Clinical Implementation of MR-based motion management

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Session Program: Therapy Education

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Disclosures

- Henry Ford Health Systems hold a research agreement with Philips Healthcare
- Equipment evaluation agreement with Medspira
- If you see Mickey Mouse, pay attention
AAPM TG-76 Recommendation:
Manage patient-specific motion for tumor excursion > 5 mm in any direction
Patient-specific, multi-dimensional
Clinically available MRI options

- **Triggering**: EE from external surrogate
- **Internal navigator**: EE from internal surrogate (typically liver/lung interface)
- **Breath-hold (BH)**: can get you EE/EI, BUT...
  - Often deep inspiration/exhalation (not natural)
  - MRI scan times >>>>>CT scan times → many BHs for patients
- **We need a clinically useable solution to properly determine the 3D target volume**
MRI Cine Imaging

- Single slice acquisition
  - Axial, sagittal, coronal
- Can interleave but they are still not acquired at the exact same time
- High temporal resolution (~1-10 fps)
- Can image over many breathing cycles
- Typically not susceptible to motion artifacts
- Yield overall excursion, but not out of plane motion
**Cine-MRI liver motion**

- Axial/sagittal/coronal
- 5 mm thick T2-W
- 1 fps over 60 s
- Resolution: 1.6-2.5 mm

**Median motion**
- CC: 13.3 mm
- AP: 9.2 mm
- ML: 6.9 mm

Cine-MRI pancreas motion

- Sagittal & coronal
- 7 mm thick T2-W, 2 fps over 60 s
- In-plane resolution: 1.5-2.0 mm

- Coronal plane angulated so primary motion positioned in scan plane
- Removed outliers w/95%

Other Limitations: State of the Art

- MR-compatible equipment
- Similar to 4DCT: external surrogates
- Internal navigators being evaluated
  - No current correlation to clinically available 4DCT
- Subject to sorting artifacts
- MRI scan time >> CT scan time
- Currently evaluating 4DMRI for clinical use
4DMRI Acquisition

- Single shot T2W-TSE 2DMS
- Prospective amplitude-based triggering
  - External surrogate (air-filled cushion)
  - Acquires images at specific phases
- Implementing on 1.0T Open Magnet

Clinical Questions

- How many 4DMRI phases do we need?
- Is the algorithm reproducible & robust?
- Is it efficient enough for the clinic, and if not, how can we improve the efficiency?
Initial Evaluation: Equipment

In-house Lego™ Phantom  
QUASAR™ MRI-Compatible Respiratory Motion Phantom

We needed to develop MATLAB software to make AVG, MIP, MinIP datasets.

- 2, 4 phases may underestimate volume
- Acquisition time increases with:
  - Increased phases
  - Slower breathing rates
  - Irregular breathing patterns
- 8 phase: best trade-offs for acquisition time, temporal resolution, and volume assessment
Reproducible, 8 phases, ~8 minutes
Incorporating Visual Feedback (VF)

- Efficiency & regularity evaluation in 10 volunteers with and without VF
### Results: Scan Efficiency

**Scan Time (VF vs. FB)**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Scan Time (min) Visual Feedback</th>
<th>Scan Time (min) Unguided Free Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.07</td>
<td>10.24</td>
</tr>
<tr>
<td>2</td>
<td>6.90</td>
<td>8.56</td>
</tr>
<tr>
<td>3</td>
<td>7.43</td>
<td>9.36</td>
</tr>
<tr>
<td>4</td>
<td>8.50</td>
<td>10.24</td>
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<tr>
<td>5</td>
<td>7.43</td>
<td>9.36</td>
</tr>
<tr>
<td>6</td>
<td>7.43</td>
<td>9.36</td>
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<tr>
<td>7</td>
<td>7.43</td>
<td>9.36</td>
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<tr>
<td>8</td>
<td>7.43</td>
<td>9.36</td>
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<tr>
<td>9</td>
<td>7.43</td>
<td>9.36</td>
</tr>
<tr>
<td>10</td>
<td>7.43</td>
<td>9.36</td>
</tr>
</tbody>
</table>

Visual Feedback: Average = 7.43 min, Standard Deviation = 1.99 min

Unguided Free Breathing: Average = 9.36 min, Standard Deviation = 2.77 min

Duty Cycle improved by 27±22%
Results: Regularity

Regularity (VF vs. FB)

