

**Parallel MR Imaging with iPAT**  
More than Just Common SENSE

# Parallel MR Imaging with iPAT More than Just Common SENSE

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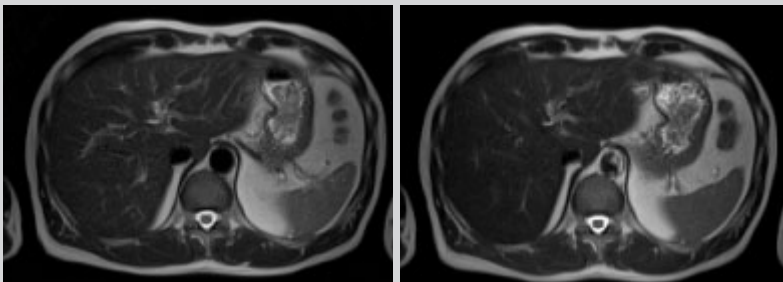
Conventional  
2min36s

iPAT x2  
1min20s

iPAT x3  
54s

iPAT x4  
44s

**Figure 1:**  
Improved speed with iPAT: spine imaging using 4 CP elements of the CP Spine Array Coil (built into the patient table).  
MAGNETOM Symphony Quantum. Matrix: 256x256.



**Figure 2:**  
Improved spatial resolution with iPAT: single-shot HASTE imaging using IPA (CP Body Array Coil + CP Spine Array Coil). MAGNETOM Symphony Quantum.

- **Left:** conventional imaging (no iPAT). 128x256 matrix in 350ms.
- **Right:** imaging with iPAT (x2). 256x256 matrix in 350ms.

Courtesy of University of Würzburg,  
Germany

Parallel imaging has taken the world of MRI by storm in the last few years, promising dramatic gains in imaging speed, a reduction in motion and susceptibility artifacts, and ultimately increased throughput and revenue for MRI centers. As the technology leader in MRI, Siemens has been at the forefront of these developments and currently offers the most robust and versatile parallel imaging solution on the market through its iPAT (integrated Parallel Acquisition Techniques) package.

## Once Upon a Time: A Bit of History

Speed has always been a critical consideration in MR imaging. Early clinical applications required hours for even the simplest examinations. During the 1990s, advances in field strength, gradient hardware, and pulse sequences brought tremendous improvements in imaging speed. At the same time, it became obvious that further increases in speed along these lines would be progressively difficult to achieve because of physiological limitations. Rapidly switched field gradients produce neuromuscular stimulation, and excessively dense RF pulse trains can lead to unacceptable levels of RF energy deposition (specific absorption rate, or SAR) and tissue heating. The evolution of MR imaging appeared to have encountered fundamental constraints in terms of speed.

## Parallel Future

Fortunately, in the late 1990s, researchers demonstrated that MR imaging could be dramatically accelerated using techniques other than incremental improvements in gradient technology and pulse sequence design. These new techniques employ sophisticated computational techniques (reconstruction algorithms) and arrays of coils wherein each coil would independently and simultaneously image a given volume – hence “parallel imaging”.

In conventional MR imaging, the phase-encoding steps are performed in sequential order by switching a magnetic field gradient step by step, and this determines the speed of the measurement. The number of phase-encoding steps also defines image resolution in the phase-encoding direction (e.g., 256 steps for a 256x256 matrix). In parallel imaging, spatial encoding using multiple coils partially replaces the spatial encoding normally accomplished using gradients, because additional information is obtained from the spatial variation in the coil sensitivity profiles.

Simply put, parallel imaging techniques use the spatial information inherent in local coil arrays to replace time-consuming phase encoding steps. In the example above, parallel imaging with an acceleration factor of 2 would require only 128 phase encoding steps to produce the same 256x256 matrix – in virtually half the time; the speed advantage is even greater with higher acceleration factors (Figure 1). The physics of MR dictate that the signal-to-noise ratio (SNR) will be reduced when using parallel imaging techniques. However, many MR applications today are not “signal-starved”, and acceleration factors of 2 or higher can be achieved with virtually no loss in diagnostic accuracy and utility.

