# Magnetic Resonance Imaging

**RLE Group**
Magnetic Resonance Imaging Group

**Academic and Research Staff**
Prof. Elfar Adalsteinsson

**Graduate Students**
Mr. Borjan A. Gagoski, M.S., Mr. Kawin Setsompop, M.S., Ms. Karen J. Lee, Mr. Joonsung Lee, M.S., Mr. Pádraig Cantillon-Murphy, M.S., Mr. Joseph Y. Cheng, Mr. Divya S. Bolar.

**Collaborators**
At the HST Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital (MGH), and the Harvard-MIT Division of Health Sciences and Technology (HST): Prof. Larry L. Wald, Prof. A. Gregory Sorensen, M.D., Prof. Nouchine Hadjikhani, M.D., Franz Hebrank, Ph.D., Mr. Vijay Alagappan, M.S., Mr. Daniel T. Wehner; at MIT: Prof. Markus Zahn, Prof. Vivek Goyal, Prof. John Gabrieli, Mr. Adam Zelinski, M.S., Christina Triantafyllou, Ph.D.; at Siemens Medical Solutions, Erlangen, Germany: Stefan Roell Ph.D., Gunnar Krueger Ph.D., J. Ulrich Fontius, Ph.D., Franz Schmitt, Ph.D.

**Technical and Support Staff**
Laura M. von Bosau

**MRI Group Overview**
The MRI group has been in operation for two years now, and we have seen our group grow substantially in the last couple of semesters. Our research area is medical imaging with magnetic resonance, focusing on methods for excitation, acquisition, reconstruction, and processing of *in vivo* imaging data. Currently, our primary effort is divided among three areas: (1) efficient encoding of spectroscopic magnetic resonance data with RF coil receive arrays; (2) estimation of low-SNR brain metabolites with joint information from high-resolution structural imaging; (3) development of radio-frequency (RF) excitation on multiple, simultaneous channels. The group consists of EECS and HST graduate students along with several collaborating faculty and students who are associated with MIT and with the HST Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital, (or, more briefly, the Martinos Center.)

The extensive resources of the Martinos Center, under the direction of Dr. Bruce Rosen and Dr. Greg Sorensen, are available to our group through collaborations with members in the Center. The Martinos Center is unique in the scope and variety of imaging equipment available, including four whole-body MRI scanners, one 3 Tesla (3T) head-only machine, and three high-field animal scanners. In the past year, the equipment options of the Martinos Center were further extended by the addition of a whole-body, 3T human imager on MIT campus under the direction of Professor John Gabrieli.

Support for our work includes startup funds from HST and EECS; equipment, engineering expertise, and software training from Siemens Medical Solutions; equipment support from the Athinoula A. Martinos Center for Biomedical Imaging; National Institutes of Health (NIH) – National Center for Research Resources (P41RR14075); the Mental Illness and Neuroscience Discovery (MIND) Institute. Collaborators on ferrofluid research received support from the Thomas and Gerd Perkins Chair held by Professor Mark Zahn; and generous alumnus Thomas F. Peterson. Prof. Adalsteinsson receives generous support through the Robert J. Shillman career development award.

## 1. Chemical Shift Imaging with Spiral-based k-space Trajectories (Spiral CSI)

**Sponsors:**
HST, EECS, NIH Grant Number P41RR14075, The Korean Foundation for Advanced Studies, National Defense Science and Engineering Graduate Fellowship, Robert J. Shillman career development award.

**Project Staff:**
Mr. Borjan Gagoski, Mr. Joonsung Lee, Mr. Joseph Y. Cheng, Prof. Larry L. Wald, Prof. Elfar Adalsteinsson

Borjan Gagoski received his masters degree in EECS in spring 2006, working on chemical shift imaging encoding with spiral k-space trajectories and arrays of receive coils. Conventional Magnetic Resonance Spectroscopic Imaging (MRSI) suffers from both low signal-to-noise (SNR), as well as long acquisition times. The development of high-fidelity gradient coils has opened opportunities for fast k-space encoding schemes that are already used in structural imaging. At the same time, receive-coil arrays using 4 and 23 channels have been developed and reported to produce improved SNR over conventional quadrature detection by single coils. Fast spectroscopic imaging algorithm using spiral k-space trajectories and multiple-channel coil arrays is proposed in order to overcome the long acquisition-time limitations of conventional MRSI.

