SPACE: An Innovative Solution to Rapid, Low SAR, T2-Weighted Contrast in 3D Spin Echo Imaging

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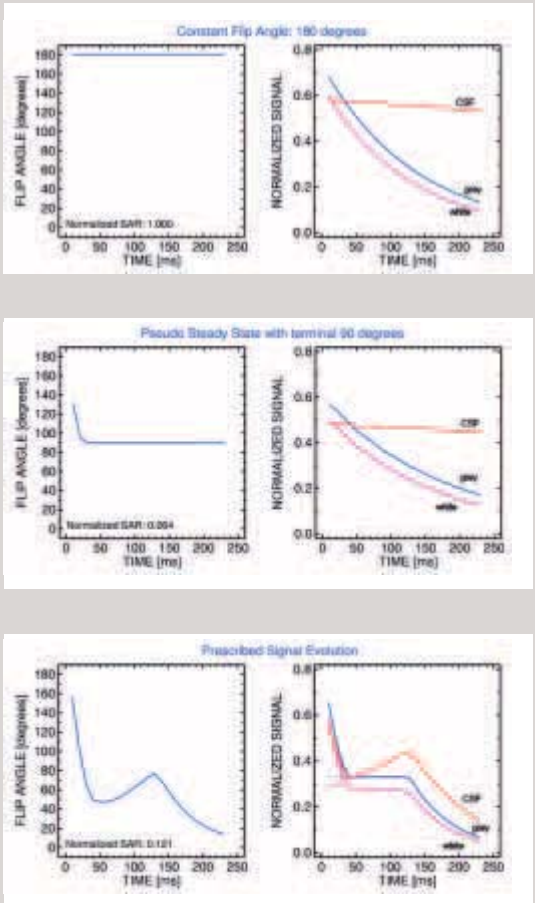
The contrast properties and inherent insensitivity of spin echo based sequences to RF and magnetic field inhomogenities make them a particularly desirable addition to a clinical high field protocol, where susceptibility effects can be quite pronounced. Fast imaging methods, such as Turbo Spin Echo (TSE), use a train of refocusing pulses (the Turbo factor or Echo Train Length (ETL)) to enable multiple phase encoding steps to be carried out after each excitation pulse. The increased RF power deposition can, however, severely limit the coverage possible in multi-slice applications at high field, since power deposition or Specific Absorption Rate (SAR) increases as the square of field strength as well as the square of the flip angle. Additionally, increased saturation and magnetization transfer effects reduce contrast and signal-to-noise ratios (CNR and SNR). High resolution 3D acquisitions enable precise characterization and localization of anatomy and pathology, but acquisition times are prohibitively long and T2-weighted sequences are usually only a viable option in 2D mode. Acquisition speed increases are limited by the length of the echo train (T2 decay restraints) and very long echo trains are generally not possible due to loss of contrast and blurring. To enable high field and 3D imaging with these sequences at 3T and above, appropriate measures to address these issues need to be implemented.

Method

Reduced flip angle refocusing approaches[1] lengthen the usable echo train length, since the complex combination of spin and stimulated echoes introduces a T1 dependence to the signal evolution. Significantly reduced SAR at comparable SNR can be obtained by replacing a constant low flip angle refocusing train by a variable flip angle pulse train designed to produce a constant echo amplitude[2,3] – see Fig. 1. Starting the pulse train with higher amplitude pulses and slowly decreasing to approach a constant ("asymptotic") value, enables acquisition of images with SNR values close to those acquired with 180 degree refocusing pulses, for asymptotic flip angles as low as 60 degrees[3]. This "pseudo steady state" of signal intensities decays slowly due to T1 and



[Figure 1] *Diagrams on the left show refocusing flip angle variation as a function of time for the three cases: constant; pseudo-steady state and prescribed signal evolution. Those on the right depict corresponding signal intensity changes for gray matter, white matter and CSF. Note the reduction in SAR for the three cases and the range over which tissue signal intensities are approximately constant for the prescribed signal evolution case. (Figure from J. P. Mugler III, University of Virginia.)*

T2 effects. It is possible to obtain both an increase in signal intensity and an almost constant signal from the tissue of interest (e.g. gray matter) for the bulk of the signal acquisition, by using prescribed signal evolutions which include relaxation effects in the calculation of refocusing flip angles[4]. Flip angles need to be optimized for only one tissue of interest (e.g. gray matter in the brain) as the prescribed signal evolutions depend only weakly on the T1 and T2 relaxation times and are therefore similar for many other tissues. Using an initial exponential decay, a constant and then another exponential decay for the prescribed signal evolution produces images in which the contrast is similar to those obtained using conventional T2-weighted Spin Echo sequences. This approach allows very long echo trains and 3D imaging, since the effective T2 of the echo train is longer than the tissue T2 for tissues with long T1s (≥ 10 T2) and acquisition times can be commensurately reduced or resolution increased. "T2-weighted" 3D TSE whole brain images with SAR values well below FDA limits have been acquired at both 1.5 and 3T[4,5] and with echo train lengths of up to 250 echoes, enabling 3D datasets of the whole brain to be acquired in 3.5 minutes[6].

