Treatment Planning and Delivery for Proton Thoracic Therapy:
An US Center's Experience

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Outline

- ❑ Background
- ❑ Impact of motion in proton therapy
- ❑ Proton treatment: free breathing techniques
- ❑ Proton treatment: active breathing motion control techniques
- ❑ Discussion and Summary

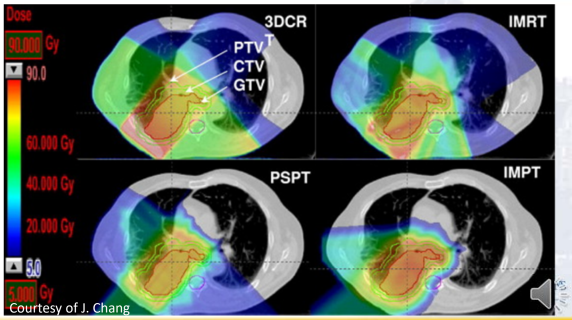
Why Proton Therapy for thoracic and abdominal malignancies?

- Maximize disease control
- Improve overall survival
- Minimize both early and late side effects
- Preserve organ function
- Preserve quality of life
- *Eliminate unnecessary radiation* to the patient

"One cannot have a radiation-induced side effect in tissue that does not receive radiation."

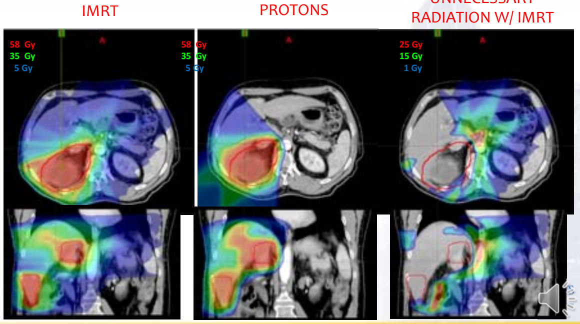
-H. Suit

Potential of IMPT for Thoracic Cancer



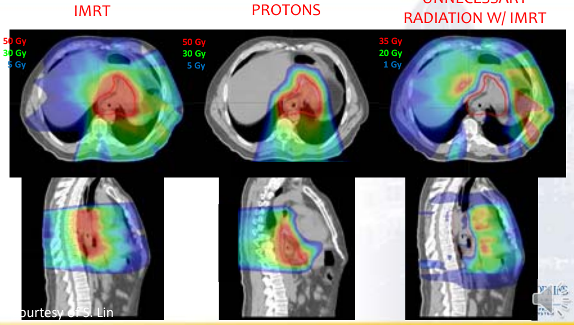
Gastrointestinal/Liver Cancer

IMRT | PROTONS | UNNECESSARY RADIATION W/ IMRT



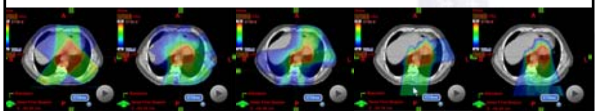
Esophagus Cancer

IMRT | PROTONS | UNNECESSARY RADIATION W/ IMRT



Esophagus Cancer

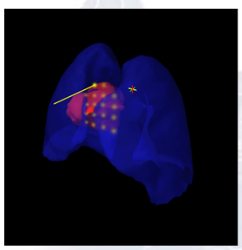
1980's	1990's	2000's	2005+	2013+
3D-CRT X-RAYS	IMRT X-RAYS	VMAT X-RAYS	PASSIVE PROTONS	IMPT PROTONS



HEART DOSE (cGy):				
2833	1933	2200	1301	**943**
LUNG DOSE (cGy):				
1747	1324	1103	966	**775**
LIVER DOSE (cGy):				
1184	1141	986	218	**235**

Challenges: Intra-fractional Respiratory Motion

- The motion of the beam could interfere with the respiratory motion of the target
- May result in distortion of the planned dose distribution, severe local over- and under-dosage



Respiratory Motion Management for Proton

- Motion management techniques could be categorized into
  - Passive motion management techniques: patient breathing and beam delivery independent of each other
  - Active motion management techniques: adjust patient breathing and/or beam delivery according to one and other

Passive Motion Management

- Free breathing delivery
- Treatment planning and delivery based techniques
  - IGTV/ITV and margin based planning
  - 4D (robust) planning
  - Rescanning
  - Optimization of delivery sequence

Active Motion Management

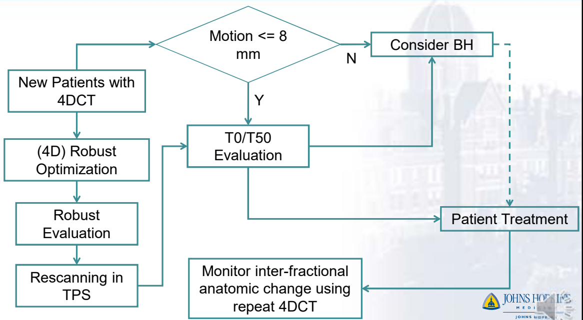
- Real time monitor of patient motion is essential
- Regulation of patient breathing
  - Breath hold
  - Abdominal compression
- Adjusting proton delivery
  - Gating
  - Tracking – not quite practical

