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The Rapid Imaging Renaissance

"There is in this Earth no maneuver more unnerving than the Spin. Just when one thinks to have advanced into the twilight, Dawn comes round again."
Samuel Bowditch

In imaging, we are all spies. Like true intelligence agents or their glamorized counterparts onscreen, imaging scientists and practitioners are charged with gathering critical information in space and time. We employ the latest technology to acquire encoded signals, and deploy laboriously optimized algorithms to decode them. We do what is necessary, piercing the veil of the skin, the skull, the cell, or whatever stands in our way, in order to see what was once invisible.

The MAGNETOM Flash Magazine represents a chronicle of this evolving intelligence work in the worldwide Siemens MR community. And one theme which emerges clearly from such a chronicle is the theme of advancing imaging speed.

Like floors at a construction site, or else like accreted archaeological layers, today's rapid imaging techniques build upon yesterday's techniques, compressed sensing combining with parallel imaging joining forces with rapid gradient switching to yield ever higher accelerations. Recently, however, something new and unexpected has begun to emerge from this gradual accumulation. There is something more fundamental and more revolutionary afoot than mere acceleration.

This 'something' is reflected in quite a few of the articles in the current issue of MAGNETOM Flash. Relevant themes include

- streamlined workflow (see Rapalino et al. on clinical protocol optimization with GOBrain, Reiner et al. on the Whole-Body Dot Engine for combined chest, abdomen, and pelvis exams; Egelhof et al. on workflow improvements with Fit-Upgrades, and Schraa on AutoCoverage in several Dot engines)
- fast, motion-insensitive imaging (such as FREEZEit in pediatric lung MRI* by Kinner et al.; parotid tumor imaging with GRASP by Patel et al.; or cardiac DTI by Ennis et al.)
- efficient multiparametric imaging, whether for diagnostics or for guidance of therapeutic interventions (see Gulani et al. on MR Fingerprinting; Bickelhaupt et al. on fast and non-invasive characterization of suspicious breast lesions; and Pham et al., on the prediction of treatment response in rectal cancer.)

The thread of rapid, efficient imaging with rich and diverse information content may of course be traced not only through this MAGNETOM Flash issue, but also through numerous past issues, and indeed across much of the history of magnetic resonance. That said, we occupy a time of unique challenge and unique opportunity for MR. In the clinical arena to be sure, we are being subjected to unprecedented levels of pressure for efficient delivery of value. We are also, I would argue, witnessing a unique convergence of disruptive innovations that have the potential to reframe radically the value proposition in our field.

Before I release you to enjoy the contents of this issue, then, let me attempt to touch briefly on some of the dimensions of what I see as a rapid imaging renaissance [1].

*MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.

A brief history of rapid imaging

One might argue that there is a natural evolutionary tendency for imaging modalities to get faster over time. This tendency is certainly driven by the inherent inventiveness of those who use imaging devices. It is also driven by a particular selection pressure – namely, the need for speed. In the context of biomedical imaging, this need is obvious and multifold. First of all, patients and organs move, and fast images are required to image moving structures such as the beating heart. Injected contrast agents used to highlight particular internal structures also move, and catching the contrast on its way through the vascular system requires speed. Second, patients get restless. Due to underlying disease or understandable agitation, subjects often cannot sustain long breath-holds, and long total examination times can be challenging. Third, time is money. Scanner throughput, and workflow in general, becomes an important practical consideration in an era like ours of intense cost-consciousness, in which the premium on efficiency is high. Finally, and perhaps most importantly, time is information. Greater imaging efficiency enables the acquisition of more information per unit time, which enhances the value of imaging studies, both for clinical evaluation and for basic research.

Figure 1 summarizes the evolution of imaging speed for MRI in particular, since its inception in the 1970s. Various hardware developments, such as strong and fast-switching magnetic field gradients, enabled progressively more rapid transitions between sequentially acquired data points. Meanwhile, changes to the acquisition sequence – including rapid MR pulse sequences incorporating rectangular raster patterns (Echo Planar Imaging) or spiral trajectories – further accelerated sequential scanning. It was not until the 1990s that arrays of RF detector coils were employed in practice to gather multiple data points simultaneously, rather than in the traditional sequential fashion. This use of parallelism, which harks back, of course, to the massively parallel configuration of our eyes, enabled further advances in imaging speed beyond previous hardware and software limits. The next decade saw a race to incorporate ever larger numbers of detectors, until this trend, too, began to mature and new practical limits of acceleration began to be reached.