Applications

This prescribed signal evolution approach has been adapted and implemented in the software of all current Siemens 1.5T and 3T systems as the SPACE sequence and provides high quality 3D Turbo Spin Echo images in which the contrast is similar to those of conventional T2-weighted Spin Echo sequences for head and knee applications. Some examples are shown here:

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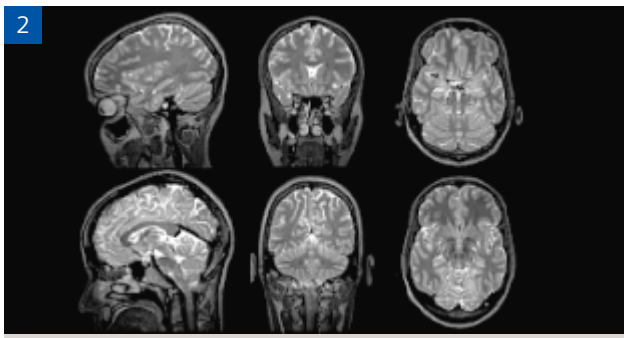

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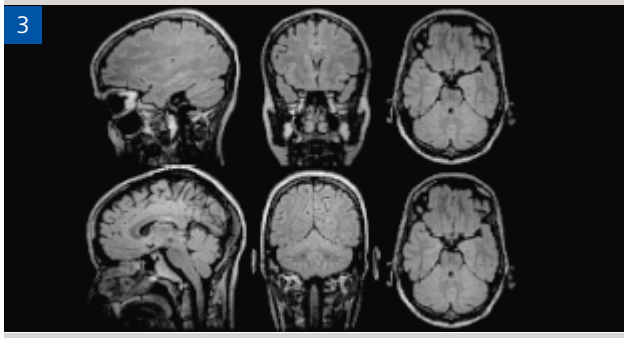
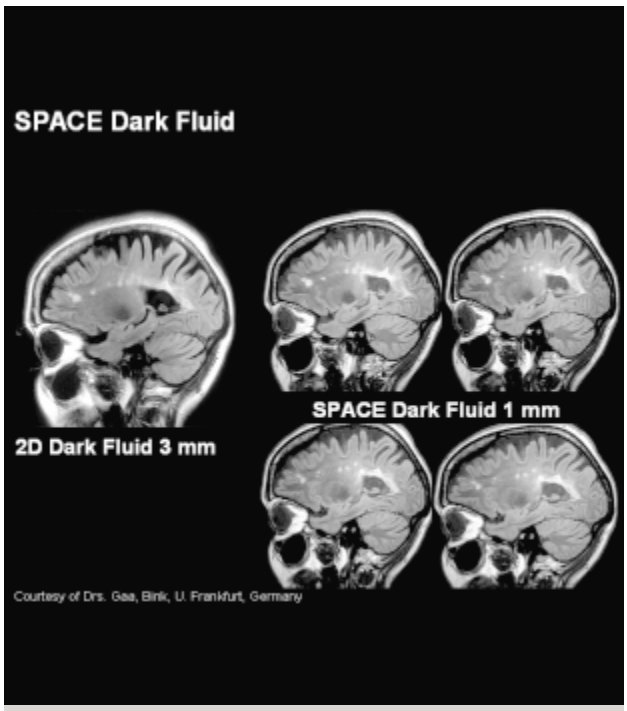


[Figure 2] *T2-weigted sagittal, coronal and axial brain images reconstructed from a 4.4 min. single-slab 3D-TSE acquisition with isotropic 0.9 mm spatial resolution.*

