Transitioning from 3D IMRT to 4D IMRT and the Role of Image Guidance

Part II: Thoracic
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Disclosure
• Dr. Balter is Physics PI on a trial comparing Cyberknife based SBRT with surgery, funded by Accuray
• Dr. Balter is co-PI on a sponsored research agreement with Philips Medical Systems.
• MDACC has a sponsored research agreement with Varian Medical Systems (Dr. Balter is not named on this agreement but Varian equipment is presented in this course)

Outline
• IMRT in the Lung
• Inter-fraction motion of thoracic tumors (4DCT)
• How to treat tumors that move with respiration
• IMRT and tumor motion/Interplay effect
• Thoracic tumor volumes changing with time (the other 4th D)
Are you using IMRT in the lung

A. No
B. Yes for all cases
C. Yes for selective cases

How is IMRT in the lung different from other sites

- All sites
  - Create a conformal dose distribution
- Prostate
  - Create concave dose distributions around avoidance structures
- Head and Neck
  - Multiple targets at different dose levels
- Lung
  - Compensate for different scatter conditions
  - Between the GTV and CTV (between tissue and air)
  - Between center and sides of targets
  - Between medial and lateral sides of targets
  - And the other stuff from prostate and H&N

Example: Small Mass in Lung

Unmodulated field vs IMRT
TomoTherapy study of 5 patients

- Improved tumor coverage
- Reduced dose to all critical structures

Table 1: Summary of the results for total lung V_{10} and V_{20}.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2D x RT</th>
<th>IMRT</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lung V_{10} (cc)</td>
<td>53 (18-86)</td>
<td>54 (31-76)</td>
<td>0.612</td>
</tr>
<tr>
<td>Total lung V_{20} (cc)</td>
<td>49 (22-90)</td>
<td>58 (41-95)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Total lung V_{30} (cc)</td>
<td>19 (10-41)</td>
<td>25 (16-49)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Total lung volume (cc)</td>
<td>86 (40-170)</td>
<td>95 (30-185)</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

IMRT was shown to decrease lung at all levels except V_{30}.
Why you should not use IMRT in Lung

- Interplay effect
  - Step and shoot
  - Sliding Window
  - VMAT (Rapid Arc)
- Geometric Miss
  - Tumor motion
  - Setup uncertainty

Both of these concerns are manageable!

How much do thoracic tumors move?

90% of thoracic tumors move less than 1 cm
50% move less than 5 mm

Assessing respiration-induced tumor motion and internal target volume using four-dimensional computed tomography for radiotherapy of lung cancer.

Standard Treatment

ITV

ITV: Treat track of tumor motion
- Based on a 4-D dataset:
- Explicitly account for tumor motion in delineating ITV
- Optimize the plan based on respiratory motion
Tumor Tracking

Gating
Dynamic: Deliver dose when tumor is within the beam portal
Breath-hold: Deliver the beam when breath is held at a given level

Tumor tracking
Follow the tumor with the beam portal

How is tumor motion accounted for at your clinic

A. Generic Margins
B. Patient specific margins determined from dynamic imaging (ie 4DCT)
C. Gating
D. B or C depending on the patient
E. A, B or C depending on the patient

How does respiration affect dose distributions
Changes in Dose Distribution and DVH vs Respiration

Megavoltage photons are relatively insensitive to local density changes.

Large doses differences occur only when objects move in and out of the dose distribution.

Changes in lung DVH are mainly due to changes in lung volume with respiration.

Changes in other DVHs only occur when objects move in and out of the high dose region.

- Dose distribution remains relatively stable during breathing except where it crosses the diaphragm.
- However, lung volume is increased from expiration to inspiration.

DVH vs Respiratory Phase

The DVH is a function of respiratory phase, but is generally bounded by the Inspiration and Expiration DVH.

The choice of dataset for calculation is less important than using all the data for targeting (but don’t use the MIP for heterogeneity corrections).

MDACC policy:
- Determine the ITV from all datasets (MIP is a useful starting point)
- Transfer the location of the target onto the calculation dataset (average or FB)
  - by CT coordinates if all CTs are from the same imaging session
  - by registering on anatomy that does not move with respiration.
IMRT and the Interplay Effect

Some Publications on Interplay 1998-

PTV coverage is compromised by not CTV - PTV did its job (assuming a portion of PTV was internal margin (IM).
Phantom measurements of sliding window IMRT
- Included Radiobiological effect modeling
- Showed stability at 5 fractions with no effect on TCP

**Treatment of Moving Tumors: An Inter-Modality Comparison Under Realistic Clinical Conditions**

Common conclusions
- Interplay effects can be large for small number of fractions
- Interplay effects cancel out over a large number of fractions
- Interplay effect can be minimized
  - Choosing MLC direction
  - Lowering modulation
  - Lowering dose rate
  - Gating
- Appropriate margins are more important than interplay effect
IGRT, Margins and Localization in the Thorax

IGRT in the thorax

- Reduced margins (or achieve the ones we have been planning with)
- Gating with verification
- Adaptive planning
  - Correct for geometric miss
  - Adapt to changing anatomy

How well are we targeting in the thorax?

Conclusions

- Boney anatomy based setup reduced systematic errors
- Non-isotropic margins
- IGRT still requires appropriate PTV
Adaptive Planning-Thorax

- Many tumors change size and shape during the course of radiotherapy
- Normal anatomy/breathing pattern can change more
- If we do not adapt to these changes
  - We may miss tumor
  - We may overdose normal anatomy
  - We may miss an opportunity to dose escalate
- Thorax: big cavity where tumor, fluid and air can all change places with no external indication
  - Often the goal of radiotherapy is to open airways which then cause changes in internal anatomy

Do you regularly adapt for tumor changes in the thorax

A. No
B. Yes based on scheduled re-simulation (ie resim at 4 weeks) but only for Small Cell
C. Yes based on scheduled re-simulation (ie resim at 4 weeks) for all thoracic cancers
D. Yes based on daily or weekly imaging

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Week 8
• Average reduction of 17%
• 10/25 regressed by > 20%
  • It took 4.5 ± 1 (1 s) week for this to occur

Patients were put in three groups: Partial Response, Marginal Response, or Stable Disease.
No patient treatment, or tumor characteristics were found to be associated with tumor regression.
It is not clear if the CTV shrinks at the same rate as the GTV.
When to adapt the plan

When the anatomy shifts
  - Plan should be changed
  - Isocenter should be moved
  - New reference images need to be establish

When the tumor (GTV) shrinks
  - Does the CTV shrink as well

3DIMRT to 4DIMRT

- IMRT allows dose distributions high conformal to the treatment volume
- IMRT requires appropriate margins
  - Motion
  - Setup
- Changes in anatomy
- If IMRT is adapted without taking these factors into effect it may decrease local control
- Dose escalation possible with IMRT is greater than the dose uncertainty related to interplay
- 4DCT, IMRT, and IGRT have the potential to allow us to create dose distributions highly conformal to the suspected area of disease and with higher dose
  - Without decreasing TCP due to geometric missed
  - Without increasing NTCP due to large margins

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