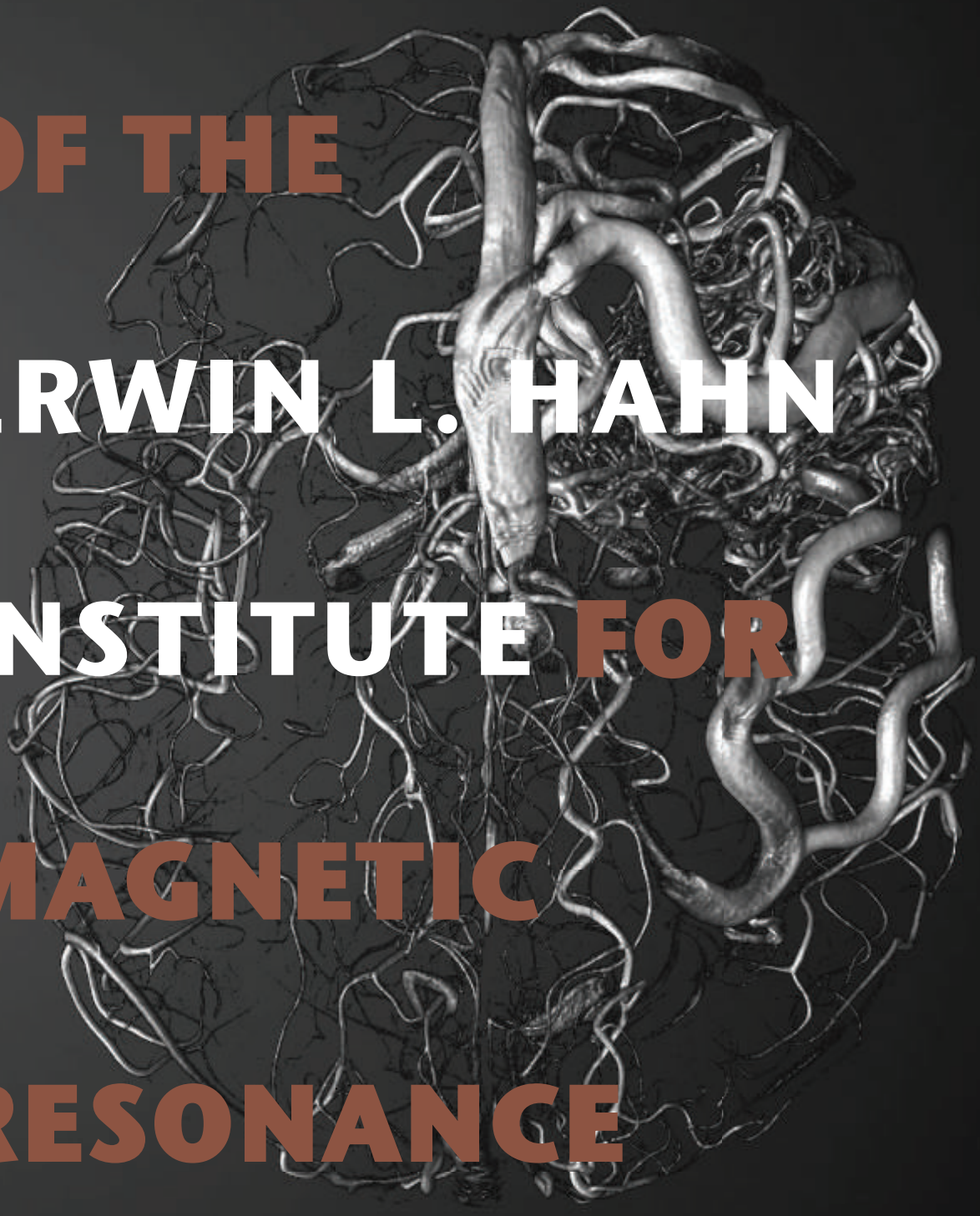
ANNUAL REPORT OF THE ERWIN L. HAHN INSTITUTE FOR MAGNETIC RESONANCE IMAGING



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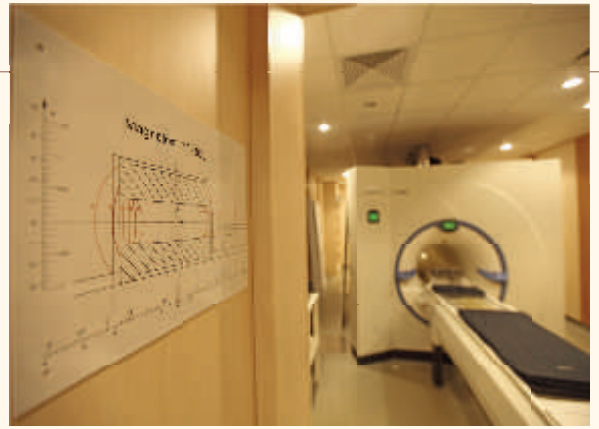

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Preface

2014 was a year of continued development at the Erwin L Hahn Institute. The arrivals of Harald Quick, as a new PI, and the director from the medical faculty, and of Ulrike Bingel also as a PI from the medical faculty meant that we have now reached our full complement of PIs. This combined with the close collaboration with the group of Dagmar Timmann Braun and the continued participation of Mark Ladd has given fresh impetus to our research activities.

The Institute also continues to receive marks of recognition, the highlight of which was the visit of Hannelore Kraft, Prime Minister of the Federal State of North Rhine-Westphalia, and of Mark Rutte, Prime Minister of the Netherlands. The politicians were accompanied by the rector of the University Duisburg-Essen and the President of the Radboud University Nijmegen. Both politicians showed great interest in the presentations given, and were daring enough to go into the scanner room and view the 7 Tesla system at first hand.

The usual process of academic life has continued, with staff joining and leaving. The major departure being that of Beate Fraß, our first administrative director, who was instrumental in setting up many of our internal structures, and for keeping the finances on an even keel.

The Erwin L Hahn lecture of 2014 was given by Arend Heerschap of the Radboud University who gave an illuminating lecture entitled 'MR spectroscopy: from insight to impact'. This was the highlight of a day-long meeting devoted to in vivo spectroscopy and nuclei other than protons. At which Stephan Orzada also received the Erwin L Hahn prize for his outstanding thesis.

We look forward now to what 2015 will bring and I would like to wish Harald Quick every success in taking over from me as managing director for the coming two years. We also hope that you enjoy reading this brief summary of our research activities and will continue to be interested in the activities of the Erwin L Hahn Institute.