<table>
<thead>
<tr>
<th>Subject</th>
<th>EI-COV (A.U.)</th>
<th>Visual Feedback</th>
<th>Unguided Free Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>4</td>
<td>0.25</td>
<td>0.2</td>
<td>0.4</td>
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<tr>
<td>5</td>
<td>0.3</td>
<td>0.25</td>
<td>0.45</td>
</tr>
<tr>
<td>6</td>
<td>0.35</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>0.4</td>
<td>0.35</td>
<td>0.55</td>
</tr>
<tr>
<td>8</td>
<td>0.45</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>9</td>
<td>0.5</td>
<td>0.45</td>
<td>0.65</td>
</tr>
<tr>
<td>10</td>
<td>0.55</td>
<td>0.5</td>
<td>0.7</td>
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</tbody>
</table>

EI-COV reduced by 40±25%

Visual Feedback

Unguided Free Breathing

EI-COV (%)

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard Deviation</th>
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<tbody>
<tr>
<td>VF</td>
<td>8.2</td>
<td>4.3</td>
</tr>
<tr>
<td>FB</td>
<td>14.8</td>
<td>8.9</td>
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</tbody>
</table>
EI COV = 6.7%  Visual Feedback

225 s

EI COV = 17.3%  Unguided Free Breathing
**EI COV = 6.1%**  
Unguided Free Breathing

**EI COV = 7.2%**  
Visual Feedback
CAUTION: Liver excursion increased with VF

- Centroid to centroid analysis to extract liver excursion
- Will require integration throughout the clinical workflow

<table>
<thead>
<tr>
<th></th>
<th>Average Liver Excursion (mm) (Range)</th>
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<tbody>
<tr>
<td></td>
<td>S-I</td>
</tr>
<tr>
<td>VF</td>
<td>13.7 ± 5.4 (8.3-20.6)</td>
</tr>
<tr>
<td>FB</td>
<td>12.4 ± 5.6 (6.8-24.1)</td>
</tr>
<tr>
<td></td>
<td>A-P</td>
</tr>
<tr>
<td>VF</td>
<td>4.6 ± 1.9 (1.5-8.2)</td>
</tr>
<tr>
<td>FB</td>
<td>3.8 ± 2.2 (1.2-7.8)</td>
</tr>
<tr>
<td></td>
<td>L-R</td>
</tr>
<tr>
<td>VF</td>
<td>1.3 ± 1.1 (0.1-3.1)</td>
</tr>
<tr>
<td>FB</td>
<td>1.2 ± 1.3 (0-3.7)</td>
</tr>
</tbody>
</table>
Patient 4DMRI

- Good image quality
- ~7 minutes
- Tagging acceptable
Remaining Challenges

- Much like 4DCT, 4DMRI requires patient-specific assessment for candidacy
- Patients with irregular breathing patterns may require audio/visual coaching
- Efforts to improve acquisition efficiency are desirable
Ways to improve efficiency

- Use higher field strengths: increase SNR/CNR
- Parallel imaging: reduce data in phase-encode direction
  - Decreases acquisition time 2-3X via combined signal from several coil arrays
- Compressed sensing (undersampling)
- Interleaving planar cine sequences
  - Not acquired at same instance but improves robustness compared to sequential acquisitions
Oh boy! Get out your clickers!
Which technique is most appropriate for assessment of liver cancer motion?

1. 4DCT (5%)
2. Axial plane cine-MRI images (8%)
3. Coronal plane cine-MRI images (44%)
4. 4DMRI (43%)
5. Fluoroscopy (1%)
Answer 4: 4DMRI

- Adequate liver tumor motion requires soft tissue characterization in all three dimensions, which is possible with 4DMRI.
- Single plane cine images will not allow for out-of-plane motion assessment.

What is an advantage of cine MRI?

1. Multi-planar acquisition (20%)
2. No sorting artifacts (52%)
3. Can measure out of plane motion (19%)
4. Slow acquisition frame rate (4%)
5. Requires a breathing waveform (5%)
Answer: 2

- Cine images do not require a breathing waveform and thus will not be susceptible to sorting artifacts.

References:


Prospective 4DMRI acquisition efficiency is decreased by:

1. Irregular breathing patterns (78%)
2. Applying compressed sensing (1%)
3. Faster respiratory rate (8%)
4. Incorporating visual feedback (9%)
5. Using higher field strength MRIs (4%)
Because prospective 4DMRI triggers off of the respiratory waveform, irregular breathing decreases acquisition efficiency.

References:
Thank you!