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Optimization of Multi-Modality Proton-Photon Treatments

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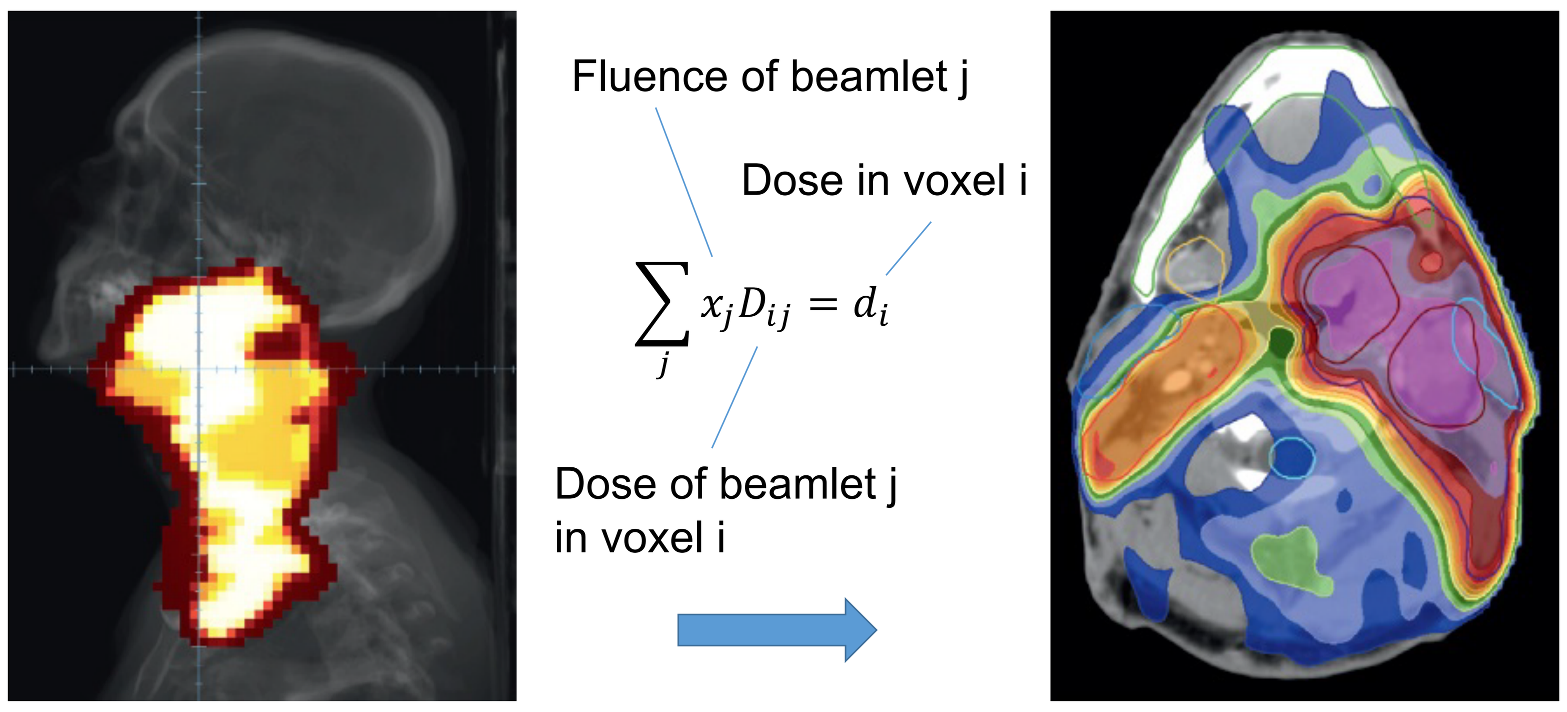
Introduction

External beam radiation therapy is one of the key players in cancer treatment along with surgery and chemotherapy. Approximately 50% of cancer patients receive ionizing radiations as part of their treatment. The main goal of treatment planning in radiation therapy is to deliver high and curative doses to the tumor while sparing the surrounding normal tissues. This is achieved via dose conformity and fractionation. Intensity-modulated radiation therapy (IMRT) and intensity-modulated proton therapy (IMPT) have been key technological developments for achieving conformity. Fractionation means that the total dose is split into many fractions delivered over several days or weeks, in order to exploit repair processes in normal tissues. Nowadays, treatment planning is a highly computerized process. Mathematical optimization algorithms are applied to determine the optimal intensity profiles of radiation beams for each individual patient.