David Norris
Essen, March 2015

Biosketch

Harald H. Quick, PhD

Academic education

- 1996 MSc, Biomedical Engineering, University of Applied Sciences, Aachen, Germany
- 2002 PhD, Medical Sciences, University of Duisburg-Essen, Essen, Germany
- 2004 Habilitation in MR Physics, University of Duisburg-Essen, Germany
- 2009 Full Professor (W2), MR Imaging, University of Erlangen-Nurnberg, Germany
- 2014 Full Professor (W3), High Field and Hybrid MR Imaging, University of Duisburg-Essen

Fig.1: Harald H. Quick, PhD

Academic positions

- 1995-1996 Diploma student, Institute of Molecular Biophysics, Radiopharmacy, and Nuclear Medicine, Heart and Diabetes Center NRW, Bad Oeynhausen, Germany
- 1996-1999 Scientist, MR Center, Department of Diagnostic Radiology, University Hospital Zurich, Zurich, Switzerland
- 1999-2000 Scientist and Faculty, Department of Radiology and Radiological Sciences, Johns Hopkins University, Baltimore, MD, USA
- 2000-2004 Scientist and PhD Student, Department of Radiology, University Hospital Essen, University of Duisburg-Essen, Germany
- 2004-2009 Senior Scientist, Department of Radiology, University Hospital Essen, University of Duisburg-Essen, Germany
- 2006-2009 Senior Scientist, Erwin L. Hahn Institute for MRI, University of Duisburg-Essen, Germany
- 2009-2014 Director MR Imaging, Institute of Medical Physics, University of Erlangen-Nuremberg, Germany
- Since 2014 Director Erwin L. Hahn Institute for MRI, University of Duisburg-Essen, Germany, Director High Field and Hybrid MR Imaging, University Hospital Essen, Germany

Further activities

- 2000-2010 Founder and CEO of MR Innovation GmbH, Essen, Germany
- 2009-2014 Deputy Chairman of the Promotions Committee, Medical Faculty, University of Erlangen-Nuremberg, Germany
- since 2012 Deputy Editor of EJNMMI Physics
- since 2010 President of the German Chapter of the ISMRM

Research areas

- Ultra high field MR imaging - methods and hardware development
- Hybrid MR imaging (PET/MR) - methods and hardware development
- Development of hardware components and radiofrequency (RF) coils
- Development of clinical high field and hybrid whole-body MR imaging applications
- MR imaging safety

Harald Quicks' research focuses on developments of new methods, hardware components, and clinical whole-body imaging applications in ultra-high field MR and hybrid MR imaging (PET/MR). At the junction of new technical developments and early clinical applications his research team works in close collaboration with the medical imaging partners from Radiology, Nuclear Medicine, Neuro Surgery, Cardiology and other disciplines relying on MR imaging expertise.
In February 2014 Harald Quick (re)joined the Medical Faculty of the University of Duisburg-Essen as Professor for High Field and Hybrid MR Imaging. This position is associated with heading two sites: Director of the Erwin L. Hahn Institute for MRI (succeeding Mark Ladd), located at the grounds of UNESCO World Heritage Zeche Zollverein, Essen, and Head of High Field and Hybrid MR Imaging, located at the University Hospital Essen.
With regards to the 7 Tesla high-field activities at the ELH, Quick's group develops methods and technologies to enable clinically oriented high-field MRI studies. More specific the following high-field MRI research topics are in the focus: whole-body MR imaging applications, cardiovascular and MR angiography applications, development of hardware components and RF coils, and safety of high-field MR imaging.
Against this backdrop, a new body/cardiac 8-ch transmit/32-ch receive RF coil is currently being simulated and built to support 7T MR body imaging of the abdomen and the heart. This RF coil will be connected to the ELH proprietary RF chain and can be used in conjunction with the TIAMO method for B1 shimming and signal homogenization [1]. Connection to the Siemens pTx system will also be an option. As soon as the EU-grant funded MRexcite project multi-channel transmit/receive RF hardware developed by Mark Ladd's group is fully operational at the ELH, this RF coil can also be used in conjunction with the MRexcite hardware to fully exploit B1-shimming and imaging capabilities. Furthermore, designing, testing, and applying new multichannel RF coils for various high-field body MR imaging applications are under continuous development [2,3]. These developments also serve to support the clinical research activities of current and future IFORES stipendiaries [4,5].
With regards to the hybrid MR imaging activities in the field of integrated PET/MR, Quick's research group was the world's first research group with access to an integrated PET/MR system (Biograph mMR, Siemens AG) and had the opportunity to support the transfer of this new hybrid technology into the clinic [6,7]. The research focus here is on emerging technical developments and clinical applications. More specific, MR-based attenuation correction (AC) of patient tissues [8] and hardware components [9], motion correction (MC), dose reduction [10], and development of PET-transparent RF coils [9] are only some examples for the current PET/MR research activities of Quick's group in close collaboration with the industrial partner and with the Departments of Radiology and Nuclear Medicine at the University Hospital Essen.
Harald Quick's future work at the ELH will focus on the development and refinements of new methods and technology to enable and support early clinical applications and the application of 7-Tesla high-field MR to neuro and body imaging. In this context, close collaboration with Mark Ladd's MRexcite project but also with the other PIs and clinical IFORES stipendiaries at the ELH is center to Quick's activities at the ELH.

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Biosketch

Present academic position

- Professor for Functional Brain Imaging, University Clinic Essen, University Duisburg-Essen, Germany
- Head of the Interdisciplinary Pain Clinic, Department of Neurology, University Clinic Essen, University Duisburg-Essen, Germany
- Principle Investigator Erwin L. Hahn Institut

Fig. 2: Ulrike Bingel, MD

Education and academic positions

- Study of Medicine, University of Essen (1994-2000) and Queen Square Hospital, London (2000)
- Residency training Program of Neurology, University of Hamburg (2001-1008)
- Board Qualification Neurology (2008)
- Visiting postdoctoral research fellow, Pain Group, FMRIB, University of Oxford (2008/2009)
- Attending of Neurology and research group leader of BMBF funded neuroscience group (2009)
- Habilitation and Venia Legendy for Neurology 2010

Further activities

- since 2012 Science Board of the German Association for the Study of Pain

Research area

- Information processing in the nociceptive system
- Neurobiology of pain-cognition interactions
- Neurobiology of placebo and nocebo phenomena
- Interaction of cognition and drug action

Ulrike Bingel's research focuses on the interface between pain processing of the central nervous system and cognitive neuroscience. A major interest is the neurobiology pain. Specifically her group studies the underlying mechanisms of an individual's pain sensitivity, susceptibility for pain chronification and ability to modulate pain under distinct contextual circumstances. Ulrike Bingel's group investigates these mechanisms using functional and structural brain imaging in combination with pharmacological and psychophysical approaches in healthy volunteers and in patient groups suffering from chronic pain or neurological disorders frequently associated with pain, such as Parkinson's Disease. As part of this research focus her group also investigates the detrimental effects of acute and chronic pain on cognitive processes which represents a major complaint in patients suffering from pain. By using fMRI she has revealed underlying neural mechanisms of this "interruptive effect of pain" as well as mediating and moderating variables [2; 8].

Another strand of research is dedicated to study the neurobiological mechanisms of placebo- and nocebo responses and their contribution to active medical treatments. Her work has revealed critical insights into the contribution of pain modulatory mechanisms involving endogenous opioidergic activity in the descending pain modulatory system to placebo analgesia [1; 4; 5; 11]. As part of this research she has also used spinal cord fMRI to show that these cognitively triggered top-down mechanisms even impact nociceptive information processing at the level of the dorsal horn of the spinal cord [6].

Recently, her group has moved on to study the contribution placebo mechanisms (expectation and associative learning) to the efficacy and tolerability of active pharmacological treatments.

Together with Prof. Irene Tracey (FMRIB Centre, Oxford) she revealed that expectation crucially modulates analgesia to the potent opioid remifentanil. By using pharmacological fMRI in combination with verbally induced expectancy modulation she discovered how cognitive mechanisms combine and interact with drug action at the neurobiological level [3].

In another study she showed how treatment experiences with a medical treatment modulate the response to subsequent medical treatments at the behavioural and neural level [10]. Current investigations are dedicated to understand interindividual differences in placebo responsiveness [12] and how to exploit placebo responses in combination with pharmacological treatments to optimize overall treatment outcome [7; 9]

Ulrike Bingel' work at the ELH will focus on high resolution imaging of the brainstem and ideally the spinal cord, to further elucidate the contribution of distinct subcortical circuitry and the spinal cord to pain and pain modulation in health and disease. The collaboration with David Norris and Dagmar Timmann at the ELH represents an ideal situation to push forward these necessary methodological techniques.

