How to Make it Happen - Practical and Strategic Issues of Interventional MRI

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For many image-guided interventional procedures MRI is the imaging modality of choice since it offers an excellent soft tissue contrast, a three-dimensional visualization of both the target organ and the access pathways, morphological and functional imaging techniques, and it does not use ionizing radiation. Unfortunately, interventional procedures can be difficult to perform in the hostile environment of an MR system because only non-magnetic instruments can be used, access to the patient is very limited, devices can heat up significantly during MR imaging, and gradient noise makes communication difficult.

In the past MR-guided interventions have predominantly been performed in open, low-field MRI systems which offer good access to the patient. Low field systems however are limited in the achievable signal-to-noise ratio and the gradient strength, so that real-time imaging with high frame rates is hardly possible. High field solenoid magnets have increasingly been applied for MR-guided interventions, where a separation of several tens of centimeters between the operator at the magnet opening and the target organ at magnet isocenter is possible. This separation is naturally achieved in intravascular interventions with the help of a catheter, however, percutaneous interventions are significantly more difficult to perform in closed-bore MR systems since instruments such as needles are inserted through the skin. For this application a robotic assistance system has been designed which aligns the needle along a pre-defined trajectory.

To perform interventions in high-field MRI systems a dedicated interface is required for pulse sequence control which allows for changing the orientation and position of the imaging slice in real time. The interface must be easy to use from the interior of the magnet room and should control several selected imaging parameters as for example the imaging contrast, the spatial resolution and the image update rate. For imaging of interventional procedures pulse sequences such as spoiled gradient echo and balanced SSFP are favored as they allow for short repetition times, high SNR and good image contrast. For intravascular applications also projection imaging techniques have been utilized which provide an overview over the vasculature similar to digital subtraction angiography.

During an intervention images need to be reconstructed and displayed with minimal latency to provide the operator with an immediate feedback. Real time image reconstruction can be challenging when raw data acquisition rates are high due to the use of multiple imaging coils and parallel imaging techniques. Under these circumstances image reconstruction can be performed on dedicated hardware processors or on distributed computer systems. For in-room image display shielded monitors, projector systems, back-projection wall screens, or head-mounted displays can be used.

Devices can be difficult to locate in MR images since the imaging plane does not necessarily coincide with the instrument's axis. To localize the instrument in an image several MR techniques have been proposed: Susceptibility markers have been attached to instruments which create a signal void in the MR images. Small coils have been mounted on the devices that were energized with a direct current to create a controllable signal reduction. Inductively coupled resonant marker coils have been designed that locally amplify the rf field e.g. at the tip of a catheter to provide a bright positive contrast. Finally, small rf coils have been attached to the device which are directly connected to the MR system's receiver channels. The marker systems can be localized using fast projection pulse sequences that are integrated into the real-time image acquisition. The position information is then typically used to guide the imaging plane so that the operator controls the slice position via the interventional instrument. In more refined implementations of automatic slice tracking not only the position but also the device velocity is utilized to zoom in onto the device when the operator stops the device motion.

The introduction of electrically conducting structures (e.g. co-axial cables) into the devices can lead to excessive device heating if the lengths approach the resonance length of the rf field in tissue. To avoid device heating rf chokes can be integrated into the cables or the cables can be segmented into shorter sections by transformers. Alternative localization strategies do not use an MR signal but determine the position information by measuring the local magnetic field strength. The field strength is linearly modulated by the imaging gradients and can be assessed inductively, with Hall sensors, or by measuring the optical Faraday effect.

At present there is a trend to shorter and more open magnet designs for interventional MRI - these superconducting interventional magnets are realized either in the shape of a C-arc magnet with vertical field or a short open-bore solenoid magnet. MRI is combined with X-ray imaging systems using either a common patient table and two separate systems or an integrated X-ray setup. The number of MR compatible interventional devices is steadily growing, and there is hope, that even active tracking techniques will become clinically available in the near future. Nevertheless, many technical solutions to problems of interventional MRI (though being solved experimentally) still need to be implemented in commercially available MR systems.