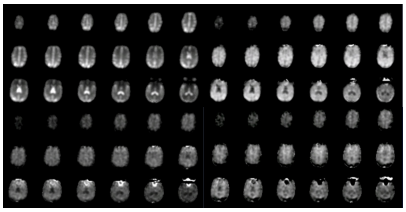

**Figure 1** Four-channel acquisition of spiral-encoded spectroscopic imaging data, showing a high-SNR water reference scan (upper left), NAA (upper right), choline (lower left), and creatine maps with 1.1 cc resolution acquired in 15 minutes.

With the application of large-N array receive coils, the problem of undesired lipid signals becomes more pronounced, as these components derive from subcutaneous tissue in close proximity to the coil elements. Current work includes improving the estimation of the low-SNR metabolites in the presence of such disturbances, with the goal of robust, rapid, and reliable separation of desired and artifactual signals.

Future work includes optimization of these methods to study of disease, including migraine, Alzheimer's disease, brain tumors, and stroke.

## 2. Segmented Gray/White Matter Spectroscopy

**Sponsors:**
HST, EECS, NIH Grant Number P41RR14075, NIH Grant Number 5P01NS 3561, The Korean Foundation for Advanced Studies, Robert J. Shillman career development award.

**Project Staff:**
Mr. Joonsung Lee, Ms. Karen J. Lee, Prof. Nouchine Hadjikhani, Prof. Elfar Adalsteinsson

In the previous year, we initiated a collaborative project with Dr. Hadjikhani at MGH and HST to study the spectroscopic profile of gray-matter regions that were identified on cortical thickness maps as important to the study of migraine. We developed a whole-brain, spiral-based spectroscopic acquisition protocol joint with whole-brain structural imaging to evaluate areas that show cortical thickness changes to determine whether these changes are due to a difference in the neuronal or glial population.

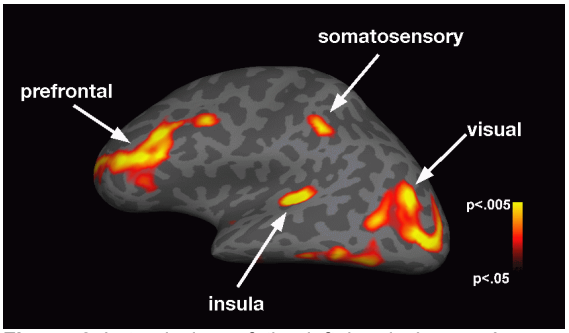


**Figure 2** Lateral view of the left hemisphere. Average cortical thickness difference of 24 migraineurs compared with age- and gender-matched healthy controls. Areas of thickening are present in the pain-processing network (Somatosensory cortex, insula, prefrontal cortex) as well as in visual areas (Source: Dr. N. Hadjikhani).

We are now conducting a pilot study of normal controls and subjects with migraine to evaluate the feasibility of the application of the acquisition and processing method. The data processing will combine estimation of tissue compartments from segmented structural imaging with data from the much lower resolution spectroscopic imaging to derive gray matter and white matter spectroscopic markers of interest. With promising pilot data, we will launch a larger study that to yield insight into whether gliosis or neuronal density contribute to the detected structural white and gray matter changes in migraine.

## 3. Parallel RF Transmission in Magnetic Resonance Imaging

**Sponsors:**
HST, EECS, National Defense Science and Engineering Graduate Fellowship, Robert J. Shillman career development award.

**Project Staff:**
Mr. Kawin Setsompop, M.S., Mr. Borjan Gagoski, Mr. Adam Zelinski, M.S., Prof. Larry Wald, Prof. Elfar Adalsteinsson

RF excitation in the presence of time-varying gradients for multi-dimensional selective excitation offers several interesting applications, including flexibly shaped excitation volumes, and spatial modulation of the B1 excitation profile to mitigate RF field inhomogeneity at high field. Due to limitations on gradient hardware and RF power, such pulse designs can result in long waveforms that may limit their performance and practical applicability. Using parallel excitation design in conjunction with coil arrays capable of simultaneous, independent RF transmission, the pulse duration can be shortened by taking advantage of variations in spatial excitation profiles among coils in the array.

