Magnetic Resonance Coils for Magnetic Resonance Imaging Scanners

Frank Volke
Fraunhofer Institute for Biomedical Engineering, St Ingbert, Germany

There is a clinical need for more complex magnetic resonance imaging capabilities. Advances in magnetic resonance coils are meeting this demand. This article looks at the ongoing developments in this area.

Components of an MRI system

For clinical magnetic resonance imaging (MRI) studies and clinical diagnostics, standard coils are usually delivered on request with the MRI system. The MRI system basically consists of the static magnetic field (typically, 1.5 and 2.0 Tesla), the gradients for space-encoding the frequencies, and some basic coils (typically, 1H proton coils). The coils stimulate the nuclei in the object being studied and receive the signal after excitation of the nuclei "on their way back to equilibrium" (relaxation). Amplifiers for radio-frequency (RF) transmission, and receivers and amplifiers for the magnetic field gradients are also required, together with sophisticated computer hardware and software to operate the whole system. The MRI system is then able to reconstruct images out of the radio-wave signals sent by the excited and "relaxing" nuclei to the receiver MR coil.

Innovations in coil capabilities

There is a demand for more advanced coils. Interdisciplinary teams of physicians, physicists, engineers and others like to obtain images from other nuclei such as 31P, 23, Na and 13C in the complex biomolecular structure of the human body. Usually, commercial MRI scanners are equipped with the most commonly used 1H MRI coils, in different types (volume and surface coils), because hydrogen has the best sensitivity and molecules such as water and fat are easily detectable in the human body. Only nuclei that have a so-called spin (magnetic moments) are usable for MRI. Therefore, the natural occurring isotope 13C (approximately 1%) is suitable for MRI studies, although the low concentration gives rise to sensitivity problems and limits the application.

In addition to natural, stable isotopes such as 31P, 23Na, 19F and 13C, nonradioactive stable isotopes such as 3He, 2H, 17O and others can be used as contrast agents to improve image quality by triggering the contrast. This contrast occurs because of nuclei–nuclei magnetic interactions that change relaxation time (spatial distance and motional properties) with other nuclei under observation during MRI, or by "working" with the stable isotope as the observed nuclei itself.

Furthermore, there is a demand to have double- and triple-tunable coils to work with protons as well as any other nuclei that are useful for the research task. Sophisticated coils of this type allow, for example, the selective decoupling of special signals forming the MR image and provide better insight into the underlying molecular details of the object(s) being investigated; the decoupling of hydrogen interacting with phosphorous provides sharper, well-resolved 31P signals (images). Furthermore, images from the same object, but contrasted by, for example, 1H, 23Na and 19F are possible. Custom coils of this type are being produced and they are approved for use in clinical studies in the MRI scanner for which they are designed. There are exciting possibilities in the number of extra features that can be designed into a coil.

Triple-tunable coils

For example, a triple-tunable MRI coil has been developed for a 1.5 Tesla Siemens scanner (Figure 1). It is for detection of sodium, fluorine and protons to study metabolic changes in

Figure 1: Triple-tunable MRI coil.

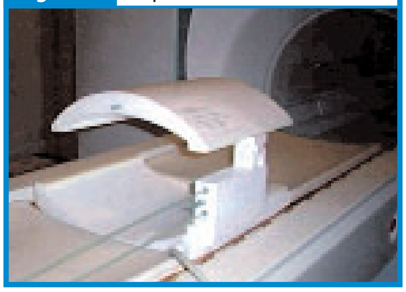
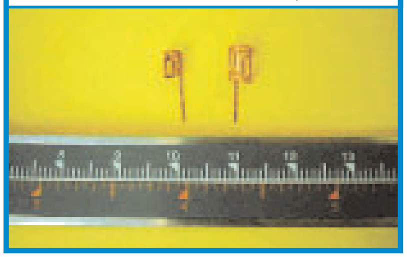


Figure 2: The opened and closed 3H/1H MR coil with green tuning and matching rods at maximum size for a 1.5 Tesla Siemens scanner. The design allows the investigation of large-size humans within the limit of the 60-cm opening of the MRI scanner. The coil inside the housing is a variation of a volume-type coil, where the electronic connection between the upper and lower parts of the wires of the coil is performed within the distance-adjustable spacers.

Figure 3: Microcoils for online pharmaceutical studies over several days.



the liver for pharmaceutical research.[1] The green rods are for tuning/matching to the desired resonance. The RF coils within the polyoxymethylene housing are of surface-coil type. The upper part of the MRI coil can be flipped away for easier positioning and moving of the patient. Other materials such as acrylate-type polymers are available for the housing. The MRI coils are positioned within that housing and need to be fixed well for mechanical stability and therefore high spatial resolution.

Alternative contrast agents

By using hyperpolarised 3He stable isotopes as contrast agents it has been possible to obtain high quality information (images and relaxation studies) on the human lung's morphological details and its air circulation and oxygen use. 3He/1H coils have been developed and approved for clinical use (Figure 2). Those coils yield images from the isotope 3He by tuning the coil to the 3He-MRI frequency as well as 1H images by tuning the electronics to hydrogen. These coils yield better signal-to-noise ratios if the filling factor is high (that is, if the coil's volume is completely filled with the object/section of object being studied), and the size of the coil is adjustable by the physician using spacers between the upper and lower part of this volume-type coil. Relaxation processes between oxygen, helium and protons can be exploited to obtain a much better insight into oxygen circulation within the lung.

The availability of hyperpolarised 3He stable isotopes is rare. Reliable cooperation with physicists for the production and delivery of the 3He isotope to the MRI scanner is required. A few companies are working hard to develop hyperpolarised 3He delivery apparatus, which can be used close up to the MRI scanner. Food and Drug Administration approval is currently being sought for use of the 3He as a clinical MRI contrast agent.

Microcoils

Extremely small coils (Figure 3) are in demand for biochemical and morphological studies on, for example, tumour-cell tissues or small tumour-cell spheroids (of approximately 1 mm in size). With this type of a coil and strong magnetic field gradients, it is possible (using a vertical wide-bore, superconductivity magnet) to observe online the action of drugs on the tumour, as well as morphology changes and biochemistry. The objects can be studied over a period of days, using a special supply system that delivers nutrition such as oxygen and ions.

The microcoils, which in further research and development will be reduced in size for single-cell work, are produced using an Nd:YAG laser with variable optics for clean cuts of between 60–200 µm. The coils themselves are made from gold-covered copper. These minicoils are fixed within MRI probes and mechanically stabilised by quartz, glass and Teflon parts that also allow fine adjustment in the direction of airflow and nutrition supply. It is important to use absolutely nonmagnetic capacitors to tune these coils to the right resonance frequency.

It is clear that there are only a few hurdles to cross before newer and better MR coils and MRI equipment are available for all types of applications within the rapidly growing field of biomedical, biotechnological and medical research on a biomolecular and nanobiology level.

References

1. More information on the coil is available at www.fmi.uni-passau.de/gmunden/5031.htm mdt

Priv.-Doz-Dr Frank Volke is Head of Magnetic Resonance Group at Fraunhofer Institute for Biomedical Engineering (IBMT), Ensheimeer Strasse 48, D-66386 St Ingbert/Saar, Germany, tel. +49 6894 980 405, fax +49 6894 980 400, e-mail: frank.volke@ibmt.fraunhofer.de www.nmr.fraunhofer.de

Published in the October 2003 issue of *Medical Device Technology*.