Intensity-Modulated Radiation Therapy



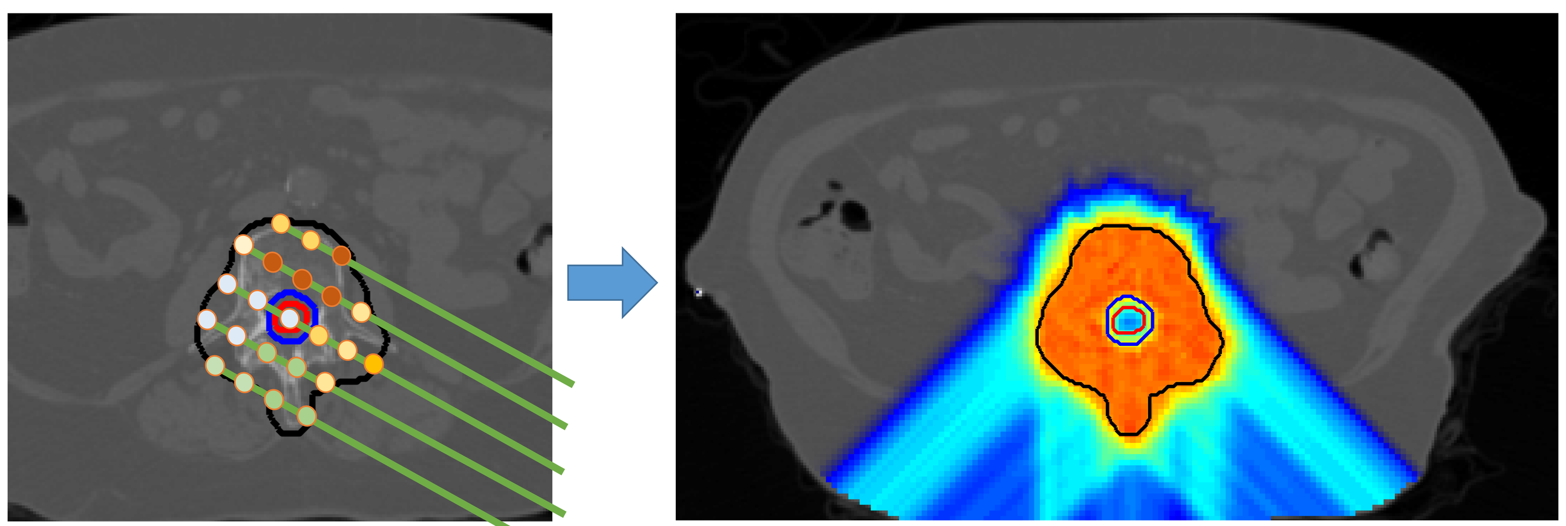
$$\sum_j x_j D_{ij} = d_i$$

Fluence distribution

Dose distribution

- Crossfire arrangement of multiple x-ray beams
- Radiation fields subdivided into intensity-modulated beamlets
- Highly conformal dose distribution to complex-shaped target volumes
- **Unavoidable dose bath in normal tissues**