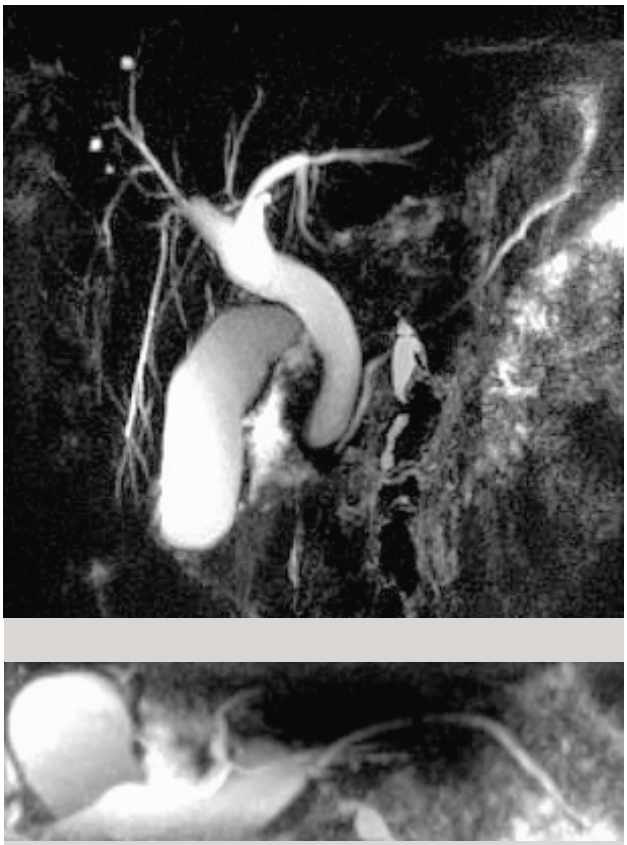
[Figure 3] *FLAIR sagittal, coronal and axial brain images reconstructed from a 7.1 min. single-slab 3D-TSE acquisition with isotropic 0.9 mm spatial resolution.*



[Figure 4] *Thinner partitions and the flexibility to reformat in any orientation enables better definition of multiple sclerosis lesions in images obtained using the SPACE sequence than in those acquired with the corresponding 2D TSE sequence. One 3 mm slice from a 2D Dark Fluid contrast acquisition is shown on the left, while the same anatomy is covered with four 1 mm partitions from the SPACE 3D acquisition on the right.*

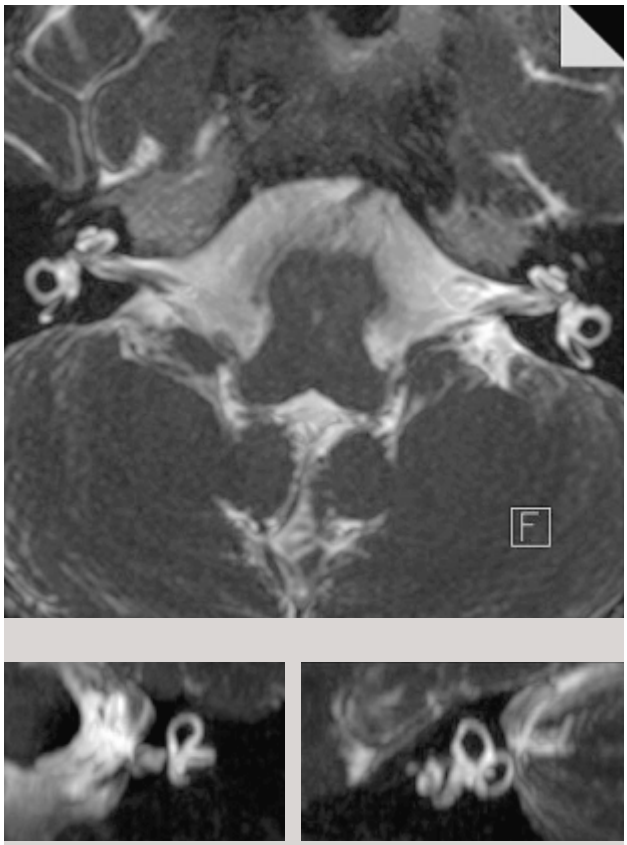
More recently, spatially (slice) selective single slab 3D TSE imaging has been developed and demonstrated[7], extending the range of clinical applications to examinations previously precluded due to aliasing concerns. Prescribed signal evolutions of over 1,000 echoes per excitation have been shown to be possible and by making use of long echo trains to acquire multiple k-space planes after each excitation – rather than the usual single plane – further increases in acquisition speed have been achieved[8]. Combining this approach with parallel imaging techniques (iPAT), has enabled the acquisition of whole-brain 3D TSE data sets with isotropic 0.9 mm spatial resolution at 3T in 4.5 minutes (T2 contrast) and 7 minutes (Dark Fluid) respectively, with reduced susceptibility and chemical shift artefacts[9].

The latest Siemens version of the SPACE sequence incorporates all of these advances and now includes protocols with a range of contrasts for head, inner ear, spine, MRCP (Magnetic Resonance Cholangio-Pancreatography) and pelvic examinations.



