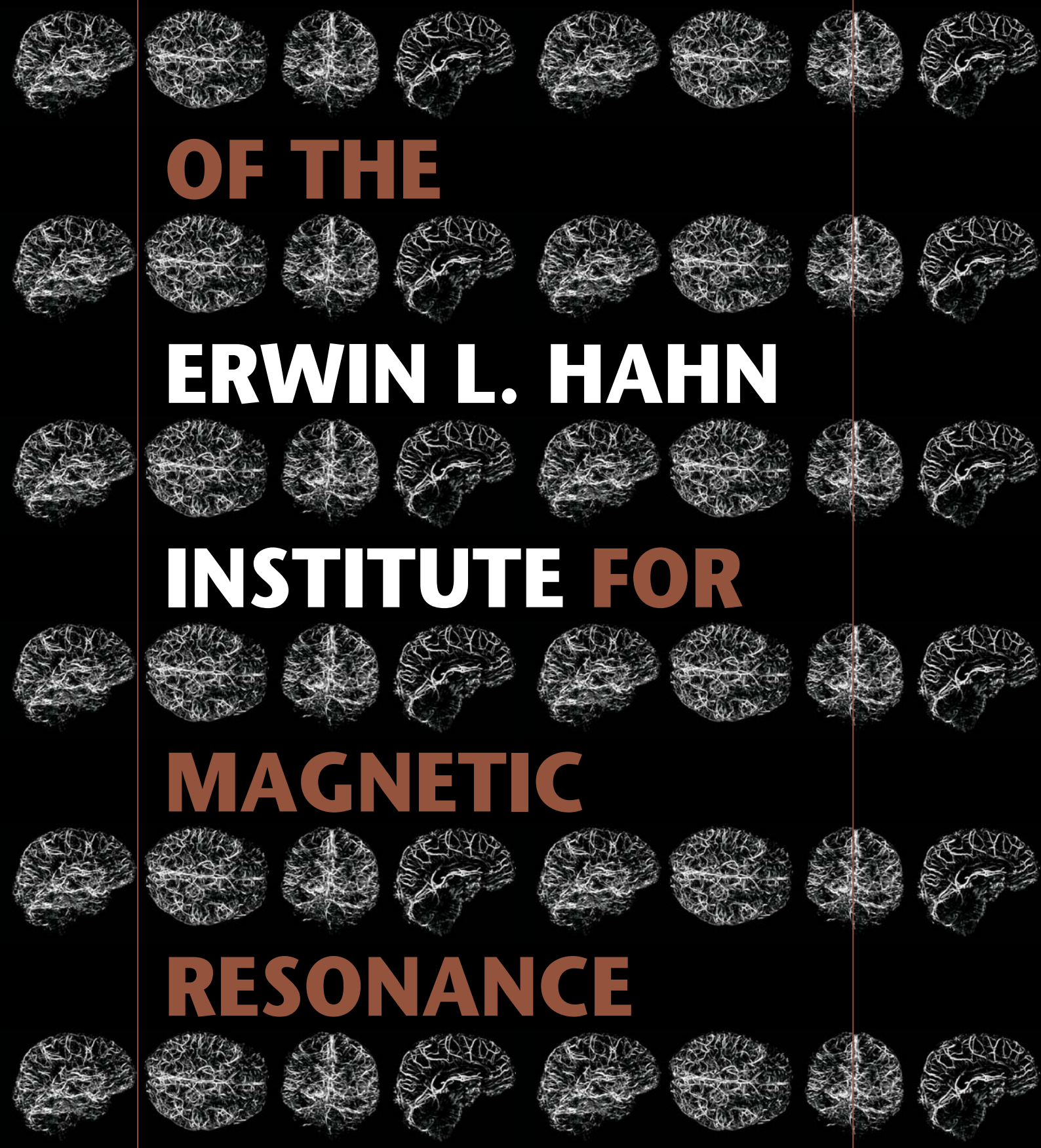
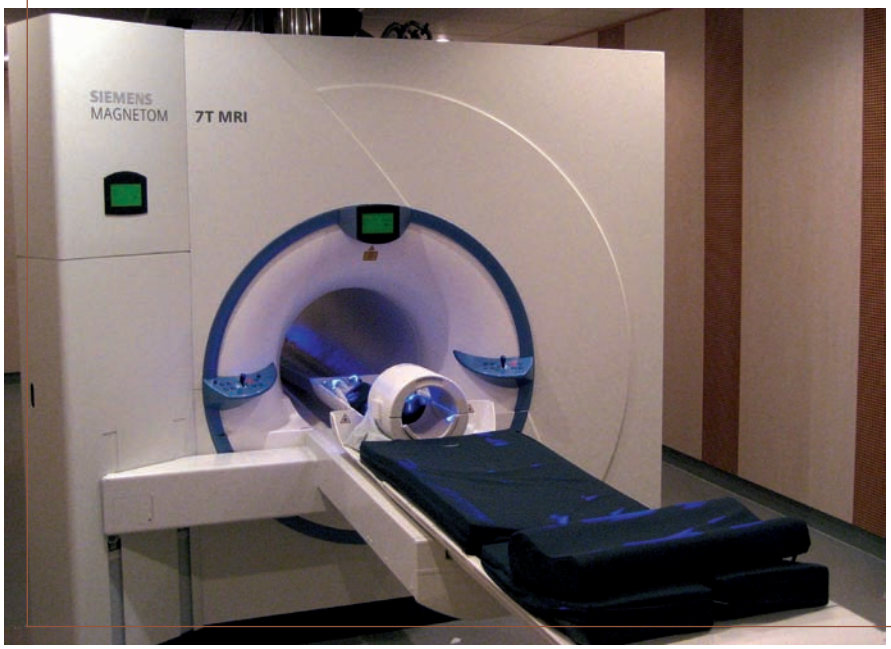
# ANNUAL REPORT OF THE ERWIN L. HAHN INSTITUTE FOR MAGNETIC RESONANCE IMAGING

