Strategically Acquired On-Board MRI for ART

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Disclosures

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  - NIH R01CA204189
  - Philips Healthcare
  - HFHS Grant
- Collaborations with Modus Medical Devices, MedSpira Medical, ViewRay
- Research conducted in conjunction with Mark Haacke, PhD & colleagues

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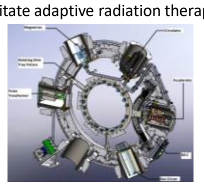
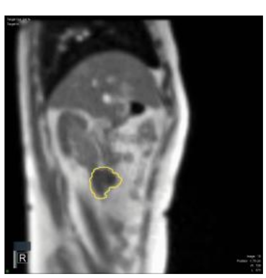
Why MR-IGRT?

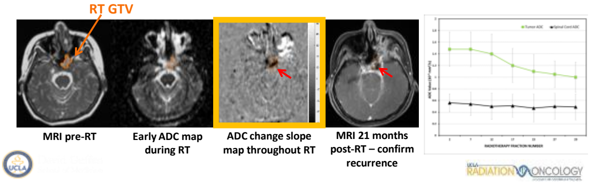
- Bring powerful soft-tissue contrast into the treatment room
- Enable real-time gating
- Monitoring
- Facilitate adaptive radiation therapy





Treatment response prediction

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



Slide courtesy of Yingli Yang, PhD

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

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Background: STAGE


Magnetic Resonance Imaging 46 (2018) 130–139

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Magnetic Resonance Imaging

journal homepage: www.elsevier.com/locate/mri

Original contribution

STrategically Acquired Gradient Echo (STAGE) imaging, part I: Creating enhanced T1 contrast and standardized susceptibility weighted imaging and quantitative susceptibility mapping

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[a] Sino-Dutch Biomedical and Information Engineering School, Northeastern University, Shenyang, China
[b] The MRI Institute for Biomedical Research, Detroit, MI, USA
[c] Department of Radiology, School of Medicine, Wayne State University, Detroit, MI, USA
[d] Shanghai Key Laboratory of Magnetic Resonance, East China Normal University, Shanghai, China

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STAGE Pipeline

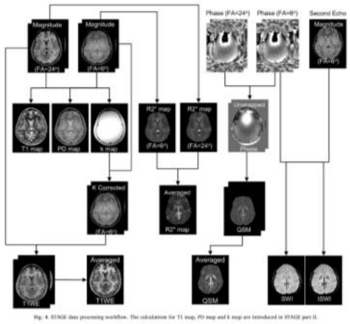
- Requires acquisition of:

 - 2 double-echo GRE scans with pair of optimal flip angles

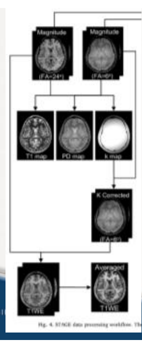
-Flip angle selection optimized to produce

✓ Proton-density weighted

✓ T1-weighted images

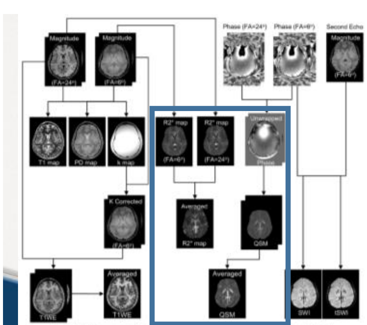


Averaged enhanced T1W (T1WE)



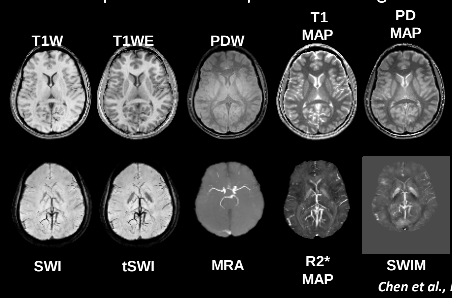
- Enhanced GM/WM contrast and improved image homogeneity by subtracting the B1t corrected PDW image from the T1W image for both short and long echoes
- Two T1WE images are averaged to generate the final T1WE image with improved GM/WM contrast-to-noise ratio (CNR), SNR and image homogeneity

R2* and QSM



- R2* maps calculated using two echoes for each scan, then averaged
- 3D phase unwrap 3DSRNCP

