Respiratory motion mitigation during radiation treatment delivery

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Types of respiratory motion management

- Abdominal compression
- Breath hold
- Respiratory gating
- Real-time motion tracking
- All the above methods in addition require image guidance for interfraction management

Abdominal compression

- Pressure device pushes down on upper abdomen
- Limits diaphragm excursion
- Most widely used motion management technique in clinical SBRT experience

Abdominal Compression

Advantages:
- Technologically simple
- Allows continuous dose delivery

Disadvantages:
- Variably successful in reducing target motion
- Uncomfortable at times

(Slide courtesy Michael Lovelock, MSKCC)
Abdominal Compression – Studies

• Heinzerling IJROBP 2008: lower lung & liver tumors, med/high AC, RCCT, n=10
• Eccles IJROBP 2011: liver tumors, cine MR, n=60
• Han RO 2010: lung tumors, RCCT, n=24

Which of the following statements about abdominal compression is true?

0% 1. It works by limiting chest wall expansion
0% 2. It eliminates almost all target motion
0% 3. It requires connection to the linac
0% 4. There is little or no discomfort
0% 5. It allows for continuous dose delivery

Breath hold methods

Advantages:
• Exploits physiological immobilization to minimize motion
• Deep or moderately deep breath hold exploits lung inflation to spare nearby normal tissues

Limitations:
• Requires patient cooperation; not all patients can perform
• Requires staff effort to train patients and coach them in a consistent manner

ANS: 5. It allows for continuous dose delivery

REFs:
Verification of breath hold

Spirometry:

Video tracking:

Video feedback guided BH

Breath hold – components of a patient-specific QA program

- Patient screening and training
- Evaluation of reproducibility between BH, stability during BH
- Imaging to check organ position constancy at simulation & treatment
- Assess adequacy of treatment margins to account for inter- and intra-fractional BH variation

Intrafraction BH repeatability

<table>
<thead>
<tr>
<th>Study</th>
<th>Site, #patients, measurement</th>
<th>Repeatability (1SD, SI,mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanley 1999</td>
<td>Lung, n=9, diaphragm</td>
<td>0.9</td>
</tr>
<tr>
<td>Remouchamps 2003</td>
<td>Breast, n=14, lung surface</td>
<td>1.1</td>
</tr>
<tr>
<td>Dawson 2001</td>
<td>Liver, n=8, diaphragm/microcoils</td>
<td>2.5</td>
</tr>
<tr>
<td>Eccles 2006</td>
<td>Liver, n=21, diaphragm/liver</td>
<td>1.5</td>
</tr>
<tr>
<td>Koshani 2006</td>
<td>Lung, n=10, GTV</td>
<td>1.4</td>
</tr>
<tr>
<td>Hurst 2010</td>
<td>Lung, n=9, GTV</td>
<td>mean &lt;2 mm</td>
</tr>
<tr>
<td>Nakamura 2010</td>
<td>Pancreas, n=10, GTV</td>
<td>1.0</td>
</tr>
<tr>
<td>Peng 2011</td>
<td>Lung, n=13, GTV</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Intrafraction variation larger: requires image guidance

The following items should be part of patient-specific QA when using breath-hold EXCEPT

0% 1. Patient screening and training
0% 2. Compare performance of BH & gating
0% 3. Repeatability of breath hold
0% 4. Imaging check of organ positions
0% 5. Check adequacy of treatment margins
The following items should be part of patient-specific QA when using breath-hold EXCEPT

1. Patient screening and training
2. Compare performance of BH & gating
3. Repeatability of breath hold
4. Imaging check of organ positions
5. Check adequacy of treatment margins

ANS: 2.