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# Preface

In our first yearly report of the Erwin L. Hahn Institute we hope to give you a flavour of the current activities in our new centre. At the present stage of development of 7T MRI, methodological developments and the exploration of basic contrasts are still central to our activities. The first report shows the sensational contrast in the hippocampus that can be obtained at 7T, something that will certainly lead to numerous applications. Our second highlighted activity shows stunning images of the brain obtained using the intrinsic contrast of venous deoxyhaemoglobin. The final report documents the progress made in one of our central activities, development of a whole-body coil for human imaging, without which 7T will be restricted solely to neurological applications and the extremities..
The list of publications and running grants shows a high level of activity at the Institute and gives promise for future years. In terms of numbers the Institute continues to grow, with the number of new arrivals clearly exceeding the number departing. One departure however deserves special mention, Prof. Edgar Heineken, one of the founding directors retired in October 2008: we shall miss his contribution, and wish him a long and happy retirement.

*David G. Norris* *Mark E. Ladd*

Essen, October 2008.

# Brain Imaging

*The Human Hippocampus Revealed*

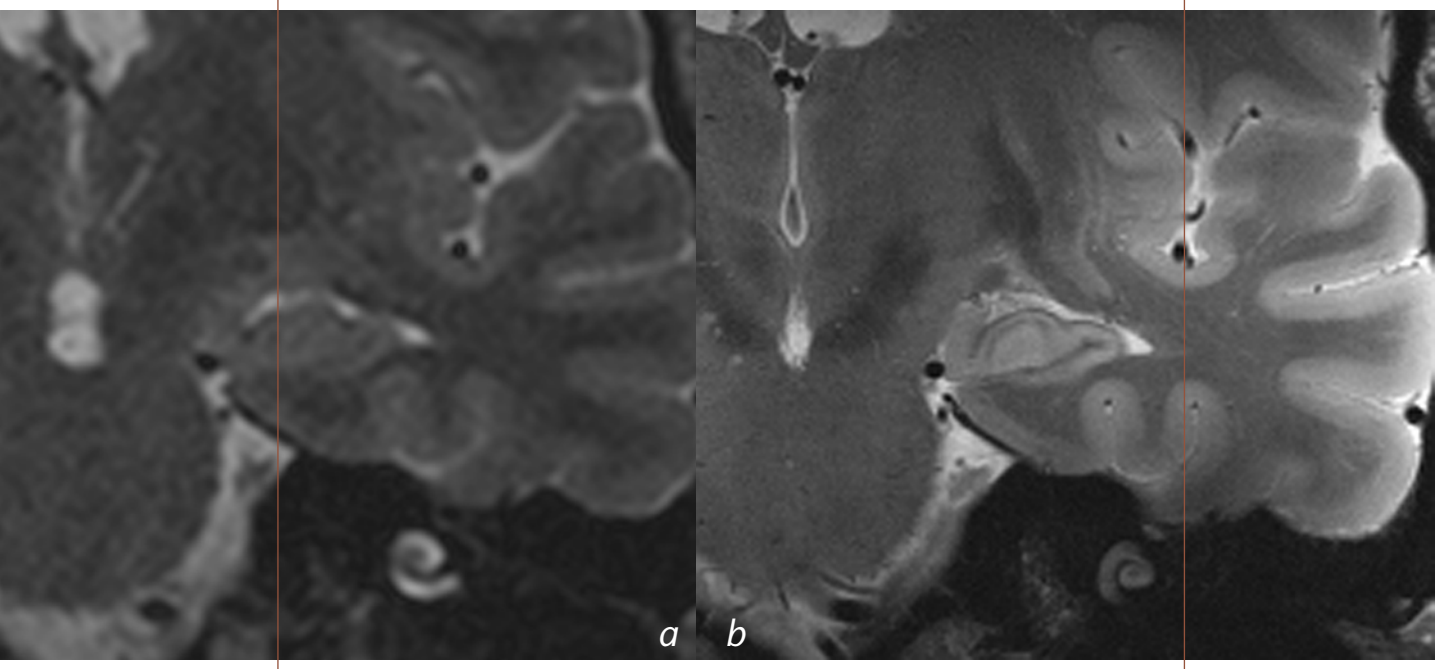



*Fig. 1: Comparison of 1.5T (a) and 7T (b) images with $T_2$ contrast in the temporal lobe of two different subjects.*

**WORKING with one of the world's first human 7 Tesla scanners has led us to explore the depths of the brain, seeing fine structures in a way not previously possible. But just how large is the advantage at 7T, and how much can we really see? Clinically, hopes are high to enhance detail or to detect more subtle changes than before. We focused on an essential yet complex substructure of the brain's neuronal network: the hippocampus.**

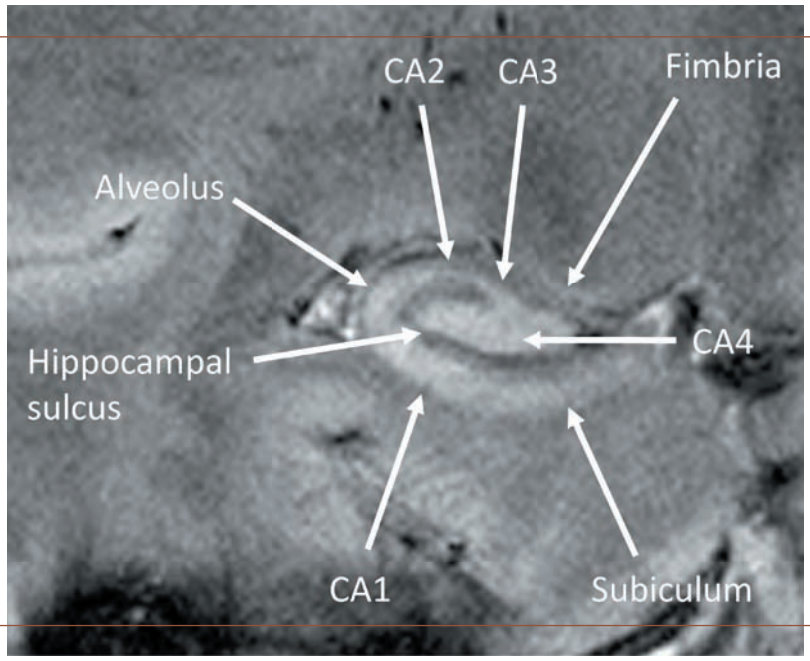



*Fig. 2: Hippocampal anatomy; coronal $T_2$* at 7T.*

The human hippocampus is part of the limbic system, located bilaterally at the base of the brain, and mainly involved in short-term memory processing and spatial navigation. Variations are known to be linked to handedness, gender, age, and IQ, and pathological changes are related to a variety of medical conditions (epilepsy, Alzheimer's dementia, dementia with Lewy bodies, vascular dementia, mild cognitive impairment, schizophrenia). Using 7T to solve clinical questions which cannot be answered with current diagnostic methods is one of the main goals of the Erwin L. Hahn Institute.

