Motion Management for Proton Lung SBRT

AAPM 2016

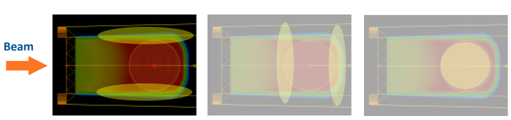
UFHealth
PROTON THERAPY INSTITUTE

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 ⊥ 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

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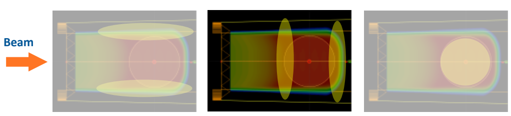
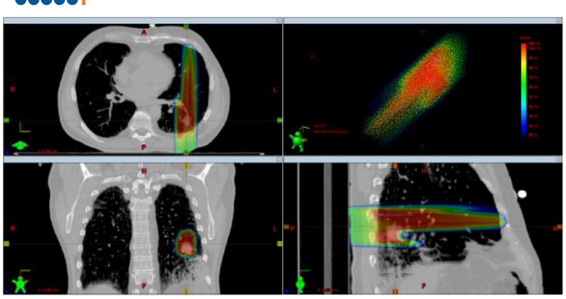
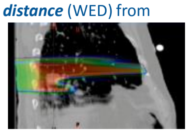


Dose perturbation along the beam axis



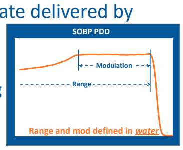
Dose perturbation along the beam axis

- 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: σ = 3 – 8mm in air
    - Layer switching times: 0.08 – 7s
    - Rescanning capabilities

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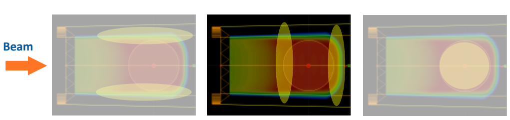
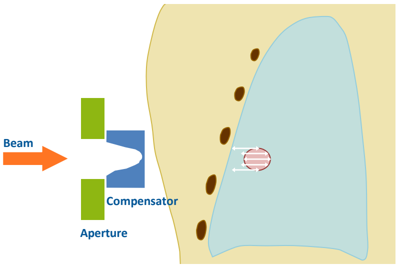


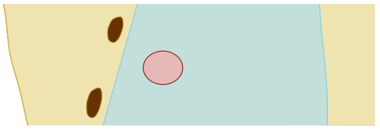
WED changes and passive scattering



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

Dose perturbation along proton beam

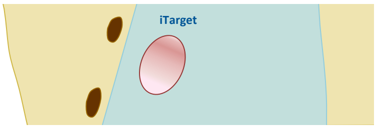
WED changes and passive scattering



- Moving Target

Dose perturbation along proton beam

WED changes and passive scattering

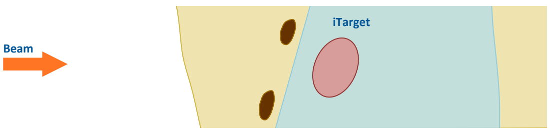


- iTarget*: geometrical expansion to include moving target
- On average 4DCT, iTarget has variable density depending how long the target spends on every position

* No new nomenclature just an alias for iGTV or ITV or iCTV or …

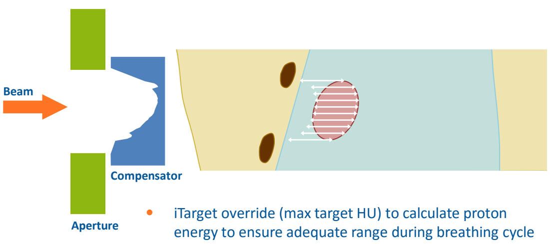
Dose perturbation along proton beam

WED changes and passive scattering



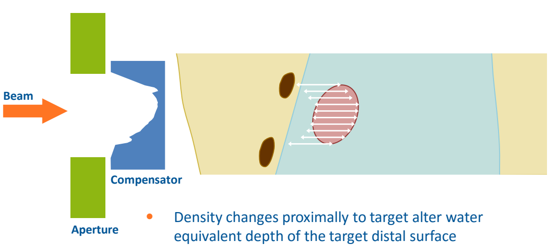
- iTarget override (max target HU) to calculate proton energy to ensure adequate range during breathing cycle

