Classification of Intensity-Modulated Proton Therapy Plans

Alice Liu & Louise Lima
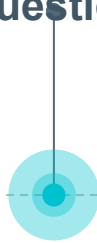
IMSA
Illinois Mathematics and Science Academy

Northwestern Medicine®

Overview

1. Proton Therapy

3. Research Question

5. Results and Discussion

2. SFUD and MFO

4. Methodology

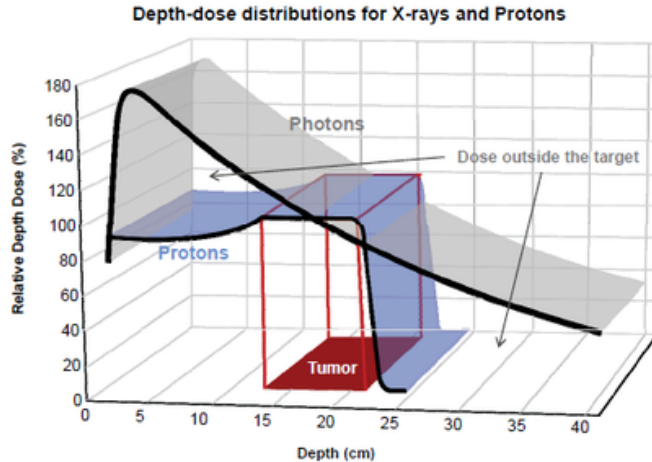# 1.
What is Proton Radiotherapy?

Radiation Treatment

▷ **Energized Particles**

▷ **Cell Damage**

▷ **Amount covered vs Risk**

The Physics of Protons

X-rays deliver a much greater dose outside the target for the same dose within the target volume as protons

Depth-dose distributions for X-rays and Protons

Source: Thomas DeLaney and Hanne Kooy Proton and Charged Particle Radiotherapy
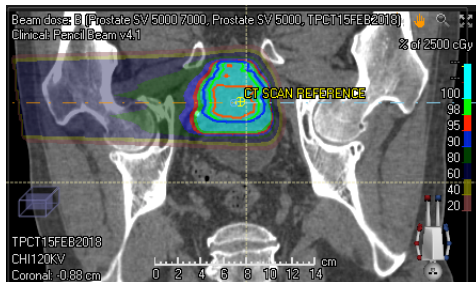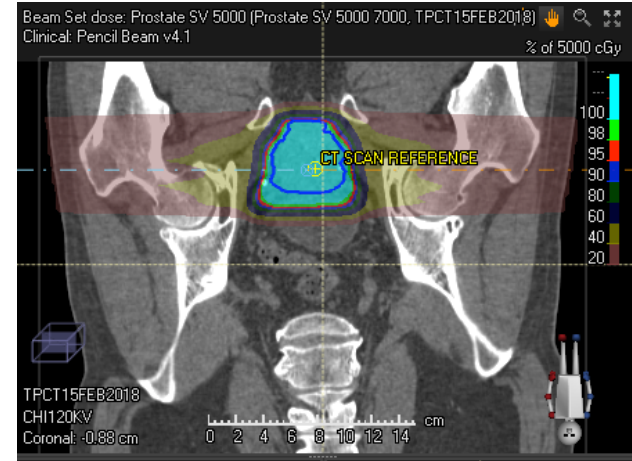
Protons vs Photons

▷ **Mass**

▷ **Charge**

▷ **Bragg Peak**
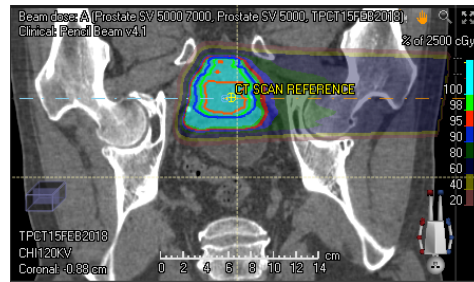 ▶ **Extended Bragg Peak**

▷ **Organs at Risk (OAR) & Accuracy**

2.
IMPT: SFUD vs MFO

Single-Field Uniform Dose (SFUD)

▷ Homogeneous dose
▷ Dosage distributed evenly across beams
▷ Beams optimized individually