We started the project with the goal to get the most out of 7T, which in our case meant acquiring high contrast structural images of the hippocampus at ultra high resolution. The most obvious distinguishing property of 7 Tesla MRI is the gain in sensitivity. The theoretical benefit derived versus clinical 1.5T imagers is a signal boost by a factor of 4.7; this signal improvement is surpassed in appeal only by exciting changes in image contrasts that have been observed at higher magnetic fields. Since "everything is different at 7T", many imaging parameters had to be adapted and optimized, starting off with settings optimal for standard MRI and optimizing them for 7T. Furthermore, we needed to learn about and to counteract limitations arising from the changed physics at higher field.

The results, which were recently published in the journal Hippocampus, reflect our success in utilizing the advantages while controlling the challenges: ultra high resolution images were acquired (7T/1.5T comparison, see Fig. 1); new contrasts provided micro-anatomic delineation of hippocampal substructures: cornu ammonis (regions CA 1-4), hippocampal sulcus, alveolus, subiculum, and fimbria (see Fig. 2); and multi-channel transmit/receive radiofrequency coils enabled better utilization of the inherent advantages at ultra high field.

For the hippocampal region in particular, and moreover for neuroradiological questions in general, high-field MRI at 7T provides a promising perspective in the evaluation of a broad variety of neuropsychiatric disorders, especially in cases that today are not diagnosable at 1.5T but are nevertheless assumed to be linked to structural changes.

# Susceptibility Weighted Imaging

*A New Window On The Brain*

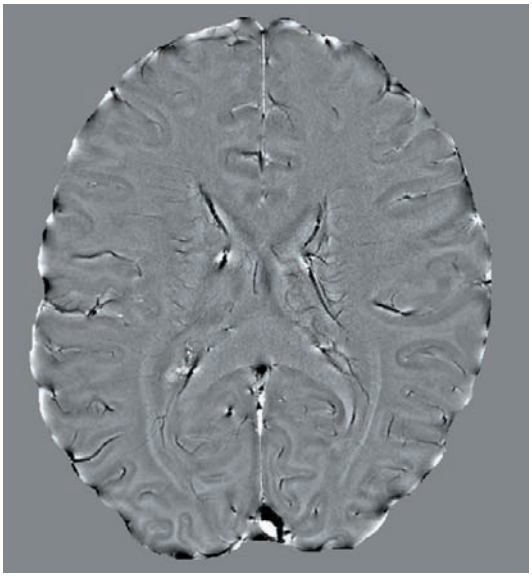
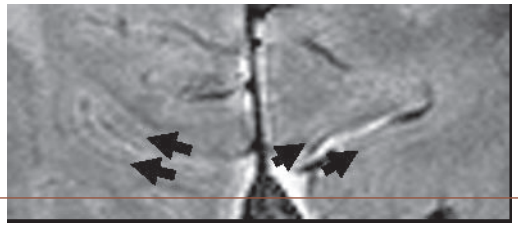


*Fig. 3: Axial brain slice depicting the MR phase that reveals the information about magnetic susceptibility of different tissues such as veins and iron-carrying tissues. This slice was taken from a 3D data set which was acquired with a resolution of 0.22x0.22x1 mm³ within 13 minutes. The whole slice is shown above, the picture below shows the region around the calcarine sulcus with the stripe of Gennari highlighted by the arrows.*



**THE strong susceptibility gradients present at 7T are often seen as a disadvantage, but in this project the resulting strong $T_2$* contrast is utilized both to obtain images of the vasculature and to delineate fine structures in the cortex that are difficult to detect at lower field strengths.**