Suddenly, in the middle of the last decade, the landscape of rapid imaging started to shift again. The impetus this time could be traced to developments in the mathematics of image reconstruction. Previous rapid imaging approaches such as parallel MRI or non-Cartesian acquisitions had already necessitated substantial changes to image reconstruction algorithms. However, more recent developments had their root in a new appreciation of the role of sparsity and incoherence in the solution of inverse problems like image reconstruction. Modified acquisition approaches were soon being proposed to take advantage of the new reconstruction methods, which tended to be grouped under the label of compressed (or compressive) sensing. Many would argue that we now occupy the era of sparsity in rapid imaging. It is a 'post-Nyquist' era, somewhat unsettling to those raised on linear inverse problems, but extraordinarily rich in possibilities for innovation. The outcome in terms of raw acceleration of MR image acquisition is already striking: appropriate combinations of compressed sensing with parallel imaging have, in many cases, been shown to yield order-of-magnitude accelerations as compared with parallel imaging alone. Meanwhile, compressed sensing and related approaches have begun to change the way we view the problem of image formation.

Sparsity and incoherence: the rise of compressed sensing

Compressed sensing may be argued to have arisen out of at least two central observations: 1) that most signals (including images) are simpler than they might at first appear, if they are viewed from the right perspective, and 2) that we can generally control how we encode and decode signals or images, such that undersampling does not necessarily lead to irretrievable loss of information. Over time, numerous particular reconstruction algorithms, taking advantage of various kinds of prior information to reconstruct undersampled datasets, had previously been proposed. However, it is the work of Candès [2], Romberg [2], Tao [2], and Donoho [3] that is generally credited with establishing the rigorous theoretical underpinnings of sparse signal recovery from

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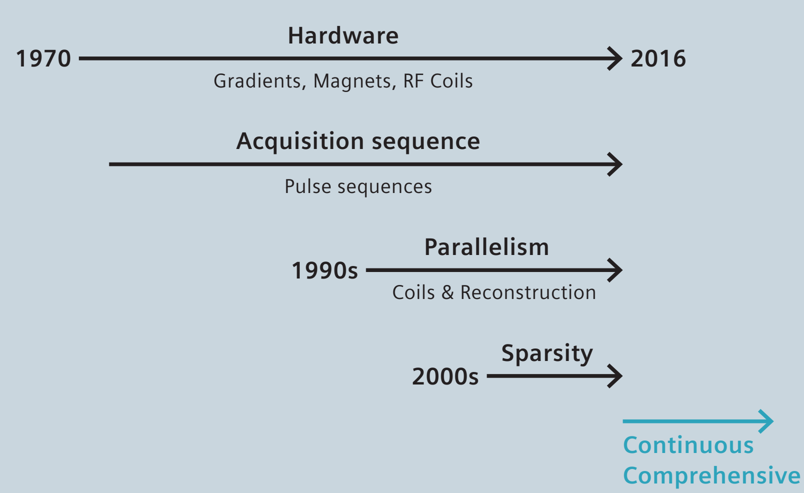


1 A brief history of rapid MRI.

incoherent acquisitions – or, in other words, compressed sensing. Very soon thereafter, Lustig [4] demonstrated concrete applications of compressed sensing for rapid MRI, and in the process created a new subfield of biomedical imaging research.

The fact that we can represent images with less than the usual data is not in itself surprising. It is well known that most images are at least somewhat sparse, in the sense that they may be represented accurately by a number of parameters smaller than the number of voxels. The prevalence of image compression – an essential tool for modern data storage and transmission – serves as concrete evidence of this fact. Image compression algorithms exploit correlations between pixels to reduce the number of bits required for storage. Knowing as we do that most medical images are highly compressible, we are faced with a nagging question: why do we need to exert Herculean effort to acquire fully-sampled data, if in the end we are going to throw most of those data away? Until compressed sensing appeared on the scene, the prevailing answer was that accurate compression requires prior knowledge of image content, so that we can decide which components to discard and which to keep. By definition, however, the content of a new medical image is unknown, and it is in fact the unpredictable abnormalities that represent the most critical information for physicians and their patients. In medical imaging circles, use of prior knowledge is viewed with legitimate caution.