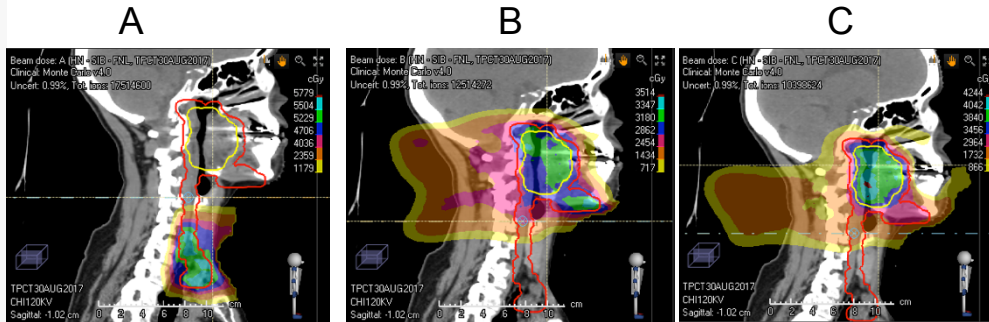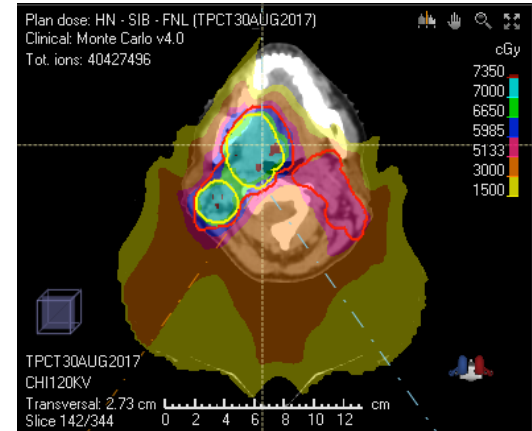# Multi-Field Optimization (MFO)

▷ Single-field restriction removed
▷ All beams optimized simultaneously
▷ Better avoids specific areas
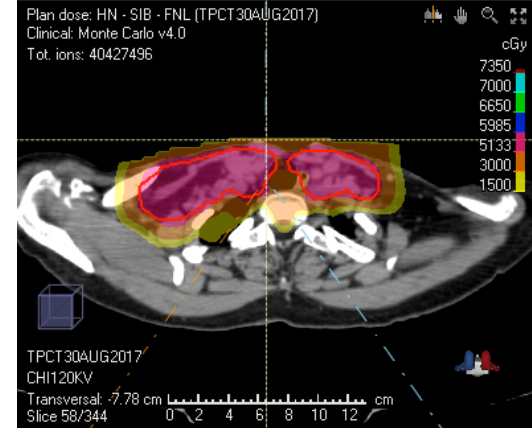
SFUD/MFO Matching

▷ Combines SFUD and MFO methods

▷ Usually done by hand
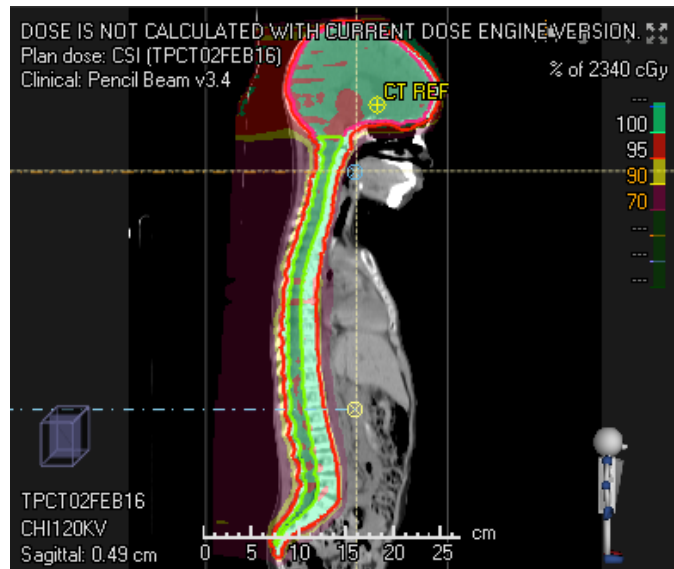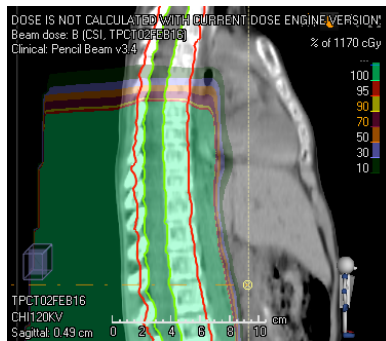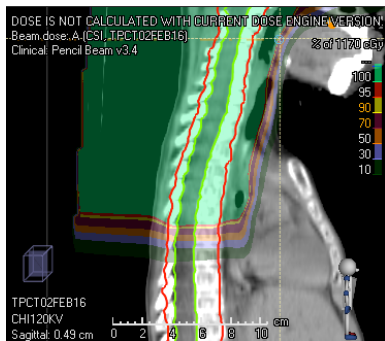
3.
Research Focus

