Image Guided Stereotactic Radiotherapy of the Lung

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September 25, 2015

Overview

• Stereotactic Body Radiotherapy
  - Clinical Dose/Fractionation
  - Normal Tissue constraints
• Planning
  - Immobilization
  - The problem of Motion Management
  - Acquisition of 4DCT
  - Treatment planning techniques
  - Dose rate
  - Plan quality assessment
• Quality Assurance
• Treatment
  - 4DCT and CBCT registration
  - Intrafraction motion monitoring

Dose/Fractionation

- SBRT < 5 fractions
- In general we give 15-20Gy in 3 fractions given over 2 weeks or less
- Conventional doses were 60-70Gy in 2Gy fractions given over 6 or 7 weeks
- RBE > 125Gy/α/β=10 and
- NTD > 104Gy for Progression Free survival >99% at 30 months (NSCLC)
- Consider cell cycle, hypoxic effects and tumor doubling/repopulation time
Normal Tissue Constraints in 3 fractions

<table>
<thead>
<tr>
<th>Site</th>
<th>Tolerable Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial Plexus</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Heart/Pericardium</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Great vessels</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Trachea and Large Bronchus</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Trachea and Large Bronchus</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Rib pain or fracture</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Lung (right &amp; left)</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Lung (right &amp; left)</td>
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• Motion of the target can cause skewed size, shape, and density on a CT image, and therefore inaccurate delineation of the target.

• Stereotactic body radiation therapy requires precise delivery of a few high-dose fractions to a small target volume.

Immobilization

Problems with motion during CT

• Motion of the target can cause skewed size, shape, and density on a CT image, and therefore inaccurate delineation of the target.

• Stereotactic body radiation therapy requires precise delivery of a few high-dose fractions to a small target volume.
Problems with motion during CT

Tumor spatial motion is greatest in superior-inferior direction (average ~15mm), particularly for lower-lobe unfixed tumors.

Expected lateral and anterior-posterior motion is ~5mm, but this can vary widely.

Tumors can move with chestwall if fixed.

Temporal motion can also be seen.

Evaluation of spatial/temporal hysteresis can be used to predict future motion.

How do lung tumors move?

- Tumor spatial motion is greatest in superior-inferior direction (average ~15mm), particularly for lower-lobe unfixed tumors.
- Expected lateral and anterior-posterior motion is ~5mm, but this can vary widely.
- Tumors can move with chestwall if fixed.
- Temporal motion can also be seen.
- Evaluation of spatial/temporal hysteresis can be used to predict future motion.

How do we deal with tumor motion?

- AAPM TG 76 recommends respiratory motion management if there is >5mm motion in any direction or significant normal tissue sparing is possible utilizing motion management.
- Breath hold, Slow CT, Gating, and utilizing an ITV are some methods of motion management.
4DCT
- Respiratory-correlated image-guidance
- Expects tumor motion to be related to an external surrogate
- Assumes 4DCT image data is representative of the motion during the entirety of treatment

CT Setup for 4D CT
- Patient has pressure sensor on abdomen that responds to breathing motion
- The wave-deck detects when the x-ray beam is on

Compression?
- Compression may be beneficial but must be balanced with the benefit of achieving good pressure sensor signals for correlation to tumor position
- The position of the sensor and the compression may cause problems
Acquisition Protocol

- Two scouts are taken for localization
- One standard 3D helical scan is taken over the whole lung
- One 4D Cine scan is taken over a reduced area which encompasses the tumor and any expected excursion

Axial-Cine Mode

- Scan rotation time: needs to be fast – slow time results in poor image
- Cine time between images: within a cine duration, the time between reconstructions. When one uses 1/10th of the patient’s breathing cycle, one would have one image per bin for phase sorting
- Cine offers improved slice sensitivity profiles for loss in time efficiency
- 1000-2000 slices
- ~30mGy dose

Cine Mode Parameters

Cine Duration is the patient's breathing period plus ~1s (sufficient to collect one whole breathing cycle)
Cine duration is the total time of the CT to acquire information at one couch position
The time of image acquisition is recorded along with the respiration trace for subsequent correlation of image data with respiratory phase.

This correlation allows all images that were acquired at the same phase of respiration to be grouped into “bins”.

We use 10 bins per $2\pi$ to sort our temporal and spatial data.

Binning necessitates combining adjacent slices that were acquired at slightly different phases of respiration.

This results in some uncertainty in spatial alignment.

0% and 50% phases correspond to the extremes of motion.
Sinusoidal patterns represent the ideal clinical scenario. It is important to investigate clinically relevant motions and their effects on MIP and CBCT registration. The major sources of error are breathing variability (departure from sinusoidal pattern), amplitude, and phase-binning error.

The physicist will analyze the uncertainty in the phase-binning process and in MIP creation at the time of each 4DCT simulation. The physicist will also note the variability in breathing pattern and assess the effect on CBCT registration.

How do we analyze the results of a 4DCT?
MIP takes the maximum intensity from multiple bins and creates a single image. The MIP represents the volume where the tumor is present at any time within the respiratory cycle. Generally, it will underestimate the tumor excursion in irregular breathing patterns. Caution should be used when defining a MIP near the diaphragm.

**4DCT Image Projections**

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**Gross Tumor Volume (GTV):**
- Gross palpable or visible/demonstrable extent and location of malignant growth.

**Clinical Target Volume (CTV):**
- Volume that contains a GTV and/or subclinical microscopic disease.

**Internal Margin (IM):** Physiologic variations of the CTV relative to anatomic reference points, e.g., movements of respiration.