How, then, does compressed sensing effectively accomplish pre-compression without assuming particular image content? It simply asserts that the correct image (or image series) is sparse in a known domain. This domain may be the image domain itself, or it may be defined by transforming the image using Fourier transforms, wavelet transforms, or other operations often used in image compression. Compressed sensing makes no assumption about which coefficients in particular are significant or insignificant – it only assumes that a suitably sparse solution is likely to be correct. Such an assumption does carry risks, but the risks are rather more modest than the risk of corrupting the true image with features of a specific image model.

In practice, successful compressed sensing requires three principal ingredients: 1) sparsity of true image content, 2) incoherent sampling (with incoherence, in this case, assessed between the acquisition basis and the sparse basis), and 3) non-linear reconstruction. The basic principles of compressed sensing are elucidated quite well in the literature, and for particular demonstrations of key concepts as applied to imaging, readers are referred to some of the seminal publications by Lustig et al. [4, 5]. A simple and compelling graphical example may be found in Figure 2 of Ref [4] or Figure 5 of Ref [5]. By now, some of the tradeoffs of compressed sensing, including the risk of subtle artifacts at excessively high accelerations and the challenges of quantitative image quality evaluation in the presence of nonlinear reconstruction, have also been well documented.

Stepping back from these details, however, there are a number of salutary consequences of adopting a compressed sensing *perspective*. First of all, one begins to focus less on the number of voxels in an image and more on information content. Second, one is confronted with what might be called a paradox of dimensionality: in the era of sparsity, bigger, more diverse datasets tend to result in better reconstruction performance. Multidimensional datasets tend to demonstrate more sparsity, and enable more incoherence, than datasets with fewer dimensions, and this has led to a new rule of thumb for data acquisition. Whereas in a traditional setting of ordered acquisition and linear reconstruction, simple repeatable sequences are often preferred, in a setting of compressed sensing it behooves one not to repeat oneself. Whenever possible, one should take advantage of temporal coherence and sampling-pattern incoherence. Taken together, these observations connect rapid imaging, more than ever, not just with raw acceleration but also with enhanced information content.

Hints of a new paradigm

Just as our retinas are enviable models of parallel imaging systems, so we may look to our brains as examples of sparse information recovery systems. Human neural processes are highly efficient at data compression and information extraction. As we make our ways through any typical day, our brains are constantly distilling complex inputs rapidly into their essences, and they routinely reconstruct essential information from incomplete input. In considering what is next for biomedical imaging, we might be well served by looking once again to our day-to-day experience of the world. That experience is dynamic and multifaceted, with diverse information streaming in constantly along multiple sensory channels. Can we design imaging strategies to match these aspects of our experience?

Whereas biomedical imaging protocols have traditionally been designed around well-defined snapshots or ordered series thereof, a paradigm of rapid continuous imaging and flexible image reconstruction is emerging that may be better suited to capture the dynamic nature of experience. Recent continuous acquisition approaches exploit correlations along the time domain, and, in so doing, they may often outperform traditional intermittent acquisition protocols. In keeping with the paradox of dimensionality, it has been shown that acceleration capability, just like compressibility, is much greater with a time series than with a single snapshot, and an incoherently sampled time series plays particularly to the strengths of compressed sensing.

What about the multifaceted nature of experience? A trend towards rapid comprehensive imaging is now afoot, which aims explicitly to entangle multiple distinct streams of quantitative information, which have traditionally been encoded separately and sequentially, within single dynamic multidimensional datasets. This trend represents a new form of parallelism, which promises to transform imaging devices from 'scanners' into something more closely resembling broadband communication channels.

As a complement to the diverse examples on display in the current edition of this magazine, let us briefly explore a few additional illustrative examples drawn from my own network of collaborators and from the Siemens collaboration network at large.