Parallel imaging gives you unprecedented flexibility in exploiting the MR signal, so that you can choose to “trade” speed for improved spatial resolution. In this way, higher resolution images can be obtained in the same amount of time as a conventional exam. This means that iPAT can be used to either reduce the total acquisition time of a scan (Figure 1) or to increase the resolution of a scan (Figure 2).

## Of SMASH and SENSE

All MR exams share several stages: the MR signal is detected by RF coils, and the resulting data set is digitized and arranged into mathematical construct called “k-space”. Subsequent processing of this data set – the Fast Fourier Transformation (FFT) – yields the final MR image. From the beginning, parallel imaging used one of two image reconstruction techniques. Creatively named SMASH and SENSE, these techniques differ in terms of the stage at which they operate in the MR imaging process (Figures 3a and 3b).

SMASH (SiMultaneous Acquisition of Spatial Harmonics) [1] is “k-space based” because the reconstruction algorithm operates on partial k-spaces (one from each coil), before image generation by the FFT. By contrast, SENSE (SENSitivity Encoding) [2] is “image based” because the reconstruction algorithm operates on partial images (from each coil) that have been generated by the FFT.

## From Research to Product: GRAPPA and mSENSE

As the technology leader in MRI, Siemens has adopted both techniques and perfected them into commercial products. GRAPPA (Generalized Autocalibrating Partially Parallel Acquisition) [3] is an enhanced version of SMASH, and mSENSE (modified SENSE) is an enhanced version of SENSE. Together, GRAPPA and mSENSE form the iPAT (integrated Parallel Acquisition Techniques) package, which is standard with the syngo MR 2002B software on Maestro Class systems and on Ultra High Field (3 Tesla) systems.

Both GRAPPA and mSENSE ultimately yield one final image, but they behave differently in terms of signal-to-noise (SNR) performance, slice orientation, coil set-up, robustness against various artifact sources, etc. For example, a double-oblique cardiac exam with a small field of view can be performed without wrap-around (aliasing) artifacts by using GRAPPA (Figure 4). Applications such as single-shot EPI, Diffusion, Perfusion, and fMRI are also better suited for acceleration with GRAPPA. You may

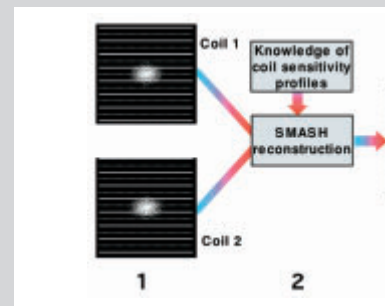


Figure 3a:  
SMASH

1. Two (or more) k-space acquisitions with two (or more) coils. Each coil fills one k-space with a reduced number of lines (e.g., for an acceleration factor of 2, only every 2nd line is acquired).
2. “Artificial” lines are calculated to fill the gaps in k-space (matrix inversion with information from the coil sensitivity profiles). This is achieved via the SMASH reconstruction algorithm.

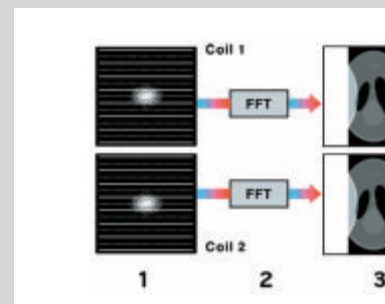
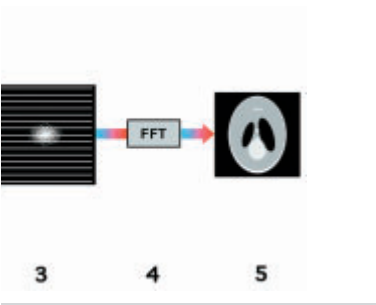
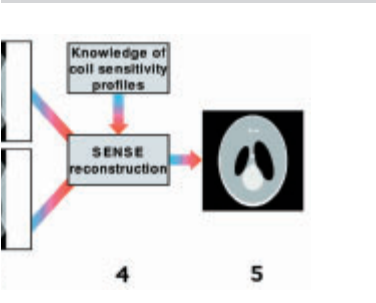