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Biosketch

Fig. 3: Dagmar Timmann, MD

Academic education

- 1988 MD, University of Tübingen, Germany
- 1990 Dr. med., University of Tübingen
- 1996 Specialist in Neurology
- 1998 Habilitation with the venia legendi for Neurology, University of Essen, Germany

Academic positions

- 1989-1993 Intern/resident Department of Neurology, University Clinic Essen, Germany
- 1993-1994 Postdoc at the Arizona State University (Dr. G. Stelmach), Tempe, and Barrow Neurological Institute (Dr. J. Bloedel), Phoenix, Arizona, USA
- 1994-1995 Postdoc at the R.S. Dow Neurological Sciences Institute (Dr. F. Horak), Portland, Oregon, USA
- 1995-1997 Resident Department of Neurology, University Clinic Essen
- 1998-1999 Postdoc at the University of Western Ontario, Department of Physiology (Dr. J. Hore), London, Ontario, Canada
- since 2000 Associate Professor (C3) of Experimental Neurology, Department of Neurology, University Clinic Essen
- 2006 Visiting Scientist at the University of Western Ontario, Department of Physiology (Dr. J. Hore), London, Ontario, Canada
- 2011 Visiting Scientist at the Human Sensorimotor Control Laboratory (Dr. J. Konczak), University of Minnesota, USA

Further activities

- since 1997 Medical advisory board, German Heredo-Ataxia Society
- since 2000 Head of the Ataxia Clinic, Department of Neurology, University Clinic Essen
- since 2006 Deputy chairman of the Human research ethics committee, University Clinic Essen
- 2007-2012 Treasurer, Society for Research on Cerebellum

Research area

Dagmar Timmann's research group is interested in the physiology and pathophysiology of the human cerebellum. A major interest is the involvement of the human cerebellum in different forms of motor learning. One focus are classical human cerebellar lesion studies. Behavioral changes are assessed in patients with defined cerebellar pathology, and findings are correlated with lesion side based on high-resolution structural MR images. Another focus are functional MRI studies of the cerebellar cortex and deep cerebellar nuclei.

The main input structure of the cerebellum is the cerebellar cortex, and the main output structure are the deep cerebellar nuclei. In humans, little is known about the function of the cerebellar nuclei, and the interaction between the cerebellar cortex and nuclei. For example, there are controversies whether motor learning primarily takes place within the cerebellar cortex, the cerebellar nuclei or both. Dagmar Timmann's group makes use of the much improved signal to noise ratio at 7T to resolve these questions. 7T MRI is applied to visualize the cerebellar nuclei and to perform reliable fMRI studies of the cerebellar nuclei in humans.

Her research group is working closely together with researchers of the ELH since 2007. Joint studies are supported by the German Research Foundation (DFG). As yet, Dagmar Timmann and Mark Ladd have successfully applied for three grants of the German Research Foundation. Studies are currently funded by the DFG research group "Extinction Learning: Neural Mechanisms, Behavioral Manifestations and Clinical Implications".

Susceptibility weighted-imaging (SWI) is helpful to visualize the cerebellar nuclei in individual subjects. Cerebellar nuclei are seen as signal loss (hypointensities) because of their high iron content (Maderwald et al., 2012). Susceptibility artefacts increase with increasing field strength, allowing for increased spatial resolution. Structural 7T MRI data in a group of healthy subjects has been used to develop a probabilistic atlas of the cerebellar nuclei together with Jörn Diedrichsen at UCL (Diedrichsen et al., 2011). More recently Dagmar Timmann's group has used successfully SWI at 7T to show abnormalities of the cerebellar nuclei in patients with different forms of cerebellar ataxia (Solbach et al. 2014; Stefanescu et al., in revision).

In addition to the use of ultra-high-field 7T MRI the development of optimized normalization methods has made reliable fMRI studies at the level of the dentate nuclei possible (Diedrichsen et al., 2011). Initial studies have focused on the dentate nuclei. Dagmar Timmann's group was able to show that the human dentate nucleus has different functional compartments both in the motor and cognitive domain (Küper et al., 2012; Thürling et al., 2011, 2012).

Very recently her group was able to establish a set-up to perform and record eyeblink conditioning (a simple form of cerebellar dependent motor learning) in the 7T MR scanner in humans using a novel optical approach. This work has been done in collaboration with colleagues from the Department of Neuroscience, Erasmus MC, Rotterdam (Chris de Zeeuw). Furthermore with the help of Jörn Diedrichsen normalization methods were extended from the dentate nuclei to the level of the even smaller interposed nuclei (which are of main importance in eyeblink conditioning). Data of their first eyeblink conditioning study in the 7T MR scanner show that during early acquisition of conditioned eyeblinks fMRI signals increase simultaneously within the cerebellar cortex and nuclei. These findings are consistent with the view that the cerebellar cortex and nuclei contribute to early acquisition in a concomitant and likely ongoing synergistic manner (Thürling et al., in press).

Dagmar Timmann's future work at the ELH will continue to focus on the visualization of the cerebellar nuclei and their abnormalities in cerebellar ataxias. It is planned to establish the more advanced method of Quantitative Susceptibility Mapping (QSM). She will also continue to use the recently developed eyeblink conditioning set up to further understand the specific contributions of the human cerebellar cortex and nuclei not only to the acquisition but also to the extinction of learned motor responses.

References

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Clinical Body Imaging Applications at 7 Tesla

Research activities of our one-year clinical IFORES stipendiaries

Harald H. Quick
Bixia Chen
Juliane Schelhorn
Maria Hahnemann
Johannes Grüneisen
Andrea Lazik

In 2014 five clinical researchers received 12-months of intramural funding of the Medical Faculty, University of Duisburg-Essen (Interne Forschungsförderung Essen, IFORES), to conduct defined clinical research projects using 7T MRI at the Erwin L. Hahn Institute. The following medical doctors and project applications have received a 12-months IFORES stipend in 2014:

- Andrea Lazik, MD, Dept. of Radiology: 7T MRI of hip cartilage; start in July 2014
- Maria Hahnemann, MD, Dept. of Radiology: 7T MR enterography; start in July 2014
- Bixia Chen, MD, Dept. of Neurosurgery: 7T MRI of brain tumors and aneurysms; start in August 2014
- Juliane Schelhorn, MD, Dept. of Radiology: 7T Cardiovascular MRI; start in November 2014
- Johannes Grüneisen, MD, Dept. of Radiology: 7T MRI in cervical cancer; start in October 2013

All IFORES projects reflect efforts and advances to assess and employ the inherent high signal-to-noise ratio (SNR) and the excellent soft-tissue contrast of 7-Tesla MRI to improve spatial resolution and image contrast in selected clinical MR imaging applications. Key motivations in this context are to expand the success of 7T neuro imaging also to body imaging and, furthermore, to explore potentially relevant clinical applications in high-field body MRI.
To achieve these goals, most of the current IFORES projects make use of the ELH-unique radiofrequency (RF) hardware and B1-shimming infrastructure at the ELH consisting of an 8-channel RF transmit/receive system, the capability for signal homogenization with the TIAMO (time interleaved acquisition of modes) method [1,2], and various custom-build multi-channel transmit/receive RF coils [3,4].
The clinical projects start off with feasibility testing and sequence parameter optimization in volunteers, followed by defined studies in patients. Here, 7T MRI with its potential advantages and, otherwise, challenges and limitations is compared in intra-individual comparisons to the respective clinical standard MR method at 1.5 T and/or at 3.0 T magnetic field strength.
The following short descriptions of the year 2014 IFORES projects may provide a brief insight into current and ongoing research with a clinical focus in 7T high field body MRI from the head down to the hip joints.