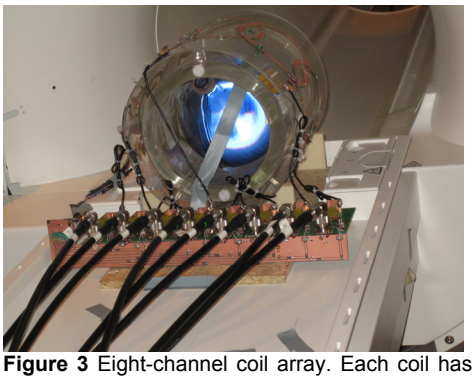

**Figure 3** Eight-channel coil array. Each coil has 17 cm diameter, and placed in an overlapping pattern on an acrylic cylinder with a 28 cm diameter. Centered in the coil is a 18-cm diameter oil-filled spherical phantom that was used for evaluation of the parallel RF excitation designs.

To demonstrate the feasibility of these methods, spatially-selective RF waveforms were designed and demonstrated for parallel excitation with a dedicated 8-coil transmit array on a modified 3T human MRI scanner in a close collaboration with members of the Martinos Center and Siemens Medical Solutions. Experiments took place at Siemens Medical Headquarters in Erlangen, Germany, where we measured excitation profiles of individual coils in the array, and used in low flip angle pulse design to achieve desired spatial target profiles with two- and three-dimensional k-space excitation with simultaneous transmission of RF on 8 channels. The 2D pulse excited a high-resolution spatial pattern in-plane, while the 3D trajectory produced high-quality slice selection with a uniform in-plane excitation in spite of the highly non-uniform

individual spatial profiles of the coil array. The multi-channel parallel RF excitation was used to accelerate the 2D excitation by factors of 2-8, with experimental results in excellent agreement with simulations based on the measured coil maps.

As we consider our future work in this area, it's worth noting that a critical limitation of the current designs is the low flip angle constraint. While this assumption provides an attractive framework for the design and enables computationally tractable solutions, an extension of parallel excitation to arbitrary flip angle is an important step toward future applications. Further, not addressed in this study is the contribution to the specific absorption ratio (SAR) due to the multiple simultaneous transmission RF channels. Ideally, SAR should be incorporated as a constraint or a trade-off parameter in the pulse design. This issue obviously needs analysis and evaluation before parallel excitation becomes useful for human imaging.

Particularly relevant to high-field imaging, e.g. at 7T, is the challenge of uniform slice-selective excitation, where standard single-channel coil designs and conventional slice-selective RF pulses produce very large spatial inhomogeneity. At 3T we were able to design and implement pulses with duration 3.42 and 5.67 ms, which were able to render an otherwise inhomogeneous B1 profile relatively homogeneous. We anticipate that with the current excitation hardware configured for 7T, in combination with fast insert head gradients (e.g. 70 mT/m, 700 T/m/s, such as currently available on our 7T system), homogenous slice-selective RF pulses could be achieved in 1.66 ms for the same 4 spokes design used in this work.

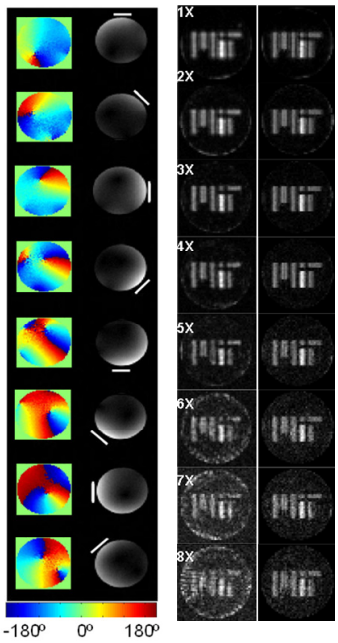


**Figure 4** Phase and Magnitude of the Coil Profiles. 2D excitation with 1X through 8X acceleration of the MIT logo excited in the phantom. Experimental data are shown on the left, and simulations on the right based on the measured B1 maps.

## Publications

### Journal Articles, Published

Adalsteinsson E, Sullivan EV, Mayer D, Pfefferbaum A. “In Vivo Quantification of Ethanol Kinetics in Rat Brain” Neuropsychopharmacology 2006. (e-publication ahead of print)

Mayer D, Kim DH, Adalsteinsson E, Spielman DM. “Fast CT-PRESS-based spiral chemical shift imaging at 3 Tesla” Magn Reson Med 2006;55(5):974-978.