Figure 3b:  
SENSE

1. The first step is identical to the first step in SMASH (see above).
2. Each k-space (with a reduced number of lines) is subjected to a conventional FFT at this stage.
3. This results in two (or more) aliased images with rectangular FoVs.



3, 4, 5. The result is one complete k-space, which is subjected to a conventional Fast Fourier Transformation (FFT) to generate the final, unaliased image with a full field of view (FoV).



4, 5. The solution of a linear equation system, with information from the coil sensitivity profiles, leads (via the SENSE reconstruction algorithm) to the final, unaliased image with a full FoV.

be severely limited in a number of applications if you do not have a SMASH-based technique (such as GRAPPA).

Clearly, the particular technique employed will depend on the application; therefore, access to both techniques is essential for exploiting the full range of benefits with parallel imaging. Siemens is currently the only MR vendor to offer both a k-space based technique (GRAPPA) and an image based technique (mSENSE), allowing the widest range of clinical applications to benefit from iPAT. Both techniques are specifically optimized for SNR performance and are available with acceleration factors of up to 4 (Figure 1).

And, both can be used with all relevant existing pulse sequences to enhance temporal and/or spatial resolution. All other vendors currently offer only standard SENSE, and no k-space based techniques (like GRAPPA) at all. This leaves many applications without the full benefits of parallel imaging!

Since all relevant existing sequences are iPAT-compatible, virtually all of your clinical exams can now benefit from the new technology. At the software level, starting an iPAT exam is a one-click operation: simply select "GRAPPA" or "mSENSE" from the syngo MR user interface, and you are ready to scan!

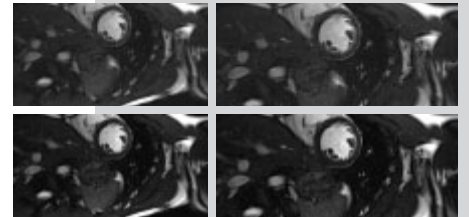


Figure 4:

- **Left:** SENSE-based techniques do not work well with "pre-aliased" images. If the original field of view (before using parallel acquisition) is smaller than the object and is already aliased, a wrap-around artifact will be present.
- **Right:** By contrast, GRAPPA (a SMASHbased technique) can be used with small fields of view (and therefore allows higher spatial resolutions) without wrap-around (aliasing) artifacts.



**Figure 5:**  
High-resolution 2-stage TSE study of the whole CNS in less than 5 minutes, using IPA and iPAT (GRAPPA x3 for both stages). After the initial patient setup, the operator does not have to enter the MR room again until the end of the exam. MAGNETOM Quantum. 512x512 matrix. Without the advantages of IPA and iPAT, this study would take at least 10 minutes.

- Patient positioning and coil setup (done only once, at the beginning of the study): 1min30s.
- Localizer: 18s.
- Upper stage: 1min20s.  
Coils/elements used:  
CP Head Array (1 element) + CP Neck Array (2 elements) + CP Spine Array (3 upper elements).
- Remote-controlled table movement, and element selection (for second stage): 8s.
- Localizer: 18s.
- Lower stage: 1min20s.  
Coils/elements used: CP Spine Array (4 lower elements).

