Motion Management for Proton Lung SBRT

Outline

• Protons and Motion
  • Dosimetric effects
  • Remedies and mitigation techniques
• Proton lung SBRT
• Future directions

Protons and motion

• Dosimetric perturbation due to motion
  • On the beam periphery laterally to the axis
  • Proximal and distal target edge along the beam
  • Within the target
Dose perturbation \perp to beam axis

- Similar to photons
  - Tumor motion lateral to beam axis evaluated by distance usually based on 4DCT
  - Effects
    - Dose blurring at the edge of the field
    - Geographical misses, OAR overdosing
  - Remedies
    - Margins (ITV), Motion reduction techniques
- Unfortunately, older delivery systems not yet retrofitted with CBCT or real-time imaging capabilities
  - No soft tissue imaging, no motion monitoring of target or internal surrogates during treatment

Dose perturbation \perp to proton beam

Protons and motion

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Dose perturbation along the beam axis
### Dose perturbation along the beam axis

- Proton range in patient depends on **proton energy** and **stopping power** of tissues crossed
  - SP of a material depends on density and elementary composition
- Density changes along beam greatly affect proton path-length
  - Motion evaluated in **water equivalent distance (WED)** from patient surface to distal target surface along the beam
  - Effect is beam specific (contribution of proximal-to-target tissues)

### Proton delivery techniques

- Most proton lung treatments up to date delivered by **passively scattered protons**
  - Whole SOBP delivered in 0.1 s or less → instantaneous compared to breathing → each field delivers uniform dose
- **Pencil beam scanning** also used
  - Dose distribution painted with Bragg peaks magnetically deflected (spots)
  - Pattern of spots delivered layer-by-layer, every layer corresponding to a proton energy
  - SFUD more common than full IMPT for lung targets
  - Large variation in beam parameters
    - Spot size: $\sigma = 3–8$ mm in air
    - Layer switching times: 0.08–7 s
    - Rescanning capabilities

### Protons and motion

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WED changes and passive scattering

- Static target
- Lateral beam
- Collimator for lateral conformity
- Compensator for distal conformity

Dose perturbation along proton beam

WED changes and passive scattering

- Moving Target

Dose perturbation along proton beam

WED changes and passive scattering

- iTarget*: geometrical expansion to include moving target
- On average 4DCT, iTarget has variable density depending how long the target spends on every position

* No new nomenclature just an alias for iGTV or ITV or iCTV or …
WED changes and passive scattering

- $\text{iTarget}$ override (max target HU) to calculate proton energy to ensure adequate range during breathing cycle

Dose perturbation along proton beam

WED changes and passive scattering

- $\text{iTarget}$ override (max target HU) to calculate proton energy to ensure adequate range during breathing cycle
- Aperture to cover expanded target
- Compensator to conform the beam distally

Dose perturbation along proton beam

WED changes and passive scattering

- Density changes proximally to target alter water equivalent depth of the target distal surface → loss of target coverage

Dose perturbation along proton beam
WED changes and passive scattering

- Compensator smearing (thinning) to ensure coverage under density changes

Dose perturbation along proton beam

WED changes and PBS

- For PBS deliveries
  - iTarget overrides similar to passive scattering or
  - 4D robust optimization (density of all CT phases used during optimization)
  - Motion robustness analysis (e.g., dose re-calculation on inhale, exhale CTs)
    - Important
      - In the first case because there is no smearing
      - In the second case because 4D robust optimization is a recent development

Protons and motion

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**Dose perturbation within target**

- Interplay effect of pencil beam scanning and motion
- Interference of dynamic pencil beam delivery with the target motion results in local dose heterogeneities within the target
- Geometric expansions do not compensate for the effect
- Magnitude of effect depends on target characteristics and beam delivery parameters
- Motion amplitude alone does not predict the effect

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**PBS and motion**

- Static target
- Moving proton beam
  - Variable position, energy and intensity

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**PBS and motion - Interplay**

- Moving target
- Moving proton beam
Re-painting

- Volumetric re-painting ideal (fast systems)
- Synchronization issues for repetition (slow systems)
- Iso-layered re-painting helpful

Dose perturbation within target

PBS and motion – Enlarged spot

Small spot

Large spot
- Smaller dose perturbation
- Larger penumbra

Dose perturbation within target

More remedies for interplay

- Fractionation – not applicable to SBRT
- Set motion limits for PBS treatment
- Motion reduction – needs to be reproducible
- Gating
- Robust optimization (implemented currently only for setup, range uncertainties and density changes makes plans more resilient to interplay)
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Hypo-fx proton lung treatment studies

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• From clinicaltrials.gov currently recruiting studies
  • 4 Hypo-fractionated proton therapy for lung cancer
  • 1 Lung SBRT allowing protons
  • 1 Lung IMRT/SIB

Survey on Proton SBRT

• Distributed to 20 US proton centers in March 2016
• 14 replies 17-28/3/2016
• 8 centers offer hypofractionated and/or SBRT lung treatments
• The responds showed that there is no standard approach in delivery, planning or motion management
Survey on Proton SBRT

- MGH has gating all others use 4DCT or breath-hold
- Multiple scans are often acquired at sim to check breathing variability or breath-hold reproducibility
- All delivery techniques used
- For PBS, re-painting is most common interplay reduction method
- IGRT done with planar x-rays, only 2 centers with CBCT
- Surface imaging used for monitoring during treatment in some centers

UFPTI lung SBRT approach

- Stage I NSCLC
- 48CGE in 4fx (peripheral) or 60CGE in 10fx (central)
- 4DCT/ITV or breath-hold/ITV (multiple scans)
- Repeat CTs before first treatment and periodically thereafter
- Passive scattering delivery, 3-4 fields
- Implanted fiducial markers, kV imaging on inhale and exhale
- Occasionally, monitoring of breathing during irradiation using the ABC device

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What is next

- On-board imaging equipment capable of target imaging and real-time imaging
- Gating and tracking capabilities
- 4D robust optimization that includes interplay effect
- Tools to calculate interplay effect
- Techniques and technologies to make proton treatments less sensitive to motion

References