Advances in MRI for Radiation Therapy

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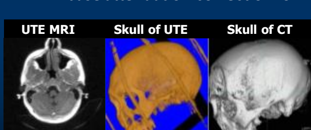
Advances in MRI

- Structural Imaging
- Fast Imaging
- Motion Imaging
- Functional Imaging
- System and QA

Ultrashort Echo-Time (UTE) MRI

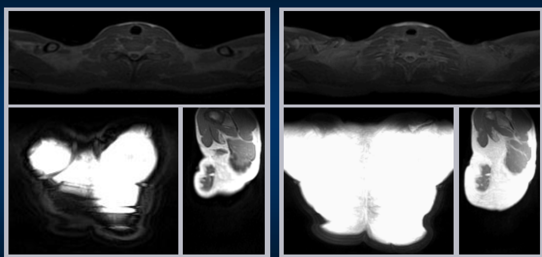
- To image tissues with short T2*, such as bone and lung parenchyma that generally disappear too quickly for accurate MR imaging.
- Generating synthetic CT from MRI for MRI-based planning, and for MRI-base attenuation correction for PET/MRI



J Nucl Med September 1, 2010 vol. 51 no. 9 1431-1438

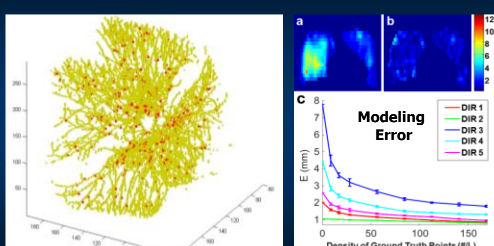
Toshiba UTE and the Vantage Titan 3T MR

Ultra-resolution Body MRI



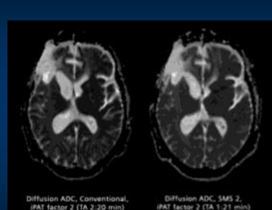
G. Wilson Miller, University of Virginia

Physiological Motion Modeling



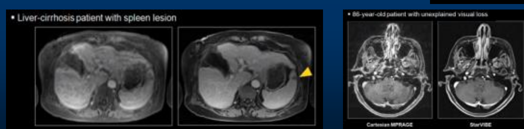
Simultaneous Multi-Slice MRI

- Speed up 2D imaging significantly through the simultaneous multiband excitation and readout of multiple slices.
- Reduce scan time and/or achieve higher spatial/diffusion resolution
- Particularly useful for functional imaging (DWI, DTI, BOLD perfusion MRI)



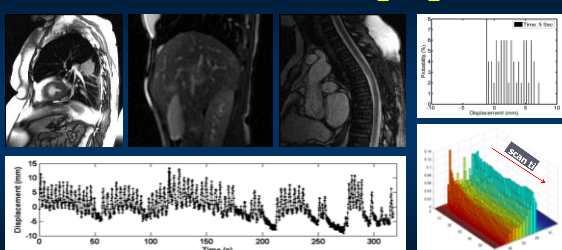
Motion Robust Rapid MRI

- TWIST-VIBE/StarVIBE/GRASP, Fat-suppressed T1-w 3D GRE
- Radial version of VIBE, Stacks of star k-space sampling
- Compressed sensing & parallel imaging
- High robustness to motion artifacts
- Thorax, abdomen, pelvis, DCE, 4D, cardiac

