IMPLEMENTATION OF PBS PROTON THERAPY TREATMENT FOR FREE BREATHING LUNG CANCER PATIENTS

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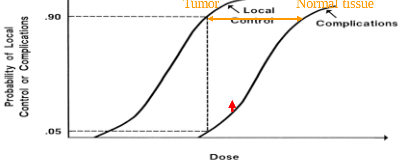
Overview

- Background
- Understand the motion-induced dose uncertainty in IMPT
- Implementation of IMPT for selected lung patients
- Conclusion

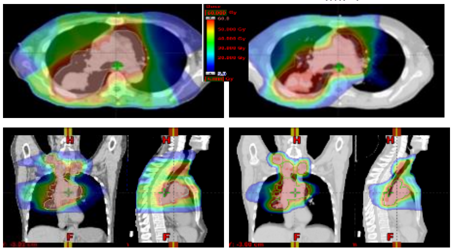
Proton Therapy in lung cancer

- Potential to improves therapeutic ratio and allows dose escalation/acceleration
  - By limiting dose to normal tissue



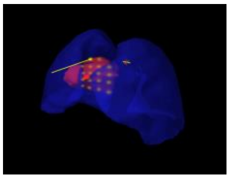
Rationale

IMPT: Reduce normal tissue dose compared with IMRT in stage IIIB NSCLC (Zhang et al IJROBP 2010)



Motion Induced Dose Uncertainties

- The motion of the beam could interfere with the motion of target (interplay effect)
- May result in distortion of the planned dose distribution, local over- and under- dosage
- One of the major concerns for treating lung cancer with scanning beam proton



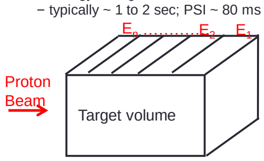
Understanding Motion Induced Dose Uncertainties

- Determine the relationship between the delivered dose and the plan dose
- Statistical quantification of the dose uncertainty with consideration of
  - Fractionation
  - Breathing period
  - Repainting
  - Total delivery time

Repainting

Zenklusen *et al*. PMB 2010

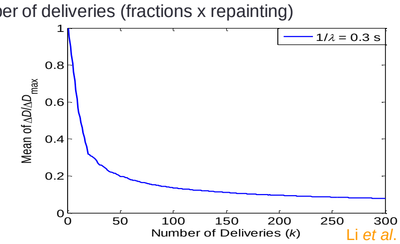
- Iso-layer repainting (within each energy)
  - Not necessary helpful – repainting could complete within a short time relative to breathing cycle
- Volumetric repainting (visit all energies, then repeat)
  - To simulate passive scattering beam delivery
  - The total irradiation time would increase considerably
  - Energy change needs to be fast
  - typically ~ 1 to 2 sec; PSI ~ 80 ms



- Require large number of repainting
- Scanning motion and target motion are uncorrelated.

Motion Induced Dose Uncertainties - Scanning Beam Proton

- Mean dose difference between 4D dose and delivered dose as a function of number of deliveries (fractions x repainting)



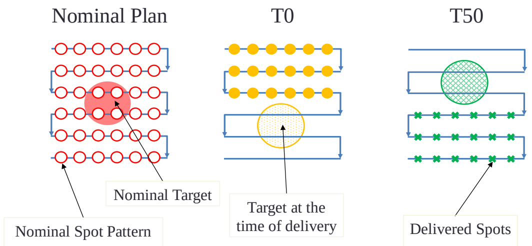
Li *et al*. Med Phys 2012

Delivery Sequence Optimization

- Minimize the motion-induced dose uncertainty by optimizing delivery sequence
- Evaluate the efficacy of spot delivery sequence by measurements and compare measurements to analytical model
- Patient study to validate the technique

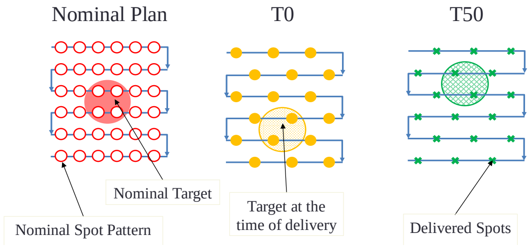
Reducing Dose Uncertainty for Spot-Scanning Proton Beam Therapy of Moving Tumors by Optimizing the Spot Delivery Sequence
Li *et. al.*
IJROBP 2015

Delivery Sequence for SSPT

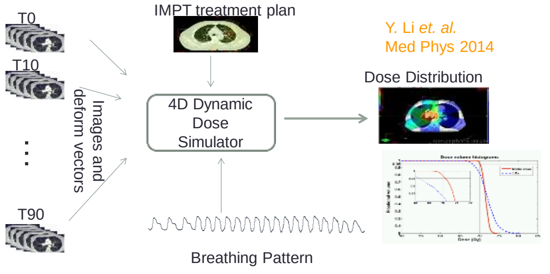


Optimization of Delivery Sequence

- No rescanning
- Same delivery time



4D Dynamic Dose

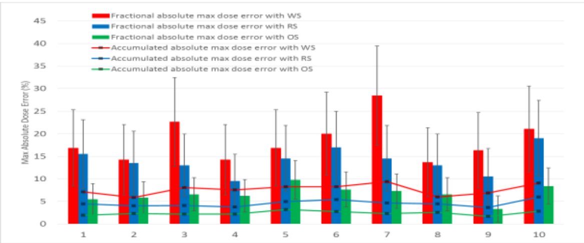


Patient Study
– Optimization of Delivery Sequence

Regular sequence (RS) Worst sequence (WS) Optimized sequence (OS)

