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HUMAN & BIOTECHNOLOGY

Fields of Expertise TU Graz

Gabriele Berg, Human & Biotechnology

Source: Lunghammer – TU Graz

When this new issue of TU Graz *research* appears, our university will be returning to "normal" life after more than two years of crisis. This is gratifying for all students within our FoE, but also for the teaching staff and especially for our research. Research needs experiments, laboratories and team spirit to obtain results and develop new technologies. These are urgently needed, because the time of crises is not over. On the contrary, the list is long: climate crisis, biodiversity crisis, antibiotic crisis, microplastic crisis… Fortunately, work on solving almost all of these issues is also being done successfully within our FoE.

The first step to successful research is often through small projects, such as those enabled by FoE-specific seed funding. They are easy to apply for, receive a high percentage of funding and often plant the seeds for larger projects. Here is a small example: Ahmed Abdelfattah, originally from Egypt, who has already done research at the Universities of Palermo, Bari and Stockholm as well as at the USDA (United States Department of Agriculture), chose to go to TU Graz to gain further experience within a Marie Curie Fellowship. In order to also integrate students into his research project, he applied for additional experimental costs in "Exploring the apple microbiome". The results of the now completed project are convincing: Daniel Höfle has already submitted his Master's thesis (Master's in Molecular Microbiology) and, based on the results, two new EU projects have been submitted. Imitation is encouraged here!

Furthermore, there is good news: the former Institute of Medical Technology has undergone two innovations: a new director and a new name. Last autumn Martin Uecker took up his post as head of the institute (an article by him is in this issue) and Rudolf Stollberger has retired. He was a very active member of our FoE, and we would like to take the opportunity here to wish him all the very best for the future. With the new appointment, the name of the institute was also changed and it is now called the Institute of Biomedical Imaging.

Bernd Nidetzky, Gernot Müller-Putz & Gabriele Berg wish you a healthy summer semester in presence.

Martin Uecker

Computational Magnetic Resonance Imaging

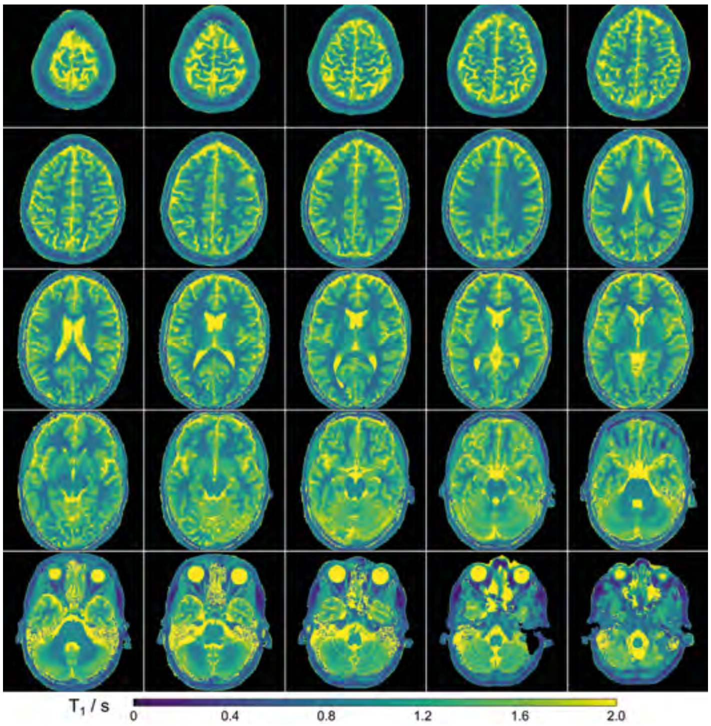
Magnetic Resonance Imaging (MRI) is a non-invasive medical imaging technology that can produce detailed images from the inside of the human body. It is a computational imaging technique that is based on the physical principles of nuclear magnetic resonance. At the Institute of Biomedical Imaging we develop new MRI techniques and their clinical applications.

Modern Magnetic Resonance Imaging (MRI) scanners are impressive machines. A huge superconducting electromagnet weighing several tons which is cooled down to temperatures just above absolute zero using liquid helium creates a strong magnetic field. When one lies down inside the bore of such a magnet, the nuclei of the hydrogen and other atoms in the body align themselves with this magnetic field.