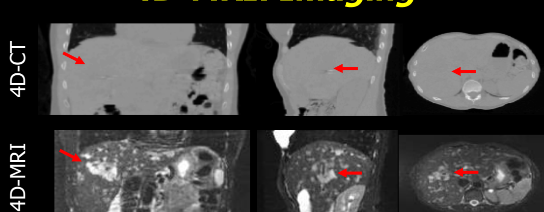


Siemens, NYU Langone Medical Center

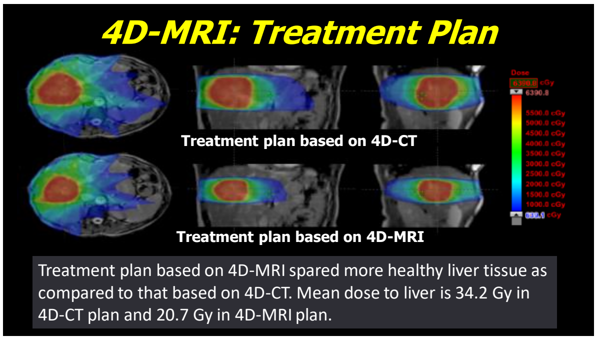
2D Cine MR Imaging

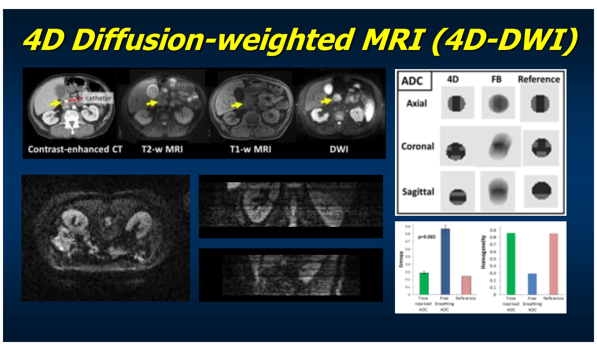


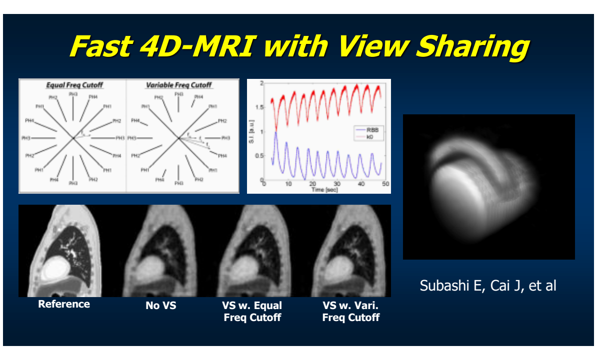
4D-MRI: Imaging

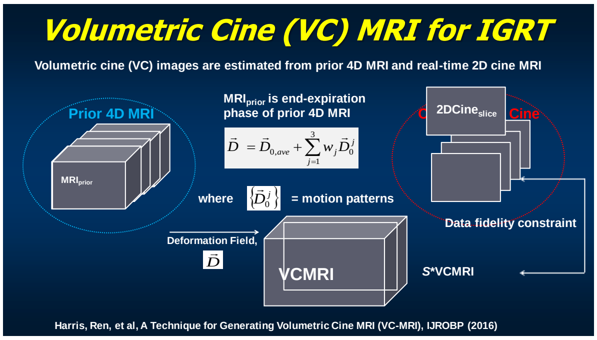


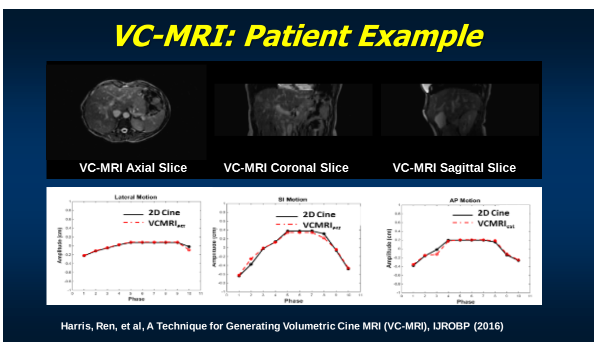
Compared to 4D-CT, 4D-MRI improves tumor contrast and tumor motion measurement for abdominal cancers.

