

## **Methods En Vogue: How Have They Fared Over Time?**

### **Parallel imaging**

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The general advantages of parallel acquisition techniques (PAT) for clinical MRI are the possibilities for either a higher spatial resolution or shorter scan times which subsequently allow shorter breath holds or multiple averaging within the same total scan time. Due to the shorter echo-trains, less blurring and image distortion is found in single-shot applications such as HASTE or EPI. Shorter echo times result in less signal decay in tissues with a short T2\* such as the lungs. Overall, PAT can be applied to different morphologic and functional imaging techniques in all areas of the human body. In addition, reduction of the applied RF-power by using parallel imaging helps to overcome specific absorption rate (SAR) limitations particularly at 3.0T. Hence, within a reasonable scan time, comprehensive exams become feasible with large anatomic coverage.

For imaging of the lung, the introduction of PAT opened new possibilities for assessment of pulmonary infiltrates with T2-weighted HASTE sequences. Detection of pulmonary abnormalities is almost as good as with CT with a sensitivity, specificity, positive predictive value and negative predictive value of 95%, 88%, 95% and 88%, respectively [1]. For assessment of pulmonary perfusion, both temporal and spatial resolution can be significantly increased by PAT compared with conventional imaging [2]. The combination of fast MR perfusion imaging and high-spatial-resolution MR angiography with PAT enables the differentiation of PPH from CTEPH with a high accuracy of 90% [3].

In addition, quantification of pulmonary perfusion is feasible using PAT [4]. Cardiac imaging has greatly benefited from PAT. One-dimensional acceleration factors up to R = 4 allow accurate SSFP CINE MRI even though CNR is significantly reduced [5]. For evaluation of global and regional cardiac function in patients the acquisition of an entire stack of short-axis Cine SSFP images can be reduced to 2 breath-holds using a TSENSE approach [6]. The application of PAT to SSFP CINE MRI enables the use of higher flip angles at 3.0T hence providing a better blood-myocardium contrast. EDV, ESV, and EF based on TSENSE cine showed excellent correlation to the nonTSENSE cine approach (all  $r = 0.99$ ,  $P < 0.001$ ). For assessment of cardiac perfusion, single-heartbeat temporal resolution could be accomplished with spatial coverage of eight slices at heart rates up to 71 bpm, six slices up to 95 bpm, and four slices up to 143 bpm in one study with the implementation of TSENSE [7].

For the liver, PAT allows reduction of acquisition time by approximately 40% without loss of image quality [8]. This facilitates the implementation of motion correction techniques such as respiratory triggering. In addition, PAT drives the use of single-shot black-blood T2-weighted spin-echo EPI sequences with reduced distortion artifacts for improved lesion detection [9].

With the development of multi-channel MRI systems with up to 128 independent receiver channels, PAT applications can be implemented for whole-body MRI imaging (WB-MRI). One study has reported high accuracy for detection of metastases with a sensitivity/specificity of 96%/82% for WB-MRI compared with 82% for PET-CT. Accuracy for correct TNM staging was 96% for PET-CT and 91% for WB-MRI [10]. For detection of bone metastases the accuracy of WB-MRI with PAT appears to be superior to PET-CT [11].

MR Angiography (MRA) has also greatly benefited from PAT with early reports dating already back to the year 2000 [12]. PAT offers the possibility to improve both spatial and temporal resolution while decreasing the acquisition time. High resolution contrast-enhanced (CE) MRA of the renal arteries with sub-millimeter voxel sizes is now feasible in less than 20 s [13]. This allows the quantification of area stenosis on cross-sectional cuts with significantly higher accuracy and inter-observer agreement in comparison with measurements of inplane diameter stenosis. On multi-channel MRI scanners, high-resolution WB CE MRA can be acquired with excellent image quality which allows screening for cardiovascular disease [15]. In combination with techniques such as view-sharing time-resolved CE MRA is possible at a frame-rate of less than 2 seconds

[16]. This approach may permit the characterization of tumor vascularity for differential diagnosis of head and neck tumors.

Neuro-imaging and MSK-imaging were traditionally not in the focus of PAT as measurement times were not critical. The combination of dedicated coil technology, higher field strength and functional imaging techniques led to a broader use of PAT. PAT in combination with radial imaging allows to acquire diffusion-weighted images of the brain with almost no geometrical distortion in every direction [17]. This particularly facilitates detection of small ischemic lesions in the brain-stem and at the base of the brain. Also simply decreasing the acquisition time in spine imaging without loss of diagnostic image quality can be achieved with PAT [18].

One major disadvantage of PAT is the loss of SNR, which decreases by the square root of the acceleration factor, but can be effectively counterbalanced by using higher field strengths and dedicated multi-element coils with higher SNR [19-21].

In the last few years, 3 major developments have further increased the versatility of parallel imaging techniques for clinical routine: the introduction of new acquisition schemes with acceleration in 2 dimensions, the implementation of parallel transmit as well as the advent of different mechanism for reduction of scan time such as compressed sensing (CS) techniques which are highly effective by itself but could potentially also be used synergistically with parallel imaging:

Recent parallel imaging techniques such CAIPIRINHA outperform conventional acceleration strategies in 2D. In a study on liver MRI, the overall image quality and SNR of CAIPIRINHA with 2x2 acceleration was significantly higher compared with conventional one-dimensional 2fold, 3fold and 4fold acceleration along with significantly less parallel imaging artifacts [22]. Acquisition time was only 6.9s compared with 21.1s for the conventional 2fold acceleration. Thus, the authors concluded that this technique is particularly well suited for increasing robustness of liver MRI in clinical routine.

The use of 2 or more entirely separate radiofrequency channels allows the selective excitation of an inner volume within the field-of-view. This is particularly valuable for single-shot sequences such as echoplanar imaging to further reduce the echo train length and the overall echo time. The combination of single-shot EPI with reduced-FOV imaging in the phase-encoding direction and spatially-selective RF excitations results in a decreased number of acquisition steps and therefore reduction in the EPI echo train. In a recent study applying a two-dimensional spatially-selective RF pulse with a FOV reduced by a factor of 3 the pancreas was found to be better delineated in all cases compared to a conventional acquisition with standard receive 2-fold accelerated parallel imaging, while ADC values did not differ significantly between the two sequences [23].

Other concepts for scan acceleration such as compressed sensing (CS) exploit the principles of data sparsity. This is particularly promising for real-time cardiac imaging in patients with tachycardia or reduced capability for breath holding. A recent study applied eight-fold-accelerated real-time cine MRI with CS compared to conventional ECG-gated cine cardiac MRI. The authors found an acceptable diagnostic image quality and relatively accurate left ventricular ejection fraction measurements in the setting of tachycardia [24]. Thus, these techniques hold promise to eliminate time-intensive, multibreathhold imaging for sick patients and could be potentially combined parallel imaging techniques for further improvement of image quality. Further studies are ongoing to assess the ultimate clinical value of CS for patients with different types of cardiac diseases.

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