Reducing T2-related bias in mq-BOLD derived maps of Oxygen Extraction Fraction by 3D acquisition

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Room: Exhibition Hall
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Date: Wednesday, June 20, 2018

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I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.
Reducing $T_2$-bias in mq-BOLD imaging

**Motivation**

**Background**
- Oxygen extraction fraction (OEF) is a fundamental marker of brain function.
- Relative OEF (rOEF) can be measured by multiparametric quantitative BOLD (mq-BOLD) with 3 separate measurements of $T_2$, $T_2^*$ & rCBV.
- mq-BOLD was successfully applied in stroke, tumor and cerebrovascular disease.

**Issue**
- However, rOEF values systematically elevated.

**Hypothesis**
- rOEF elevations caused by $T_2$ elevations.
- rOEF elevations can be reduced by 3D GraSE $T_2$ acquisition.

Material & Methods

Multi-parametric quantitative BOLD (mq-BOLD)

Model vasculature by randomly oriented cylinders with infinite length

Estimate deoxygenated blood volume by total relative cerebral blood volume

\[ rOEF = \frac{R_2'}{c \cdot rCBV} \quad \text{with} \quad R_2' = \frac{1}{T_2^*} - \frac{1}{T_2} \]

rCBV: relative cerebral blood volume

\[ c = \frac{4}{3} \gamma \cdot \pi \cdot \Delta \chi \cdot B_0 = 317 \text{ Hz @3T} \]

Material & Methods

Participants

1. Phantom

2. Young healthy controls (YHC)

3. Elderly healthy controls (EHC)

4. Internal carotid artery stenosis (ICAS)

- 3T Philips Ingenia
- Software release 5.1.8
- 32 channel head coil
- Custom patches

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## Material & Methods

### MR Sequences

<table>
<thead>
<tr>
<th>Subjects</th>
<th>T₂ mapping</th>
<th>T₂*</th>
<th>DSC</th>
<th>Main parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-SE</td>
<td>2D-GraSE</td>
<td>3D-GraSE I</td>
<td>3D GraSE II</td>
</tr>
<tr>
<td><strong>Stage 1</strong></td>
<td>Phantom 6 different VOI’s</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Stage 2</strong></td>
<td>10 YHC age: 28.4 ± 4.1 y</td>
<td>(Literature)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Stage 3</strong></td>
<td>8 EHC age: 69.5 ± 4.8 y</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Stage 4</strong></td>
<td>3 ICAS age: 63.0 ± 9.6 y</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

- **TE = 60, 70, 80, 100, 120, 140, 160 ms**
- **TE₁ = ΔTE = 16 ms**
- **TE₁ = ΔTE = 16 ms**
- **TE₁ = ΔTE = 10 ms**
- **TE₁ = ΔTE = 5 ms**
- **TE = 30 ms**
- **7 echoes**
- **8/4 echoes**
- **8 echoes**
- **16 echoes**
- **12 echoes**
- **1 echo**
- **TR=3000 ms**
- **TR=8596 ms**
- **TR=251 ms**
- **TR=487 ms**
- **TR=1950 ms**
- **TR=1513 ms**
- **3.5x4x4 mm³**
- **2x2x3 mm³**
- **2x2x3 mm³**
- **2x2x3 mm³**
- **2x2x3 mm³**
- **2x2x3.5 mm³**
- **5 slices**
- **30 slices**
- **30 slices**
- **30 slices**
- **30 slices**
- **26 slices**
- **each 2:36 min**
- **2:23 min**
- **2:09 min**
- **4:09 min**
- **6:08 min**
- **2:01 min**

- **T₂**
- **R₂’**
- **rOEF**
- **rOEF**
Reducing $T_2$-bias in mq-BOLD imaging

## Results

### Stage 1: Phantom $T_2$

<table>
<thead>
<tr>
<th>Sequence</th>
<th>T$_2$ in phantom volumes of interest [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Single-SE</td>
<td>32.4 ± 1.7</td>
</tr>
<tr>
<td>2D-GraSE all echoes</td>
<td>37.9 ± 1.2</td>
</tr>
<tr>
<td>2D-GraSE even echoes</td>
<td>36.7 ± 0.9</td>
</tr>
<tr>
<td>3D-GraSE I</td>
<td>33.1 ± 1.7</td>
</tr>
<tr>
<td>3D-GraSE II</td>
<td>34.1 ± 1.6</td>
</tr>
</tbody>
</table>