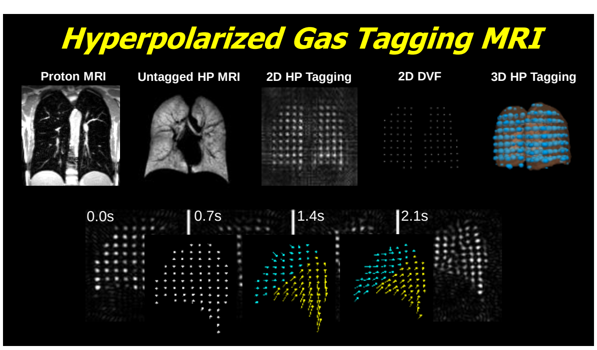

4D-MRI: Treatment Plan
Treatment plan based on 4D-CT
Treatment plan based on 4D-MRI
Treatment plan based on 4D-MRI spared more healthy liver tissue as compared to that based on 4D-CT. Mean dose to liver is 34.2 Gy in 4D-CT plan and 20.7 Gy in 4D-MRI plan.


4D Diffusion-weighted MRI (4D-DWI)
catheter
Contrast-enhanced CT
T2-w MRI
T1-w MRI
DWI
ADC
4D
FB
Reference
Axial
Coronal
Sagittal

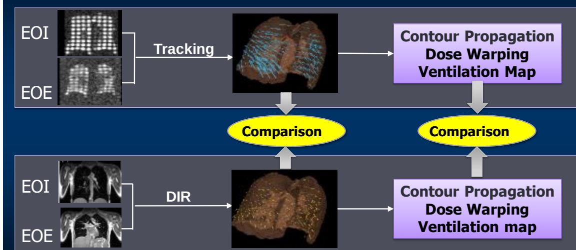

Fast 4D-MRI with View Sharing
Equal Freq Cutoff
Variable Freq Cutoff
Reference
No VS
VS w. Equal Freq Cutoff
VS w. Vari. Freq Cutoff
Subashi E, Cai J, et al


Volumetric Cine (VC) MRI for IGRT
Volumetric cine (VC) images are estimated from prior 4D MRI and real-time 2D cine MRI
Prior 4D MRI
MRI_{prior}
MRI_{prior} is end-expiration phase of prior 4D MRI
$\vec{D} = \vec{D}_{0,ave} + \sum_{j=1}^{3} w_j \vec{D}_0^j$
where $\{\vec{D}_0^j\}$ = motion patterns
$2DCine_{slice}$
Cine
Data fidelity constraint
Deformation Field, $\vec{D}$
VCMRI
S*VCMRI
Harris, Ren, et al, A Technique for Generating Volumetric Cine MRI (VC-MRI), IJROBP (2016)

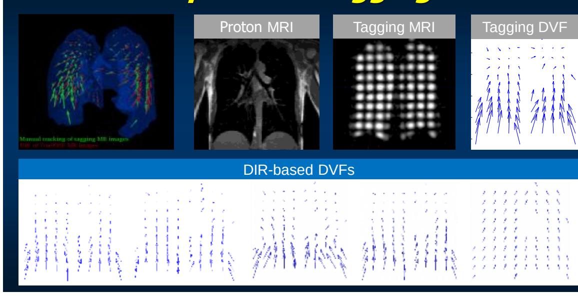

VC-MRI: Patient Example
VC-MRI Axial Slice
VC-MRI Coronal Slice
VC-MRI Sagittal Slice
Lateral Motion
SI Motion
AP Motion
2D Cine
$VCMRI_{est}$
Phase
Harris, Ren, et al, A Technique for Generating Volumetric Cine MRI (VC-MRI), IJROBP (2016)


Hyperpolarized Gas Tagging MRI
Proton MRI
Untagged HP MRI
2D HP Tagging
2D DVF
3D HP Tagging
0.0s
0.7s
1.4s
2.1s