How can we evaluate proton treatment plans based on the degree of their optimization?

"

4. Approach and Process

Differential Dose-Volume Histogram (DVH)

Graphical presentation of volume given specific amounts of dosage
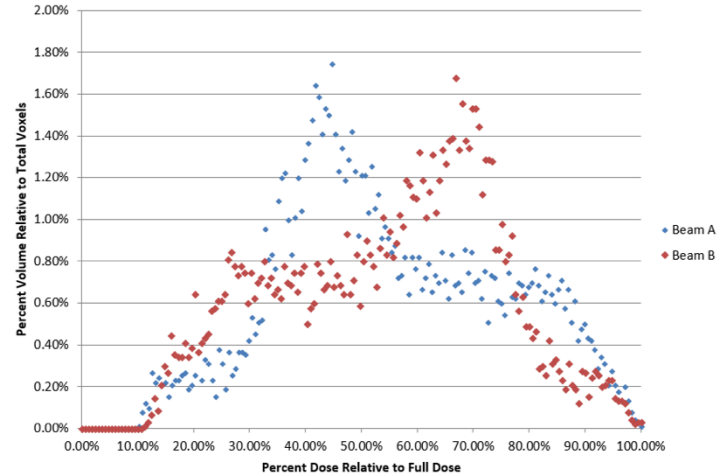
Typical Traits

SFUD

▷ Identical Beams

▷ Single peak/beam

▷ Tall peak at end of graph
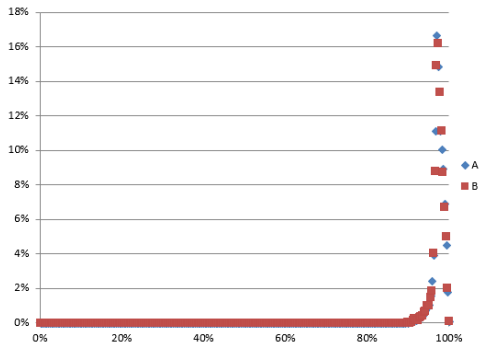
MFO-Matching

▷ Beams may match

▷ Peaks in front or closer to the middle
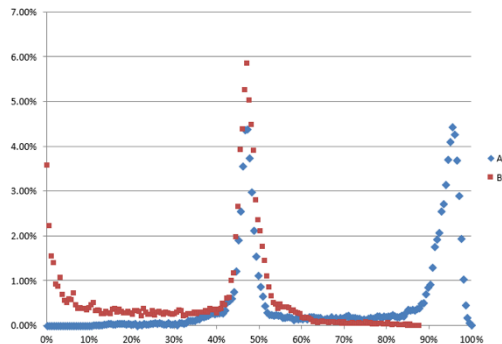
MFO

▷ Beams don't match

▷ Usually 2+ peaks/ beam
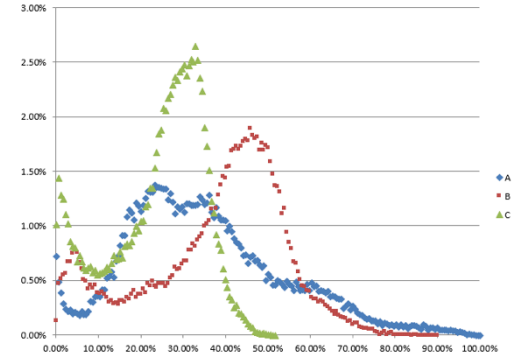
Important Factors

