EE225E/BIOE265: MRI Research Presentations

General Guidelines There are several options below for your MRI research topic. Many of the references can be found in b-space of this course website. Feel free to add papers, read textbooks on reserve in the Engineering library, etc. If you wish to cover another topic, please check first with me to make sure that the topic is appropriate. Details below.

1. Work as a team of two. Students have the option of presenting the research in an oral presentation of 12 minutes in duration, plus 3 minutes of questions, or as a 10 page report.
2. Partners should share the work equally and share the presentation time roughly equally.
3. The presentations will take place ***TBD***
4. Level of presentation: Textbook level of knowledge.
5. Grading: The grade will based on accuracy, clarity and normalized by the scope of the project.
6. There will be food during the presentations. Its like a dinner and a movie date.

MRI Research Topic Options

1. **Hyperpolarized 13C**
   Hyperpolarization methods (PHIP, dynamic polarization) have been shown to create non-equilibrium polarization levels for Carbon that are 10,000 times higher than normally encountered in vivo. The hyperpolarized agent must be injected but can then undergo biochemical reactions, much like nuclear medicine tracer studies. The polarization last only a few T1, so this may help elucidate faster biochemical reactions in vivo.

[1] J. H. Ardenkjaer-Larsen, B. Fridlund, A. Gram, G. Hansson, L. Hansson, M. H. Lerche, R. Servin, M. Thaning, and K. Golman. Increase in signal-to-noise ratio of ¿ 10,000 times in liquid-state nmr. *Proc Natl Acad Sci U S A*, 100(18):10158–63, Sep 2003.

[2] K. Golman, J. H. Ardenkjaer-Larsen, J. S. Petersson, S. Mansson, and I. Leunbach. Molecular imaging with endogenous substances. *Proc Natl Acad Sci U S A*, 100(18):10435–9, Sep 2003.

[3] J. Kurhanewicz, D. B. Vigneron, K. Brindle, E. Y. Chekmenev, A. Comment, C. H. Cunningham, R. J. Deberardinis, G. G. Green, M. O. Leach, S. S. Rajan, R. R. Rizi, B. D. Ross, W. S. Warren, and C. R. Malloy. Analysis of cancer metabolism by imaging hyperpolarized nuclei: prospects for translation to clinical research. *Neoplasia*, 13(2):81–97, Feb 2011.

2. **Temperature mapping in vivo with MRI**
   Over the last decade, several groups have explored MRI as a method to guide ablation (RF ablation, cyroablation, IVUS, etc). MRI has a weak sensitivity to temperature called the Proton Resonance Frequency shift that, with care, can image in real time the temperature of tissue while it is being ablated.

[1] V. Rieke and K. Butts Pauly. Mr thermometry. *J Magn Reson Imaging*, 27(2):376–90, Feb 2008.

[2] K. B. Pauly, V. Rieke, A. B. Holbrook, W. Grissom, J. Chen, and E. Kaye. Mr-guidance of hifu therapy. *Conf Proc IEEE Eng Med Biol Soc*, 2009:141–4, 2009.

[3] A. Napoli, M. Anzidei, F. Ciolina, E. Marotta, B. Cavallo Marincola, G. Brachetti, L. Di Mare, G. Cartocci, F. Boni, V. Noce, L. Bertaccini, and C. Catalano. Mr-guided high-intensity focused ultrasound: Current status of an emerging technology. *Cardiovasc Intervent Radiol*, Mar 2013.

3. **Multidimensional RF pulses**

   RF pulse Design Boernert.pdf (260453 Bytes)

   We touched briefly on the k-space theory for RF pulses. The complete theory is in one paper and explains how to design RF pulses that excite cylinders or squares 2D space or in space-frequency. So called spectral-spatial pulses are very important for imaging methods that are sensitive to off-resonance.

   Pauly J, Nishimura D, Macovski A. A k-space analysis of small-tip-angle excitation. Journal of Magnetic Resonance 81:43-56, 1989.