Tagging MRI for DIR Assessment

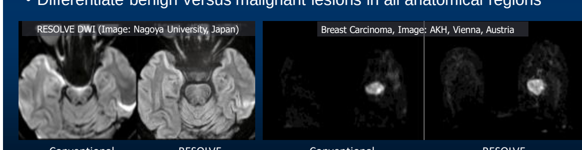


DVF Comparison: Tagging vs DIR



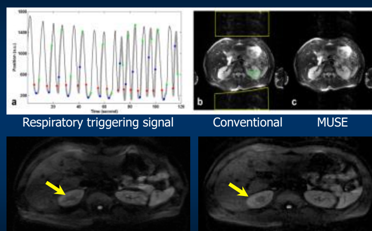
High Resolution DWI

- RESOLVE, high quality DWI images in brain and body sites
- Readout-segmented, multi-shot EPI for reduced TE and encoding time
- Reduced susceptibility and blurring artifacts
- Insensitive to motion-induced phase error
- Differentiate benign versus malignant lesions in all anatomical regions



Motion Suppressed DWI

- MUSE: post-processing algorithm to minimize motion-induced inconsistencies among different portions of the k-space data.
- Further reduce residual motion-related artifacts in MRI data produced by existing motion artifact reduction procedures.
- Compatible with MRI data obtained with different pulse sequences

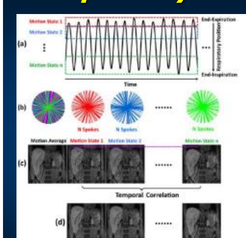


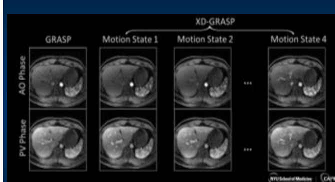
Respiratory triggering signal — Conventional — MUSE

Low Resolution DWI — DWI with MUSE

Chu et al, MRM 74:1336–1348 (2015)

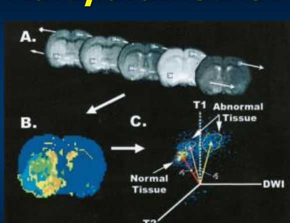
Respiratory Motion-Resolved DCE MRI



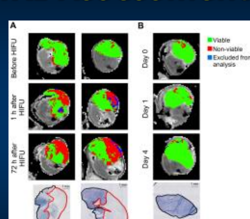


Li F, 2015 IEEE 12th International Symposium on Biomedical Imaging (ISBI)

Multiparametric MRI Assessment



Jacobs et al Part 1: Model for Tissue Characterization Using ISODATA *Stroke* April 2001



Hectors SJCG, et al (2014) Multiparametric MRI Analysis for the Identification of High Intensity Focused Ultrasound-Treated Tumor Tissue. PLoS ONE 9(6): e99936.

MRI QA for RT

TABLE IV. MRI simulator quality assurance protocols (frequency and measurements) established at our institution.

Weekly QA (MRI technologists)	Monthly QA (Therapy physicists)	Annual QA (MRI physicists)
• Transmitter gain constancy • Center frequency constancy • Signal-to-noise ratio constancy • Slice thickness accuracy • Slice position accuracy	• Patient safety (monitors, intercom, panic ball, emergency offs, and signage) • Patient comfort (bore lights, and bore fan) • Percent signal ghosting • Percent image uniformity • High/low contrast constancy • Laser alignment • Couch position accuracy • Image artifacts	• RF coil integrity check • B0 constancy • B1 + constancy • Gradient linearity constancy

Medical Physics

Comprehensive MRI simulation methodology using a dedicated MRI scanner in radiation oncology for external beam radiation treatment planning

Eric S. Paulson, Beth Erickson, Chris Schultz, and X. Allen Li

Summary

- Significant improvement in MR imaging technology has been achieved recently, especially in body imaging via the development of fast imaging techniques.
- High spatial and temporal accuracy is now achievable with the state-of-the-art MRI technology. Applications of these advanced MRI techniques in RT are yet to be fully explored and validated.