## Coil Availability, Setup, and Auto-Calibration

**Coil Availability:** All existing Siemens array coils (and many 3rd party coils) are iPAT compatible. You can immediately enjoy all the benefits of iPAT – using your current coils – by simply upgrading your software to include iPAT. By contrast, parallel imaging offerings from other vendors require the purchase of new, costly “dedicated” coils before parallel imaging can be performed. Moreover, Siemens’ unique IPA concept (see below) allows you to create a virtually unlimited number of customized coil arrays that can be used to perform parallel imaging (Figure 5), since all IPA coils are iPAT-compatible. This greatly extends the range of applications for iPAT – at no extra cost to you! Siemens also offers several dedicated array coils for certain high-end Neuro and Body iPAT applications.

**Coil Setup:** Siemens is currently the only MR vendor to offer a modular coil concept, for the ultimate in coil setup versatility. The innovative IPA (Integrated Panoramic Array) concept allows you to combine existing coils (up to 32 LP elements simultaneously) to create customized coil arrays for optimal imaging of any body region; this is made possible by Siemens’ leading RF receiver chain technology, featuring 8 independent high-bandwidth (1MHz) RF channels. With IPA, coil setup is performed only once, at the beginning of the examination. Selection of individual coil elements, and even table movement control, can be performed from the MR console outside the MR room. A multi-stage MR exam with IPA and iPAT can therefore be performed with a dramatic reduction in total exam time (Figure 5).

**Coil Auto-Calibration:** Image reconstruction in parallel acquisition relies on the use of coil sensitivity maps. With iPAT, the required calibration is done during the scanning; this Auto-Calibration feature is unique to Siemens. You do not have to spend additional time for calibration before scanning, and in case there is any patient motion between scans you do not have to pre-scan before each series to guarantee image quality. With other MR systems, coil calibration is a distinct pre-scanning task requiring one minute or more, which negates the speed advantage of parallel imaging.

## iPAT: A Sound Investment

Siemens’ iPAT greatly enhances the performance of the strongest gradient hardware on the market, enabling you to perform the full range of clinical MR studies faster than ever before. Full compatibility with Siemens’ unique IPA coil concept affords maximum versatility and makes good economic sense: you can start doing iPAT exams with your existing IPA coils (and coil combinations!) as soon as you install the iPAT software. There is no need to purchase new “dedicated” coils. Auto-Calibration (a Siemens exclusive) preserves the speed advantages of iPAT. And, with both image based and k-space based techniques (another Siemens exclusive!), you are ready to perform parallel imaging for the widest range of clinical applications – even at 3 Tesla! [4]

The cumulative impact of these technologies is tremendous. You will repeat fewer exams because of greater patient compliance, and the shorter imaging times will also enhance patient comfort. MR imaging workflow is accelerated, and throughput can be easily increased by 20% or more simply by incorporating iPAT and IPA into your imaging routine. The associated boost in revenue can be considerable, especially for high volume MRI operations. Clearly, iPAT is an exceptionally sound investment in your MR imaging capabilities, and this is demonstrated by its success in the marketplace: more than 500 Siemens MR systems featuring iPAT are currently installed worldwide.



The information in this document contains general descriptions of the technical options available, which do not always have to be present in individual cases. The required features should therefore be specified in each individual case at the time of closing the contract.

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**References**

- [1] Sodickson DK, Manning WJ., "Simultaneous acquisition of spatial harmonics (SMASH): fast imaging with radiofrequency coil arrays". *Magn Reson Med* 1997 Oct; 38(4):591-603.
- [2] Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P., "SENSE: sensitivity encoding for fast MRI". *Magn Reson Med* 1999 Nov; 42(5):952-62.
- [3] Griswold MA, Jakob PM, Heidemann RM, Nittka M, Jellus V, Wang J, Kiefer B, Haase A., "Generalized autocalibrating partially parallel acquisitions (GRAPPA)". *Magn Reson Med* 2002 Jun; 47(6):1202-10.
- [4] Ask your local Siemens MR representative about additional MRI Hot Topics on the clinical applications of iPAT. Or, download them yourself at [www.SiemensMedical.com/MAGNETOM-World](http://www.SiemensMedical.com/MAGNETOM-World)

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