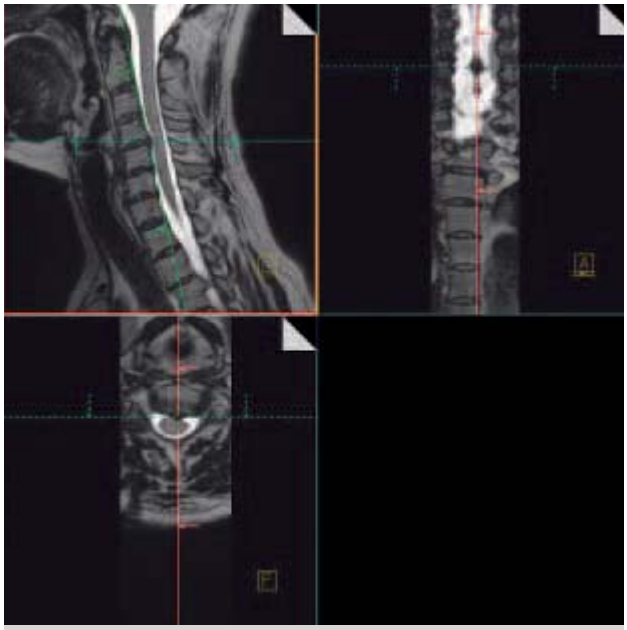
Axial reformat for pancreatic duct evaluation

[Figure 5] *Previous MRCP techniques required rapid single shot slabs or breath hold acquisitions that were limited in spatial resolution and anatomic detail. The SPACE MRCP technique incorporates PACE free breathing techniques for a 3D volumetric evaluation of the entire cholangio-pancreatic ductal system in a heavily T2-weighted acquisition. The volumetric data can also be loaded into 3D evaluation software for partitioning in additional orientations.*

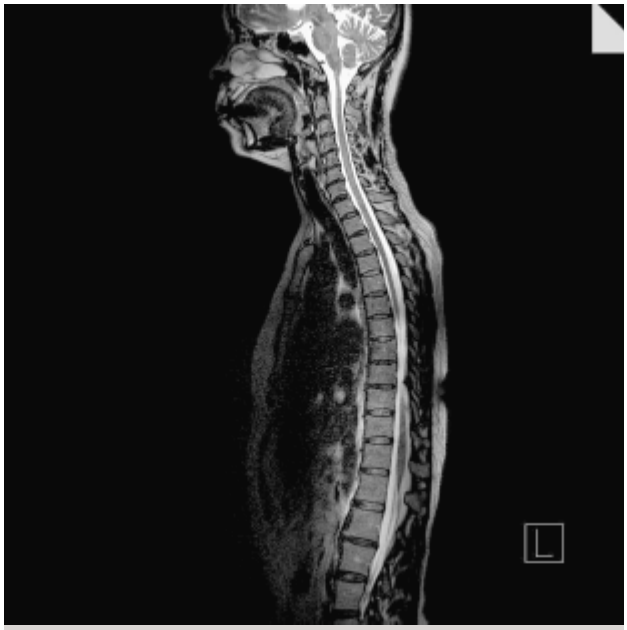


Sagittal Reformat *Coronal Reformat*

[Figure 6] *Isotropic (0.4 mm) 3D acquisitions of the inner ear clearly delineate the nerve pathways in some cases reducing or eliminating the need for IV contrasts. MAGNETOM Trio, A Tim System images below.*



[Figure 7] *Multi-planar reconstructions (MPR) of isotropic 3D acquisitions of the spine provide an interactive approach to evaluating pathology in multiple orientations and angles without the need for additional acquisitions. This isotropic (0.9 mm) sagittal acquisition demonstrates a bulging disc at the level of C4-C5 evaluated axially and coronally without additional measurements.*



[Figure 8] *SPACE acquisitions of the spine in conjunction with the large field of view capable on the MAGNETOM Trio provide a more complete evaluation of spinal anatomy than ever before. The example below demonstrates an 0.9 mm 3D isotropic evaluation of the spine from the mid-brain to L5 without patient repositioning.*

Summary

The SPACE sequence enables acquisition of high resolution 3D datasets with contrasts similar to those obtained from 2D T2-weighted and dark fluid protocols at 1.5T and 3T within a clinically acceptable timeframe and without SAR limitations. This allows the data to be viewed in multiple orientations and retrospectively reformatted to better view features of interest, as well as to generate views that correspond to slices acquired with other sequences, if desired. Current developments focus on applications requiring reduced fields of view in one or more dimensions such as the spine and internal auditory canal. Applying iPAT and the large field of view functionality provided by the Tim technology enables 3D data sets of the complete CNS to be acquired in as little as 10 minutes without patient repositioning.

References

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Acknowledgements

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