Figure 1: MRI Scanner at TU Graz.
Source: Lunghammer – TU Graz

The reason for this is that the proton has a spin – a quantum mechanical property that is related to angular momentum and magnetic moment. These nuclear spins can be manipulated by using electromagnetic waves that match a specific resonance frequency that depends on the nucleus and the strength of the main magnetic field. For a typical field strength of 3T as used in a high-end MRI scanner, the proton resonance frequency is 128 MHz – so in the radio frequency range. Using software-defined radios attached to powerful amplifiers, radio frequency pulses can then be used to excite and manipulate the spins. After excitation they start to precess and this rotating magnetic moment produces an echo, i.e. it induces a measurable voltage in our receiver coils which is then digitized and processed by a computer to compute MR images. But how can we compute images from the echos? To be able to create images, i.e. to resolve the spatial distribution of the magnetic moments, the main magnetic field is modified by switching on additional magnetic fields that change their strength with position. The resonance frequency then also changes with position, translating spatial information into frequency. A mathematical technique called Fourier transformation can then be used to analyze the frequency spectrum of the recorded echos and to compute images that show the distribution of the spins in the body. In 2003, Paul Lauterbur and Sir Peter Mansfield were awarded the Nobel Prize in Medicine for developing these concepts. A major advantage of the measurement principles used in MRI is that no ionizing radiation is used and that it can therefore be safely used also in research studies.

As we have seen, the biomedical engineering behind an MRI machine relies on advanced physics, mathematics, and computer technology. But the full power of MRI only becomes clear when looking at applications. Extending the basic principles described above, MRI is not only able to measure the spatial distribution of proton (or certain other) spins, it can also measure various physical and chemical properties, such as T1, T2, and T2* relaxation constants that provide information about the microscopic environment of the spins, as well as chemical shift, diffusion, flow velocity, perfusion, temperature and much more. All this can be achieved without modifying the hardware of an MRI only by changing the software that controls the different magnetic fields and by adapting the algorithms that process the digitized data. This opened up the possibility to develop many applications for clinical use and scientific research. Just to list some possibilities: Diffusion measurements became an important clinical tool for the diagnosis of acute stroke. Exploiting the fact that diffusion in the brain is not isotropic but stronger along the nerve fibers, MRI can be used to create maps of the nerve connections in the brain. Blood oxygenation influences again influences the relaxation constants and this again allows us to study which parts of the brain are active **>**



Accelerated whole brain T1 mapping in one minute using computational MRI.
Source: Uecker

Software toolbox "BART" for computational MRI developed at the Institute of Biomedical Imaging.
Source: Uecker

Martin Uecker
is full Professor of Biomedical Imaging at TU Graz. After completing his PhD at the Max-Planck-Institute of Biophysical Chemistry in Göttingen and a research stay at the University of California, Berkeley, he was appointed associate professor for real-time MRI at the University Medical Center Göttingen and the German Centre for Cardiovascular Research. Since October 2021 he has been head of the Institute of Biomedical Imaging. His primary research interest is the development of new computational methods for magnetic resonance imaging.

Source: Herzzentrum Göttingen

during different mental tasks. Acquiring images of the beating heart allows a quantification of heart function. Phase-contrast flow MRI allows blood velocities in the aorta and other vessels to be measured, as well as the flow of cerebrospinal fluid. The use of contrast agents opens up even more possibilities, e.g. to visualize perfusion of tumors or of the heart after myocardial infarction. Measuring the temperature is useful to guide interventional procedures such as highly focused ultrasound techniques, which are currently being developed. And these are just a few of many examples.

But not everything is perfect. One major disadvantage of MRI is that it is rather slow. Spatial encoding is done piece by piece in a repeated series of individual MRI experiments that each take only a couple of microseconds, but hundreds of such experiments are needed to collect the information to obtain a complete image with the Fourier transformation. Thus, scan time is slow and any motion during the scan may corrupt the image. Many advanced applications are not used in clinical practice because scan time is limited or because they are not robust enough to be useful. A special challenge is imaging of dynamic processes, such as imaging the beating heart during free breathing. Thus, a major research focus at the Institute of Biomedical Imaging is to investigate new computational imaging approaches that combine concepts from physics, mathematics, and computational sciences to develop new methods for faster and more robust quantitative MRI. Here, we often work closely with mathematicians to develop new algorithms that can extract the information from fewer data points, thus reducing the scan time. These techniques then need to be implemented on high-performance computers that make use of graphical processing units to compute images in a clinically feasible time. State-of-the-art approaches often combine physical modeling of the measurement process, advanced optimization algorithms and machine learning with Bayesian approaches that provideimages with confidence bounds. Another challenge is the high complexity of such advanced MRI techniques, which requires solid software engineering. The research community started to address this by jointly developing open source software for research and making results available in a reproducible way. Software developed at the Institute of Biomedical Imaging is used worldwide by MRI research groups. But not only scientists and engineers are involved, new approaches for MRI also need to be tested and optimized in a clinical setting together with physicians. In conclusion, MRI is an exciting medical imaging technology that is still continuously being improved by an interdisciplinary community.