Pfefferbaum A, Adalsteinsson E, Bell RL, Sullivan EV. “Development and Resolution of Brain Lesions Caused by Pyrithiamine- and Dietary-Induced Thiamine Deficiency and Alcohol Exposure in the Alcohol-Preferring Rat: A Longitudinal Magnetic Resonance Imaging and Spectroscopy Study” Neuropsychopharmacology 2006. (e-publication ahead of print)

Pfefferbaum A, Adalsteinsson E, Sullivan EV. “Supratentorial profile of white matter microstructural integrity in recovering alcoholic men and women” Biol Psychiatry 2006;59(4):364-372.

Pfefferbaum A, Adalsteinsson E, Sullivan EV. “Dysmorphology and microstructural degradation of the corpus callosum: Interaction of age and alcoholism” Neurobiol Aging 2006;27(7):994-1009.

Schulte T, Chen SH, Muller-Oehring EM, Adalsteinsson E, Pfefferbaum A, Sullivan EV. “fMRI evidence for individual differences in premotor modulation of extrastriatal visual-perceptual processing of redundant targets” Neuroimage 2006;30(3):973-982.

Sullivan EV, Adalsteinsson E, Pfefferbaum A. “Selective Age-related Degradation of Anterior Callosal Fiber Bundles Quantified In Vivo with Fiber Tracking” Cereb Cortex 2006;16(7):1030-1039.

### Journal Articles, Submitted for Publication

Kawin Setsompop, Lawrence L. Wald, Vijayanand Alagappan, Borjan Gagoski, Franz Hebrank, Ulrich Fontius, Franz Schmitt, Elfar Adalsteinsson, “Parallel RF Transmission with 8 Channels at 3 Tesla,”

### Meeting Papers, Published

Alagappan V, Wiggins G, Potthast A, Setsompop K, Adalsteinsson E, Wald L., “An 8 Channel Transmit Coil for Transmit Sense at 3T”. Proceedings 13th Scientific Meeting, International Society for Magnetic Resonance in Medicine 2006:121.

Fontius U, Baumgartl R, Doerfler G, Adalsteinson E, Alagappan V, Gagoski B, Fischer D, Hebrank F, Jeschke H, Kannengießer S, Kwapil G, Nerreter U, Nistler J, Pirkl G, Potthast A, Boettcher U, Schor S, Setsompop K, Adriany G, Stoeckel B, Roell S, Wald L, Schmitt F., “A flexible 8-channel RF transmit array system for parallel excitation.” Proceedings 13th Scientific Meeting, International Society for Magnetic Resonance in Medicine 2006:127.

Mayer D, Adalsteinsson E, Rutt B, Pfefferbaum A, Zahr N, Sullivan E., “In Vivo Diffusion Tensor Imaging of Rat Brain Acquired with a 3T Clinical MRI System and a High Strength Insert Gradient Coil.” Proceedings 13th Scientific Meeting, International Society for Magnetic Resonance in Medicine 2006:1057.

Setsompop K, Wald L, Alagappan V, Gagoski B, Hebrank F, Fontius U, Schmitt F, Adalsteinsson E, Triantafyllou C. “2D and 3D Parallel RF Pulse Design for Inhomogeneity Correction and Volume Localization” Proceedings 13th Scientific Meeting, International Society for Magnetic Resonance in Medicine 2006:3011.

Setsompop K, Wald L, Gagoski B, Alagappan V, Hebrank F, Fontius U, Schmitt F, Adalsteinsson E., “Parallel RF Excitation Design and Testing with an 8 Channel Array at 3T” Proceedings 13th Scientific Meeting, International Society for Magnetic Resonance in Medicine 2006:3014.

Sullivan E, Adalsteinsson E, Pfefferbaum A. “White matter integrity quantified with diffusion tensor imaging and fiber tracking in normal aging and chronic alcoholism” In:International Neuropsychological Society. Boston, MA, USA, 2006.

**Book Chapters, Accepted for Publication**

Wald LL, Adalsteinsson E “Parallel excitation techniques for ultra high-field MRI”, in "Parallel imaging in clinical MR applications” Springer Verlag, Series: Medical Radiology, Subseries Diagnostic Imaging, O. Dietrich, S Schoenberg, M Reiser Eds. 2006 ISBN: 3-540-23102-1. Available Nov 15, 2006.