Rapid continuous imaging

There has been a recent resurgence in non-Cartesian imaging approaches, sparked in large part by considerations of sparsity. Radial *k*-space patterns in particular (arguably a throwback to Lauterbur's original encircling projections) tend to have favorably incoherent undersampling properties, well suited to compressed sensing reconstruction. Radial trajectories are also robust to motion, and they lend themselves to flexible angular ordering schemes such as the 'golden angle' scheme, in which each new radial spoke fills in the largest remaining gap in the angular distribution and provides complementary spatial information in a continuous nonrepeating sequence. The GRASP technique [6] described in a recent edition of MAGNETOM Flash [7] exploits such a golden angle radial sequence. Since this sequence has no preferred starting or ending point in time or angular distribution, and since even small sets of time-adjacent spokes provide nearly isotropic, if highly undersampled, coverage of *k*-space, the same dataset may be reconstructed with flexible temporal resolution (within the limits of achievable acceleration), at essentially any time point of interest. This flexibility and robustness tends to be greatly appreciated by clinicians (see Patel et al. on permeability imaging of parotid tumors using GRASP). Clinical GRASP studies have been performed for more than ten thousand patients at NYU Langone Medical Center to date, for applications ranging from head to toe, and GRASP is now being evaluated in multicenter trials within the Siemens network.

Though GRASP is sufficiently motion-robust to obviate the need for breath-holding in many applications, motion can still degrade image quality, either by causing intraframe blurring for low-temporal-resolution reconstructions, or by degrading temporal sparsity and engendering residual inter-frame blurring in high-temporal-resolution reconstructions. Radial trajectories, however, have the additional advantage that each spoke passes through the center of *k*-space, and this repeated central data may be used as a sensitive indicator of changing motion states. The eXtra-Dimensional GRASP (XD-GRASP) reconstruction method [8] uses inherent self-navigation properties to sort GRASP data into multiple distinct motion states. Rather than simply grouping temporally sequential spokes, the XD-GRASP algorithm groups spokes within a given motion state, and organizes the data into additional temporal dimensions representing the different types of motion. Respiratory motion and contrast enhancement may be captured in distinct dimensions for dynamic contrast-enhanced studies; or the extra dimensions may represent respiratory motion and cardiac motion for cardiac MRI. (In this case, coils near the heart and the diaphragm are used to characterize the cardiac and the respiratory motion signals, respectively.) Sorting the continuously-acquired data into additional dimensions has a number of advantages. The extra dimensionality results in improved signal sparsity, since disparate motional frequencies and other dynamic characteristics are no longer intermingled. This results in improved image quality and increased acceleration capability. At the same time, extradimensional sorting is an efficient means of motion correction, which, unlike some traditional navigation methods, does not require that any data be discarded. Finally, XD-GRASP enables not just correction for but also characterization of motion. It has been shown to be useful, for instance, in separating and visualizing arrhythmic cardiac cycles. It has also proven useful in characterizing respiratory dynamics, for example enabling direct visualization of left-right ventricular (LV-RV) interaction over the course of the respiratory cycle. Note that all of this information may be obtained from the same continuously acquired dataset, simply by adapting the reconstruction algorithm and by slicing through the resulting multidimensional image series as desired.

There is still more information to be gleaned from the same datasets. While XD-GRASP enables visualization of distinct motion states, it does not directly quantify the extent of the motion. One could, of course, attempt to coregister distinct frames to derive approximate motion fields. It turns out, however, that one may derive motion fields more directly from within the reconstruction algorithm itself, by appealing to a domain of mathematics closely related to that of sparse information recovery – namely, low-rank matrix completion. The 'motion-guided L+S' reconstruction of Otazo et al. [9] takes advantage of self-consistency within diverse continuously acquired datasets to self-discover accurate quantitative motion models, rather than trying to fit the data to a particular *a priori* model.

Rapid comprehensive imaging

The question of quantitation highlights one of the longstanding challenges of magnetic resonance. The highly flexible tissue contrast and rich endogenous information content associated with MRI also result in a high degree of potential operator- and scanner-dependence. Therefore, whereas the interpretation of most varieties of clinical MR images is qualitative, specialized MR pulse sequences are usually deployed for the quantitative mapping of tissue parameters such as relaxation times or diffusion constants. These specialized sequences come at a significant cost in scan time and, even when carefully calibrated, they suffer from residual errors and interferences which result in undesirable variability.

