Motion Management in Liver SABR

Kausik Bhattacharya
How to reduce ITV

GTV: gross tumor volume, defined as visible tumor volume in images

CTV: clinical target volume, defined as GTV + subclinical/invisible invasion

ITV: internal target volume, defined as CTV + IM (internal margin for organ motion)

PTV: planning target volume, defined as ITV + SM (setup margin for setup error)
Segments of liver
Liver moves with Respiration

- Asymmetric
- Non reproducible
- Individual variation
- Deformation
- Hysteresis
MOVEMENT OF LIVER

- Measured by
  - Fluoroscopy
  - 4D CT
  - Cine MRI

- Influenced by
  - Ascites
  - Stomach filling
  - Abdominal gas
MOVEMENT OF LIVER

Table 1

Movement of organs in respiration examined by ultrasound. Mean and range

<table>
<thead>
<tr>
<th>Organ</th>
<th>Excursion</th>
<th>Maxium respiration (cm)</th>
<th>Normal respiration (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>5.5 (3-8)</td>
<td>2.5 (1-4)</td>
<td></td>
</tr>
<tr>
<td>Pancreas</td>
<td>4.3 (2-8)</td>
<td>2.0 (1-3)</td>
<td></td>
</tr>
<tr>
<td>Right kidney</td>
<td>4.0 (2-7)</td>
<td>1.9 (1-4)</td>
<td></td>
</tr>
<tr>
<td>Left kidney</td>
<td>4.1 (2-7)</td>
<td>1.9 (1-4)</td>
<td></td>
</tr>
</tbody>
</table>
MOVEMENT OF LIVER

Table 2: Amplitudes of respiration-induced liver motion of each liver segment during expiration period in free breathing

<table>
<thead>
<tr>
<th>Segment</th>
<th>Average amplitude ± SD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LR</td>
</tr>
<tr>
<td>S1</td>
<td>20  ± 2.6</td>
</tr>
<tr>
<td>S2</td>
<td>0.3 ± 2.2</td>
</tr>
<tr>
<td>S3</td>
<td>0.3 ± 1.9</td>
</tr>
<tr>
<td>S4a</td>
<td>1.4 ± 3.3</td>
</tr>
<tr>
<td>S4b</td>
<td>1.2 ± 1.6</td>
</tr>
<tr>
<td>S5</td>
<td>0.2 ± 2.1</td>
</tr>
<tr>
<td>S6</td>
<td>0.1 ± 4.6</td>
</tr>
<tr>
<td>S7</td>
<td>1.4 ± 3.8</td>
</tr>
<tr>
<td>S8</td>
<td>1.0 ± 2.6</td>
</tr>
</tbody>
</table>

Positive values denote excursion in the left, posterior, or superior directions; Negative values, right, anterior, or inferior
Abbreviations: LR left-right, AP anterior-posterior, SI superior-inferior, SD standard deviation
Why manage motion

- Right Target
- Right Dose
Strategies to Manage Motion

• 1. Reduce Motion
• 2. Follow the Motion
AAPM TG 76

- DIBH (DEBH)
- Active Breath Control
- Self breath-hold
- Shallow Breathing
- Abdominal Compression
- Tumour Tracking
  - Fiducial
  - IR Surrogate
  - RF device
UK SABR Guidelines

• Reducing
  • Compression
  • ABC
  • Voluntary/ Coached Breath-holding

• Mitigating
  • Passive Gating
  • Fiducial tracking
  • Unrestrained Respiration
    • ITV
    • 4DCT
Passive vs Active
ITV Approach

- Inspiration phase CT
- Expiration phase CT
- Free breathing
- Fuse image sets
- Combine all phases
- *Poor man’s 4DCT*
- Best for Lungs
- Time for scan is a concern in Liver
Table 2: Amplitudes of respiration-induced liver motion of each liver segment during expiration period in free breathing

<table>
<thead>
<tr>
<th>Segment</th>
<th>Average amplitude ± SD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LR</td>
</tr>
<tr>
<td>S1</td>
<td>-2.0 ± 2.6</td>
</tr>
<tr>
<td>S2</td>
<td>0.3 ± 2.2</td>
</tr>
<tr>
<td>S3</td>
<td>-0.3 ± 1.9</td>
</tr>
<tr>
<td>S4a</td>
<td>-1.4 ± 3.3</td>
</tr>
<tr>
<td>S4b</td>
<td>-1.2 ± 1.6</td>
</tr>
<tr>
<td>S5</td>
<td>-0.2 ± 2.1</td>
</tr>
<tr>
<td>S6</td>
<td>-0.1 ± 4.6</td>
</tr>
<tr>
<td>S7</td>
<td>-1.4 ± 3.8</td>
</tr>
<tr>
<td>S8</td>
<td>1.0 ± 2.6</td>
</tr>
<tr>
<td>mean</td>
<td>-0.6 ± 3.0</td>
</tr>
</tbody>
</table>

Positive values denote excursion in the left, posterior, or superior directions; Negative values, right, anterior, or inferior

Abbreviations: LR left-right, AP anterior-posterior, SI superior-inferior, SD standard deviation

Typical ITV

Segment | ITV margin (mm)  
(to cover more than 95% of each tumor)