▷ Number of "peaks"
▷ Distance to end of beam
▷ Absolute difference
▷ Width at half-height
▷ Slope
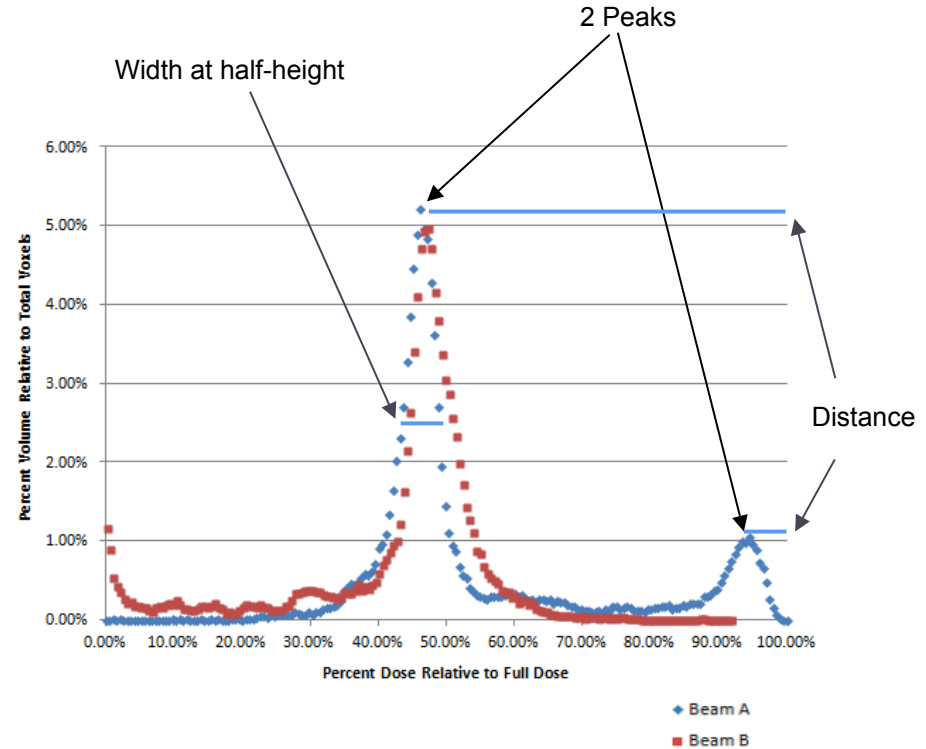
Scaling

Plan starts at 100% SFUD

Increase
  ▷ Slope

Decrease
  ▷ Number of peaks
  ▷ Distance
  ▷ Midwidth
  ▷ Difference

```python
ranking = 100.0

if(avgBeamPeak > 1):
    ranking = ranking - (25*(1-.5**(avgBeamPeak-1))/.5)
print("ranking after peak count: " + str(ranking))

if(avgDist >= 40):
    ranking = ranking - 40
else:
    ranking = ranking - avgDist
print("ranking after distance: " + str(ranking))

ranking = ranking - avgMidWidth
print("ranking after midwidth: " + str(ranking))

if(avgAbsDiff >= 1):
    ranking = ranking - 25
else:
    ranking = ranking - avgAbsDiff*25
print("ranking after diff:" + str(ranking))

ranking = ranking - avgSlope/2
print("ranking after slope: " + str(ranking))

if(ranking > 100):
    ranking = 100

if(ranking < 0):
    ranking = 0
```

5. Results and Further Discussion

Data Collection

Patient Number	Rank	Peak	Slope	MW	DtE	Diff
1	0.000%	3	-1.3315	9.096%	33.93%	88.19%
5	9.517%	3 2/3	-1.7429	2.648%	46.45%	57.74%
11	20.07%	3	-1.7848	1.627%	25.15%	58.91%
21	30.39%	2	-14.34	2.474%	36.95%	44.6%
29	42.21%	1.5	-3.6143	3.031%	5.128%	21.42%
31	53.49%	1	-1.9974	3.682%	46.41%	15.3%
32	61.72%	1	-2.8183	3.100%	34.77%	6.43%
36	76.40%	1	-2.1068	5.714%	11.11%	31.31%
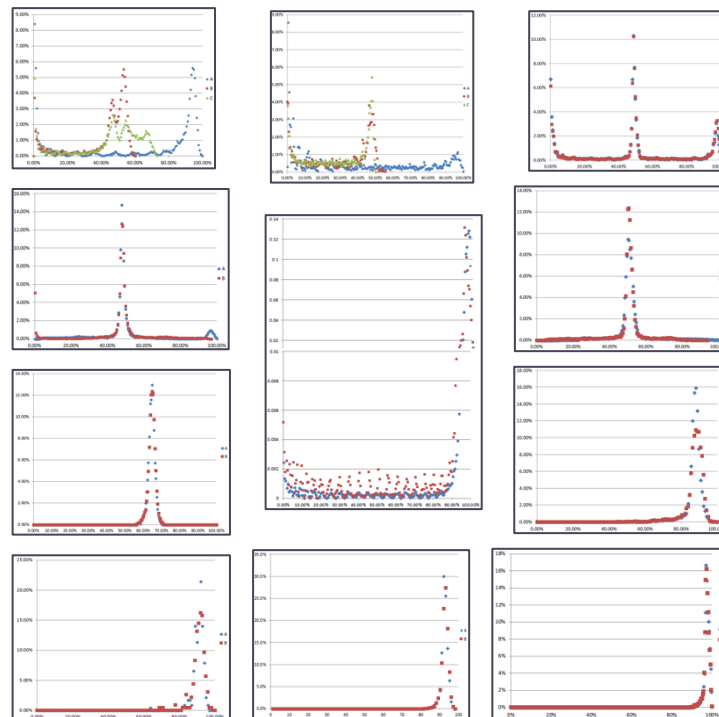
Rankings vs Type of Treatment