Bixia Chen: 7T MRI of brain tumors and aneurysms

Project summary

Giant intracranial aneurysms with a diameter larger than 25 mm are rare vascular lesions with a high rupture risk. Subarachnoid hemorrhages from ruptured aneurysms are associated with high morbidity and mortality. Inflammatory processes and intraluminal thromboses are believed to be related to wall degeneration and aneurysm rupture. This study aims to characterize giant intracranial aneurysms with focus on aneurysm wall properties and thickness at 7 Tesla MRI. So far, six patients with giant intracranial aneurysms have successfully been investigated at 7T MRI employing a 32-channel RF head coil (Fig. 4). Ultra-high-field MRI of this rare intracranial vascular pathology can contribute to understanding the complex pathophysiology of aneurysm growth and rupture.

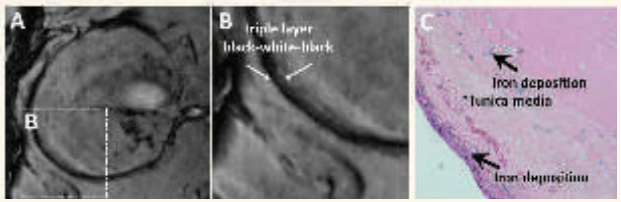

Fig. 4: (A) Intracranial giant aneurysm on susceptibility weighted (SWI) sequence at 7T. (B) Triple-layered aneurysm wall in the magnified SWI image. (C) Histopathology (Prussian blue): Absence of iron staining in the tunica media.

Juliane Schelhorn: Cardiovascular MR imaging at 7T

Project summary

Aortic valve stenosis is the most common cardiac valve disease in the developed countries. It affects mainly the elderly, and an untreated symptomatic aortic valve stenosis has a poor prognosis (annual mortality rate of 25% [5]). The severity of aortic stenosis can be investigated by MRI either by velocity-encoded phase contrast imaging or by planimetry. For planimetry at 1.5T/3T routinely fast gradient echo cine sequences are used because of their high spatial and temporal resolution. This study investigates whether aortic planimetry is improved using 7T MRI, and compares it to aortic valve planimetry at 1.5T/3T. So far, eight healthy volunteers have been examined at 7T employing an 8-channel body RF coil. In five volunteers cardiac triggering was challenging. In three volunteers phonocardiographic sequence triggering worked effectively and, accordingly, first aortic valve images with improved spatial resolution were acquired (Fig. 5). Intra-individual comparison with 1.5T/3T MRI and imaging protocol optimization is still ongoing.

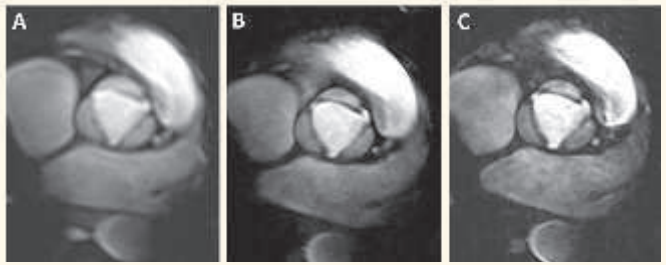

Fig. 5: Aortic valve imaging at 7T field strength. A time-resolved cine-FLASH fast gradient echo sequence with cardiac gating was used to display the three leaflets of the aortic valve in a healthy volunteer with high spatial resolution. Spatial resolution was increased from (A) 1.4 x 1.4 x 4.0 mm^3 to (B) 1.4 x 1.4 x 3.0 mm^3 to (C) 1.4 x 1.4 x 1.5 mm^3. The SNR in (C) was sufficient to progressively reduce the slice thickness for improved delineation of the aortic valve.

Maria Hahnemann: 7T MR Enterography

Project summary

MRI is playing an increasing role in the evaluation of inflammatory bowel diseases and other small bowel diseases, as tumors or bleedings. Although 1.5T is still considered field strength of choice for MRI of the small bowel, improvements in image quality have been recently shown at 3T. The purpose of this study is to implement contrast-enhanced T1-weighted as well as T2-weighted MR imaging of the small bowel at 7T and to compare imaging results with the current standard field strength of small bowel MRI at 1.5T. Contrast-enhanced T1-weighted and T2-weighted MR imaging of the small bowel was performed in 12 healthy volunteers at 1.5T and 7T. Quality of MR images and image impairment by artifacts was directly compared between 1.5T and 7T. Results of this ongoing study are that MR images of the small bowel at 7T can be generated with diagnostic image quality (Fig. 6). Despite an increasing number of artifacts at 7T, tissue contrast and image quality were equivalent as compared with those achieved with 1.5T. This study provides first insights into ultra-high field MRI of the small bowel. Further improvements in B1-shimming are needed to minimize residual B1 inhomogeneities. The possibility of improved detection of pathologic conditions at 7T MRI remains to be seen in studies including patients with small bowel pathologies.

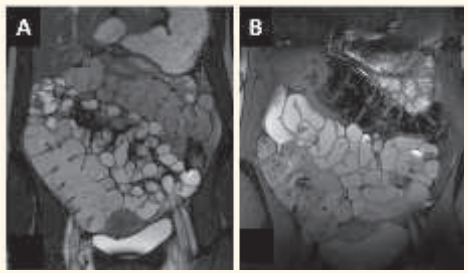

Fig. 6: Coronal TrueFISP images of a healthy volunteer revealing comparable tissue contrast and fine details of the small bowel at 1.5T (A) and 7T (B) field strength. Note the good signal homogeneity across the large abdominal field-of-view in 7T MRI (B).

Johannes Grüneisen: Imaging of cervical cancer at 7T MRI

Project summary

The aim of this study is to compare the diagnostic ability of 3T and 7T MRI for assessment of primary cervical cancer staging. Nine subjects with cervical cancer were examined on a 3T MR system utilizing a 16 channel RF body coil and on a 7T MR system using a custom-built 8-channel RF body coil for imaging [6]. The study protocol for both field strengths comprised T1 and T2-weighted imaging as well as contrast-enhanced dynamic (multi-phase) VIBE imaging. As results both, 3T and 7T MRI, enabled correct identification of the tumor stage in all subjects. Both field strengths provide comparably high-quality assessment of tumor extent, potential infiltration into surrounding tissue and overall image quality (Fig. 7). While 7T T1-weighted 2D FLASH imaging shows superior image sharpness based on improved spatial resolution, 7T T2-weighted MRI remains impaired due to image artifacts.

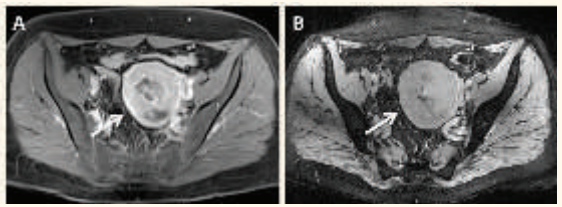

Fig. 7: Images of a 55-year-old patient with locally advanced cervical carcinoma (arrows) after contrast agent administration at 3 Tesla (A: T1-weighted VIBE sequence; spatial resolution: 0.8 x 0.8 x 5.0 mm^3) and with a higher spatial resolution at 7 Tesla (B: T1-weighted FLASH sequence; 0.6 x 0.6 x 2.0 mm^3).

