From Technical Innovations to Clinical Routine

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As the practice of Radiology has evolved during the past two decades, there has been increasing emphasis on intervention, bringing Radiologists into a much more prominent role in the care of patients with a growing list of disorders. In parallel, open surgical procedures have demonstrated a trend toward image-based navigation, endoscopic approaches, and other methods to decrease the invasiveness of more traditional surgery. Radiological interventional skills and surgical minimally-invasive trends have converged to create a burgeoning interest in the use of magnetic resonance imaging for guidance of radiological and surgical procedures.

There are many procedures in which the information provided by MR imaging can be used to *monitor* a therapeutic intervention. Examples include thermal ablation, in which thermal energy is deposited and the resulting tissue changes are continuously or intermittently observed, or surgical intervention, in which tumor resection or cyst aspiration may be intermittently examined. These forms of interventional MRI require much less modification to standard imaging systems because access to the patient is not necessarily required during the monitoring process. The use of MR imaging for interventional procedure *guidance* includes its use by Radiologists and other physicians during manipulation of needles, electrodes, catheters, or laser fibers, and its application by Surgeons to guide endoscopes, scalpels, or curettes. This form of more active intervention requires a significant departure from conventional diagnostic concepts and traditional imaging systems.

There are several technical developments that have facilitated the guidance phase of interventional procedures in a time-efficient manner: 1) the construction of higher-quality low-noise receiver chains has allowed lower field systems to provide relatively high signal-to-noise ratio images; 2) the development of wider-bore shorter magnet designs for higher-field systems; 3) the development of rapid gradient-echo pulse sequences for use in interactive guidance during device placement; 4) the development of an interface between optically-linked 3D digitizer and the measurement control software of the MR imager; and, 5) the ability to view images in the magnetic field through the development of in-room high-resolution RF-shielded monitors and projectors.

One of the most straightforward interventional applications for a cross-sectional imaging modality is percutaneous biopsy and aspiration. The soft tissue contrast and multiplanar capabilities of MR have obvious benefits for guidance of biopsy and aspiration applications, and this application was the first reported clinical use of MR imaging to guide intervention. Another benefit of MR for biopsy of lesions in regions of complex vascular anatomy is the high vascular conspicuity that arises from the flow-related enhancement inherent in two-dimensional gradient-echo imaging,.

Much of the excitement surrounding MR image guided procedures has been due to the tremendous sensitivity of MR imaging for temperature change and tissue damage. In these areas, MR imaging provides an unequivocal advantage over the often subtle and indistinct changes noted on CT and ultrasound. Thermal ablation has been performed using several different energy sources, including radiofrequency, laser, cryotherapy, and focused ultrasound. The key advantage of MR that has been driving the application of these techniques has been the ability to monitor tissue destruction in near real-time during the procedure using a variety of MR imaging techniques, allowing interactive repositioning of the interventional device and tailoring of the thermal lesion in order to provide adequate destruction of the targeted tumor and surrounding margin of normal tissue. The ultimate cost-effectiveness of these procedures remains to be proven, although the remarkably lower cost of MR image-guided tumor ablation as compared to open surgical excision provides a strong rationale for the further development of these techniques.

An additional use of MR imaging for percutaneous minimally-invasive treatment is in the guidance and monitoring of direct intralesional drug injection, including injection for sclerotherapy of vascular malformations. The same rapid image updates used for interactive needle placement can be used to monitor the injection of sclerosing agents for the treatment of low-flow vascular malformations. The multiplanar cross-sectional images obtained with MR allow the injection of alcohol or other sclerosing agents to be monitored during administration, to ensure filling of the entire targeted portion of the malformation and to exclude extravasation or dissipation of the agent through venous egress.

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