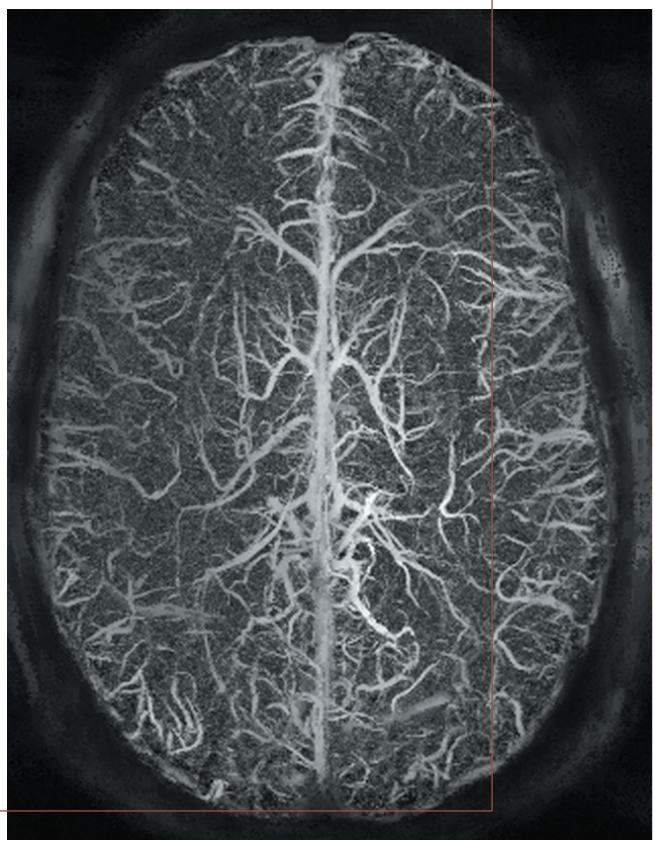


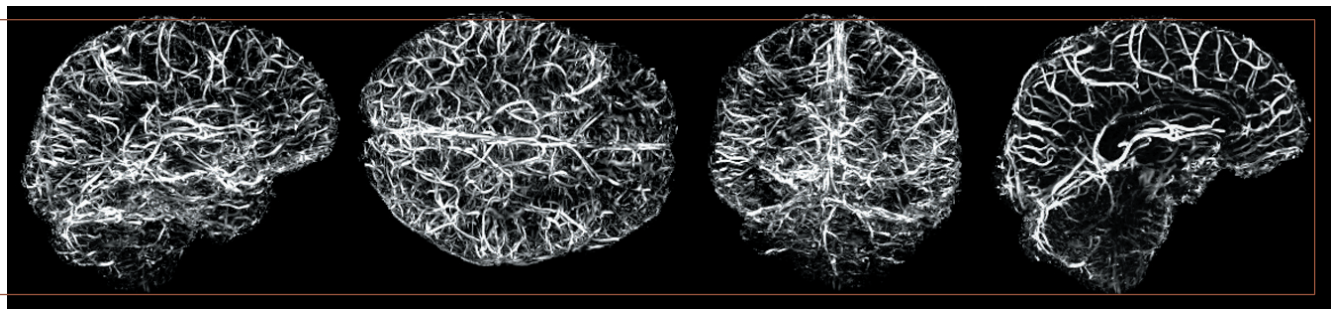
*Fig. 4: Whole brain MR venogram at 7 Tesla using minimum intensity projection.*

*Fig. 5: Projections of a 3D data set where veins were classified using vessel filters which makes it possible to perform visualization from all angles. The first three images show whole brain maximum intensity projections in sagittal, axial, and coronal direction, the last image a projection over a few slices surrounding the interhemispheric fissure.*

*Peter Koopmans*
*Markus Barth*

Susceptibility weighted imaging (SWI) can be described as a method that uses both the $T_2$*-weighted magnitude information and the generally unused MR phase information. SWI employs a long echo time to enhance $T_2$* and phase contrast. It needs a 3-dimensional acquisition and high spatial resolution to reduce the influence of the inhomogeneities of the main magnetic field and those of the head itself, which is challenging at 7 Tesla. The short $T_2$* of tissue and venous blood and the abundant signal at this high field strength allow for a short echo time and a very high resolution of 200 micrometers in-plane. Because the whole voxel is affected by the SWI contrast, veins as small as around 100 micrometers – such as the intracortical veins – can still be seen. Despite this very high spatial resolution the acquisition time is only 13 minutes when accelerated by parallel imaging.

MR venography based upon susceptibility weighted imaging can depict the veins with excellent detail by using the MR phase and magnitude [Fig. 3, top]. Furthermore, using the phase information and the higher contrast at 7 Tesla, we could depict the laminar structure of the cortex [Fig. 3, bottom]. While visualization of the venous vascular tree using minimum intensity projections over several slices works quite nicely [Fig. 4], this approach does not classify veins, which can be necessary for advanced visualization and to remove veins from high-resolution functional MRI scans. In a further study we assessed the performance of two such filters known from angiography: the Utrecht vesselness filter and vessel enhancing diffusion. The higher field strength proved to be beneficial for MR venography because it allowed a higher spatial resolution and shorter measurement times compared to lower field strengths [Fig. 5]. SWI has also been shown to provide additional information in certain pathologies of the brain such as tumours, trauma, stroke, cavernomas, and microbleeds. We are currently exploring the potential to use the phase information as a disease marker for diseases such as Parkinson's disease which can cause altered iron concentrations in some parts of the brain.