- Max dose error in 1 fx
  - 23.4% for WS
  - 14.3% for RS
  - 7.3% for OS

Patient Study



Li *et. al.*
IJROBP 2015

Understanding Motion Induced Dose Uncertainties

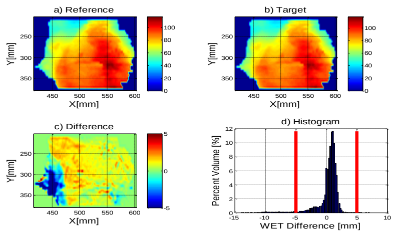
- The delivered dose converges to the 4D dose
- The dose difference between the delivered dose (4D Dynamic dose) and the planned dose (4D dose) reduces with
  - Fractionation ↑
  - Breathing period ↓
  - Repainting ↑
  - Total delivery time ↑

Summary of Current Techniques (FB)

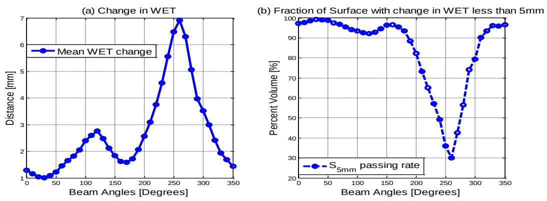
- Margin based approach
  - Needed but likely not sufficient
- Motion assessment
  - 4DCT and Water equivalent thickness (WET) based analysis
- Optimization based techniques
  - 4D optimization and dynamic dose analysis
  - Robust optimization and analysis
- Delivery based techniques
  - Scanning direction
  - Rescanning
  - Delivery sequence optimization
- Patient specific dose evaluation
  - 4D Dynamic dose calculation
  - Repeated CT and adaptive planning

Clinical Implementation of Intensity Modulated Proton Therapy for Thoracic Malignancies
Chang *et. al.*
IJROBP 2014

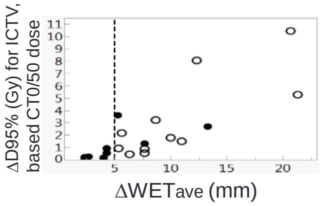
WET Analysis Example



WET Analysis Example

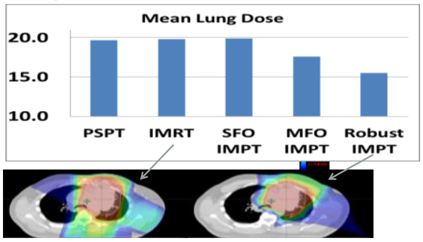


WET change and Motion Induced Dose Uncertainties



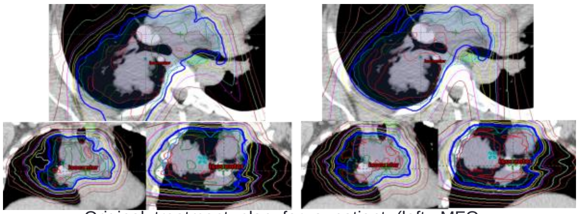
Yu *et. al.*
Med Phys 2016

Robust Optimization



5 different plans were needed to decide the best treatment plan for a lung patient: IMRT, PSPT, SFO, MFO and robust MFO.

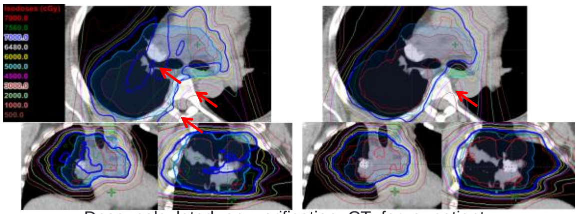
Robust Optimization



Original treatment plan for a patient (left, MFO-PTV; right, MFO-RO)

Robust optimization in intensity-modulated proton therapy to account for anatomy changes in lung cancer patients
Li *et. al.*
Radiotherapy and Oncology 2015

Robust Optimization



Dose calculated on verification CT for a patient (left, MFO-PTV; right, MFO-RO)

4D Robust Optimization

- Interplay effect could be more significant for scanning beam
- 4D accumulated dose predicts the dynamic dose to patient after multiple fractions and/or repainting and deviates from planned (static) dose generated on single phase
- 4D robust optimization technique could be adopted to produce a deliverable plan with reduced interplay effect

Liu *et. al.*
IJROBP 2016

Conclusion

- Accurate dose calculation is challenging for treating moving targets with proton
- A (not perfect) system was developed and running
- Continue developing and improving on the scanning beam proton treatment of moving targets

Acknowledgments

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- Radiation Oncologists
- Physicists
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- Therapists
- Others