Recently – and arguably as a partial outcome of the 'compressed sensing perspective' alluded to earlier – it has been recognized that the multifactorial complexity of spin dynamics may represent an asset rather than a liability for quantitation. In particular, there is an emerging trend towards fitting multiple physical parameters (and, as desired, deriving multiple contrasts) from the same acquired data. This trend is in direct contradistinction to the traditional approach of designing sequences around as simple a dynamical effect as possible, then correcting for undesired effects though painstaking calibration. Such a trend can also be viewed as another manifestation of the paradox of dimensionality. Whenever possible, the reasoning goes, mix together disparate encoding mechanisms such that the whole dataset is greater than the sum of its parts.

The current archetype of this new comprehensive quantitative mapping approach is the MR Fingerprinting (MRF)[1] technique, as championed by Griswold and colleagues at Case Western Reserve University [10]. Gulani et al. provide a helpful introduction to MRF in this issue of MAGNETOM Flash. MRF entangles the effects of multiple physical parameters (T1 and T2 relaxation, proton density, magnetic field inhomogeneity, etc.) in long pulse sequences with irregular timing. Spin evolution under the influence of these sequences results in complex temporal signals that serve as distinctive 'fingerprints' for particular sets of parameter values. Individual voxel fingerprints from a series of successive image frames are matched to a database of simulated spin dynamics with a range of known parameter values. Since the MRF sequences are arranged such that undersampling artifacts are incoherent with the spin dynamics, the fingerprints may be matched reliably to the database even for highly undersampled image sets, enabling high degrees of acceleration that compensate for the duration of the lengthy pulse trains. In this way, multiple quantitative parameter maps are derived rapidly and simultaneously from images that, on their own, would be essentially uninterpretable.

Though the simple pattern-matching reconstruction in MRF is quite different from the iterative sparsity-enforcing reconstructions discussed earlier, there is nonetheless a strong connection to compressed sensing. MRF makes liberal use of incoherent acquisition, and Bloch equation models serve to capture the key dynamical coherences in the data, effectively standing in for a sparsifying transform. MRF also has some of the provocative effect of compressed sensing, spurring out-of-the-box thinking about potential new encoding or reconstruction methods. Ben-Eliezer et al. have demonstrated that, even with more highly coherent acquisitions, for example traditional multi-spin-echo sequences optimized for rapid T2 mapping, one can map multiple quantitative parameters, including not only T2 and proton density but also the B_1^+ RF transmission field distribution, by fitting to Bloch equation models [11]. Recent work by Cloos et al., moreover, has shown that MRF pattern matching may be extended to map the B_1^+ transmit field pattern of multiple RF coils [12]. In addition to enriching the information content of fingerprinting sequences at no cost in acquisition time, this new 'multi-illumination' fingerprinting approach has been shown to enable robust imaging in the presence of strong RF field inhomogeneities. As a result, it promises to reduce the calibration-heavy and workflow-intensive field of parallel RF transmission to a simple 'plug and play' mode of operation [12].