*Whole-Body Imaging At 7 Tesla*

# The Big Picture

**7 Tesla has thus far shown dramatic first results in the brain, revealing new aspects of brain structure and function. Can these advantages be applied outside the brain? A midterm goal of the research at the Erwin L. Hahn Institute is to enable MR imaging and spectroscopy at 7T in body regions not currently assessable with the technology, so that the benefits of 7 Tesla can be evaluated for clinical use in these areas. The goal of a key research project is the development of a whole-body excitation coil.**

Compared with lower field strengths, the higher signal of 7T should provide improved spatial resolution for morphologic imaging and higher sensitivity for depicting functional and metabolic processes. It can thus be expected that 7T can expand the already excellent diagnostic capability of lower field MRI with improved specificity and sensitivity by revealing structural details and tissue contrasts heretofore not achievable. These advantages of high field MR should be made available for disease detection and characterization throughout the entire body.

This research project is thus pursuing the development of:

- multi-channel transmit radiofrequency (RF) coils,
- new approaches for achieving homogeneous excitation through use of multiple transmit channels,
- innovative RF distribution networks, and
- strategies for marketing the project results.

For excitation of hydrogen protons in water and fat at 7T, radiofrequency energy at 300 MHz is required. At this frequency, the corresponding wavelength in body tissue is on the order of the dimensions of the human body. As a result, interferences in the RF field inside the body can result, leading to a strongly non-uniform excitation of the protons and thus to inhomogeneous contrast and signal distribution in the images [Fig. 6]. These interferences are more severe in body regions with larger extent. Therefore, the utility of high-field MRI is currently mainly limited to the head and extremities, i.e. anatomical regions with limited dimension. A body excitation coil, which is a standard MR system component at lower field strengths, is not available at 7T. The multi-channel transmit coil to be developed in this project, along with new strategies for driving the coil with independent RF pulses, should enable a homogeneous contrast even within large body regions such as the abdomen and thorax.

The development of the coil hardware is being pursued with the aid of numerical electromagnetic simulations that simultaneously minimize the absorption of high

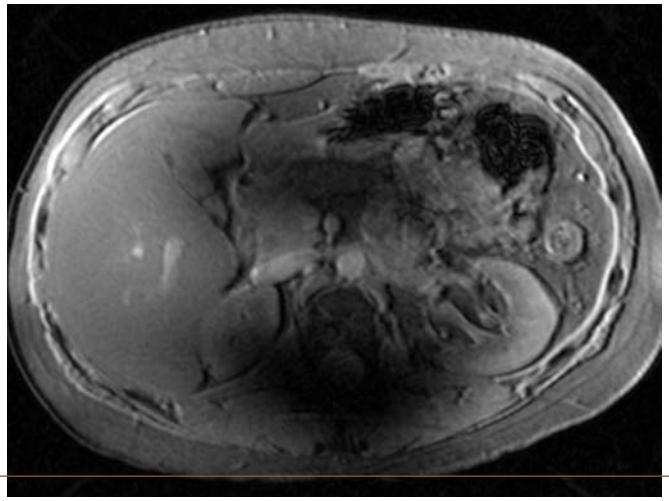


*Fig. 6. Inhomogeneous excitation in a cross-section of the abdomen at 7 Tesla using a conventional, circularly-polarised excitation coil.*