Andrea Lazik: Quantitative MRI of hip cartilage at 7T

Project summary

In this project morphological and quantitative MRI techniques are evaluated for hip cartilage imaging at 7 Tesla and are then applied to patients with acetabular cartilage lesions, treated by autologous chondrocyte transplantation. The hips of 11 healthy volunteers were examined with 7T MRI [7,8], using high-resolution DESS (0.7 mm^3 isotropic, TA 5:12 min) and T1 VIBE (0.4 x 0.4 x 0.8 mm^3, TA 5:57 min) sequences for morphological imaging, multi-contrast sequences with 5 echoes each for T2- and T2*-mapping, and a dual-flip angle technique for T1-mapping prior to and after contrast agent administration. Accurate and reproducible scan-rescan conditions were monitored with a fast B1-mapping technique (DREAM). Until now, four patients were examined using the established contrast enhanced 7T protocol. Images were compared to 3T MRI regarding the delineation of the cartilage transplant resp. residual cartilage defects in the morphological sequences, and regarding relaxation times of the cartilage transplant in the quantitative sequences. Results of the ongoing study are that the delineation of acetabular and femoral cartilage was excellent in T2- and T2*-maps. Contrast agent administration improved cartilage delineation in T1-maps and in T1 VIBE. A comprehensive hip cartilage protocol following intra-venous contrast agent administration is possible at 7T, including morphological sequences as well as T1-, T2-, and T2*-mapping (Fig. 8). First applications of this protocol in patients with hip cartilage transplants show at least equivalent image quality compared to 3T.

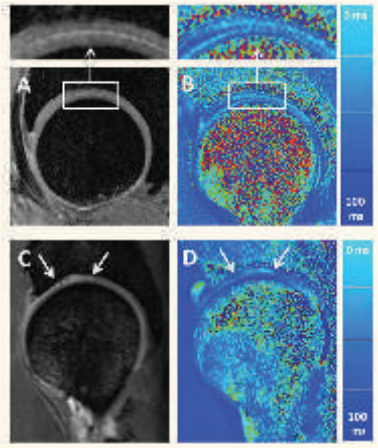

Fig. 8: (A,B) Sagittal 7T MRI of the hip of a healthy volunteer with enlarged views of central cartilage above: (A) contrast enhanced T1 VIBE sequence, (B) T2-map. (C,D): Sagittal 7T hip MRI of a patient with acetabular cartilage transplantation (arrows): (C) T2-map, (D) DESS sequence. Note the hyper intense signal enhancement in the DESS sequence (C) and in the T2-map (D).

Neural correlates of human-robot interaction at 7T

Project summary

In our past and current projects, we were able to show valid task-dependent activity in the aforementioned brain regions, which are known to be prone to distortions and artefacts, even at lower field strengths. The paradigm used in our food study (Grabenhorst et al., 2014), which consists of evaluation trials and decision trials, has been transferred to further research questions. One example is the investigation of the neural correlates of evaluating the humaneness, sympathy and familiarity of robots. In this project, which has been done together with Dr. Astrid Rosenthal-von der Pütten, Dr. Fabian Grabenhorst, and Prof. Dr. Nicole Krämer, we tested the famous Uncanny-Valley-Hypothesis. Results indicate that brains react differentially to humanoid and android robots in comparison to humans, in particular with activity in mediofrontal and temporo-parietal regions, as well as with activities in the precuneus, the fusiform gyrus and the cingulate gyrus (Rosenthal-von der Pütten et al., 2014). In conclusion, humans' brains react stronger with activities in regions known to be involved in mentalizing and theory-of-mind when robots look like humans, although they explicitly know that these robots are machines.

References

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Rosenthal-von der Pütten, A.M., Grabenhorst, F., Maderwald, S., Brand, M., & Krämer, N.C. (2014). Uncanny Valley related behavioral responses are driven by neural processes of face perception. 9th ACM/IEEE International Conference on Human-Robot Interaction.

Abdominal Imaging

Comparison of Fat Saturation Techniques for Single-Shot Fast Spin Echo Sequences for 7T Body Imaging

Sören Johst

Homogenous fat suppression (FS) is crucial for diagnosis in T2-weighted abdominal images. As fat is displayed with high signal intensities in single-shot fast spin echo (SSFSE) sequences, pathologies also producing high signal intensities may be obscured by the bright fat signal. Due to inherent B0 and B1 inhomogeneities, abdominal imaging at 7T is challenging and complete FS is not easily achieved.

In this work, several different FS techniques for SSFSE were compared, whereby the recently proposed Time Interleaved Acquisition of Modes (TIAMO) was used for the imaging portion of the sequence to reduce B1 artifacts.

The first technique, TIAMO FS, uses multiple fat-selective 90° (nominal) RF pulses, each applied with different RF shims followed by spoiler gradients on each axis. Here, six such preparation pulses were chosen alternating between the first- and second-order circularly-polarized modes (CP^+ and CP^{2+}). A sequence diagram of TIAMO FS with TIAMO imaging is shown in Figure 9.

A second technique, slice-selective gradient reversal (SSGR), applies the slice selection gradients of the 90° excitation pulse and the 180° refocusing pulses with opposite polarity leading to opposite directions of the chemical shift, which means that no spin echo is formed from fat.

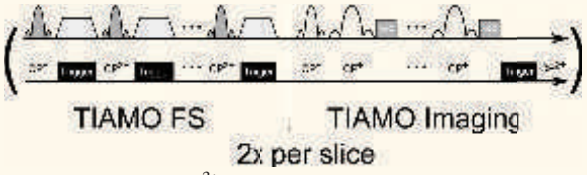

Fig. 9: Sequence timing for TIAMO FS. The modes of the fat-selective RF pulses are altered by triggering during the spoiler gradients. The sequence segment shown has to be repeated twice, as TIAMO imaging requires the acquisition of at least two modes. Triggers are placed such that the imaging part is acquired in the CP^+ mode in the first run and in the CP^{2+} mode in the second run. SSGR and SSB use the same TIAMO imaging scheme except for changes in gradient polarity or pulse duration.

A further technique, slice-selective smaller bandwidth refocusing pulses (SSB), takes advantage of the increased chemical shift to omit the fat signal. The duration of the refocusing pulses is prolonged compared to the excitation pulse while the time-bandwidth product (TBWP) is kept constant. In this way, SSB diminishes the amplitude of the slice-selection gradient. The lower gradient amplitude shifts the refocusing bandwidth away from the excited fat signal.

Due to their previously observed inadequacy and inhomogeneity of FS in abdominal SSFSE imaging, spectrally-selective 90° saturation pulses (SPS) and spectral attenuated inversion recovery (SPAIR) were not considered.

All volunteer examinations were made with a custom-built 8-channel transmit / receive body coil and a custom 8-channel RF shimming and SAR supervision system capable of fast switching between different RF shim sets (amplitudes and phases). The image acquisition was performed with a 2D SSFSE using a FOV of 384 mm x 288 mm and a resolution of 1 mm x 1 mm, with a thickness of 5 mm. Eleven transversal slices were acquired. A TR of 1500 ms, TE of 91 ms (97 ms for SSB technique), phase partial Fourier of 5/8, GRAPPA factor 3, a bandwidth of 766 Hz/px, and a total acquisition time TA of 33 s were used. For the imaging portions of all sequences, TIAMO with the CP^+ and CP^{2+} modes was used.

