THE EFFECTS OF MOTION COMPENSATED ENCODING WAVEFORMS IN CARDIAC DIFFUSION TENSOR IMAGING: A MOVING PHANTOM STUDY

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DECLARATION OF FINANCIAL INTERESTS OR RELATIONSHIPS

SPEAKER: Tyler Cork

I have no financial interests or relationships to disclose with regards to the subject matter of this presentation.
Spin Echo DTI

- 1 heartbeat
- Small diffusion time
- Large diffusion gradients
- Feasible and reliable approach

Clinical Applications

- Hypertrophic cardiomyopathy
- Myocardial infarct characterization
- Characterization of fibrosis
- Acute myocarditis
- Idiopathic dilated cardiomyopathy
Spin Echo DTI

- 1 heartbeat
- Small diffusion time
- Large diffusion gradients
- Feasible and reliable approach

Clinical Applications

- Hypertrophic cardiomyopathy [1-3]
- Chronic myocardial infarction [4]
- Acute myocardial infarction [5]
Types of Cardiac Motion

• In-plane motion
  ▪ Intra-voxel dephasing
  ▪ Tissue deformation

Accounting for Motion in cDTI

• Motion compensation gradient waveforms [6-9]
  ▪ Position Compensated: $M_0$
  ▪ Velocity Compensated: $M_1$
  ▪ Acceleration Compensated: $M_2$

In-Plane Motion
Types of Cardiac Motion

- In-plane motion
  - Intra-voxel dephasing
  - Tissue deformation
- Through-plane motion
  - Slice movement

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- Motion compensation gradient waveforms [6-9]
  - Position Compensated: \( M_0 \)
  - Velocity Compensated: \( M_1 \)
  - Acceleration Compensated: \( M_2 \)
Evaluate the effects of through-plane motion for various motion compensated diffusion encoding strategies.
Experimental Set Up

Phantom Setup

• Structured isotropic agar phantom

Through-Plane Experimental Set up
**Experimental Set Up**

**Phantom Setup**
- Structured isotropic agar phantom

**Programable Linear Motion Stage**
- Stationary acquisition
- \[ y = 5 \text{ mm} \cdot \sin\left(\frac{2\pi \cdot t}{1000 \text{ ms}}\right) \]
  - 10 mm peak-to-peak displacement
  - 1000 ms R-R interval
- 8 time points with programmed motion
  - 125 ms delays between each timepoint

<table>
<thead>
<tr>
<th>Timepoint (ms)</th>
<th>Position (mm)</th>
<th>Velocity (mm/s)</th>
<th>Acceleration (mm/s/s)</th>
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</thead>
<tbody>
<tr>
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<td>0</td>
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<td>0</td>
<td>-31.4</td>
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</tr>
<tr>
<td>625</td>
<td>-3.5</td>
<td>-22.2</td>
<td>139.6</td>
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<tr>
<td>750</td>
<td>-5.0</td>
<td>0</td>
<td>197.4</td>
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<tr>
<td>875</td>
<td>-3.5</td>
<td>22.2</td>
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<tr>
<td>1000</td>
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Imaging Parameters

• Hardware
  ▪ 3T Siemens Skyra
  ▪ 32 channel chest and spine coil
Experimental Set Up

Imaging Parameters

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• Spin-echo EPI DTI
  - b-values: 0 s/mm^2 and 350 s/mm^2
  - Number of diffusion directions: 6
  - Voxel resolution: 2.0 x 2.0 x 5.0 mm^3
  - Number of averages: 5
  - Full Fourier k-space acquisition
  - TR: 1000 ms

Sequence Synchronization schemes

a) 90° excitation pulses synchronized

b) 180° refocusing pulses synchronized

c) TE synchronized
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  - TE of motion encoding schemes:
    - Position moment nulling (M₀): 82 ms
    - Velocity moment nulling (M₁): 115 ms
    - Acceleration moment nulling (M₂): 112 ms
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  - Sequence Synchronization schemes
    - a) 90° excitation pulses synchronized
    - b) 180° refocusing pulses synchronized
    - c) TE synchronized
RESULTS

Mean Diffusivity: 90° Excitation Pulses Synchronized

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<th>Static</th>
<th>125 ms</th>
<th>250 ms</th>
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<tbody>
<tr>
<td>$M_0$</td>
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<td></td>
<td></td>
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<tr>
<td>$M_1$</td>
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<tr>
<td>$M_2$</td>
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RESULTS

90° Excitation Pulses Synchronized

Mean Diffusivity (μm²/ms)
RESULTS

Mean Diffusivity: 180° Refocusing Pulses Synchronized

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<tbody>
<tr>
<td>(M_0)</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
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<td>(M_1)</td>
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<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
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<tr>
<td>(M_2)</td>
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<td><img src="image21" alt="Image" /></td>
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<td><img src="image23" alt="Image" /></td>
<td><img src="image24" alt="Image" /></td>
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RESULTS

180° Refocusing Pulses Synchronized

Mean Diffusivity, \( \mu \) (\( \text{mm}^2/\text{ms} \))

- Static
- 125 ms
- 250 ms
- 375 ms
- 500 ms
- 625 ms
- 750 ms
- 875 ms
- 1000 ms

Sequence

\( M_0 \)

\( M_1 \)

\( M_2 \)
**RESULTS**

Mean Diffusivity: TE Synchronized

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TE Synchronized
CONCLUSION

Main Findings:
1. Design through-plane experiments with a focal point on the refocusing pulse when comparing different encoding strategies
2. Crushers appear to make the $M_1$ encoding strategy more robust to through-plane motion

Limitations:
• The $M_0$ and $M_2$ sequences did not contain crushers around the refocusing pulse
• The phantom only provided bulk through-plane motion, while the heart is still subject to potential intra-voxel dephasing

Future Work:
• Incorporate crushers on $M_0$ and $M_2$ sequences to verify our first main finding
• Incorporate an in-plane experiment to further characterize the effects of motion encoding waveforms
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Acknowledgements:
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