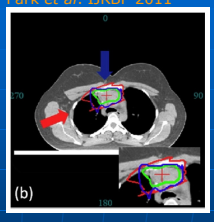
bsPTV & Approximated bsPTV

Park *et al*. IJRBP 2011

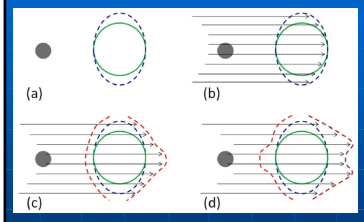


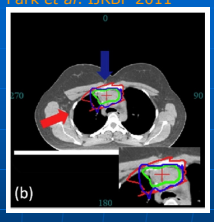


CTV

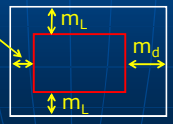
bsPTV & Approximated bsPTV

Park *et al*. IJRBP 2011





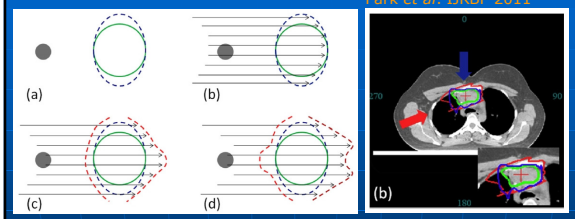
Field 1 →

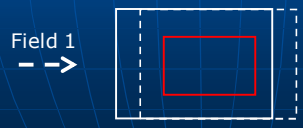


Approximated bsPTV for field 1

bsPTV & Approximated bsPTV

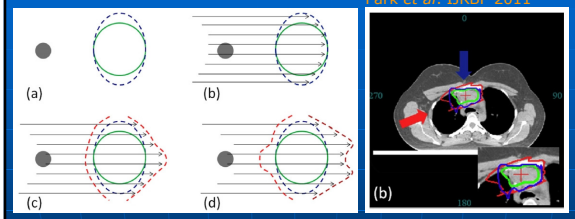
Park *et al*. IJRBP 2011

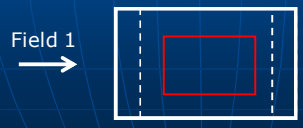




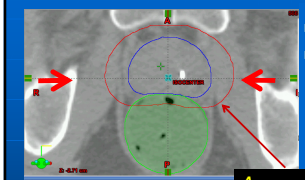
bsPTV & Approximated bsPTV

Park *et al*. IJRBP 2011

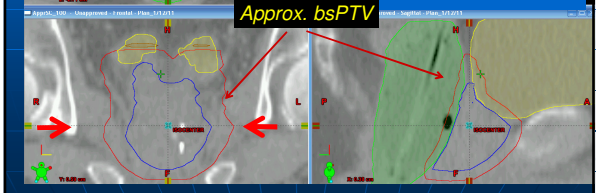




Approximated bsPTV – Example

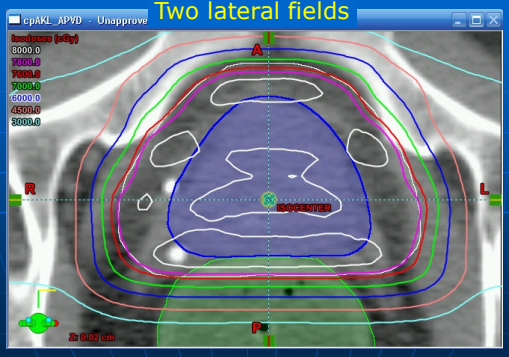


- = CTV + Margins
- Margins:
  - Lateral: Distal margin ~ 1.1 cm
  - Posterior: ~ 0.5 cm
  - Else where: ~ 0.6 cm