Imaging was performed in 10 volunteers in 6 different ways in the following order: without any FS, with TIAMO FS, with SSGR, SSGR with preceding TIAMO FS, SSB, and SSB with preceding TIAMO FS. 12 ROIs were placed identically for all 6 protocols per volunteer in subcutaneous fat, intra-abdominal fat, organs, and muscle. Overall image quality, artifacts, quality and homogeneity of FS were rated by two radiologists.

Comparing the FS techniques, only SSGR and SSGR combined with TIAMO FS led to nearly homogeneous FS over the entire FOV and all slices (Figure 10). All other techniques showed severe FS inhomogeneities: areas with very high FS next to areas with nearly no effect on the fat signal.

Figure 11 shows signal intensities of fat and tissue relative to the sequence acquired without any FS. Subcutaneous fat could be suppressed slightly better than intraabdominal fat. Subcutaneous fat was suppressed best with SSGR combined with TIAMO FS and with SSGR alone, whereby the combination reached slightly lower fat signal values but also tended to cause slightly more tissue signal loss. The worst suppression was reached with SSB. For SSB combined with TIAMO FS, FS was relevantly better than for SSB alone. However, tissue signals were also significantly smaller compared to all other sequence variants.

The radiologic evaluation showed that overall image quality was rated between good to moderate for all techniques. Adding up the evaluated categories for an overall rating of the FS techniques, SSGR and SSGR combined with TIAMO FS were rated best.

The inherent B0 inhomogeneities of 7T abdominal imaging lead to general loss of tissue signal when using various FS techniques.

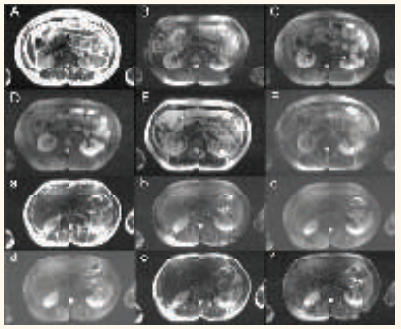

Fig. 10: Center slice of a male volunteer showing known cysts in the left kidney (A-F) and of a female volunteer (a-f). Protocol without any FS (A/a), with TIAMO FS (B/b), SSGR (C/c), SSGR and TIAMO FS combined (D/d), SSB (E/e), and SSB and TIAMO FS combined (F/f).

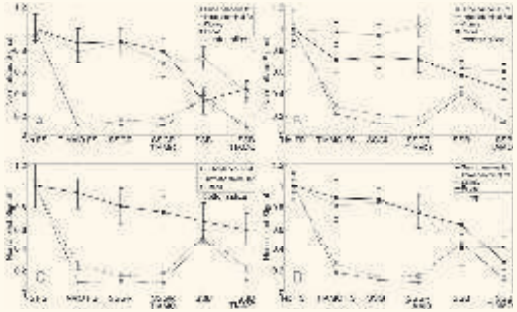

Fig. 11: Top row shows signal intensities of subcutaneous / intraabdominal fat, kidney, and psoas major muscle relative to imaging without FS for the central slice of a male (A) and a female (B) volunteer. Bottom row shows relative signal intensities from inferior (C) / superior slice (D) of the male volunteer.

Techniques like TIAMO FS that use preparation pulses tend to weaken the tissue signal because of B0 inhomogeneity and magnetization transfer effects. In general, one can see that due to the limited RF power, in the central region of the FOV only relatively low signal intensities are reached despite the use of TIAMO imaging (Figure 10). To further improve image quality, higher amplifier power would be beneficial. Also, choosing a broader slice profile for the refocusing pulses could lead to higher signals.

Of the techniques that led to satisfying FS with acceptable tissue signal decrease, SSGR was the most favorable technique, as it showed the most homogeneous and satisfying FS with no additional preparation pulses being necessary. The moderate tissue signal loss may be induced by B0 inhomogeneities combined with the gradient reversal.

SSB showed the largest signal decrease for non-fat tissue of all compared techniques. On the one hand this is mostly due to the longer TE. On the other hand this may also be caused by improper slice refocusing. SSB was also the technique with the worst FS. The reason for this may be that the displacement between fat and water is not high enough because of the B0 inhomogeneities that distort the slice profiles.

The radiologic evaluation confirmed the observations made by the quantitative analysis (Figure 11) that SSGR and SSGR combined with TIAMO FS did best regarding suppression of signal from fatty tissue and homogeneity of FS. The suppression should be enough to distinguish between fatty tissue and bright lesions. To show feasibility, the protocol was additionally applied for pelvic imaging in a female volunteer (Figure 12), and the conclusions made from the FS comparison could be confirmed.

In summary, this work shows that most FS techniques lead to inhomogeneous FS and to tissue signal loss at 7T. Of the compared techniques, the most favorable was SSGR, as with this technique a homogeneous FS with only moderate tissue signal loss is possible. Using this FS technique combined with TIAMO image acquisition, it is possible to delineate between fatty tissue and bright liquids in SSFSE images at 7T, which is essential for diagnosis.

For further details of this technique please see Sören Johst, Stephan Orzada, Anja Fischer, Lale Umutlu, Mark E. Ladd, and Stefan Maderwald: Comparison of Fat Saturation Techniques for Single-Shot Fast Spin Echo Sequences for 7-T Body Imaging. Investigative Radiology, Volume 49, Number 2, February 2014, pp. 101-108.

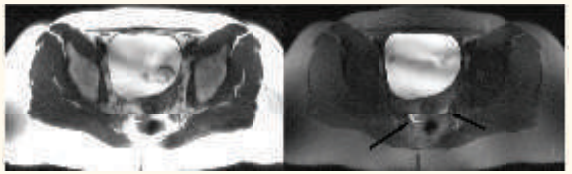

Fig. 12: SSFSE imaging of the pelvis without FS (left) and with SSGR (right). Black arrows show a small amount of fluid in the recto-uterine pouch that is better visualized after fat suppression.

Optimized ^{31}P spectroscopy of the brain

A separated transmit and receive coil setup combined with B1-shimmed NOE enhancement

Tom Scheenen

Phosphorus (^{31}P) MR spectroscopy is a tool to study tissue metabolism under various physiological and pathophysiological conditions. Metabolic changes can be followed over time with dynamic ^{31}P MRS, and MR spectroscopic imaging (MRSI) allows the two- or three-dimensional mapping of metabolites to study their spatial distribution. The intrinsic sensitivity of in vivo ^{31}P MRS and MRSI is low, hence the step towards a magnetic field strength of 7 Tesla. Next to an increase in field strength, ^{31}P sensitivity can also be improved by increasing the steady state magnetization of the ^{31}P nuclei through dipolar exchange using low-power proton irradiation on the water molecules: the nuclear Overhauser effect (NOE). Signal increase by NOE depends on the level of proton irradiation: above a certain threshold maximum enhancement is achieved.
MR signals need to be generated and received with radiofrequency (RF) coils in the magnet. Traditionally, coils for X-nuclei, such as ^{31}P, served both purposes (transmit Tx and receive Rx) at the same time. In clinical imaging, transmitting RF is done with a large body coil, which is integrated in the bore of the scanner, and receiving MR signals is done with multi-element array coils. Using a large coil for Tx with homogeneous Tx fields (B1+), and smaller coils with high local sensitivity is optimal, not only for proton at clinical field strength, but also for other nuclei. At 7T this is not the case for proton, as proton RF fields at this field strength are notoriously inhomogeneous due to the high frequency.