<table>
<thead>
<tr>
<th></th>
<th>LR</th>
<th>AP</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>-2.2 and 2.3</td>
<td>-0.4 and 2.3</td>
<td>-4.4 and 4.7</td>
</tr>
<tr>
<td>S2</td>
<td>-2.3 and 0.5</td>
<td>-2.4 and 1.6</td>
<td>-4.7 and 5.9</td>
</tr>
<tr>
<td>S3</td>
<td>-2.2 and 1.1</td>
<td>-3.3 and 2.1</td>
<td>-4.6 and 4.1</td>
</tr>
<tr>
<td>S4a</td>
<td>-1.8 and 1.8</td>
<td>-2.4 and 1.3</td>
<td>-2.4 and 4.0</td>
</tr>
<tr>
<td>S4b</td>
<td>-2.6 and 0.3</td>
<td>-2.8 and 1.4</td>
<td>-4.1 and 4.5</td>
</tr>
<tr>
<td>S5</td>
<td>-3.0 and 0.0</td>
<td>-2.4 and 2.9</td>
<td>-3.0 and 4.7</td>
</tr>
<tr>
<td>S6</td>
<td>-1.9 and 2.3</td>
<td>-2.3 and 2.1</td>
<td>-4.6 and 5.1</td>
</tr>
<tr>
<td>S7</td>
<td>-2.4 and 2.3</td>
<td>-3.1 and 2.8</td>
<td>-5.7 and 7.3</td>
</tr>
<tr>
<td>S8</td>
<td>-3.4 and 0.0</td>
<td>-2.8 and 3.0</td>
<td>-3.5 and 4.7</td>
</tr>
<tr>
<td>mean</td>
<td>-2.5 and 1.2</td>
<td>-2.5 and 2.2</td>
<td>-4.2 and 5.0</td>
</tr>
</tbody>
</table>
Surrogate Structure Matching

Liver Dome

IVC
Abdominal Compression

- Forced shallow respiration
- Reduces diaphragmatic motion significantly
- Mechanical
- Pneumatic
- Can be used with conjunction with 4DCT/gating
Abdominal Compression

- Discomfort
  - Obese
  - Ascites
- Reproducibility issues
- Significant deformity of internal organs
DIBH/DEBH

- Patient is coached to hold breath in comfortable position
- 20-30 seconds
- IR marker and IR camera
- Respiratory graph is generated
- Planning CT → Planning
- In treatment room same position is reproduced
- Beam is on only when graph is in the threshold
## DIBH VS DEBH

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>DIBH</th>
<th>DEBH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AP</td>
<td>SI</td>
</tr>
<tr>
<td>Random</td>
<td>2.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Systematic</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Mean of means</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>PTV margin</td>
<td><strong>5.7</strong></td>
<td><strong>6.3</strong></td>
</tr>
</tbody>
</table>

**Abbreviations:** AP = anterior–posterior; DEBH = deep expiration breath hold; DIBH = deep inspiration breath hold; PTV = planning target volume; RL = right–left; SI = superior–inferior.
Active Breathing Coordinator

- Simple
- Reproducible
- Cheap
- Beam On/OFF
- Very small ITV
- ‘quasi’ invasive
- Patient cooperation
Active Breathing Coordinator
Respiratory Gating (RPM)

- Infrared surrogate
- Implanted Fiducial (BrainLab)
- Implanted RFID/EM (Calypso)
- Generates a respiratory graph
Respiratory Gating (RPM)

- Define Threshold
- ITV correlates to threshold
- Track the motion on machine
- Beam is automatically switched on/off
- Comfortable
- Small ITV (with Abdominal Compression)
4D CT Acquisition

Gross Tumor Volume (GTV) defined by Conventional CT (Free Breathing)

Internal Target Volume (ITV) defined by 4 dimensional CT (10 Phases Combined)
4D CT in Liver - challenges

• Lesions are best seen in late arterial/ early venous phase
• 4DCT takes a long time to acquire
• Image quality (MnIP/AvG) is not good for marking the target
Dual 4DCT

- 2 sets of 4DCT
- Short CT - only area OF INTEREST
- Long CBCT - all OARs
- Mark in Short 4DCT
- Fuse with Long 4DCT
- Plan on Long 4DCT
Cyberkife: Synchrony & Fiducial
Fiducial Tracking (Synchrony - Cyberknife)

- Translational error 2-3 mm
- Rotational error not correctable in most cases
- 4 - 5 mm margin would suffice in 95% cases
Surface Guidance

- Uses body surface as surrogate for motion
- Produces respiratory graphs
- Can be used for
  - DIBH/DEBH
  - Gating
- Integrated with
  - IGRT Couch movement
  - Beam On/Off
Comparison of Different Techniques

- Abdominal Compression
- Voluntary Breath-hold
- Shallow Breathing
- DEBH, DIBH
- RPM Gating
- Tumor Tracking
- Fiducial Tracking
- 4DCT
- ITV Approach

<table>
<thead>
<tr>
<th>Method of RMC</th>
<th>Respiratory status</th>
<th>Timing of beam-on</th>
<th>Time-efficiency</th>
<th>Internal margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppress</td>
<td>~ ~ ~</td>
<td>~ ~ ~</td>
<td>good</td>
<td>large</td>
</tr>
<tr>
<td>Breath-hold</td>
<td>~ ~ ~ ~ ~</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>bad</td>
<td>small</td>
</tr>
<tr>
<td>Gating</td>
<td>~ ~ ~ ~ ~ ~ ~</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>bad</td>
<td>medium</td>
</tr>
<tr>
<td>Tracking</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>good</td>
<td>small</td>
</tr>
<tr>
<td>Free Breathing</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>~ ~ ~ ~ ~ ~ ~ ~ ~</td>
<td>good</td>
<td>large</td>
</tr>
</tbody>
</table>
your eyes cannot see what your mind doesn’t know
one size does not fit all
horses for courses