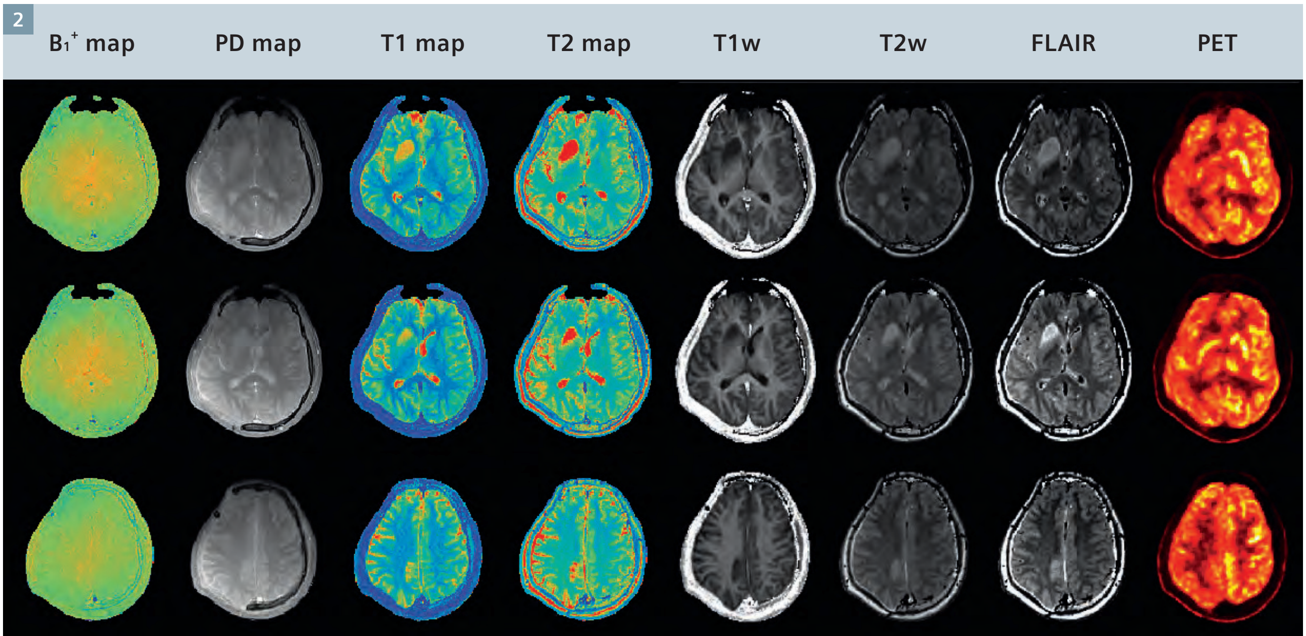
The multiparametric mapping approaches discussed so far all adhere to the general theme of allowing, or even embracing, inhomogeneities and signal imperfections. Rather than employing Herculean efforts to calibrate out imperfections, these approaches quantify inhomogeneities along with the usual desired parameter values, based on the distinctive characteristics of a multifaceted acquired signal. Like XD-GRASP or combined MR-PET, these rapid comprehensive imaging approaches represent a form of all-in-one acquisition. The example of plug and play parallel transmission, moreover, introduces once again the important theme of workflow simplification.

Toward rapid, continuous comprehensive imaging: the rapid imaging renaissance

Let me now offer two final examples of how the advances described so far can enable dramatic simplifications of MR (and multimodality) workflow, while preserving and ultimately enhancing image information content.

Cardiac MRI boasts some of the most complex workflow in the field. Both cardiac and respiratory monitoring are routinely performed, and advanced training is required merely to orient key multi-oblique image planes correctly during the planning of scans aimed at characterizing diverse aspects of cardiac anatomy and function. A few-minute comprehensive cardiac examination has long been a holy grail for those interested in cardiac MR. Collaborative work between NYU and the research group of Stuber et al. in Lausanne is addressed at a prototype few-minute continuous comprehensive cardiac MR examination, using four [13] - or five-dimensional XD-GRASP [14]. The 'spiral phyllotaxis' trajectory [15] used in this work is a generalization to three dimensions of the golden-angle radial trajectory used in prior XD-GRASP studies. In 5D cardiac XD-GRASP, continuously acquired data obtained during free breathing are sorted into cardiac and respiratory motion dimensions, in addition to the three spatial dimensions defining the imaging volume. This approach yields high-resolution isotropic whole-heart image sets in which cardiac motion, respiratory motion, and cardiac anatomy are all resolved. One can obtain robust

[1]Magnetic Resonance Fingerprinting is currently under development. It is not for sale in the U.S. and other countries. Its future availability cannot be guaranteed. As this is a research topic in predevelopment, all results shown are preliminary in nature and do not allow for generalizations or conclusions to be drawn.
Product realization and features therein cannot be assured as the product may undergo futher design iterations.



2 MRF-PET [16]. Three representative slices are shown from a 30-slice whole-brain axial image set obtained after surgery in a patient with a brain tumor. The diverse information obtained from a single continuous six-minute MRF-PET acquisition includes quantitative T1, T2, relative proton density, and B_1^+ maps, jointly reconstructed PET images, and a variety of synthesized contrast weightings, including T1, T2, and FLAIR weightings. *Figure courtesy of Drs. Martijn Cloos and Florian Knoll.*

views of cardiac and great vessel dynamics in any desired orientation, and from the same data one can derive high-resolution depictions of coronary arteries throughout the cardiac and respiratory cycles. This early work has not yet incorporated myocardial perfusion and viability studies, but in light of experience so far using XD-GRASP for other contrast-enhanced studies, this seems a natural extension.

