Editorial

Parallel and sparse MR imaging: methods and instruments—Part 2

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Just as array transducers and advanced signal processing have significantly improved ultrasound imaging, parallel imaging with transmit/receive array and sparse imaging techniques have revolutionized MRI. The high-speed MRI and high-field MRI enabled by these new developments are truly exciting, and are viewed as key to advancing MRI from anatomical imaging to functional, dynamic, and molecular imaging. MRI is a premier noninvasive imaging modality. However, it is still a relatively slow modality when compared to ultrasound, X-ray computer tomography (CT), and optical imaging; and is less sensitive than positron emission tomography (PET) in the realm of molecular imaging. High fields and ultra-high field MRI, by offering increased signal strength, speed, and novel contrast, offer an opportunity to significantly reduce such gaps. As high-field MRI and high-speed MRI are being proven to be critical for more and more applications, engineering and clinical innovations and developments will continue to emerge.

Following the first special issue published in February, this second issue on parallel and sparse MRI presents ten new articles in this exciting area. These articles cover a wide range of topics from parallel transmit hardware design, large transmit arrays, parallel transmit k-space trajectory and pulse design, parallel imaging reconstruction evaluation and optimization, to several emerging biomedical applications of parallel and sparse MRI such as fetal imaging, acute stroke imaging, and diffusion-spectrum imaging (DSI). These are by no means comprehensive but they give a glimpse of this flourishing research area.

Development of parallel transmit systems continues to be a frontier in high-field MRI. The paper by Kurpad *et al.* represents a new paradigm on transmit array design (1). Unlike most transmit systems driven by traditional voltage sources, the new multi-channel integrated transmit array uses on-coil radiofrequency current sources. The work has been well received since the concept was introduced at ISMRM a few years ago. This follow up paper provides detailed design, implementation and validation, and should be of great interest to many engineers in the field. The flexibility and efficiency offered by such array systems are expected to facilitate many high-field imaging applications.

Currently, most clinical systems have only single or dual parallel transmitters; and the transmit-arrays with more elements (such as the one discussed above) have been demonstrated in research labs. But if the history of receive arrays is any indication of the future, large transmit arrays will become more available in the coming years. The benefits and limits of large transmit arrays are still largely untested and deserve further investigation. Along this line, the paper in (2) presents a method for rapid slice excitation without involving the B_0 gradient using a 64-channel large array transmit system. This novel method is tested on both planar and cylindrical formed planar pair coil arrays. It could enable very efficient curved slice excitation and should be of great interest to man readers.

Novel receive systems continue to be developed in the high-and ultrahigh-field MRI. Paper by Yan *et al.* presents a magnetic wall decoupling method for monopole coil array for these applications (3). Arrays with radiative coils such as dipole and monopole coils, are emerging technique that can potentially offer higher SNR in the areas deep inside human body. However, traditional decoupling methods based on element overlapping and/or L/C decoupling network cannot be readily applied to such arrays. This feasibility study points to an interesting and promising direction for decoupling such arrays, and have important applications in ultrahigh-field MRI.

Another interesting and significant aspect in parallel transmission is to design the transmit k-space trajectories and the RF pulse. The paper by Pang *et al*. (4) uses a randomly perturbed sparse spiral k-space trajectory to shorten the RF pulses in parallel transmission. Quantitative error on the excitation profile from Bloch simulation shows that the proposed method is feasible and efficient. In the study (5), Feng *et al*. provide a detailed description of a fast pulse design method with Fourier domain gridding and a conjugate gradient method. Simulation results of the proposed method show that the proposed method can design parallel transmit RF pulses at an efficiency many times higher than that of the conventional conjugate-gradient based method, without reducing the accuracy of the desirable excitation patterns. Efficient pulse design is a critical piece in order to move the sophisticated parallel transmission techniques from bench study to clinical applications. In many cases, the pulse design must be performed after the transmit sensitivity is measured after the patient is in the scanner.

Evaluating and optimizing reconstruction algorithms in parallel imaging for clinical applications is an important issue. The paper by Li presents an interesting perspective on analyzing reconstruction error in parallel imaging (6). By using a k-space convolution model and decomposing the input k-space data into the “original” and “modulated” components, it shows that the recon error can be categorized into three components: image fidelity error due to the “original” components, aliasing artifacts due to the “modulated” components, and amplified noise. It shows that by adjusting the balance of the three components, images can be reconstructed with different characteristics, which can be better suitable for a particular clinical application.

Enhancing image resolution is a promising application of compressive sensing. In the paper by Pang *et al*. (7), a new scheme is presented to utilize compressive sensing to improve the multi-slice imaging. In it, the central slice is acquired with “high resolution” compressive sensing and the information is used to interpolate the k-space data for adjacent slices using a multiplicative, modulation model. Results on *in vivo* human brain imaging show the feasibility and advantage of the method.

Following these reports on technical innovations, this special issue presents three exciting clinical applications of parallel and sparse imaging. The paper by Meng *et al*. reports a study where a parallel imaging-based diffusion spectrum imaging protocol is implemented for *in vivo* fiber tracking of macaque monkey brain (8). The study is performed on a 3.0 T clinical scanner with non-human primates. DSI can address crossing and touching fibers, which is a substantial advantage over the diffusion tensor imaging (DTI). Using parallel imaging in this application significantly shortens the acquisition time for the high-resolution DSI images, which may otherwise be too long for anesthetized monkeys.

In this study (9), Liu *et al*. present preliminary results of a fast, free-breathing, *in vivo* fetal imaging using time-resolved 3D MRI technique. Clinical fetal imaging has been conventionally done with ultrasounds techniques. The potential diagnostic advantage of *in vivo* MRI for fetal imaging has been well-known but technically challenging due to the motions and limits of anesthesia on fetus. The fast imaging method, based on an in-plane multi-echo radial scan and a Cartesian encoding through planes, makes it possible to acquire 3D clinical fetal images in less than 3 minutes. Although this speed is still much slower than ultrasonic imaging, the possibility of free-breathing fetal imaging with MRI is truly exciting.

In the last article, Zhang and colleagues from Emory and Japan utilize parallel imaging-accelerated multiparameter MRI protocol to assess acute stroke in a non-human primate model on a 3T clinical scanner (10). Multiparameter MRI provides comprehensive information such as T1, T2, diffusion, temperature, flow, and magnetization transfer that can be extremely useful for the diagnosis and treatment of acute stroke injuries. However, it is often limited by the long acquisition time and the finite time window after the stroke. Parallel imaging technique in this setting can substantially reduce the scanning time and makes it possible for fast and repeated evaluation of acute stroke injuries.

Again, we hope these two special issues could provide interesting and important information on the current topics and research directions of parallel and sparse MR imaging to the readers of *Quantitative Imaging in Medicine and Surgery (QIMS)* and help to facilitate further development and clinical translation of this novel and unconventional fast MR imaging method.

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