Image-Guidance for SBRT: Technical Challenges and Pitfalls

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Outline:
• Imaging: through the process
• Margin: GTV → PTV
• Planning and delivery
• Treatment assessment and process management

Acknowledgments
• Colleagues and SBRT Teams at Duke
• Research supports from NIH and Varian Medical Systems

Imaging: 4D CT for Organ Motion

Challenges:
• Poor soft-tissue contrast
• Only produce one breathing cycle
• Correlation between internal target and external surrogates
• Imaging dose ...

4D Imaging: Sorting Types
• Retrospective – sorting same phase or amplitude
• Prospective – image at a specific phase or amplitude
• Phase gated – sorting based on phase
• Amplitude gated – sorting based on amplitude

Imaging: Motion with 4D CT and 4D MRI

4DCT
4DMRI
Single slice cine MRI

How accurate is 4-D CT?
4D Imaging: Retrospective Sorting

Pan et al. Med Phys 2004

4D Imaging: Related Images


Imaging: 4DCT Sorting Artifact

Errors from recorded breathing pattern from surface marker – irregular pattern

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Imaging: Irregular Breathing CBCT

Vergasova et al Med Phys 2011

Imaging: Volumes in Gated CT

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Imaging: Position Effect on Fusion

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**Imaging: Treatment Planning**

Often, we have CTs for lung/liver SBRT:
- FB, 4DTC, AIP, MIP, and BH CT data sets

**Handling of Motion Images**
- For contouring
- For dose calculation
- For localization (prior treat)
- For verification (during treat)
- For assessment (post treat)

**Imaging: CT for Dose Calculation?**

- Free-breathing
- Average intensity projection
- Maximum intensity projection

Yuan Tian et al, Med Phys 2012

**Imaging: CT for Dose Calculation?**

- Average intensity projection
- Maximum intensity projection

Yuan Tian et al, Med Phys 2012

**Imaging: Overall Assessment**

- A spinal SRS/SBRT was imaged three times
  - Prior to correction
  - After correction before treat
  - After treatment

- Factors determining the margin
  - PTV
  - Setup uncertainty
  - Organ motion uncertainty
  - CTV motion trajectories
  - IGRT system errors

RTOG0631

**Imaging: Gated Treatment Volumes**

- MIP GatedPhases
- MIP AllPhases

4DCT

- MIP AllPhases (0%-90%)
- MIP GatedPhases (30%-70%)
- PTV
- CBCT-ITV for online match
- Dose calculation

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**Imaging: Treatment Verification**

- Verification of implanted marker

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**Imaging: Real-time Treat Verification**

- **Implanted marker**
- **Anatomical marker**

**Goal for immobilization**
- Minimize patient motion
- Minimize organ motion
- Comfortable, stable, reproducible, or predictable motion

**Margin: Setup Uncertainty**

<table>
<thead>
<tr>
<th>Margin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing board, arm-up</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>Alpha cradle, arm-up</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Alpha cradle, arm-up</td>
<td>0.3 cm</td>
</tr>
</tbody>
</table>

**Margin: Organ Motion Uncertainty**

- Active breath control:
  - The residual errors of GTV
  - ML: 0.3±1.8 mm
  - AP: 1.2±2.3 mm
  - SI: 1.1±3.5 mm

**Margin: Motion Uncertainty**

- Abdominal Compression
  - Mean motion reduction:
    - 3.5 mm for lower lobe tumors
    - 0.8 mm for upper/middle lobe
  - Sometimes, compression increased tumor motion

**Margin: Volume Uncertainty**

- Total intravenous anesthesia (TIVA)
- High-frequency jet ventilation (HFJV)

**Animal study:**

- Yin et al 2001 IJROBP: 
  "Extracranial radiosurgery: Immobilizing liver motion using high-frequency jet ventilation and total intravenous anesthesia"
Margin: Imaging System Uncertainty

- 3 mm rotation
- 3 mm shift
- Cord dose >20%

Margin: Breathhold Uncertainty

- Breath hold 1
- Breath hold 2
- Breath hold 3

Margin needed ~ 5 mm

Delivery: Smart Choice of VMAT/IMRT

- RapidArc MU = 714
- IMRT Total MU = 1572
- Time: 1.3 min

Delivery: MLC Leaf Width

- Relative Volume (%)
- Relative dose (%)

2.5 mm
5 mm

Delivery: MLC Interplay Effect

- Beam-on timing
- Beam-on @ different points in breathing period

Differences in delivered dose

S Benedict AAPM 2012

Delivery: High Doserate (FFF)

- Doserate ~2400 MU/min
- First 20 FFF treatments analyzed
- Acute toxicities: no x 3
- 10/10 f/t: liver lesions:
  - Hounsfield Unit < 50 HU
  - Toxicity: C2 - C3

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Any biological effect?
Thank you for your attention