Therefore our aim was to design and construct a 7T coil setup optimized for ^{1}H and ^{31}P signal handling, enabling optimization of the ^{1}H transmit field (B_1-shimming capabilities), uniform excitation of the human brain at ^{31}P frequency and local reception of MR signal at the same frequency. It consists of an optimized 8-channel ^{1}H head coil with multi transmit capabilities, and an insertable, detunable ^{31}P-birdcage (TxRx and Tx only) that can be combined with a 7 channel Rx ^{31}P-array. With separating transmission and reception we can locally acquire a 7-fold increase in SNR of the ^{31}P-signals and an additional boost of 30 ± 9% can be attained by exploiting NOE-enhancement. All these features combined enables acquisition of ^{31}P MRSI of the brain at 7T with high resolution (7.3cc voxel size) in acceptable scan times.

The coil design (Fig. 13) was validated regarding safety with extensive modeling and bench measurements. Performance of the final coil design was evaluated with a large phantom with a salty phosphate solution. Integration of the single phosphate peak in every spectrum of a 3D ^{31}P-MRSI experiment with and without using the array-coil for reception resulted in images of ^{31}P signal intensities with and without using the array. The local increase in signal intensity was up to a factor 7 (Fig. 14).

When optimizing RF homogeneity in the occipital lobe of the volunteer, low-power irradiation of the water signal in this area resulted in ~30% NOE enhancement of the PCr signal (different percentages for different resonances, spectral examples in figure 15 F and G).
Altogether, we ran a 16 minute pulse-acquire ^{31}P-MRSI examination of the brain of a healthy volunteer with B1-shimmed NOE enhancement (technical details: TR 1500 ms, flip angle 45 degrees, block pulse duration 0.3 ms, true voxel size after spatial filtering 7.3 cc). The spectral map of the occipital region of the brain (Fig. 16) illustrates the coverage of the ^{31}P-array coil. Individual voxels of this dataset show high quality spectra with narrow linewidths and a spectral resolution high enough to resolve phosphomono-esters and di-esters separately. At a spatial resolution of 7 cc, acquired within 16 minutes, we are now able to spatially resolve differences in the different ^{31}P metabolites and exploit this in studies of healthy volunteers and volunteers with different brain diseases.

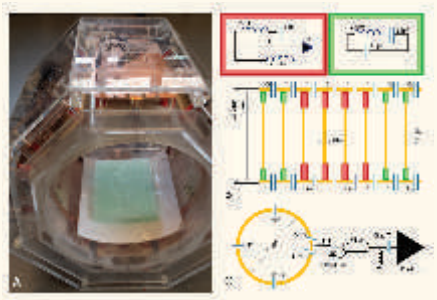

Fig. 13: Overview of the complete coil setup. A) The octagonal shaped 8-channel ^{1}H head coil (6) was used as basis for the design of the insertable, detunable ^{31}P birdcage coil, and an additional 7-channel receive only array. B) Schematic representation of the 8-rung high-pass birdcage coil, with details of the tank- (green-box) and detune-circuits (red-box). Capacitor values used to tune and match the birdcage coil were: Cm = 15.6pF, Ct = 13.3pF, Cc = 27pF and Cp = 10pF. C) A pictorial overview of a single element of the 7-channel receive-only array, where each adjacent element is decoupled by overlap and by additional pre-amplifier decoupling.

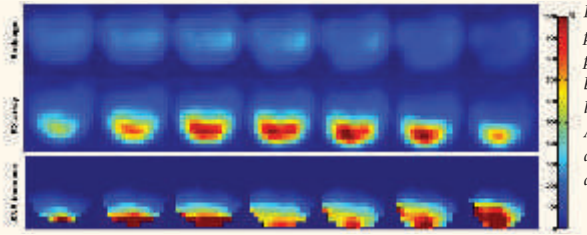

Fig. 14: SNR images of a spherical phantom containing 100mM in-organic phosphate as were obtained with the birdcage coil (top row) and with the local receive-only array (middle row). A more than 7-fold SNR increase was achieved by separating transmission and acquisition of the signal.

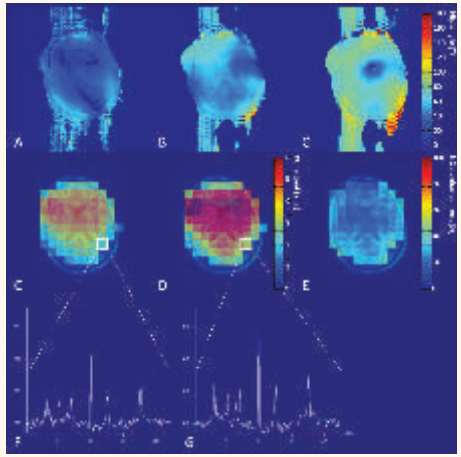

Fig. 15: In-vivo examination with the complete setup. Different B1-maps of the 1H-field in A) CP+-mode, B) homogenized for the complete brain, C) local optimization for occipital lobe. 31P signal was excited and acquired with the birdcage D) with and C) without NOE-enhancement, resulting in E) a NOE enhancement map. An example of 31P spectra taken from the same voxel are shown in F) without NOE-enhancement and in G) with NOE-enhancement.

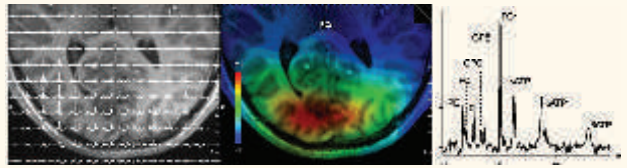

Fig. 16: High resolution 3D^{31}P-MRSI using all available options to boost SNR. The signals were enhanced using NOE and received with the local receive array. A) Transversal view of the human brain overlapped with ^{31}P spectra as acquired with the receive array. B) Transversal view of the human brain overlapped with PCr-map covering the occipital lobe. C) single spectrum with assignments (G)PE (glycerol-)phosphoethanolamine, (G)PC (glycerol-) phosphocholine, Pi inorganic phosphate, PCr phosphocreatine, ATP adenosine triphosphate.

Investigating fMRI sensitivity with multiband at 7T

Aiding the detection and removal of artifacts with fast acquisitions or providing higher resolution data

Rasim Boyacioglu
Peter Koopmans

Jenni Schulz
Markus Barth
David Norris

Multiband imaging refers to the phenomena of simultaneous excitation and acquisition of multiple slices which are then reconstructed into individual slices. Even though the initial ideas have been laid out quite early[1,2] multiband imaging started to claim its full potential recently[3,4]. It is fair to say that it almost caused a paradigm shift in some research areas just like what parallel imaging did in the early 2000s. Its simplicity and orthogonality to other acceleration techniques enables it to be applied to a range of research areas such as arterial spin labeling, angiography, diffusion, anatomical imaging and fMRI. Many researchers are involved in improving different aspects of multiband acquisition. The RF power and the heating of the tissue increase linearly with the number of simultaneously excited multiband slices. We have been working on reducing the power deposition of high SAR multiband pulses. The PINS (Power Independent Number of Slices) were invented in 2011[5] and its value has been demonstrated theoretically[6] and in practice[7]. After that the focus has been on the potential advantage of multiband imaging for fMRI.