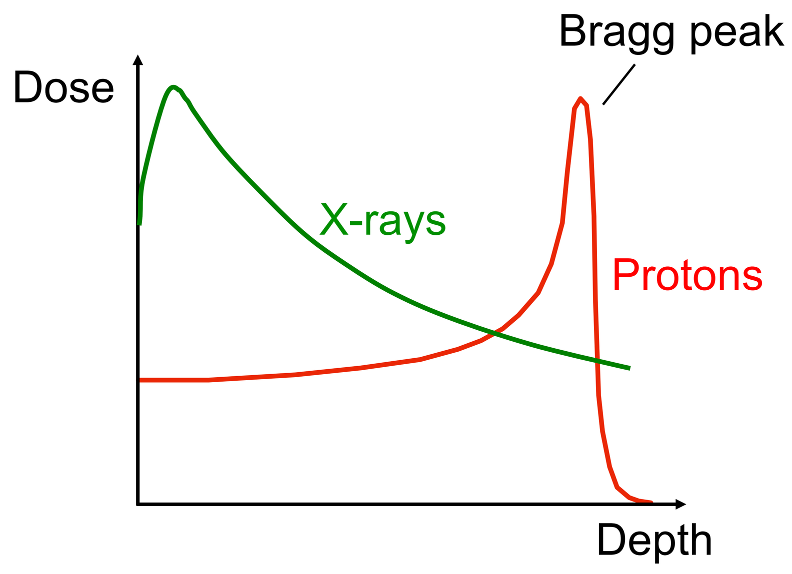
Intensity-Modulated Proton Therapy



Fluence distribution

Dose distribution

- Radiation fields subdivided into intensity-modulated proton pencil beams of different energies
- Highly conformal dose distribution
- **Integral dose reduction in healthy tissues** by a factor of 2-3 compared to high energy x-rays



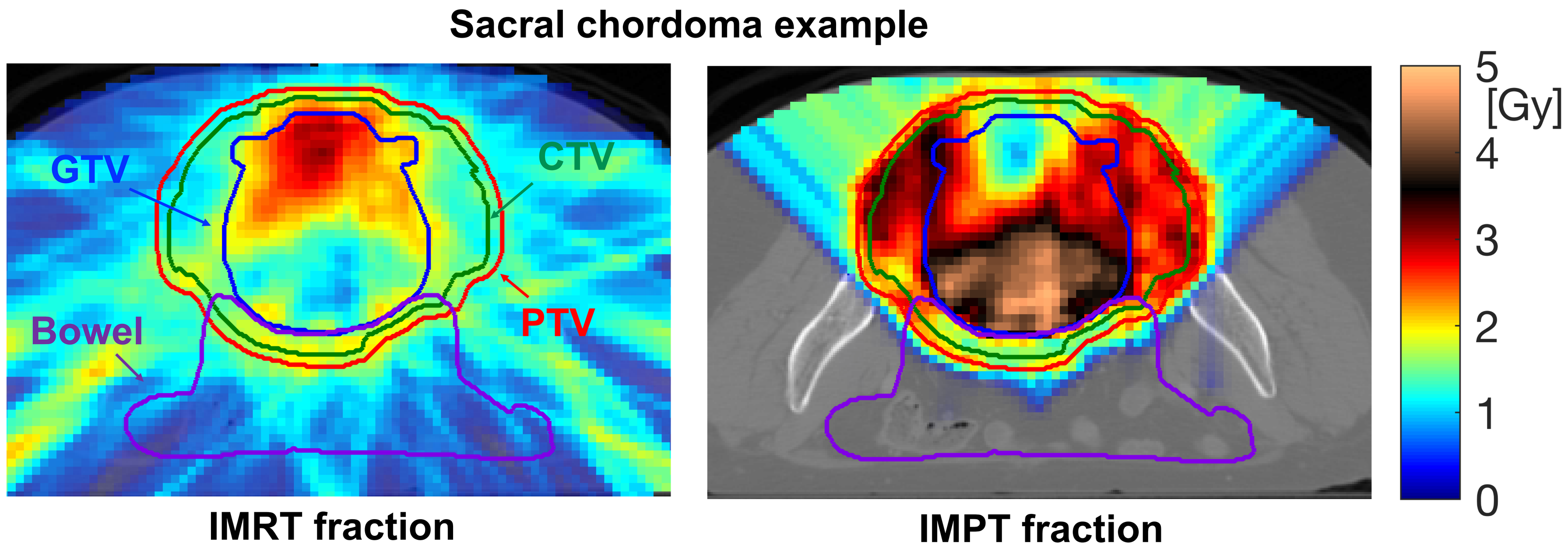
Combined Proton-Photon Radiation Therapy