   Meyer CH. Pauly JM. Macovski A. Nishimura DG. Simultaneous spatial and spectral selective excitation. Magnetic Resonance in Medicine. 15(2):287-304, 1990

   Also check out handwritten notes and Matlab M-files on 2D RF pulse design at the Website for EE469B, "RF Pulse Design for Magnetic Resonance Imaging," from Stanford Electrical Engineering, taught by Professor John Pauly: http://www.stanford.edu/class/ee469b/

4. **Diffusion Weighted MRI**

   Spin echoes refocus any static magnetic field disturbance. Spins that diffuse through inhomogeneous magnetic fields do not see constant fields on both sides of the spin echo, and they accumulate some phase. Since different spins in the same voxel see different phase histories, significant phase cancellation can occur. Large bipolar gradient pulses are effective for labeling spin diffusion and creating diffusion contrast. This has enabled white matter tracking studies in the brain.

[1] D. Le Bihan. Looking into the functional architecture of the brain with diffusion mri. *Nat Rev Neurosci*, 4(6):469–80, Jun 2003.

[2] S. Mori and P. B. Barker. Diffusion magnetic resonance imaging: its principle and applications. *Anat Rec*, 257(3):102–9, Jun 1999.

[3] D. S. Tuch, T. G. Reese, M. R. Wiegell, N. Makris, J. W. Belliveau, and V. J. Wedeen. High angular resolution diffusion imaging reveals intravoxel white matter fiber heterogeneity. *Magn Reson Med*, 48(4):577–82, Oct 2002.

5. **Real-Time MRI**

   In Real-time MRI images are acquired, reconstructed and displayed in real time. Performing MRI in real-time is challenging due to the slow acquisition time of MRI. This can be done with fast readout trajectories like spirals and EPI or with fast sequences like radial Flash and and fast Spin echo.

   Real time MRI is useful for imaging the heart, fetal imaging and for interventional applications.

[1] A. B. Kerr, J. M. Pauly, B. S. Hu, K. C. Li, C. J. Hardy, C. H. Meyer, A. Macovski, and D. G. Nishimura. Real-time interactive mri on a conventional scanner. *Magn Reson Med*, 38(3):355–67, Sep 1997.

[2] C. J. Hardy, R. D. Darrow, J. M. Pauly, A. B. Kerr, C. L. Dumoulin, B. S. Hu, and K. M. Martin. Interactive coronary mri. *Magn Reson Med*, 40(1):105–11, Jul 1998.

[3] J. M. Santos, G. A. Wright, and J. M. Pauly. Flexible real-time magnetic resonance imaging framework. *Conf Proc IEEE Eng Med Biol Soc*, 2:1048–51, 2004.

[4] Uecker, Martin and Zhang, Shuo and Voit, Dirk and Karaus, Alexander and Merboldt, Klaus-Dietmar and Frahm, Jens Real-time MRI at a resolution of 20 ms. *NMR Biomed*, 23(8):986–94, Oct 2010.

6. **High Field MRI**

   Over the last decade, 3T and 7T magnets have emerged for human in vivo studies. The high field magnets promise excellent fMRI scans since the T2* effect is much stronger at higher fields and offers better SNR and possibly better spectral resolution for spectroscopic MRI. Technical challenges include increased SAR, poor RF penetration, susceptibility artifacts, longer T1s and shorter T2s.

[1] F. Schick. Whole-body mri at high field: technical limits and clinical potential. *Eur Radiol*, 15(5):946–59, May 2005.

[2] D. I. Hoult and D. Phil. Sensitivity and power deposition in a high-field imaging experiment. *J Magn Reson Imaging*, 12(1):46–67, Jul 2000.

[3] D. G. Norris. High field human imaging. *J Magn Reson Imaging*, 18(5):519–29, Nov 2003.

[4] B. K. Rutt and D. H. Lee. The impact of field strength on image quality in mri. *J Magn Reson Imaging*, 6(1):57–62, 1996.

7. **Prepolarized MRI**

   Prepolarized MRI is an interesting architecture for low-cost MRI. Here we use a mid-field electromagnet to polarize spins and image with another homogeneous low-field magnet. One can show that if you obtain body noise dominance and use 3D imaging, that SNR and CNR depend only on the polarizing field. A good quality knee and wrist scanner has been constructed with good SNR and image quality. This very unconventional (there are only 3 PMRI scanners in the world!) scanner enjoys many benefits: about 10-fold cost and complexity reduction relative to a conventional MRI scanner; nearly silent gradients; greatly suppressed susceptibility artifacts; greatly reduced (100x) SAR; and several unique contrast mechanisms.

