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 III B 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)

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
Delivery Sequence for SSPT

Optimization of Delivery Sequence

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
- 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

(a) Reference
(b) Target
(c) Difference

WET Analysis Example

(a) Change in WET
(b) Fraction of Surface with change in WET less than base
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

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
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The entire team of Radiation Oncology:
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