Imaging for Planning

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• Cynthia Eccles
• Douglas Moseley
• Tom Purdie
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• M Ghilezan – Beaumont Hospital

Imaging for Treatment Planning

Comprehensive Patient Model

Anatomy

Tumor Location
Tumor Boundary
Normal Tissue

CT
MR
PET

Function & Physiology

Tumor Characteristics
Normal Tissue Function

Dynamics

Tumor Motion
Normal Tissue Motion
Time Scale of Motion

CE 8:30 Today – Ballroom A:
PET
CE 8:30 Tomorrow –
Ballroom B: fMR

Imaging for Treatment Planning
Anatomy

- Multi-modality imaging
  - Reproduce patient set-up
  - Integration: Image Registration
- Reduce/eliminate motion
- Contrast enhancement
- Optimize image resolution & timing

Multi-modality Imaging
Prostate

*Courtesy Cynthia Ménard
**Patient Set-up**

- Reproduce the patient set-up between imaging modalities
- Match the set-up at the treatment unit

**Integration: Image Registration**

- Rigid registration has limitation
- Limit the field of view
  - Contour driven
  - Clip box
- Beware of errors outside of your field of view
Reducing Motion Artifacts

- Abdominal Motion
  - Heart beat
  - Breathing
  - Peristalsis

Reducing Motion: Breathing

- Respiration correlation
- "4D" Imaging
- Breath hold
- Abdominal Compression
**Respiration Correlated**

- Surrogate of breathing motion
  - External (RPM)
  - Internal (image-based aperture)
  - Physical (flow sensor)
- Over-sampling of image space
  - Repeat acquisition of anatomy over the course of breathing period

**Breath Hold**

- Voluntary
- Assisted
  - Monitor breathing cycle
  - Forced breath hold at pre-determined position

- Intra-fx reproducibility of diaphragm
  - End-inh 4.0 mm +/- 3.5 mm
  - End-exh 2.4 mm +/- 2.0 mm
- Mean organ movement relative to bones as studied with repeat nephrograms in 32 patients

<table>
<thead>
<tr>
<th>Structure</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kidney-inh</td>
<td>7.7 mm</td>
</tr>
<tr>
<td>Kidney-exh</td>
<td>4.9 mm</td>
</tr>
</tbody>
</table>

*Kim, IJROBP 49, 2001*
*Kimura T et al., IJROBP 1307, 2004*
*Kuhns, J of Comp Ass Tomography 3(5), 1979*

**Breath Hold**

- Voluntary
- Assisted
  - Monitor breathing cycle
  - Forced breath hold at pre-determined position

<table>
<thead>
<tr>
<th>No. Images</th>
<th>Reprod. (σ)</th>
<th>Inter-fx</th>
<th>Intra-fx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan²</td>
<td>262</td>
<td>4.4 mm</td>
<td>2.5 mm</td>
</tr>
<tr>
<td>Toronto¹</td>
<td>257</td>
<td>3.4 mm</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

- IGRT required for maximal PTV reduction

1) Dawson LA. IJROBP 2001
2) Bristow C. IJROBP 2000
Abdominal Compression

- Mean organ movement as studied with serial CT scans

<table>
<thead>
<tr>
<th>Structure</th>
<th>CC Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no comp.</td>
</tr>
<tr>
<td>Kidney</td>
<td>4 mm</td>
</tr>
<tr>
<td>Liver</td>
<td>10 mm</td>
</tr>
<tr>
<td>Pancreas</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

Suramo, Acta Radiologica Diagnosis 25, 1984

Reducing Motion: Peristalsis

- Peristalsis may decrease with fasting
  - Fasting
  - 15 min after eating

Barbara Wysocka, Princess Margaret Hospital

Reducing Motion: Peristalsis

- Peristalsis may decrease with fasting
  - Fasting
  - 15 min after eating

Barbara Wysocka, Princess Margaret Hospital

Reducing Motion: Rectal Motion

- Full Bladder Prep
  - One hour before the appointment, empty the bladder
  - Drink 500mls of water and do not void until after the appointment

- Empty Rectum Prep
  - Take 2 tablespoons of Milk of Magnesia every night, starting 2-3 days before the appointment
Tumor Definition

