Treatment Simulation, Planning and Delivery for Stereotactic Body Radiation Therapy

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Outline

- Immobilization and Simulation
- Treatment Planning
- Target Localization & Plan Delivery
- Summary

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Immobilization

- Accurately re-position patient
- Reduce/Minimize patient voluntary and involuntary motion
- Reduce/Minimize organ/target motion
  - Abdominal compression
- Comfortable for long treatment
- Compatible with IGRT
- Not interfere with treatment beam
- Consider machine safety zones

Immobilization and Simulation

Body Fix Abdominal Compression
Thermoplastic Long Mask
Body Fix
Abdominal Compression

Body Pro-Lok™ Frame
Lung tumor motion under varying levels of abdominal compression (pressure plate)  
Heinzerling et al., IJROBP 2008

Comparison of free breathing, BodyFix and abdominal compression in 24 patients  
Han et al., RadOnc 2010

Limitations
- Patient discomfort
- Variable daily distortion in abdominal anatomy

Changes in abdomen geometry with abdominal compression  
Eccles et al., IJROBP 2011

Limitations
- Patient discomfort
- Variable daily distortion in abdominal anatomy

Multimodality of high resolution (1-2mm slice thickness) images (CT/MRI, PET/CT)  
4DCT/PET to evaluate internal motion

Imaging

How to accurately define target?  --- 4D imaging
How to accurately localize target?  --- IGRT
How to obtain conformal dose and steep dose gradients?  --- 3DCRT, Inverse Planning, IMRT, VMAT...
How to minimize dose to surrounding critical organs?  --- Gating, Tracking...

Challenges for SBRT

4D CT Acquisition (Retrospective)

PET/CT Scanner

1st Table Position  2nd Table Position

4D CT Images
**4D PET Acquisition (Prospective)**

- Improve image quality
- Precisely define target shape and size and its motion during the entire respiratory cycle

**PET/CT Scanner**

- RPM System
- PET/CT Scanner
- PET raw data

**PET/CT**

- Multimodality images
  - CT, MRI, PET/CT, 4D CT/PET...
- TPS
- 4D PET/CT
- Define PTV, Inverse Planning, Plan Evaluation, ...
- SRS/SBRT Plan
- Region Center
- Treatment

**SBRT Planning**

- Multimodality images
  - CT, MRI, PET/CT, 4D CT/PET...
- Target definition
- Motion management
- 3DCRT or IMRT/VMAT
- Interplay effect
- Isocenter/Non-isocenter
- Dose calculation

**Target Definition**

- PET/CT, 4D CT/PET, MRI, MIP, MinIP, ...
- --- Target definition
- AveIP, 3D CT-FR/BH, ...
- --- Critical organs, planning, ref. images...

**ITV** = Σ GTV_i or GTV_MIP

**PTV** = ITV+3-5mm setup margin

- For a patient with irregular breathing, a larger margin may need to consider the inaccuracy of ITV
- MIP/MinIP should not be used for contouring normal anatomy and dose calculation

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**Target Definition (ICRU 50)**

- GTV
- CTV
- ITV
- PTV
- Margin
Motion Analysis

- Analyze target motion in different phase
- Consistency of motion of fiducial markers with target
- Analyze target size and shape change
- Determine residual error and target margin for gating treatment

PTV : ITV +3~5mm margin

Liver example

Pancreas example

Motion Management (Delivery)

- Large Margin
- Gating Technique
- Breath-holding Technique
- Tracking Technique

Motion Management (Delivery)

Liver example

Pancreas example

PTV : ITV +3~5mm margin

Motion Analysis

3DCRT or IMRT/VMAT?

- Advantages:
  - Better dose conformality
  - Easy to control/constrain dose to OARs
  - Inverse planning
- Disadvantages:
  - Higher MU, longer treatment time
  - Interplay effect between target and MLC motion

3DCRT or IMRT/VMAT?