Free Breathing Treatment

- Uses passive motion management
  - 4DCT based planning
- Motion and water equivalent thickness (WET) analysis for every patient
  - 8 mm or less
- Robust optimization and evaluation
- Rescanning in TPS
- T0/T50 and 4D dynamic dose evaluation
- Adaptive radiotherapy

Chang, Li *et al.*, IJROBP (2014)

Free Breathing Treatment



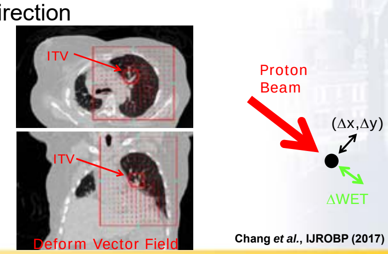
Chang, Li *et al.*, IJROBP (2014)

Tumor Motion Analysis

- IMPT plans are more sensitive to tumor motion than IMRT plans
- Treating patient with larger motion requires additional analysis.
  - Motion less than 8 mm is considered acceptable without extra analysis
- Patient specific 4D water equivalent thickness (WET) analysis is also performed
  - It is acceptable if more than 80% of range uncertainties caused by motion can be accommodated by 5 mm range margins

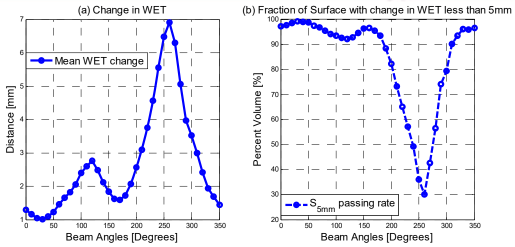
Tumor Motion Analysis

- Deformable image registration for motion perpendicular to the beam direction
- Ray-tracing for WET changes along the beam direction



Chang *et al.*, IJROBP (2017)

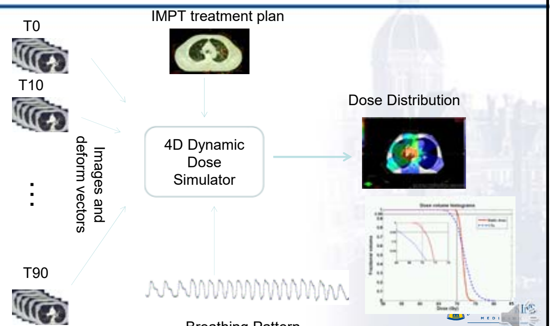
WET Analysis Example – Angle Specific



S_5mm Percentage of range differences of the voxels in PTV covered by 5mm margin. Current criteria >80%
This results was also used in beam angle selection

Chang *et al.*, IJROBP (2017)

Dynamic 4D Dose Calculation



Li *et al.*, Med. Phys, (2014)

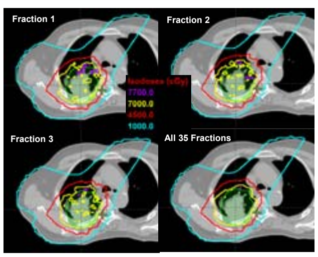
4D Dose Calculation

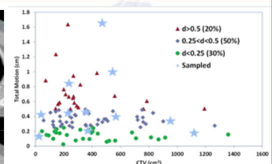
1) Compute the dose on the different phases using the same treatment plan casting on individual-phase CT data.
2) Map individual-phase doses to the reference phase using deformable image registrations (DIR).
3) Take the weighted average of all mapped individual-phase doses on the reference phase.

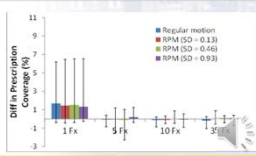
Dynamic 4D Dose Calculation

1) Distribute spots over different phases according to delivery parameters, including beam starting time, spot timings, and patient breathing traces, which could be obtained either directly (eg. fluoroscopy) or via a surrogate (eg. external marker).
2) Compute the dose on the different phases on the basis of individual-phase CT data and the assigned spot distribution.
3) Map individual-phase doses to the reference phase using DIR and accumulate the mapped doses on the reference phase.