**Internal Target Volume (ITV):**
- CTV + IM

**Set-up Margin:** Uncertainties in patient positioning and alignment.

**Planning Target Volume:** ITV + Set-up margin.
Why do we use a MIP and a 3D GTV to create an ITV?

- 4DCT might not accurately depict the excursion of a moving tumor
- Using a MIP alone might cause under dosing and an increased risk of subsequent treatment failure
- Respiratory variability might be a useful predictor of error in MIP-based ITV determination

Kwangyoul Park et al., IJROBP., Vol. 73, No. 2, pp. 618-625, 2009
Hong Ge et al., IJROBP., Vol. 85, No. 2, pp. 438-443, 2013

Treatment Planning Techniques

- Volumetric-modulated arc therapy (VMAT)
  - VMAT delivers dose to the target volume in a full 360° rotation with varying gantry speed, multileaf collimator (MLC) positions, and dose rate

Dose Rate: Flattening Filter Free

- Flattening-filter free option reduces treatment time
Treatment Planning: Optimization

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<tr>
<th>Volume</th>
<th>Voxel(s)</th>
<th>Voxel Size</th>
<th>Plan Value</th>
<th>Max Point Dose</th>
<th>Plan Value</th>
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<tr>
<td>FDCA</td>
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<td>10 x 10 x 10 cm³</td>
<td>95.7%</td>
<td>100.0 Gy</td>
<td>100.0 Gy</td>
</tr>
<tr>
<td>Spinal Cord</td>
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<td>40 x 40 x 40 cm³</td>
<td>97.5%</td>
<td>100.0 Gy</td>
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<td>Brain</td>
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<td>20 x 20 x 20 cm³</td>
<td>98.2%</td>
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Plan Quality Assessment

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9/21/2015
Plan Quality Assessment

Quality Assurance for SBRT Lung

What is Gamma Analysis?

\[ G(x, y) = \frac{\left| D_1 - D_2 \right|}{\max(D_1, D_2)} \leq 1 \]
Volumetric guidance based on tomographic images acquired at the time of therapy
- Submillimeter spatial resolution
- Soft-tissue contrast resolution

kV Cone Beam CT
- Volumetric guidance based on tomographic images acquired at the time of therapy
- Submillimeter spatial resolution
- Soft-tissue contrast resolution
CBCTs are harder to visualize at the extremes of motion, particularly with larger amplitudes. Breathing cycles with a “rest” (Trace D) will induce weighted contrast at an extreme of excursion on CBCT. Clements et al., Med Phys., Vol. 40, No. 2, 2013.

The visible CBCT ITV is smaller than the true CBCT ITV and may shift the ITV center away from the center of motion resulting in a misalignment to the true ITV contour.

An optical surface imaging system, used to image the skin surface of a patient in 3D before and during patient treatment. Uses 3 pods each with 2 cameras in each to create a 3D image from 2D stereoscopic imaging. NO radiation dose.
How Align RT works

- Each pod has 2 cameras to view the patient
- Each pod displays pseudo random image on the patient to allow each red speckle spot to be unique
- 2 cameras in different locations allow for 3D rendering from 2 2D images from stereoscopic techniques.
- 3 pods in 3 different locations allow for full 3D rendering of the patient
- AlignRT software performs analysis of the similarity between two surfaces

Surface Registration

- Minimization problem – trying to minimize disagreement between surfaces
  - Identical surfaces have 1 unique solution, “similar” surfaces have multiple solutions
  - Topography for comparison (ROI) must be chosen wisely

Align RT: Regions of Interest (ROIs)

- Therapists choose the ROIs
- These are the surface topologies that will be compared to the reference or VRT
Problems with ROIs

- Patient with little topography (flat chest)
- ROI too large
- ROI impacts frame rate acquisition

Why we use Align RT

- Align RT rendering can be captured and used during treatment
- Can be compared to reference from TPS or a previously captured "VRT" surface
- Can be used to help position and monitor patients relative to the prescribed treatment isocenter
- Can help identify patient, gross setup errors and incorrect setups
- Can determine corrections in 6 degrees of freedom
- Can be used to track patient’s respiratory pattern
- AlignRT can be calibrated directly to the beam iso and in turn assists the physics in performing QA on MLC, VM images, room lasers and treatment couch
- May reduce imaging dose

Accuracy Claims & Tolerances

- 3D Surface Data: <1mm
- Positioning accuracy: RMS <1mm
- SSD: RMS <2mm
- Calibration drift: < 1mm/mo
- Static capture: ~3s
- Monitoring: <1s
- Gated Capture reconstruction: < 0.2s
- Acquisition time: 2ms-25ms
- Tolerances apply to all skin tones and reasonable hairiness
- 10k to 20k 3D points per reference model
Patient set-up

Below are two examples of how capturing a treatment setup can assist with whole-body general alignment prior to internal imaging.

Lung/Liver/SBRT

<table>
<thead>
<tr>
<th>DON'T INCLUDE</th>
<th>DO INCLUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-reproducible area</td>
<td>Select isocenter or Central based shift</td>
</tr>
<tr>
<td>Anything not part of the patient</td>
<td>AP Chest</td>
</tr>
<tr>
<td>Diaphragm/abdomen area</td>
<td>Lateral chest</td>
</tr>
</tbody>
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Intrafraction Motion Monitoring
Image Guided SBRT of the Lung

- 4DCT
- Creation of ITV
- Treatment Planning
- Quality Assurance
- kV CBCT
- Alignment of CBCT with ITV
- Verification and intrafraction motion monitoring with AlignRT
- Treatment

Thank You