- Multi-modality imaging
- Contrast Enhancement
- Optimal Imaging parameters

CT: Importance of Contrast

- Triphasic liver CT in treatment position
  - Omnipaque 300 2cc/kg to a maximum of 200cc
  - Injected 5 cc/sec
  - Arterial Delay (best for hepatoma) 30 sec
  - Venous Delay (best for metastases) 60 sec

Importance of Contrast

- T2w – no contrast
- T1w - gadolinium
Optimizing Imaging Time

• Obtain the entire imaging FOV in 1 Breath hold
  – Reduces repeat breath hold artifacts
  – ~15-30 s imaging time
✓ 64 slice CT
✓ MR w/ Parallel Imaging

Parallel Imaging

• Reduce K space data obtained
  – Interpolate remaining
• Faster imaging time
• Small reduction in image quality
• Beneficial for cine and volumetric (breath hold) imaging

Axial Fast-Spin Gradient Recovery (FSPGR)
(TE/TR 1.6/325 ms, 1 NEX, FOV 34 – 44 cm)
Array Spatial Sensitivity Encoding Techniques (ASSET™)
GE 1.5T MR unit (Excite, 4 channel, GE Medical Systems)
256 x 256 x 34 (0.14 x 0.14 x 0.4 cm resolution), ~30 sec

Dynamics

• Measure motion
  – Periodic motion (breathing)
  – Random motion (bladder/bowel/stomach filling)
• Reduce artifacts

Quantifying Motion

• Fluoroscopy
  – 2D Imaging
  – Limited to high contrast
  – ‘Real-Time’
• 4D CT
• Breath hold CT
• Breath hold MR
• Cine MR
Quantifying Motion

- Fluoroscopy
- 4D CT
  - Multiple 3D datasets
  - Soft tissue contrast
  - May have artifacts due to respiration correlation
- Breath hold CT
- Breath hold MR
- Cine MR

GTV motion in esophageal cancer

- 17 esophageal patients
- 4D CT during normal breathing
- Manual tumor delineation at 0 and 50-60%

KL Wiltshire, R Wong, H Alawi, A Abbas, F Cheung, K Brock, J Ringash & J Brierley CARO 2005

Esophageal movement
Max motion – population AVG, SD [cm]

<table>
<thead>
<tr>
<th></th>
<th>Sup</th>
<th>Inf</th>
<th>Right</th>
<th>Left</th>
<th>Ant</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>(n=2)</td>
<td>(0.0)</td>
<td>(0.1)</td>
<td>(0.1)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>Mid</td>
<td>0.8</td>
<td>0.8</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>(n=4)</td>
<td>(0.3)</td>
<td>(0.4)</td>
<td>(0.2)</td>
<td>(0.1)</td>
<td>(0.1)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>Lower</td>
<td>0.9</td>
<td>1.0</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>(n=12)</td>
<td>(0.7)</td>
<td>(0.6)</td>
<td>(0.2)</td>
<td>(0.2)</td>
<td>(0.3)</td>
<td>(0.4)</td>
</tr>
</tbody>
</table>

Quantifying Motion

- Fluoroscopy
- 4D CT
- Breath hold CT
  - Normal Inhale BH
  - Normal Exhale BH
- Breath hold MR
- Cine MR

5 mm/2.5 mm reconstruction
Pitch 0.75:1
120 kV, 200+ mA
Quantifying Motion

- Fluoroscopy
- 4D CT
- Breath hold CT
- Breath hold MR
  - Normal Inhale BH
  - Normal Exhale BH
- Cine MR

Axial Fast-Spin Gradient Recovery (FSPGR)
(T1/STIR 1.6/325 ms, 1 NEX, FOV 34 – 44 cm)
Array Spatial Sensitivity Encoding Techniques (ASSET)
Scanning time ~30 s, 256 x 256 x N (5 mm slice)

Breathing Motion – Liver Cancer

MR liver tumor motion due to breathing (mm)

