Peter Jezzard trained as an undergraduate in physics at the University of Manchester, before commencing a PhD in non-medical MR physics at the University of Cambridge. In 1991 he switched to biomedical MR, having moved to the National Institutes of Health, USA, to take up a post-doctoral, and later Unit Chief, position. He remained there for seven years, working in the NHLBI and NIMH, mostly on projects related to the development of functional measurements in the brain. In 1998 he moved back to the UK where he became a founding member of the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB). Initially a member of the MRC External Staff embedded in Oxford University, he was appointed to a tenured university professorship in neuroimaging in 2003, and to a fellowship at University College. His current scientific interests lie in the development of non-invasive measures of brain physiology, and their application to cerebrovascular and neuropsychiatric disorders. He also directs the Oxford-Nottingham EPSRC-MRC Centre for Doctoral Training in Biomedical Imaging, and is a past President of the International Society for Magnetic Resonance in Medicine.

Dear MAGNETOM Flash reader,

It is my pleasure to introduce this special MAGNETOM Flash issue on the topic of simultaneous multi-slice (SMS) imaging [1, 2]. It is quite a technical topic, but it is my firm belief that this is a huge advance for the modality of magnetic resonance imaging, and soon you will all be using this technology. So here is your opportunity to understand this revolutionary technique from the pioneers themselves, and to prepare yourself for using SMS in your daily practice.

To understand the SMS revolution it is first necessary to understand another recent innovation in the field, namely parallel imaging. In parallel imaging (whether SENSE image-based [3], or GRAPPA raw-data-based [4]) the amount of data acquired in the phase-encode direction is reduced (under-sampled) and the missing information is provided by the differing spatial sensitivity profiles of the array elements in the receive RF coil. Thus, the process of spatial encoding has moved in recent years from being something that is entirely achieved by manipulating the field gradients (once slice selection has occurred) to something that is shared between field gradient encoding and the sensitivity profiles of the RF coil array elements.

Simultaneous multi-slice imaging takes this a stage further by exciting multiple slices at the same time, and then spatially encoding their signals in a simultaneous manner. Historically this would have led to the images from each slice sitting on top of one another, resulting in a rather horrible mess. But with the advent of array receive coils, and with image reconstruction principles that are closely related to parallel imaging, it is possible to separate the signals from the various slices. This can be accomplished since the different array elements of the receive coil 'see' each slice with a different sensitivity (due to their greater or lesser proximity to a given slice). The image reconstruction algorithm can then unpick the signal contributions and restore them to their separate slice locations, especially if the aliasing from the different images is arranged in a controlled pattern (see the discussion on CAIPIRINHA in the article by Breuer et al. [5]).

So what is the advantage of simultaneous multi-slice? The main advantage is that it offers yet another means by which the scan time can be reduced. In principle the imaging speed can be increased by a factor equal to the number of slices that are excited simultaneously. Typically this is a factor of 2 to 4. It is also possible to combine SMS and conventional parallel imaging, although there are limits to what can be achieved since the tricks used to restore under-sampled data in conventional SENSE/GRAPPA are the same ones that separate signals from the different slices in SMS. Nevertheless, and as this special issue shows, there are plenty of applications where SMS principles can be deployed to great benefit, and where a new chapter in the story of MRI is being ushered in.

> *"There are plenty of applications where SMS principles can be deployed to great benefit, and where a new chapter in the story of MRI is being ushered in."*

Dr. Peter Jezzard

Applications of SMS

SMS approaches will have impact in many areas where imaging speed is key. In diffusion tractography imaging, for example as described by Setsompop et al. [6] and Shepherd [7] in this issue, SMS allows a greater number of diffusion directions to be sampled per unit time. This should lead to improved data quality and more feasible clinical applicability. Other articles in this issue show how clinical diffusion imaging in the musculoskeletal system, spine, body, and even the heart, is benefitted by the application of SMS. In the realm of functional imaging SMS can greatly improve the temporal sampling efficiency of fMRI, leading to better resting-state fMRI connectivity maps. Indeed, technique enhancements of SMS have constituted a major part of, and have had a major impact on, the NIH-funded Human Connectome Project [8].

SMS also offers the opportunity to bring clinically unfeasible scan times back into the realm of reality. A good example of this is the readout-segmented EPI (RESOLVE)[1] method, that allows higher resolution diffusion data to be acquired, with dramatically reduced geometric distortion and spatial blurring than is the case for snapshot EPI. However, as originally conceived the RESOLVE sequence led to unreasonable scan times for anything other than very basic diffusion-weighted imaging. With the inclusion of SMS[1] (see the articles by Frost et al. [9] and Runge et al. [10]) the scan times can be brought back down to tolerable durations.

But surely, I hear you remark, there must be a catch to this. Nothing in MRI ever comes for free. There is always a trade off. The answer is that SMS does come reasonably close to offering increased speed without much of a penalty, at least in the regime of well-behaved parallel imaging reconstruction. But clearly there are some limitations that must be acknowledged. One is that the specific absorption rate (SAR) of the pulse sequence is increased by having RF pulses that selectively excite multiple slices (to first approximation this is quadratic with the additional number of slices that are excited). The related PINS (power independent of number of slices) method [10] suggests a solution to the SAR problem, albeit with compromises in the off-resonance performance of the PINS excitation profiles. Indeed, hybrid combinations of PINS and 'conventional' SMS RF pulses can also be considered [11]. Another source of potential artifact that has had to be overcome is the possibility of signal 'bleed' between slices. A clean separation of signal is needed to avoid misinterpretation, particularly for measurements of subtle signal changes such as in fMRI. As shown in the paper by Setsompop et al. [6] LeakBlock algorithms can be used to minimize this cross-slice contamination.

In summary, this special issue describes the latest exciting developments in fast scanning that represent another technological revolution in magnetic resonance imaging. I am quite sure that if you are not already using SMS techniques to improve your scan times, and improve your image quality, then you soon will be!

Peter Jezzard.

[1] The product is still under development and not commercially available yet. Its future availability cannot be ensured.

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