3D 4D

IMRT/SBRT VMAT/SBRT

Interplay Effect

Li, Yang et al, JACMP, 2013

Interplay Effect

3D 4D

IMRT/SBRT VMAT/SBRT

Interplay Effect

Li, Yang et al, JACMP, 2013
Interplay Effect: Gated RapidArc

Case 1

Case 2

Quasar phantom with real patient data

Dose Calculation

- Inhomogeneity correction algorithms
  - PBC is not appropriate for lung SBRT
  - AcurosXB, convolution/superposition, MC should be used
- Dose calculation grid $\leq 2$mm
- Couch top should be inserted

Inhomogeneity Correction

Dose difference for targets from PBC and AcurosXB could be more than 10%

PBC should not be used for lung SBRT
Inhomogeneity Correction

For a small isolated target, even AAA is not accurate enough!

Target Localization & Plan Delivery

Pre-Tx Setup (kV/MV, CBCT)

Plan Delivery & Beam-Level Imaging (kV, Fluoro, Cine MV, kV/MV CBCT)

Post-Tx Image & Data Analysis

Image-guided Target Localization

Patient Simulation (CT/MRI/4DCT/PET)

Fluoroscopic Verification

Image-guided Target Localization

Positional setup accuracy with CT–guided correction assessed by an immediate post-treatment CT

15 cases with 90 isocenter setup

Target Positioning: Spine

Positional setup accuracy with CT–guided correction assessed by an immediate post-treatment CT

146 cases
A total of 409 patients with 427 tumors underwent 1593 fractions of lung SBRT.

Intra-fraction variation (mm):
- AP: 0.0 ± 1.7
- ML: 0.6 ± 2.2
- SI: -1.0 ± 2.0
- 3D: 3.1 ± 2.0

Beam-Level Imaging: kV Imaging
- Continuous/Fluoro kV during treatment
- Triggered kV Image At Beam On

Beam-Level Imaging: Cine MV Imaging
- Advantage:
  - No dose, 'free' information
  - Beam eye view
- Disadvantage:
  - MLC blocks image
  - Image quality
- 3D tracking if combined with kV imaging

Fluoroscopy Verification
- Tracking structures
- Yellow: in gating window, beam-on; Green: out gating window.
- Gating window should be adjusted so that fiducials fall within tracking structures when beam is on.

Target Positioning: Lung

Beam-Level kV images for the same pancreatic SBRT case

Images courtesy of Azcona, Xing et al. Med Phys 2013
Intra-fraction Verification of SABR
• 20 SABR patients (lung/liver/pancreas)
• RPM-based gating treatment
• Geometric error: 0.8 mm on average; 2.1 mm at 95th percentile

Beam-Level Imaging: Verification of Geometric Accuracy

Beam-Level kV Volumetric Imaging
• Continuous fluoroscopy during dose delivery
• In-house program for CBCT reconstruction
• 20 lung SABR patients
• Treatment verification
• Routine clinical use

Beam-Level MV Volumetric Imaging

Summary
• 4D imaging is required for accurate motion management
• New techniques (Inverse planning, IMRT/VMAT, Gating/Tracking,...) can improve target conformity and critical structure sparing
• Patients should be positioned with IGRT
• Beam-level imaging is a necessary step to insure accurate SBRT delivery
Question: Which following algorithm should NOT be used for a lung SBRT dose calculation?

- 1. Convolution/superposition
- 2. Pencil Beam Convolution
- 3. AcurosXB
- 4. Monte Carlo
- 5. None of above

Correction Answer: 2. Pencil Beam Convolution

Reference:

Question: What localization accuracy can be achieved in CBCT-guided spine SBRT?

- 1. < 1 mm
- 2. 1–3 mm
- 3. 3–4 mm
- 4. 4–5 mm
- 5. > 5 mm

Correction Answer: 2. 1–3 mm

Reference:

1.1 ± 0.7 mm


<1 mm in AP, Lat, and SI direction