<table>
<thead>
<tr>
<th></th>
<th>CC</th>
<th>AP</th>
<th>ML</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>16.1</td>
<td>10.2</td>
<td>7.6</td>
</tr>
<tr>
<td>St Dev</td>
<td>7.4</td>
<td>4.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Min.</td>
<td>7.3</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Max.</td>
<td>35.4</td>
<td>20.6</td>
<td>16.3</td>
</tr>
</tbody>
</table>

Dawson, et al., ESTRO 2004

Differences in Quantified Motion

Difference between Fluoro and MR tumor CC motion

<table>
<thead>
<tr>
<th></th>
<th>All n = 32</th>
<th>Fluoro &gt; MR</th>
<th>Fluoro &lt; MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>7 mm</td>
<td>6 mm</td>
<td>8 mm</td>
</tr>
<tr>
<td>Max</td>
<td>21 mm</td>
<td>18 mm</td>
<td>21 mm</td>
</tr>
<tr>
<td>&gt; 5 mm</td>
<td>48 %</td>
<td>43 %</td>
<td>55 %</td>
</tr>
</tbody>
</table>

Dawson, et al., ESTRO 2004
**Cine MR: Non-Periodic Motion**

- Single Shot FSE images displayed with cine loop.
  - TR/TE=1400-1600/90, FOV 30, Matrix 256x192, NEX 0.5, BW 31.2kHz, slice thickness=5/7mm.
  - Acquiring 3 sagittal slices along axis of uterus and cervix at 3 seconds (1/slice) interval for 1 min with 4 minute rest for a total of 30 min.
  - 20 images/slice/min totaling 360 images over 30 min.

**Cervical Cancer**

- Inter- and Intra-fraction Displacement

<table>
<thead>
<tr>
<th>Time Frame</th>
<th>Fundus Pt.</th>
<th>Cervical Os</th>
<th>Bladder Pt.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>Z</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Inter-</strong> (week-week)</td>
<td>S.D.</td>
<td></td>
<td>S.D.</td>
</tr>
<tr>
<td>Range</td>
<td>2.5</td>
<td></td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>51.3</td>
<td>23.4</td>
</tr>
<tr>
<td><strong>Intra-</strong> (within a 30 minute interval)</td>
<td>S.D.</td>
<td></td>
<td>S.D.</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>3.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>

(All results in mm, exclude setup errors)
Probability of Prostate Motion with Time

- Increases with full rectum

Full rectum

Empty rectum

Ghilezan, et al. IJROBP 62 (2), 406, 2005

Prostate Motion - Bowel Routine

<table>
<thead>
<tr>
<th></th>
<th>No laxative</th>
<th>Laxative used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum</strong></td>
<td>MR 1</td>
<td>MR 2 - CT</td>
</tr>
<tr>
<td></td>
<td>16.6 mm</td>
<td>6.9 mm</td>
</tr>
<tr>
<td>Probability of &gt; 3 mm displacement</td>
<td>9.8% (p = 0.30)</td>
<td>5.7% (p = 0.13)</td>
</tr>
</tbody>
</table>

* Previous investigation report probabilities of 20%.

No laxative Laxative used

Prostate and Pelvic Skeletal Breathing Motion

- Contrast agents/timing
- Respiration correlation
  – more than CT
- Parallel imaging
  – Faster and Faster Imaging @ ‘no’ expense
- Multiple slices
  – Faster and Faster Imaging
- Functional imaging
- Correlating Multi-Modality Imaging

Dawson, et al. IJROBP. 2000
Malone et al Rad Onc 2000
Summary

- Optimizing Imaging for Treatment Planning
  - Remove motion for tumor definition
  - Quantify physiological motion
  - Acquire data as fast as possible
  - Optimize contrast agents
  - Obtain information on organ function

Summary

- Remove motion for tumor definition
  - Breath hold (voluntary, assisted)
  - Respiration Correlated
  - Compression
  - Dietary guidelines
- Quantify physiological motion
  - 4D Imaging
  - Breath hold at normal inhale/exhale
  - 2D cine data
  - Fluoroscopy

Summary

- Acquire data as fast as possible
  - Multi-slice Acquisition (CT)
  - Parallel Imaging (MR)
- Optimize contrast agents
  - Correlate timing with imaging goals
- Obtain information on organ function
  - PET/SPECT/ICT/fMR