STAGE: 6 qualitative and 4 quantitative images at 3.0T



Chen et al., MRI, 2017

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

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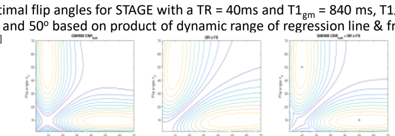
STAGE Imaging Parameters for 0.35T

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

Protocol	Acq. Resolution (mm^3)	GRAPPA	Slices	TA (m:s)
PDW	1.0x1.0x3.0	OFF	64	4:39
T1W	1.0x1.0x3.0	OFF	64	4:39
Trufi	1.0x1.0x3.0	OFF	64	0:42

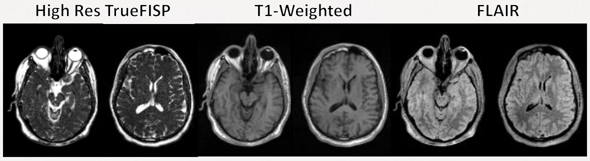
- The optimal flip angles for STAGE with a TR = 40ms and $T1_{gm}$ = 840 ms, $T1_{wm}$= 505ms [1] are 10° and 50° based on product of dynamic range of regression line & fractional signal[2]



[1] Holland, et al., AJNR 1986; [2] Chen, et al., MRI 2017

0.35T Sequence Optimization

High Res TrueFISP T1-Weighted FLAIR



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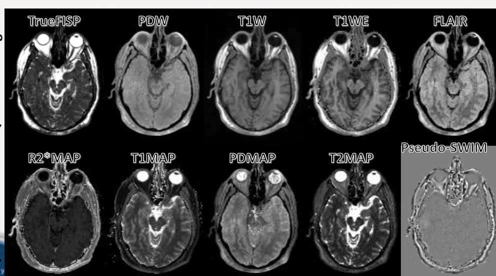
Preliminary results: Healthy Volunteer

Qualitative Images

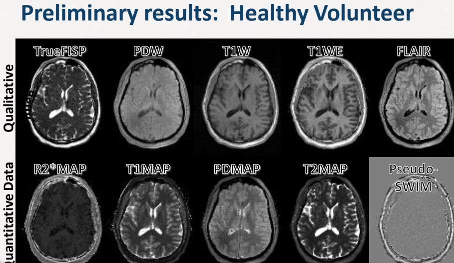
Quantitative Data



Preliminary results: Healthy Volunteer

Qualitative

Quantitative Data



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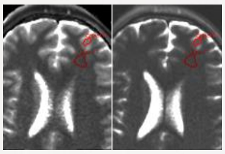
WIP: Potential Quantitative Tissue Properties



	Cortical Grey Matter		Frontal White Matter	
	T1 (ms)	T2 (ms)	T1 (ms)	T2 (ms)
This data	611±32	91±8	357±23	41±5
Literature[1]	840±90	62±7	505±55	53±35

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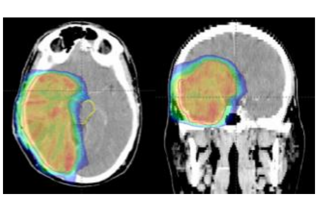
[1] Holland, et al., AJNR 1986

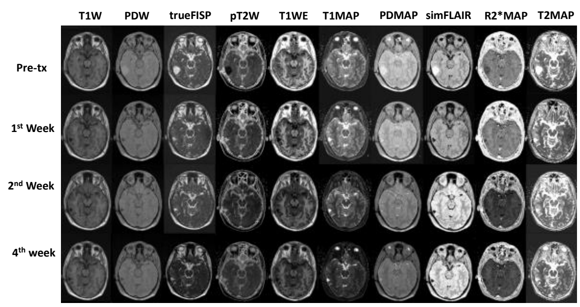
Translation to Patients: Immobilization

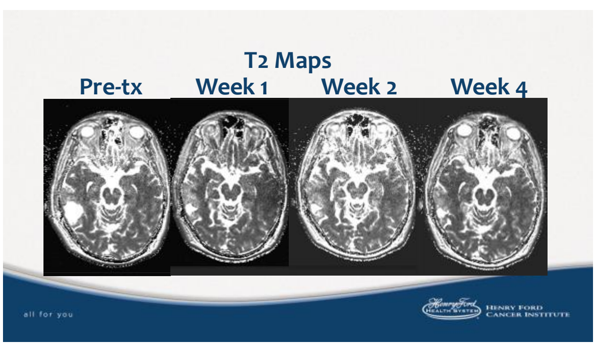
- Structural light scanning captures surface data (0.05 mm resolution), outputs .STL file inputted to CAD for 3D printing
- Fabricated with MakerBot Replicator
- 3D printer filament (ABS Copolymer, 5% infill, 3 shells, fused deposition modeling