   (NateRARE) N. I. Matter, G. C. Scott, R. D. Venook, S. E. Ungersma, T. Grafendorfer, A. Macovski, S. M. Conolly, "Three-dimensional prepolarized magnetic resonance imaging using rapid acquisition with relaxation enhancement," Magn Reson Med. 2006 Oct 6; PMID: 17029228.

   Ross D. Venook, Nathaniel I. Matter, Meena Ramachandran, Sharon E. Ungersma, Garry E. Gold, Nicholas J. Giori, Albert Macovski, Greig C. Scott, and Steven M. Conolly "Prepolarized MRI Around Metal Orthopedic Implants," Magn Reson Med. 2006 Jul;56(1):177-86.

   Sharon E. Ungersma, Nathaniel I. Matter, Jonathan W. Hardy, Ross D. Venook, Albert Macovski, Steven M. Conolly, Greig C. Scott "Magnetic resonance imaging with T1 dispersion contrast," Magnetic Resonance in Medicine, 55 (6) 1362-1371 2006.

8. **Parallel MRI**

   One of the most intensely researched areas in MRI currently is the use of multiple RF coils (and other sources of diversity) to permit significant undersampling in one or more directions in k-space (usually in the phase encode direction). This can greatly increase the speed of MRI. If you reduce your imaging time by R then you decrease your SNR by the factor g*sqrt(R), where g is the so-called geometry factor—a local measure of condition number of the coil array.

[1] K. P. Pruessmann, M. Weiger, M. B. Scheidegger, and P. Boesiger. Sense: sensitivity encoding for fast mri. *Magn Reson Med*, 42(5):952–62, Nov 1999.

[2] M. A. Griswold, P. M. Jakob, R. M. Heidemann, M. Nittka, V. Jellus, J. Wang, B. Kiefer, and A. Haase. Generalized autocalibrating partially parallel acquisitions (grappa). *Magn Reson Med*, 47(6):1202–10, Jun 2002.

[3] D. J. Larkman and R. G. Nunes. Parallel magnetic resonance imaging. *Phys Med Biol*, 52(7):R15–55, Apr 2007.

[4] A. Deshmane, V. Gulani, M. A. Griswold, and N. Seiberlich. Parallel mr imaging. *J Magn Reson Imaging*, 36(1):55–72, Jul 2012.

9. **Steady-state fMRI**
   Most of fMRI today is done using single shot gradient echo or spin-echo sequences. These methods have good functional sensitivity, but have significant limitations in terms of the spatial/temporal resolution and image artifacts. In recent years there has been considerable work showing that steady-state imaging can be made sensitive to blood oxygenation and exhibit BOLD response. These sequences have a potential to overcome the limitations of traditional BOLD fMRI, like signal decay near sinuses, geometric distortion, high sensitivity to draining vains and more.

[1] K. L. Miller. Fmri using balanced steady-state free precession (ssfp). *Neuroimage*, 62(2):713–9, Aug 2012.

[2] J. H. Lee, S. O. Dumoulin, E. U. Saritas, G. H. Glover, B. A. Wandell, D. G. Nishimura, and J. M. Pauly. Full-brain coverage and high-resolution imaging capabilities of passband b-ssfp fmri at 3t. *Magn Reson Med*, 59(5):1099–110, May 2008.

10. **Arterial Spin Labeling** [1] Wolf RL, Detre JA. Clinical neuroimaging using arterial spin-labeled perfusion magnetic resonance imaging Neurotherapeutics. 2007 Jul;4(3):346-59.

    [2] Detre JA, Wang J, Wang Z, Rao H. Arterial spin-labeled perfusion MRI in basic and clinical neuroscience. Curr Opin Neurol. 2009 Aug;22(4):348-55.

    [3] Liu TT, Brown GG. Measurement of cerebral perfusion with arterial spin labeling: Part 1. Methods. J Int Neuropsychol Soc. 2007 May;13(3):517-25.

11. **Flow Imaging** MRI can be utilized to measure three directional veloc- ities in three dimensions, using gradients to impart phase to moving spins. This unique ability has allowed the use of MR for both qualitative and quantitative assessment of complex cardiovascular hemodynamics using three-dimensional, three-directional, cardiac-gated (CINE) phase contrast (PC) sequences.

