PARALLEL MRI at 7 TESLA

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Approximately a decades and a half of work conducted to pursue magnetic fields higher than the clinical standard of 1.5 T has demonstrated that high magnetic fields can provide numerous advantages in biomedical imaging. Some of these advantages drive from the increased signal-to-noise ratio (SNR) [1] with the higher magnetic field which can be traded for improved spatial or temporal resolution, or contrast (e.g. [2]). However, there are also direct and SNR-independent benefits in physiologically relevant contrast mechanisms, most notably in functional brain imaging (fMRI) [3, 4]. Today, functional images of the entire human brain can be generated with sub-centimeter resolution in single subjects and in data acquisitions times of several minutes using 1.5 Tesla MRI scanners. However, fMRI maps are based on secondary metabolic and hemodynamic events that follow neuronal activity, and not the electrical activity itself. Therefore, the representation provided by fMRI cannot *a priori* be assumed to be exact. The spatial accuracy of such maps depend on the nature of the neuronal signaling that induces these responses and the role of vasculature in generating MR detectable signals sensitive to metabolic and hemodynamic changes. The latter has been demonstrated to be strongly magnetic field dependent, and significant improvements in accuracy of mapping signals have been demonstrated at higher magnetic fields such as 4 and 7 Tesla in humans, and higher fields in animal models. High resolution and high accuracy fMRI studies conducted at 7 T have produced insights and results into human brain function that has not been attainable in lower field studies (e.g. [5, 6]).

These high field studies, however, also suffer from increasingly difficult problems at high magnetic fields. Magnetic field inhomogeneities caused by the susceptibility differences between air filled cavities and tissue increase with higher magnetic fields. Consequently, images obtained with rapid k-space coverage approaches such as EPI or SPIRAL that form the basis of fMRI suffer from increased distortions or blurring, respectively, as well as signal loss due to the shorter T_2^*. To date, these difficulties have been circumvented by restricting the image field of view (FOV) to a small local region along the phase encode direction [7, 8], and consequently shortening the data acquisition time, or by extensively segmenting the data acquisition. Both of these approaches have significant drawbacks; the first is unable to provide coverage over the entire or large portions of the sample, and the latter leads to long acquisition times and image artifacts. Improvements in gradient performance that is bound emerge in the future will alleviate these problems, but unlikely to fully solve them because ultimately there are physiological constrains on gradient switching rates.

Another problem encountered at high fields for high resolution and high accuracy functional imaging is power deposition since one of the most promising approaches to high specificity functional mapping is based on Hahn Spin echoes at high magnetic fields rather than gradient echoes [4, 8].

Parallel imaging strategies based on multi-coil arrays [9, 10] provide a promising solution to the afore-described problems encountered at high magnetic fields. This approach is potentially an attractive alternative because high fields are expected to improve parallel imaging performance due to the more complex sensitivity profiles of each coil element and the increased SNR. Studies conducted using phantoms and analogous simulations demonstrate that g-factors that can be realized for a given reduction factor improve (decrease) with magnetic fields higher than ~ 4 Tesla, with significant gains realized at 7 Tesla and higher (e.g. [11]). In addition, it is possible to use approaches that are uniquely suited for high field (short-wave-length) conditions to build multiple element arrays that can operate as transmit/receive or simple receive array coils [12]. Using 16 to 32 channel head coils, we have been able to experimentally demonstrate that *one-dimensional aliasing* factors of 4 to 6 can be attained for brain imaging using SENSE with excellent g-factors at

7 Tesla. Functional imaging studies conducted with a 16 element coil and one-dimensional *reduction* and *aliasing factor* of 4 show that functional maps have better statistical significance than with 4-segmented EPI when the SNR loss is taken into account. Based on current results, it can be expected that 1-dimensional aliasing factors of around 4-6 is supportable at 7 Tesla and higher magnetic fields. These developments open the prospect that high specificity functional maps that are realizable at high fields will be achievable over the entire brain at 7 T or higher magnetic fields.

The problems that are addressed with parallel imaging in functional mapping at ultra-high fields is also relevant for other applications that rely on EPI or SPIRAL type image-acquisition methods, such as Diffusion Tensor Imaging (DTI). Small animal studies have demonstrated that fiber tracking with DTI improves significantly at high resolutions. Attaining such high resolution DTI images in the human brain will require parallel imaging.

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