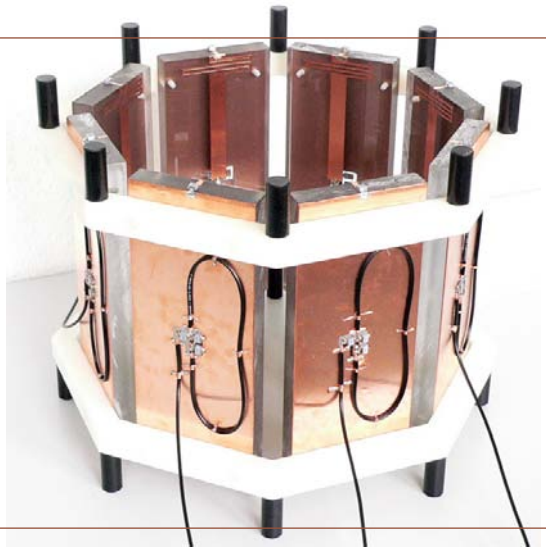


*Fig. 7. Eight-channel head coil as a testbed for multi-channel excitation strategies.*

frequency energy in the patient tissue. A prototype coil is shown in Fig. 7. Radiofrequency distribution networks are being developed to drive the coil which allow flexible power combination and individual control of each coil channel. The system control software will implement algorithms for achieving homogenous spin excitation over large anatomic regions. Primarily, this is achieved by optimizing the complex amplitude of each individual channel (RF shimming) and by adjusting the RF pulse form of each channel (Transmit SENSE). Especially Transmit SENSE provides a flexible tool for selectively exciting targeted areas within a larger field of view and for shortening the required time for applying multidimensional RF pulses.

Successful completion of the project would enable the exploitation of high field advantages throughout the entire body for obtaining improved diagnostic capability and accuracy. It is hoped that pathological changes such as tumours and arterial wall irregularities can be detected earlier and their possible health impact better characterized.

*This project is supported under grant 01EZ0714, which is financed by the German Federal Ministry of Education and Research (BMBF) and administered by the German Aerospace Center (DLR). Members of the project consortium are: IMST GmbH; University Hospital Essen, Radiology; University Duisburg-Essen, High Frequency Engineering; Tomovation GmbH; and Siemens Healthcare.*

# Current Grants

Winterhager E, Gruemmer R, Ladd ME. Effects of repeated exposure to strong static magnetic fields from magnetic resonance imagers on the endpoints reproduction and development in an animal model. German Federal Office for Radiation Protection; duration: 3 years (April 2008 – March 2011)

Timmann D, Ladd ME, Gizewski E. Structural and functional magnetic resonance imaging of the cerebellum at 7 Tesla. German Research Foundation; duration: 2 years (August 2007 – July 2009)

Bahr A, Ladd ME, Solbach K, Lehmkuehler O. 7-Tesla MRI body coil – multichannel transmit techniques and strategies for high-field magnetic resonance imaging. German Federal Ministry of Education and Research; duration: 3 years (July 2007 – June 2010)

Ladd ME, Forsting M, Ladd SG. Prevalence, co-morbidity and risk factors of non-Alzheimer dementia. Jackstädt Foundation; duration: 2 years (October 2005 – September 2007)

# Personnel

New in 2008
Dr. rer. nat. Beate Fraß
Janine Grootfaam
Dr. med. Daniela Häntzschel
Dr. med. Christina Heilmaier
Manuela Mondry
Dr. med. Kasja Rabe
Markus Thürling

Left in 2008
Prof. Dr. Edgar Heineken
Andrea Klabuhn
Stefan Kruszona
Dr. med. Jens Theysohn

# Publications


Theysohn JM, Kraff O, Maderwald S, Schlamann MU, de Greiff A, Forsting M, Ladd SC, Ladd ME, Gizewski ER. The human hippocampus at 7T – In vivo MRI. Hippocampus. 2008 Aug 25. [Epub ahead of print].

Welsch GH, Mamisch TC, Hughes T, Zilkens C, Quirbach S, Scheffler K, Kraff O, Schweitzer ME, Szomolanyi P, Trattnig S. In vivo biochemical 7.0 Tesla magnetic resonance: preliminary results of dGEMRIC, zonal $T_2$, and $T_2$* mapping of articular cartilage. Invest Radiol. 2008 Sep;43(9):619-26.

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Gizewski ER, de Greiff A, Maderwald S, Timmann D, Forsting M, Ladd ME. fMRI at 7T: whole-brain coverage and signal advantages even infratentorially? Neuroimage. 2007 Sep 1;37(3):761-8. Epub 2007 Jun 14.

Ladd ME. High-field-strength magnetic resonance: potential and limits. Top Magn Reson Imaging. 2007 Apr;18(2):139-52. Review.

Graphic design
Sander Hermsen Visuele Communicatie
www.sander-hermsen.nl

Print
Thieme MediaCenter, Nijmegen, Netherlands

Photography
All images © Hahn Institute


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