GBM Patient Planning

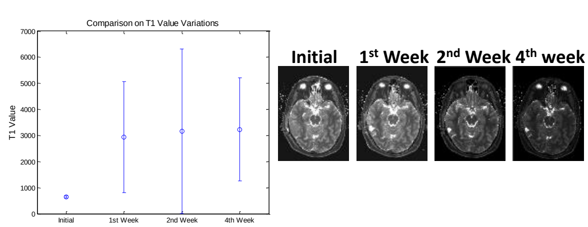


- Consented to an IRB study for immobilization device use and imaging studies
- Pre-treatment, weekly, and future follow up scans
- 10 step & shoot IMRT fields (51 segments)
- Monte Carlo based dose calculation
- 46 Gy in 23 fractions + boost

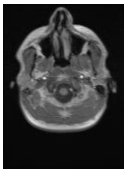




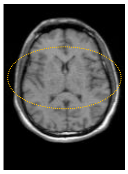
Potential to calculate T1 value changes during treatment



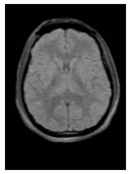
Current Challenges: SNR, Coil Configuration



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

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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 filed system. Also itself is interesting for fast imaging at low filed MRI system. I am exciting 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;
  - *Further optimizing imaging parameters such as sampling bandwidth, echo times and image resolution.*
  - *Possibly we could use GRAPPA (and or CS) for a factor of 2 or more for reducing scanning time.*
- Adapt current SWI sequences and reconstruction programs for VB19 to solve the cusp artifacts and make flow compensation possible for all echoes;
  - *For some reason, our current multi-echo SWI sequence for VB19 doesn't work for this scanner. However, this is a good point to start with by on-site MRI physicists.*
- Optimize 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 two flip angles is high-water-content tissues. Also current T2 mapping should be improved for precision and accuracy*

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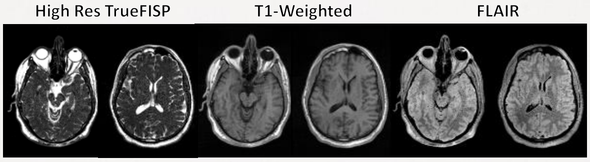
0.35T Sequence Optimization

High Res TrueFISP | T1-Weighted | FLAIR



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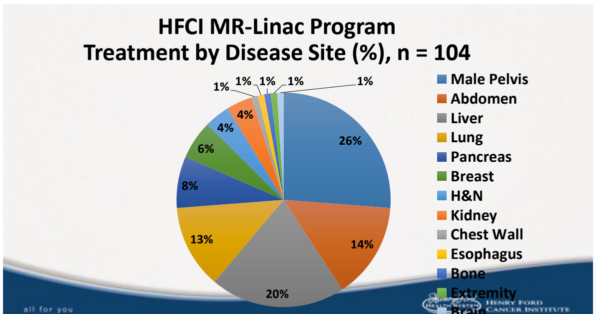
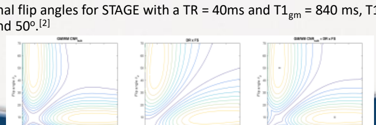


STAGE Imaging Parameters for 0.35T

- Optimized STAGE imaging parameters for this study, TA = 10 min in total.

Prot.	TR (ms)	TE (ms)	FA (deg)	BW (Hz/px)	Acq. Resolution (mm^3)	FC	GRAPPA	Slices	TA (m:s)
PDW	40	5.0/20.63/34.14	10	100/100/100	1.0x1.0x3.0	No/No/No	OFF	64	4:39
T1W	40	5.0/20.63/34.14	10	100/100/100	1.0x1.0x3.0	No/No/No	OFF	64	4:39
Trufi	3.87	1.66	60	520	1.0x1.0x3.0	No	OFF	64	0:42

- The optimal flip angles for STAGE with a TR = 40ms and $T1_{gm}$ = 840 ms, $T1_{wm}$= 505ms [1] are 10^o and 50^o.[2]



[1] Holland, et al., AJNR 1986; [2] Chen, et al., MRI 2017

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