Spin Echo (SE) vs. Gradient Echo (GE) EPI

It is suggested that SE signal becomes more localized to the true site of activation with the increasing field strength with the overall penalty of reduced signal levels. Since it was possible to do whole brain SE-EPI acquisition with acceptable TRs for fMRI at 7T (SE PINS), we have indulged in the difficult task of comparing high resolution SE EPI and GE EPI. A whole brain, multiband SE EPI sequence employing a high spatial (1.5 mm isotropic) and temporal (TR of 2 s) resolution was implemented at 7 T. Its overall performance (tSNR, sensitivity and CNR) was assessed and compared to a geometrically matched GE EPI multiband sequence (TR of 1.4 s) using a color-word Stroop task[8]. PINS RF pulses were used for refocusing to reduce RF amplitude requirements and SAR, summed and phase-optimized standard multiband pulses were used for excitation enabling a transverse or oblique slice orientation. The group level (n=6) activation results are shown in Figure 17. In general, GE EPI shows higher efficiency and higher CNR in most brain areas except in some parts of the visual cortex and superior frontal pole at both the group and individual-subject levels. Gradient-echo EPI was able to detect robust activation near the air/tissue interfaces such as the orbito-frontal and subcortical regions due to reduced intra-voxel dephasing because of the thin slices used and high in-plane resolution. The results from this study, which to our knowledge is the first to compare GE and SE at 7 T using a more standard cognitive paradigm, would seem to indicate that there is little benefit to using SE EPI, as the sensitivity is considerably lower and there is no obvious improvement in spatial specificity.

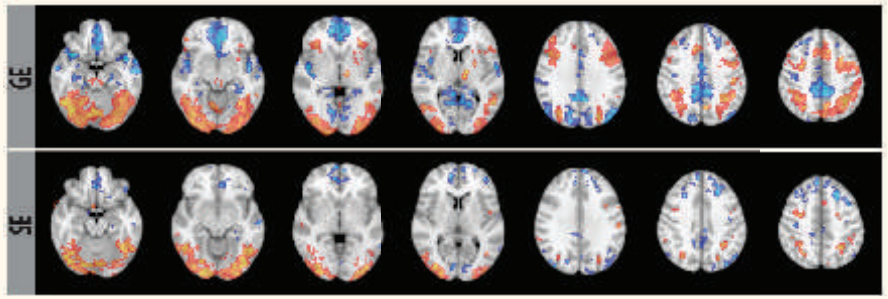

Fig. 17: Group level activation (red) and deactivation (blue) of SE- and GE EPI for Stroop task. Note the high sensitivity for GE EPI.

Multiband Multi-echo

Multi-echo (ME) is has become increasingly popular in recent years due to its commonly known advantages such as low distortion, the potential to acquire data over a broad range of T2* values and automatic elimination of non-BOLD independent components (ICs). It is only logical that it is extended to include multiband imaging so that one can achieve sub second volume TRs. For that purpose, a multiband multi-echo (MBME) sequence has been implemented and compared to a matched standard (ME) protocol to investigate the potential improvement in sensitivity and specificity at 7T for both resting state and task fMRI. We used FSL-FIX to clean ME and MBME resting state and task fMRI data (n=10) by removing artifactual ICs. After the FIX correction, the number of significantly activated networks increases for resting state data (e.g. "new" subcortical ICs shown in Figure 18), and additional activation clusters (Figure 19, yellow circles and arrows) for task data are discovered for MBME data (increased sensitivity) whereas existing clusters become more localized (improved specificity). The results obtained indicate that MBME is superior to ME at high field strengths.

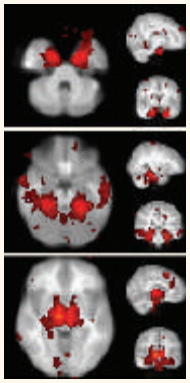

Fig. 18: Subcortical networks only discovered with MBME

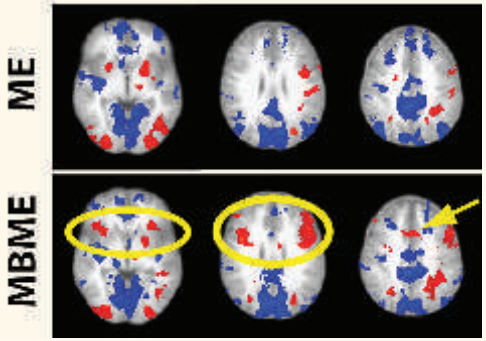

Fig.19: Stroop related activation clusters that only appear for MBME acquisition.

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Erwin L. Hahn Moments 2014

visit of the two Prime Ministers Hannelore Kraft and Mark Rutte

the Prime Ministers are impressed by the 7T MRI

same place but new street name

Hahn Lecture 2014, given by Arend Heerschap

our new team of directors with Dr. Stephan Orzada, receiver of the Erwin L. Hahn prize

very interested audience

we proudly present: our new doctor, Dr. Sören Johst

ELH on Ice

Current Grants

Suter D, Optimized noise filters for improved contrasts in MRI; German Research Foundation; duration 3 years (2014 – 2016)

Philips B, Scheenen T, Multi-parametric MRI of the prostate cancer: next level; Dutch Cancer Society; duration 4 years (2014 – 2017)

Timmann D, Ladd ME, Contribution of the human cerebellum to extinction learning and renewal, Project in the Research Unit FOR 1581; German Research Foundation; duration 3 years (2014 – 2016)

Ladd ME, Speck O, Norris DG, German Ultra-High Field Imaging (GUFI), Core Facility; German Research Foundation; duration 3 years (2013 – 2016)

Ladd ME, Gowland P, Norris DG, Möller HE, Speck O, Jezzard P, Del Guerra A, Hoogduin JM, Stancanello J, De Boer R, Roell S, Lanz T, Oberle M, Stacey ND, HiMR: Ultra-High Field Magnetic Resonance Imaging; Marie Curie Actions – Initial Training Networks, EC; duration 4 years (2012 – 2016)

Norris DG, Tendolkar I, Wiltfang J, Imaging and Curing Environmental Metabolic Diseases (ICEMED); Helmhotz-Gesellschaft; duration 6 years (2012 – 2017)

Ladd ME, MRexcite: Unlocking the potential of ultra-high field MRI through manipulation of radiofrequency excitation fields in human tissue; European Research Council; duration 5 years (2012 – 2017)

Scheenen T, Exploring the aggressiveness of prostate cancer to enable an individualized treatment approach; European Research Council; duration 6 years (2010 – 2015)

Personnel

New in 2014

- Thomas Ernst
- Eileen Frerk
- Johannes Grüneisen
- Maria Hahnemann
- Katharina Hauprich
- Britta Hühning
- Andrea Lazik
- Tristan Mathiebe
- Matthias Meyer
- Sarah Müller
- Mark Oehmigen
- Bart Philips
- Prof. Harald Quick
- Stefan Rietsch
- Christoph Ritter
- Juliane Schelhorn
- Lonja Schürmann
- Nicolai Spicher
- Lena Tiedemann
- Matthias Zunhammer

Left in 2014

- Ashraf Abuelhaija
- Dominik Beyer
- Andreas Bitz
- Sascha Brunheim
- Thomas Fiedler
- Beate Fraß
- Bettina Gathmann
- Mirjam Holbach
- Miriam Laagemat
- Tristan Mathiebe
- Nils Müller
- Ria Pradhan
- Anna Steinhoff
- Lena Tiedemann
- Markus Thürling
- Eline Vos
- Anna Voß

Publications

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