As expected, less stimulated echoes bias by even echo fitting of 2D-GraSE

3D-GraSE I better than 2D-GraSE

3D-GraSE II closest to reference
Results
Stage 2: YHC exemplary data

**Globally decreased T₂ & R₂′ by 3D-GraSE II**
## Results

### Stage 2: YHC $R_2'$

<table>
<thead>
<tr>
<th></th>
<th>GRE</th>
<th>2D-GraSE</th>
<th>3D-GraSE I</th>
<th>3D-GraSE II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_2^*$ [ms]</td>
<td>$T_2$ [ms]</td>
<td>$T_2$ [ms]</td>
<td>$T_2$ [ms]</td>
</tr>
<tr>
<td><strong>GM</strong></td>
<td>53.9 ± 1.7</td>
<td>83.9 ± 1.1</td>
<td>76.5 ± 1.2</td>
<td>78.2 ± 1.1</td>
</tr>
<tr>
<td><strong>WM</strong></td>
<td>50.3 ± 0.9</td>
<td>75.4 ± 1.0</td>
<td>66.6 ± 0.9</td>
<td>69.1 ± 1.0</td>
</tr>
<tr>
<td><strong>Fit-error [% of echo]</strong></td>
<td>1.6 ± 0.2</td>
<td>3.4 ± 0.2</td>
<td>3.3 ± 0.2</td>
<td>1.7 ± 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2D-GraSE</th>
<th>Single SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_2$ [ms]</td>
<td>$T_2$ [ms]</td>
</tr>
<tr>
<td><strong>Literature</strong></td>
<td>84.9 ± 3.5</td>
<td>73.5 ± 2.4</td>
</tr>
<tr>
<td><strong>Literature</strong></td>
<td>73.5 ± 2.4</td>
<td>68.2 ± 2.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>3D-GraSE II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R2' [1/s]</strong></td>
<td></td>
</tr>
<tr>
<td><strong>GM</strong></td>
<td>6.2 ± 0.2</td>
</tr>
<tr>
<td><strong>WM</strong></td>
<td>5.7 ± 0.2</td>
</tr>
</tbody>
</table>

3D-GraSE I & II closer to reference

3D-GraSE II with less fit-errors

Artefact exclusion further decreases $R_2'$

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* from Hirsch et al. in NMR Biomed, 27 (2014): 853-862
Results

Stage 3: EHC rOEF

3D-GraSE II with significant decrease of $T_2$, $R_2'$ & rOEF
Reducing $T_2$-bias in mq-BOLD imaging

Results

Stage 4: ICAS exemplary data

ICAS induced ipsilateral rOEF increase only visible in 3D-GraSE II

Putamen (high iron content) masked in artefact-map and corresponds to maximum rOEF values

High-grade left sided unilateral ICAS 69y, female
Results

Stage 4: ICAS rOEF

- **2D-GraSE rOEF** (no artefact removal)
- **3D-GraSE II rOEF** (no artefact removal)
- **3D-GraSE II rOEF** (with artefact removal)

### GM

- 2D-GraSE rOEF
- 3D-GraSE II rOEF
- 3D-GraSE II rOEF

### WM

- 2D-GraSE rOEF
- 3D-GraSE II rOEF
- 3D-GraSE II rOEF

- **Strong clipping for 2D-GraSE**
- **Lower rOEF peak position by 3D-GraSE II**
- **Artefact removal reduces clipping**

High-grade left sided unilateral ICAS
69y, female
Summary

- Systematically elevated rOEF values biased by elevated $T_2$
- 3D-GraSE I significantly reduces $T_2$ and shortens scan time
- 3D-GraSE II with increased echo sampling (10ms) and prolonged echo train (160 ms) shows even better results
- rOEF significantly decreased (to 0.81 in WM & 0.54 in GM) & focal hyperintensities become visible

Remaining bias requires further analysis, e.g. by CSF induced partial volume effects

3D-GraSE $T_2$-mapping further improves mq-BOLD by lowering rOEF-values closer to physiological values
Acknowledgements

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Andreas Hock

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Thank you very much
for your attention!