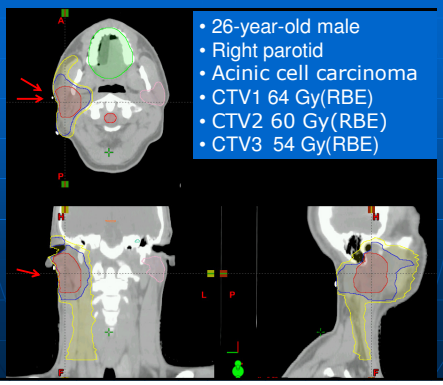


SFUD

Two lateral fields

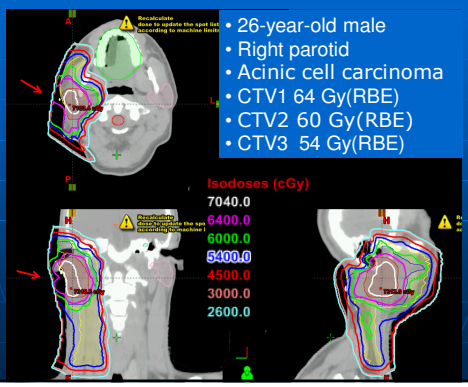


Head & Neck - SFIB



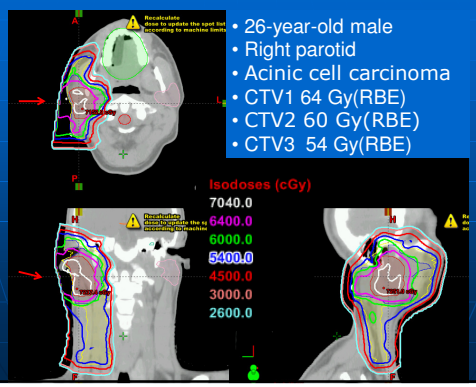
- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck – SFIB – Field 1



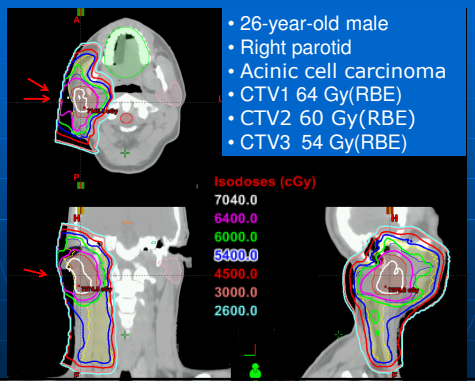
- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck – SFIB – Field 2



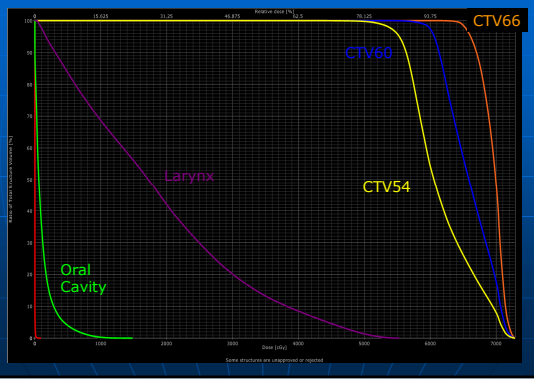
- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck - SFIB

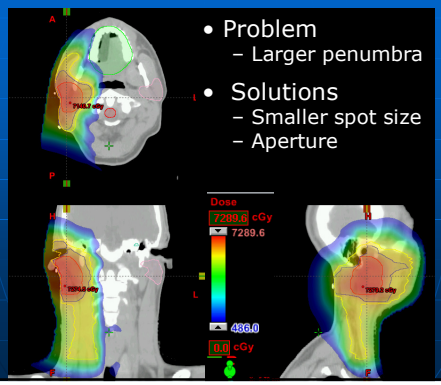


- 26-year-old male
- Right parotid
- Acinic cell carcinoma
- CTV1 64 Gy(RBE)
- CTV2 60 Gy(RBE)
- CTV3 54 Gy(RBE)