    [1] Markl, Michael and Chan, Frandics P and Alley, Marcus T and Wedding, Kris L and Draney, Mary T and Elkins, Chris J and Parker, David W and Wicker, Ryan and Taylor, Charles A and Herfkens, Robert J and Pelc, Norbert J ”Time-resolved three-dimensional phase-contrast MRI” J Magn Reson Imaging. 2003 17(4):499-506

    [2] Pelc, N J and Bernstein, M A and Shimakawa, A and Glover, G H ”Encoding strategies for three-direction phase-contrast MR imaging of flow” J Magn Reson Imaging, 1991 1(4):405-13

12. **Compressed Sensing MRI** Compressed Sensing is a recent theoretical result which shows that compressible and sparse signals can be recovered from far fewer measurements than traditionally considered necessary. It turns out that this theory can be directly applied to accelerate MRI acquisitions. This is a growing area of research.

    [1] Lustig M, Donoho D, Pauly JM. Sparse MRI: The application of compressed sensing for rapid MR imaging. Magn Reson Med. 2007 Dec;58(6):1182-95.

    [2] Michael Lustig, David L. Donoho, Juan M. Santos and John M. Pauly Compressed Sensing MRI, IEEE Signal Processing Magazine, 2008; 25(2): 72-82

13. **Large Tip Angle RF Pulse Design** The Shinnar-Le Roux algorithm for slice selective pulse design.

    [1] Pauly J, Le Roux P, Nishimura D, Macovski A. Parameter relations for the Shinnar-Le Roux selective excitation pulse design algorithm. IEEE Trans Med Imaging. 1991;10(1):53-65.

    Optimal Control

    [2] S. M. Conolly, D. G. Nishimura, and A. Macovski, Optimal control solutions to the magnetic resonance selective excitation problem, IEEE Trans. Med. Imaging, vol. MI-5,pp. 106-115, 1986.

    Adiabatic Pulses

    [3] Alberto Tanns and Michael Garwood, Adiabatic Pulses, NMR IN BIOMEDICINE, VOL. 10, 423434 (1997)

14. **Reconstruction from non-uniform sampled data**

    [1] Beatty PJ, Nishimura DG, Pauly JM Rapid gridding reconstruction with a minimal oversampling ratio IEEE Trans Med Imaging. 2005 Jun;24(6):799-808

    [2] J. G. Pipe and P. Menon, Sampling density compensation in MRI: Rationale and an iterative numerical solution, Magn. Reson. Med., vol. 41, no. 1, pp. 179186, 1999.

    [3] D. Rosenfeld, New approach to gridding using regularization and esti- mation theory, Magn. Reson. Med., vol. 48, no. 1, pp. 193202, 2002

    [4] J. Fessler and B. Sutton, Nonuniform fast Fourier transforms using min-max interpolation, IEEE Trans. Signal Process., vol. 51, no. 2, pp. 560574, Feb. 2003.

    [5] J. Jackson, C. Meyer, D. Nishimura, and A. Macovski, Selection of a convolution function for Fourier inversion using gridding, IEEE Trans. Med. Imag., vol. 10, no. 3, pp. 473478, Sep. 1991

** **Recent Topics:**

15. **Magnetic Resonance Fingerprinting:**

    A new approach for contrast generation, encoding and reconstruction based on random pulse sequence and pattern matching.

    [1] Ma, Dan and Gulani, Vikas and Seiberlich, Nicole and Liu, Kecheng and Sunshine, Jeffrey L and Duerk, Jeffrey L and Griswold, Mark A, Magnetic resonance fingerprinting, Nature 2013;495(7440):187-92

16. **New approach for imaging the brain architecture**

    Slightly controversial, yet very promising way to map the brain.

[1] C. Liu and W. Li. Imaging neural architecture of the brain based on its multipole magnetic response. *Neuroimage*, 2012.

17. **Travelling Wave MRI**

At high field, the wavelength in MRI is smaller than the object, hence wave effects create huge inhomogeneity in B1. Travelling wave MRI is a new way of creating excitation and reception in MRI in high field that uses the bore and the person as a waveguide.

[1] D. O. Brunner, N. De Zanche, J. Fröhlich, J. Paska, and K. P. Pruessmann. Travelling-wave nuclear magnetic resonance. *Nature*, 457(7232):994–998, 2009.