2 Beam Plans

Ranking Range	Treatment Area
20 - 30%	Breast w Expanders
40%	Head/Spine
60 - 80%	Prostate & Nodes
75 - 90%	Head/Neck
90-100%	Prostate

2 Beam Plans

Rankings	Area
12.08296901	Head/Neck
18.58612179	Breast
20.7144611	Prostate + Nodes
22.32948317	Breast
23.63542898	Breast
29.87991872	Breast
34.71687458	Head/Neck
38.57230405	Breast
39.56334782	Head/Spine
42.20279116	Head/Spine
53.490539	Breast
61.7219181	Prostate & Nodes
65.52117101	Prostate & Nodes
76.40080578	Head/Neck
78.36737925	Prostate & Nodes
81.20967554	Head/Neck
84.20014473	Head/Neck
88.23070152	Head/Spine
90.51896025	Head/Neck
90.95355415	Prostate (SV)
92.47610391	Prostate (SV)
92.84639367	Prostate (SV)
93.25882048	Prostate (SV)
95.62937522	Head/Neck
96.25734925	Prostate (SV)
98.56583001	Prostate (SV)

3 Beam Plans

Rankings	Area
0.0000	Head/Neck
5.6318	Head/Neck
7.5559	Head/Neck
7.6585	Head/Neck
8.8974	Head/Neck
9.5168	Head/Neck
13.2522	Head/Neck
16.7241	Head/Neck
20.0745	Head/Neck
21.1583	Head/Neck
21.3435	Head/Neck
23.8172	Head/Neck
23.8305	Head/Neck
26.4678	Head/Neck
27.4411	Head/Neck
30.3951	Head/Neck
31.4848	Head/Neck
35.9254	Head/Neck
37.2278	Head/Neck
38.7692	Head/Neck
43.0717	Head/Neck
65.4122	Head/Neck
66.8226	Head/Neck
88.7753	Head/Neck

Use and Further Research

Planning

▷ Determining optimal treatment plan

▷ Minimizing risk factor associated with plan

Clinical

▷ Degree of accuracy in patient/beam positioning

THANK YOU TO

Steve Laub & Adit Panchal

Medical physics team, Northwestern Medicine Chicago Proton Center

Questions?

References

▷ A Brief History of CT. (May, 2013). Retrieved from http://www.impactscan.org/CThistory.htm

▷ Computed Tomography. (Dec. 15, 2017). Retrieved from https://www.fda.gov/radiation-emittingproducts/radiationemittingproductsandprocedures/medicalimaging/medicalx-rays/ucm115317.htm

▷ Drzymala, R. E., Mohan, R., Brewster, L., Chu, J., Goitein, M., Harms, W., & Urie, M. (1991). Dose-Volume Histograms. Int. J. Radiation Oncology Biol. Phys, 21, 71-78. Retrieved January 2, 2018.

▷ Journal Of the ICRU Report 78. International Commision on Radiation Units and Measurements, 7(2), 5-139.

▷ Liu, W., Zhang, X., Li, Y., Mohan, R., (2012). Robust Optimization of Intensity Modulated Proton Therapy. American Association of Physicists in Medicine, Vol. 39(2), pp. 1079-1091.