Rescanning for Lung IMPT



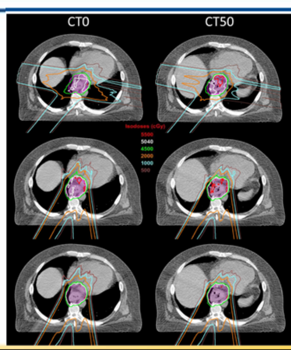




11 patients sampled from 110 patients

Li *et al.*, Med. Phys, (2014)

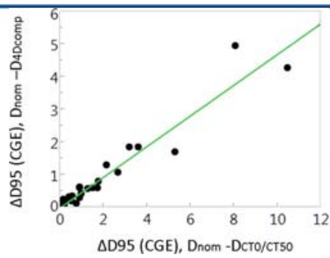
T0/T50 Evaluation



Yu *et al.*, Med. Phys, (2016)

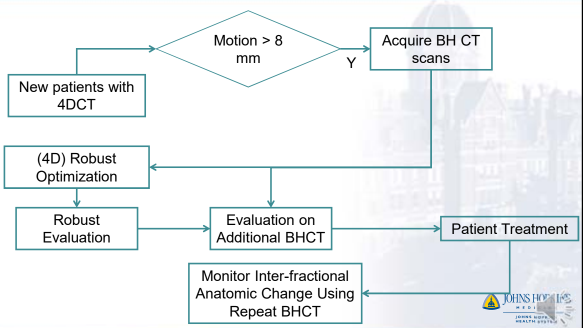
T0/T50 Evaluation

Yu *et al.*, Med. Phys, (2016)
Chang *et al.*, IJROBP, (2017)

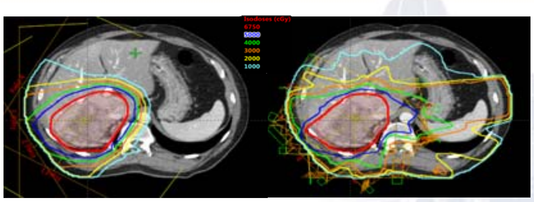


- Dose variation from nominal dose in T0/T50 highly correlated with dose variation in 4D dynamic dose
- T0/T50 evaluation can be used to evaluate the dosimetric impact of motion

Breath Hold Treatment



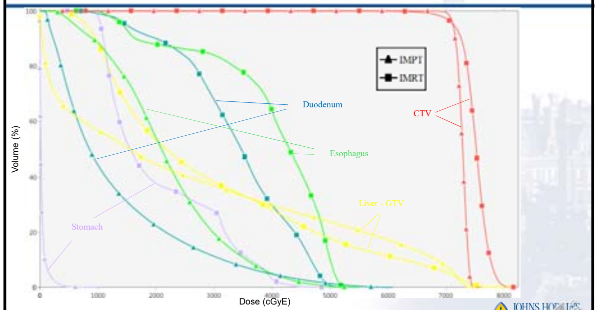
Breath Hold for Liver Patients



IMPT IMRT

Yang, …, Li, Radiother Oncol, 2019

Breath Hold for Liver Patients



Yang, …, Li, Radiother Oncol, 2019

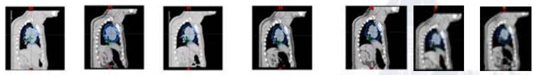
Other Motion Management Techniques

- Gated treatment
  - Requires real-time patient monitoring
- Online adaptive therapy
  - Needs real-time dose validation
- Further improve plan robustness against anatomy change
  - Understand the magnitude of anatomy change
  - Multiple CT optimization

Real-Time Patient Monitoring

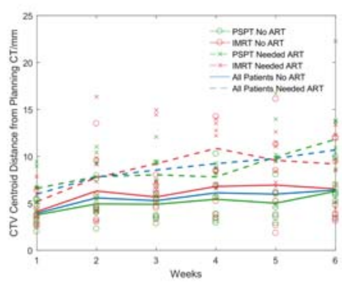
- Surrogate tracking
  - RPM system
- Optical imaging
  - External surface tracking
- Fluoroscopy imaging
  - Fiducial tracking
  - Marker-less tracking

Challenges:
Inter-fractional Anatomical Change



- Patient anatomy could change substantially over time
- Including but not limited to tumor volume change, tumor location change, patient gain/lose weight, breathing pattern change, pleural effusion, etc.
- Magnitude and timing of these changes are patient specific and currently difficult to predict
- Could have large impact on IMPT dose distribution

Magnitude of Anatomy Change for NSCLC Patients



Chen, ..., Li, Radiation Oncology, 2020

Managing Anatomical Change

- Adaptive Therapy
  - Repeated imaging in the course of treatment
- Improve robustness of the IMPT plan
  - Robust optimization – does not directly address anatomy change
  - Multiple CT optimization
- Online adaptive therapy
  - In room volumetric imaging
  - Fast and accurate dose calculation
  - Innovative system QA – may not be able to perform measurements

Summary

- Accurate dose calculation is challenging for treating moving targets with proton
- IMPT has dosimetric benefit over IMRT for different treatment sites
- A system for treating moving tumor with IMPT has been developed
- More developmental work is needed
  - Improve in room imaging
  - Improve robustness of the treatment plan

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Questions and Answers

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