Motivations

- 68 proton therapy facilities with 178 treatment rooms vs. 12000 conventional x-ray therapy machines
- Combined proton-photon treatments to optimally allocate limited proton resources over a patient population

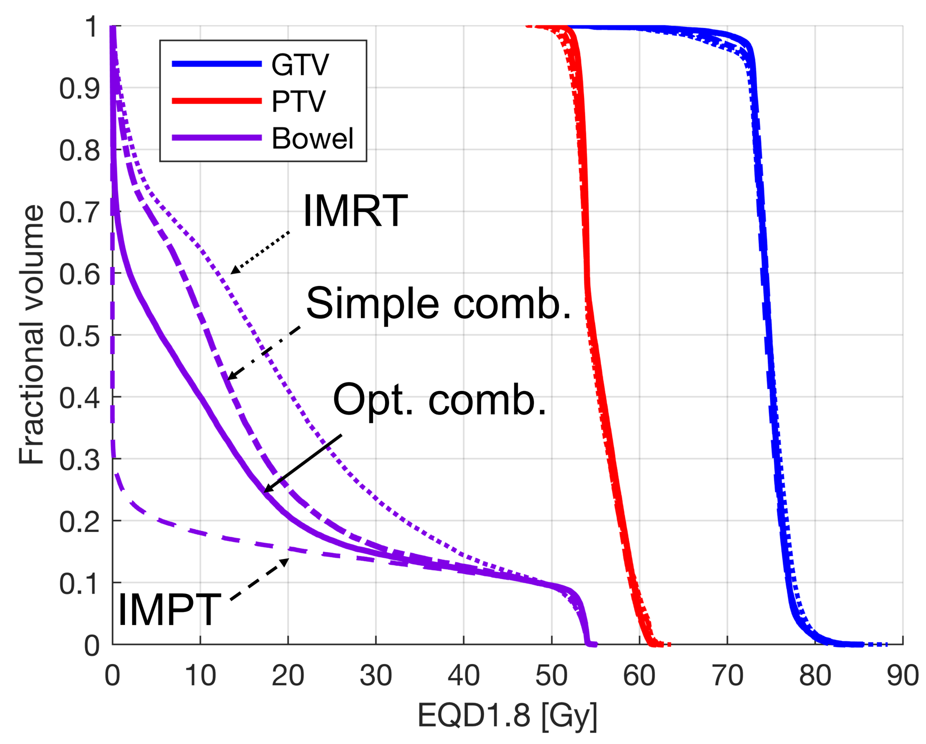
Rationale

Sacral chordoma example



IMRT fraction **IMPT fraction**

- Uniform fractionation with 1.8 Gy per fraction in the region where PTV and bowel overlap
  - To exploit the fractionation effect
  - To minimize the PTV underdose
- Hypofractionation of the GTV with protons
- Reduction of the photon dose bath



Treatment planning method

Simultaneous optimization of IMRT and IMPT plans based on cumulative BED

$$b = n^\gamma d^\gamma \left(1 + \frac{d^\gamma}{\alpha/\beta}\right) + n^p d^p \left(1 + \frac{d^p}{\alpha/\beta}\right)$$

- b: cumulative BED
- n^γ: number of photon fractions
- d^γ: photon dose per fraction
- n^p: number of proton fractions
- d^p: proton dose per fraction
- α/β: fractionation sensitivity
- $n^\gamma d^\gamma \left(1 + \frac{d^\gamma}{\alpha/\beta}\right)$: photon BED
- $n^p d^p \left(1 + \frac{d^p}{\alpha/\beta}\right)$: proton BED

Conclusions

Institutions that currently perform combined proton-photon treatments optimize IMRT and IMPT plans separately so that each modality delivers the prescribed dose per fraction to the target volume. In this work, we developed a novel treatment plan optimization algorithm to simultaneously optimize IMRT and IMPT plans, while accounting for the fractionation effect through the BED model. We show that a limited number of proton fractions is optimally used in combined treatments if protons hypofractionate parts of the target volume while maintaining near-uniform fractionation in dose-limiting serial OARs.

Related publications:

Unkelbach J. *et al.*, Optimization of combined proton-photon treatments, Radiother. Oncol. (2018)