The second example of rapid continuous comprehensive imaging was also motivated originally by workflow considerations. When we began performing simultaneous MR and PET scans on our Siemens Biograph mMR scanner at NYU, we quickly realized that the MR imaging protocol in many cases represented a temporal bottleneck. By the time the scan operator was done with gathering the multiple contrast weightings called for in clinical protocols, the typical time needed for FDG-PET acquisitions had long been exceeded. Though of course we could always continue averaging PET counts for the entire duration of the MR protocol, we were in a sense only biding our time. To address this inefficiency, we turned to MRF, and designed a joint MRF-PET acquisition and reconstruction approach [16]. MRF-PET combines joint MR-PET reconstruction with spin dynamical pattern matching to derive multiple quantitative MR maps together with improved PET images. The joint reconstruction, moreover, improves MR aliasing artifact removal, as a supplement to the incoherence effects in MRF alone. The net result is a diverse, quantitative multimodality image volume obtained in the time normally occupied by a single PET 'bed position'. Figure 2 illustrates the range of information which may be obtained from a single six-minute continuous radial MRF-PET acquisition. In the figure, only three representative slices are shown out of a total of 30 slices covering the whole head. In addition to the PET image set, matched quantitative T1 and T2 maps are obtained, along with relative proton density maps and B_1^+ maps. Entanglement of multiple streams of information in this case results not only in improved quantitation but also in marked practical convenience. When all the information of interest may be obtained in a few minutes per bed position, one can begin to contemplate efficient whole-body MR-PET screening. One can also perform retrospective data mining, in which any suspected lesion detected on MR and/or PET can be examined after the fact with a range of potential synthetic contrasts, or even directly from the multiparametric data, to clinch the diagnosis without need for any additional scanning.

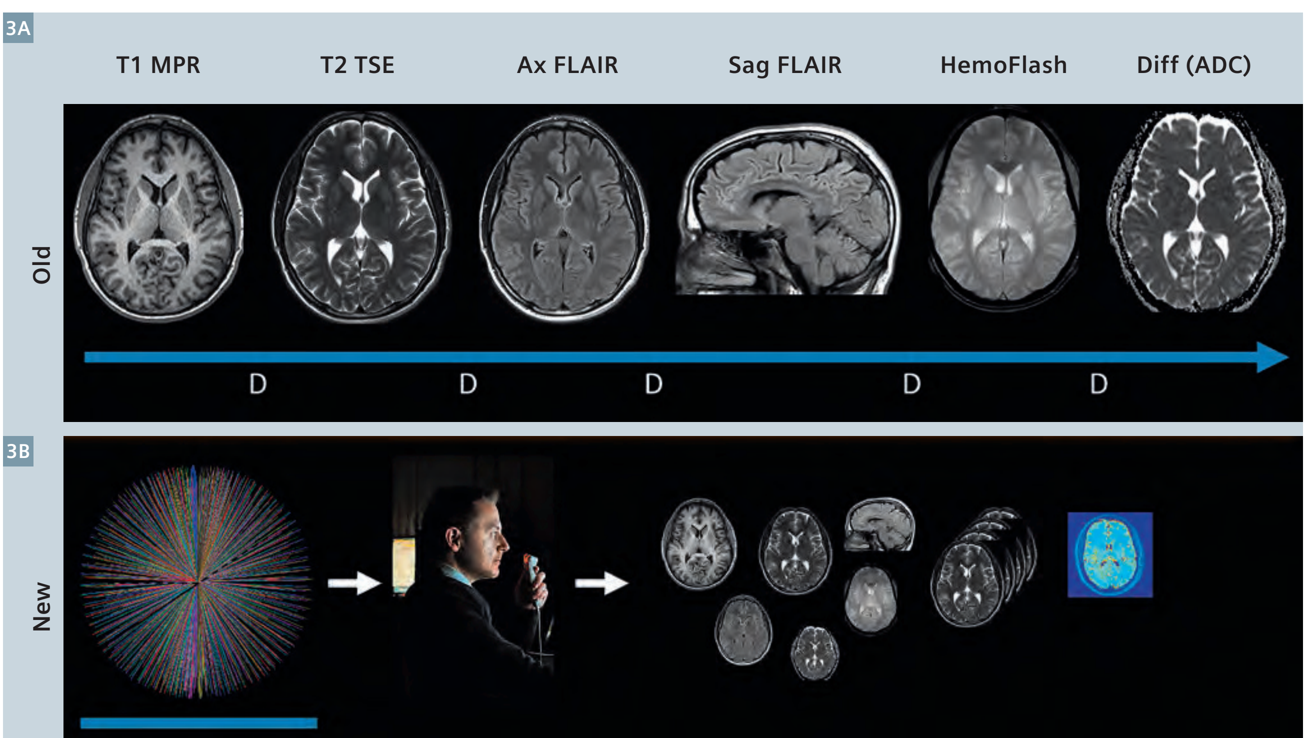
The limits of just how much information can be embedded robustly in sequences like MRF-PET are still being explored. Meanwhile, it is natural to contemplate combining MRF or MRF-PET with approaches like XD-GRASP or motion-guided L+S. Such a combination would address known challenges associated with motion in MRF. It would also represent a unified approach to quantifying physiologic dynamics along with spin dynamics (not to mention PET tracer kinetics). Traditionally, physiologic motion has been considered the nemesis of quantitative imaging, but in such a unified approach, the two would be synergistically entangled, requiring only appropriate reconstruction algorithms to disentangle them as needed.