WED changes and passive scattering



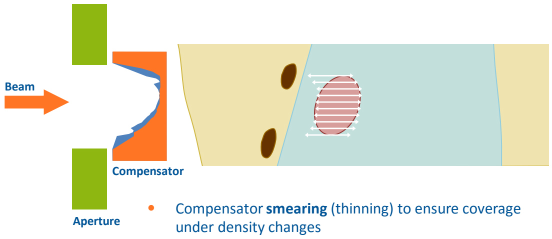
- iTarget override (max target HU) to calculate proton energy to ensure adequate range during breathing cycle
- Aperture to cover expanded target
- Compensator to conform the beam distally

WED changes and passive scattering



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

WED changes and passive scattering



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

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 (eg 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

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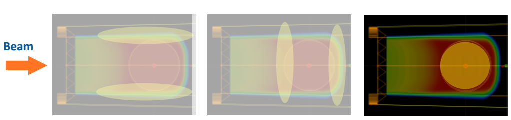
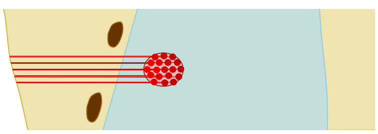


Dose perturbation within target

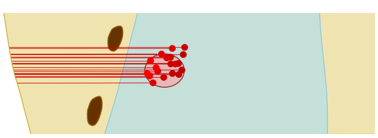
- Interplay effect of pencil beam scanning and motion
  - Interference of dynamic pencil beam delivery with the target motion results in local dose heterogeneities within the target
  - Geometric expansions do not compensate for the effect
  - Magnitude of effect depends on target characteristics and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

PBS and motion



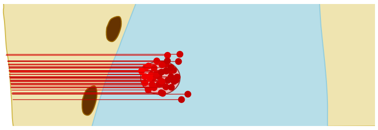
- Static target
- Moving proton beam
  - Variable position, energy and intensity

PBS and motion - Interplay



- Moving target
- Moving proton beam

Re-painting

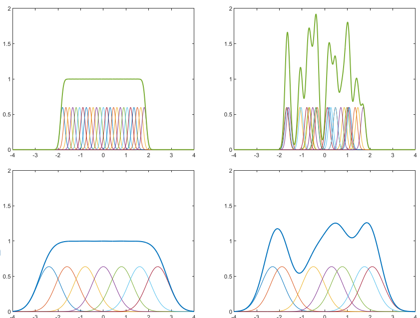


- Volumetric re-painting ideal (fast systems)
  - Synchronization issues for repetition (slow systems)
- Iso-layered re-painting helpful

PBS and motion – Enlarged spot

Small spot

Large spot
- Smaller dose perturbation
- Larger penumbra



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

Center	# Pts	Dose (CGE)	Fx Dose (CGE)	Delivery method	Simulation CT	IGRT	Motion management	Reference
Goyang, Korea	55	50, 72	10, 6	PS	4D	Planar kV x-rays	Gating	Lee, 2016
Loma Linda	111	51, 60, 70	5.1, 6, 7	PS	4D	Planar kV x-rays		Bush, 2013
MGH	15	42 - 50	10 - 16	PS	4D	Planar kV x-rays		Westover, 2012
MD Anderson	18	87.5	2.5	PS	4D	Planar kV x-rays	Repeat 4DCT	Chang, 2011
Hyogo, Japan	57	80, 60	4, 6	PS	Gated	Planar kV x-rays	Gating (exh)	Iwata, 2010
Tsukuba, Japan	21	50, 60	5, 6	PS	Gated	Fluoroscopy	Gating (exh)	Hata, 2007
Chiba, Japan	37	70-98	3.5-4.9	PS	Gated	Planar kV x-rays	Gating (exh)	Nihei, 2006

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

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