**RESERVED**

REFs:

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**Respiratory gating**

- Intermittent delivery of radiation occurring within a portion of breathing cycle (gate)
- Gate onset/duration determined by resp. monitoring, either external signal or internal fiducial markers
- Usually gate set around end expiration: tumor motion ↓
- In some apps, gate set at enhanced inspiration with coached deep breathing: normal tissue sparing ↑

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**Advantages:**

- Patient cooperation easier than BH
- 2-5x longer treatment time
- Residual tumor motion: trade-off with beam duty cycle (20-50%)
- Drift of external resp. signal wrt gating thresholds
- Variations in time shift between external signal & tumor motion

**Limitations:**

- Residual tumor motion: trade-off with beam duty cycle (20-50%)
- Drift of external resp. signal wrt gating thresholds
- Variations in time shift between external signal & tumor motion

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**Simulation**

**Treatment**

(Reedmond IROBP 2009)

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**Gating: residual intra-fx motion**

<table>
<thead>
<tr>
<th>Study</th>
<th>Monitor</th>
<th>Site, #patients, measurement</th>
<th>Residual (1SD, St, mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shimizu 2001</td>
<td>Internal</td>
<td>Lung, n=4, implanted fiducial</td>
<td>&lt;5.3 all directions</td>
</tr>
<tr>
<td>Wurm 2006</td>
<td>External</td>
<td>Lung/liver, n=6, implanted fiducial</td>
<td>1.5±0.7 to 4.3±2.0 (Mean±SD)</td>
</tr>
<tr>
<td>Briere 2009</td>
<td>External</td>
<td>Liver, n=5, implanted fiducial</td>
<td>2.0 inter-fx 1.0 intra-fx</td>
</tr>
</tbody>
</table>
Imaging with internal markers

Accuracy via marker localization limited by
• Marker migration
• Tumor & OAR motion relative to markers
• SD discrepancies between liver centroid & marker 2.5 mm (Kitamura 2002)
• Markers near peripheral lung tumors: accurate within ±2 mm in first 1-2 weeks, relationship can change after 2 weeks (Shirato 2007)

Motion tracking

• Refers to continuous adjustment of radiation beam or patient position to follow the changing position of the target or its surrogate
• A means of localizing the target in real-time is coupled to a target alignment control system

Motion tracking – Methods of target localization

• Direct methods detect implanted fiducial or anatomical landmarks, using
  – X-ray radiographs, MRI, US, electromagnetic
• Indirect methods monitor external motion & infer target position, using
  – Optical patient surface, respiratory belt, airflow
• Indirect usually combined with imaging to establish internal/external correlation

Motion tracking – Methods of target alignment

• Linac attached to robotic arm
• Gimbaled linac
• Multileaf collimator
• Magnetic deflection of particle beam
• Treatment couch translations
Accuracy of external/internal correlation models

- Cyberknife: correlates external optical signal with imaging of internal fiducials every 30-60 s
- Correlation may fail with irregular breathing, baseline drift, or large target rotation
- Analysis of tx log files, n=44 (Hoogeman 2009):

Methods of target realignment for motion tracking include all of the following EXCEPT

0% 1. Treatment couch translation
0% 2. Linac attached to robotic arm
0% 3. Magnetic deflection of particle beam
0% 4. X-ray imaging
0% 5. Multileaf collimator

ANS: 4. X-ray imaging

REF:

Summary: residual intrafraction errors
Resp. motion, deviation from planned position, SI direction

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>SD uncertainty before mitigation (mm)</th>
<th>Mitigation strategy</th>
<th>SD uncertainty after mitigation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung/liver tumor intrafraction motion</td>
<td>5 (range 3 – 8)</td>
<td>Abdominal compression</td>
<td>3 (range 2 – 4)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Active breath hold</td>
<td>2 (range 1 – 3)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Voluntary breath hold</td>
<td>2 (range 1 – 3)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Gating with internal fiducials</td>
<td>2 (range 1 – 3)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Gating with external fiducials</td>
<td>3 (range 2 – 4)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Real-time motion tracking</td>
<td>2</td>
</tr>
</tbody>
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