Conclusions, and a look to the future

In closing, I would argue that an intriguing possible future of rapid imaging lies in continuous comprehensive data acquisition coupled with flexible image reconstruction. I hereby challenge you to identify some of the outlines of this future in the current issue of MAGNETOM Flash, not to mention in issues to come. The rapid continuous comprehensive paradigm (see the blue arrow at the bottom of Figure 1) has the potential to catalyze a new use of time in imaging, as is illustrated in Figure 3. At the top of the figure is a schematic representation of the traditional MR imaging protocol, with distinct contrast weightings achieved in distinct acquisitions using tailored pulse sequences. The scanner is not active during the dead time (D) between each sequence, which may become extended if careful planning of new scan geometries or other user input is required. Motion between scans can hinder registration, and motion during scans typically leads to artifacts. By contrast, the bottom of Figure 3 illustrates the new paradigm of rapid continuous comprehensive imaging. A simple-to-plan comprehensive dataset is acquired efficiently, with no dead time. Patient motion during the acquisition is tracked using self-navigation or motion model discovery. Depending upon the clinical indication for imaging, a preset portfolio of reconstructed images may be presented initially to the radiologist. If he or she detects anything in these images which raises suspicion, and which calls for any new views or contrasts, these may be generated on the spot from the raw data by appropriate reconstruction or other processing algorithms. The acquired data, moreover, need not be limited to MR data. If multiple modalities are available, then joint reconstruction may be applied to take advantage of shared information, to highlight noteworthy differences, and, ultimately, to generate multimodality 'fingerprints' of pathology.

Despite the technological and computational complexity underlying such a continuous comprehensive imaging paradigm, its net effect will be a marked operational simplicity. One can envision a future scanner operator's tasks being distilled down to a) positioning the subject within the scanner, and b) pressing the 'go' button. The key challenge then will lie in navigating the resulting multifaceted datasets. This is a worthy challenge, which is already being taken up across a broad range of disciplines in our increasingly information-saturated age. In the meantime, much work remains to be done before the current rapid imaging renaissance reaches its peak. It will fall to our community of clinicians and scientists either to resist or to embrace the disruption and the opportunity that will ensue. The result may be nothing less than a change in the way we see the world around us.

Daniel Sodickson



3 Towards a new use of time in imaging. **(3A)** Schematic illustration of a traditional ('old') MR imaging protocol. (D = dead time between distinct contrast-weighted sequences.) **(3B)** Illustration of the new paradigm of rapid continuous comprehensive imaging.

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