Strategically Acquired On-Board MRI for ART

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- Research conducted in conjunction with Mark Haacke, PhD & colleagues

Why MR-IGRT?
- Bring powerful soft-tissue contrast into the treatment room
- Enable real-time gating
- Monitoring
- Facilitate adaptive radiation therapy
Treatment response prediction

▪ H&N cancer patient, decreased ADC observed in GTV
▪ Longitudinal DWI is feasible with the 0.35T ViewRay MRI

Purpose

▪ To introduce a multi-contrast multi-parametric image acquisition/processing pipeline at 0.35T
STAGE: STrategically Acquired Gradient Echo imaging

▪ To address the implementation and potential utility in MR-IGRT for:
  ✓ Improved targeting
  ✓ To facilitate adaptive radiation therapy

Background: STAGE
**STAGE Pipeline**

- Requires acquisition of:
  - 2 double-echo GRE scans with pair of optimal flip angles
  - Flip angle selection optimized to produce
    - Proton-density weighted
    - T1-weighted images

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**Averaged enhanced T1W (T1WE)**

- Enhanced GM/WM contrast and improved image homogeneity by subtracting the B1t corrected PDW image from the T1W image for both short and long echoes
- Two T1WE images are averaged to generate the final T1WE image with improved GM/WM contrast-to-noise ratio (CNR), SNR and image homogeneity

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**R2* and QSM**

- R2* maps calculated using two echoes for each scan, then averaged
- 3D phase unwrap 3DSRNCP
To Translate STAGE to 0.35T MR-linac in RT position

- Optimization of acquisition parameters via simulations and on human volunteers
- Develop immobilization/coil solution for brain
- Acquire prospective data on a clinical trial for brain cancer patients

STAGE Imaging Parameters for 0.35T

- ViewRay & Siemens Avanto 0.35T with 10-channel ViewRay flexible coil

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FOV (mm)</th>
<th>Slice</th>
<th>TR (ms)</th>
<th>Flip Angle</th>
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<tr>
<td>PDW</td>
<td>1.0x1.0x1.0</td>
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<td>64</td>
<td>4.39</td>
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<tr>
<td>T1W</td>
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<tr>
<td>TRufi</td>
<td>1.0x1.0x1.0</td>
<td>OFF</td>
<td>64</td>
<td>0.42</td>
</tr>
</tbody>
</table>

- The optimal flip angles for STAGE with a TR = 40ms and T1_gm = 840 ms, T1_wm = 505ms[^1] are 10° and 50° based on product of dynamic range of regression line & fractional signal[^2]

[^1]: Holland, et al., AJNR 1986;  
[^2]: Chen, et al., MRI 2017
0.35T Sequence Optimization

Glide-Hurst (HFHS)/Haacke (WSU) Collaboration

Preliminary results: Healthy Volunteer

Qualitative Images
Quantitative Data
WIP: Potential Quantitative Tissue Properties

<table>
<thead>
<tr>
<th></th>
<th>Cortical Grey Matter</th>
<th>Frontal White Matter</th>
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<tbody>
<tr>
<td>T1 (ms)</td>
<td>631 ± 32</td>
<td>357 ± 23</td>
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<tr>
<td>T2 (ms)</td>
<td>91 ± 8</td>
<td>41 ± 5</td>
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<tr>
<td>This data</td>
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<tr>
<td>Literature[1]</td>
<td>840 ± 90</td>
<td>505 ± 55</td>
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<tr>
<td></td>
<td>67 ± 7</td>
<td>53 ± 25</td>
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</table>

Translation to Patients: Immobilization

- Structural light scanning captures surface data (0.05 mm resolution), outputs .STL file inputted to CAD for 3D printing
- Fabricated with MakerBot Replicator
- 3D printer filament (ABS Copolymer, 5% infill, 3 shells, fused deposition modeling)

GBM Patient Planning

- Consented to an IRB study for immobilization device use and imaging studies
- Pre-treatment, weekly, and future follow up scans
- 10 step & shoot IMRT fields (51 segments)
- Monte Carlo based dose calculation
- 46 Gy in 23 fractions + boost
Potential to calculate T1 value changes during treatment

Comparison of T1 value variations
Current Challenges: SNR, Coil Configuration

- T1W, Magnitude
- T1W, Magnitude
- PDW, Magnitude

Potential Applications & Future Work

- To quantify lesion changes over time, subvolume targeting
- With a larger cohort, may use quantitative data to correlate to patient outcomes
- Use enhanced T1WE for autosegmentation routines
- Reduce scan time and improve SNR
  - Further optimize parameters
  - Evaluate acceleration (GRAPPA and/or compressed sensing) to reduce scan time
Discussions and further tasks

Despite all those known issues, these preliminary results show the great potential for STAGE to provide multi-parametric and multi-contrast information for assisting radiation therapy planning at this low field system. Also itself is interesting for fast imaging at low field MRI system. I am excited to see some pathological cases with this technique, especially for brain tumors with bleeding. It would be fantastic if we could do some patient using these additional 10 minutes scans.

To further improve this technique, we could do followings in the near future.

• Reducing scanning time and improving image SNR;
• Possibly we could use GRAPPA (and or CS) for a factor of 2 for reducing scanning time.
• Further optimizing imaging parameters such as sampling bandwidth, echo times and image resolution.
• Adapting current SWI sequences and reconstruction programs for VB19 to solve the cusp artifacts and make flow compensation possible for all echoes;
• Possibly we could use patient specific WBRI acquired by 0.35T for correcting other acquisition results, this is a good point to start with for in vivo SNR comparison.
• Optimizing T1 mapping and T2 mapping algorithms for data from this low field.
• RF penetration variations is negligible for this low field system. However, the current T1 mapping from low field systems seems to be overestimating T1 for CSF or high-water content tissues. Also current T2 mapping should be improved for precision and accuracy.

0.35T Sequence Optimization

Glide-Hurst (HFHS)/Haacke (WSU) Collaboration
Optimized STAGE imaging parameters for this study, TA = 10 min in total.

- The optimal flip angles for STAGE with a TR = 40ms and $T_{1\text{g}} = 840\text{ ms}$, $T_{1\text{wm}} = 505\text{ ms}$ are 10° and 50°.[2]

<table>
<thead>
<tr>
<th>Name</th>
<th>Z (m)</th>
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<th>b (m)</th>
<th>E (Pa)</th>
<th>d (kg/m³)</th>
<th>η (m²/s)</th>
<th>FC</th>
<th>OSL/ITIA</th>
<th>V (m/s)</th>
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