In Vivo imaging in proton therapy

AAPM 2018
Jeremy C. Polf
Department of Radiation Oncology
Maryland Proton Treatment Center
University of Maryland School of Medicine

Disclosures

Research Funding: National Institutes of Health National Cancer Institute award R01CA187416.

- Prompt gamma imaging for proton radiotherapy treatment verification.

Overview

- Uncertainties in proton dose delivery
  - What issues them
- Case examples of the effects of uncertainty on patient treatment
- In vivo verification methods
  - Current methods under development
- Future trends in proton therapy
  - In vivo imaging needs
- Conclusions
Overview

Protons Stop!
Photons don’t.

Maximum Proton
dose at target
Maximum Photon
dose dose at $d_{max}$

In reality there are many uncertainties in Proton treatment delivery due to a wide range of factors:
- Treatment setup,
- CT# conversion,
- Tumor motion,
- Tissue response to proton irradiation
- etc.

Dose Within and Distal to tumor
- Photons: little effect
- Protons: significant effect
Managing Uncertainties

1. Dose Calculation
2. Treatment Delivery

Range uncertainty formula:

\[ \approx 3.5\% \text{ (beam range)} + 1 \text{ mm} \]

CTV with Planning Target Volume (PTV) with Range uncertainty

- 3.5% beam range + 2 mm

Define our Clinical Target Volume (CTV): the tumor + microscopic disease

Oncologist writes a prescription: 72 Gy in 40 treatment fractions.

Planning Target Volume (PTV) account for setup uncertainty, etc.

Expand PTV to account for range uncertainty

- Reduce coverage to the ITV
- "Over range" into heart
  Increasing dose to heart
Lateral Profile Uncertainties

- Use eye deviation technique to avoid dose to lens/cornea.
- Conform dose distally to avoid optic nerve.
- Deviation of ≤2 mm could result in full dose to lens/cornea.

Managing Uncertainties: in vivo imaging methods

“In vivo” = in the room with patient on the table

- Using treatment beam
  - proton radiography/CT
- Using secondary radiation
  - induced ultrasound
  - in-room PET imaging
  - prompt gamma imaging

Managing Uncertainties

- Ion radiography / tomography
  - Direct (integral) SPR determination
  - Daily, low-dose image guidance
  - pre-treatment verification of:
    - Water equivalent path length
    - Stopping power ratio


• pretreatment verification of:
  - Water equivalent path length
  - Stopping power ratio
Managing Uncertainties

- Induced secondary emission

![Image](image1)

- Induced ultrasound imaging
- Prompt gamma imaging

![Image](image2)

- Proton beam
  - Bragg peak
- Phantom
  - Entrance Accelerometer
  - Laser Vibrometer

![Image](image3)

- Proton treatment head
  - $p^+$
- Detection system
  - $^{12}\text{C}$
  - $^{16}\text{O}$

Measure:
- 1D profile of PG emission
- Arrival time of PG
- PG spectra at given position

Provide:
- Clinical range of a given proton beam

![Image](image4)

- Courtesy of Joost Verburg, MGH
Managing Uncertainties

- Induced Ultrasound imaging
- Prompt gamma imaging

Measures:
- 3D distribution of emission

Provide:
- 3D evaluation of proton dose distribution in patient

Future needs: hypo-fractionation

- Current: 1-2 treatments a day for 15 – 45 days  \( \rightarrow \) (\( \leq \) 2 Gy per treatment)
- Future: 1 treatment a day for 1 – 10 days.  \( \rightarrow \) (10 Gy – 25 Gy per treatment)

Future Needs: functional imaging

- Need information about response of tissues to treatment.

Why does this patient develop pneumonitis. And not the other 100+ lung patients?
Future Needs: functional imaging

• Need information about response of tissues to treatment.

• If change in elemental concentration changes, is it indicative of treatment outcome?
• Would make possible to predict patient response during the course of treatment.
  - Tumor response (changes in Hypoxia)
  - Normal tissue complication

Future Needs: functional imaging

• NIST prompt gamma activation analysis beamline at NIST Center for Neutron Research
• Imaging specific PG emission lines as a function of elemental mass in the sample.

Why no clinical in vivo imaging yet.

• High beam currents [1 – 5 nA at exit of beam nozzle]
• High count rates on the detectors [up to ~1 Mhz]
• Short irradiation times [1 μs - 10 ms per beam spot]

• Detector requirements:
  – Need to handle a high count rate.
  – Fast data processing and image reconstruction
  – “Real-time” data display
Conclusions: Why do we need in vivo imaging?

- Need to improve the precision of proton treatment delivery.

**But Why?**

Because we can reduce MARGINS!!!!!