Head & Neck – SFIB DVH

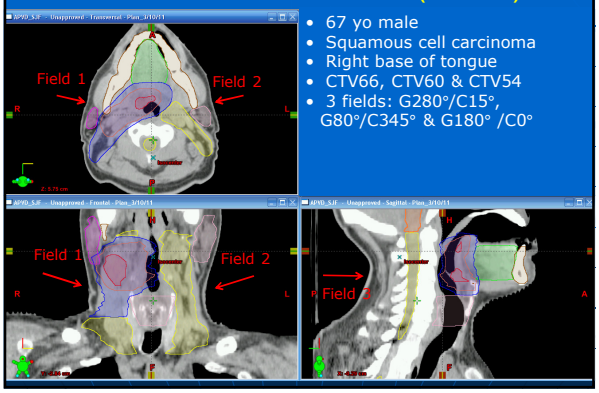


Head & Neck - SFIB



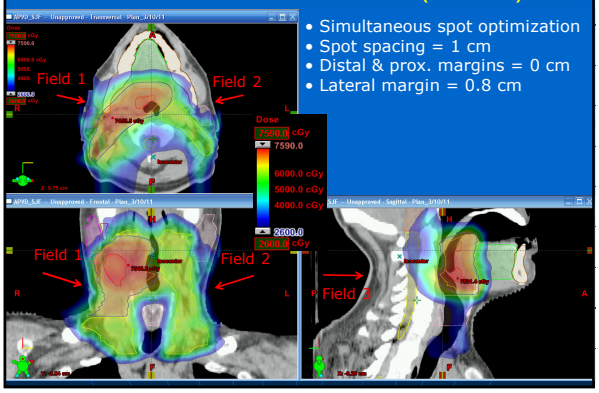
- Problem
  - Larger penumbra
- Solutions
  - Smaller spot size
  - Aperture

Head & Neck – MFO (IMPT)



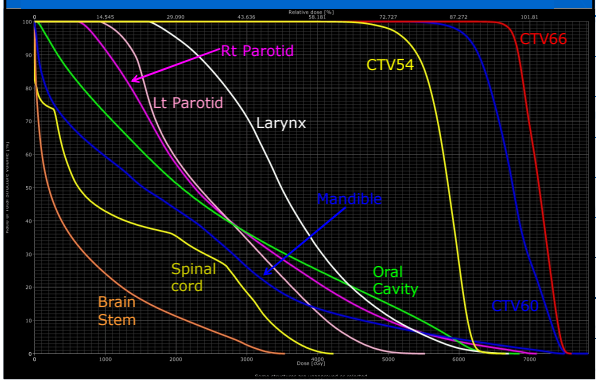
- 67 yo male
- Squamous cell carcinoma
- Right base of tongue
- CTV66, CTV60 & CTV54
- 3 fields: G280°/C15°, G80°/C345° & G180° /C0°

Head & Neck – MFO (IMPT)



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

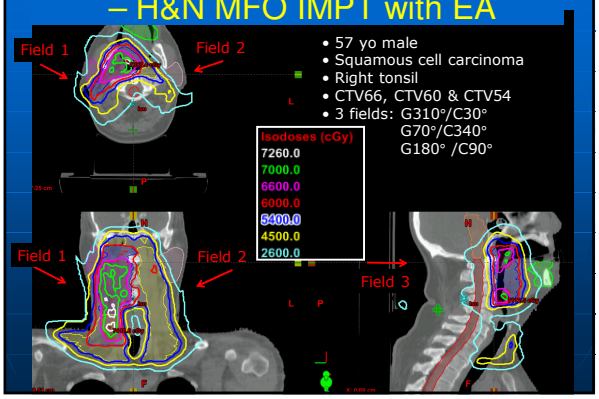
Head & Neck – MFO (IMPT) DVH



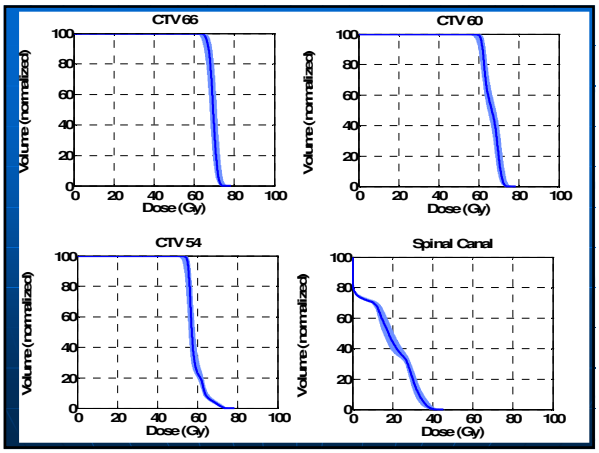
Robust evaluation

- 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°
  G70°/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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