Spiral Navigated Sensitivity Calibration for Parallel Imaging

K. F. King[1], L. Angelos[1], J. Polzin[1]

[1]Applied Science Lab, GE Medical Systems, Milwaukee, WI, United States

Introduction

Parallel imaging methods including Sensitivity Encoding (SENSE) and Simultaneous Acquisition of Spatial Harmonics (SMASH) use receive coil B1 field (sensitivity) maps measured in-vivo to either remove aliasing or restore missing k-space lines (1,2). The sensitivity map is measured using either a separate scan or extra Nyquist-sampled k-space lines near the center of k-space within the parallel imaging scan (self-calibration) (3). The two approaches have complementary advantages and disadvantages (Table I). The separate scan may require additional operator involvement and can give inadequate aliasing correction if there are patient position differences between the calibration and parallel imaging scans. The probability of position differences is higher for breath-held abdominal scans than other applications. Self-calibration does not suffer from these drawbacks, but it increases scan time because of the additional k-space lines, and the data is not reused on subsequent scans. The self-calibration acquisition is also locked to the parallel imaging acquisition. Consequently, for some applications, the calibration scan has low SNR and must use a reduced field of view (FOV) that is clinically useful for the parallel imaging scan. This can cause phase wrap in the calibration data, which is detrimental for aliasing correction.

Another approach is to append a short sensitivity measurement to the parallel imaging scan, possibly using a different pulse sequence. This approach combines some of the advantages of both existing calibration methods. If the appended sensitivity measurement is fast enough, scan time impact is negligible and the probability of motion between the two acquisitions is minimized. Using a separate acquisition gives the flexibility to use full FOV and a pulse sequence that also gives high SNR.

Separate Scan	Self-Calibration	Navigated Calibration
Optional operator involvement	No operator involvement	Optional operator involvement
No impact on scan time	Increases scan time	Minimal impact on scan time
Sensitive to cal/scan motion differences	Minimal cal/scan motion differences	Minimal cal/scan motion differences
Minimal restrictions on cal acquisition	Locked to scan acquisition	Restricted to fast acquisition
Can reuse calibration data	No calibration data reuse	No calibration data reuse

Table I. Comparison of advantages and disadvantages of separate scan, self-calibration and navigated calibration for sensitivity measurement.

Navigators were first introduced into MR for the purpose of monitoring motion (4) and were later extended to monitoring other effects such as B0 field drift and shim gradient settings. A navigator acquires a partial k-space data set, possibly using a different pulse sequence. We call this approach to sensitivity measurement a navigated sensitivity calibration in analogy with the use of navigators to measure other phenomena.

Methods

The navigator must be able to image the complete coil sensitive volume fast enough to have a minor impact on the parallel imaging scan time. The spatial resolution of the navigator can be low since the coil sensitivities are slowly varying. As a target, we chose acquiring a 48 cm^3 volume with 15 mm^3 resolution (equivalent to a 32^3 matrix) in 1 second. Since many parallel imaging scans use breath-holding and require 10 to 20 seconds, a 1 second time penalty is not substantial.

Fast 2D and 3D spin echo and gradient echo techniques are possibilities for the acquisition. The short scan time requires 3D scans to use short RF pulses that have poor excitation profiles, resulting in phase wrapping in the secondary (slice) Fourier encoding direction, if the anatomy extends beyond the excited slab. Since such wrapping can be problematic for parallel imaging, we settled on a 2D scan. The 1 second calibration time requires each of the 32 2D image to be acquired in 32 msec or less. A single shot Fast Spin Echo scan would therefore require an echo spacing of 1msec or less, which would require refocusing pulses with very small flip angles. We therefore considered gradient echo pulse sequences. Echo planar imaging can easily meet the 32 msec 2D acquisition time requirement but suffers from geometric distortion and ghosting that are likely to be problematic for parallel imaging (5).

Spiral scans can also easily meet the scan time requirement but suffer blurring for off-resonant spins. The blurring can be reduced by shortening the duration of each spiral interleave at the cost of reduced spatial resolution. Since low resolution is used for the calibration, moderate blurring is not detrimental. Spiral scans are therefore a good match for the calibration pulse sequence. For the 220 Hz water/fat resonance offset at 1.5 T, a spiral readout time of 1.5 msec is sufficiently short to result in only moderate blurring. With a slew rate of 100 T/m/sec, 15 mm spatial resolution with a 48 cm FOV is achievable with 4 spiral interleaves and a readout bandwidth of +/-125 kHz (384 readout points per interleave). The resulting TR is 4 msec, allowing a complete 2D scan in 16 msec.

We used the parallel imaging package (ASSET) on a commercial 1.5 T scanner (GE Medical Systems, Milwaukee, WI) to test the feasibility of the spiral calibration. Sensitivity maps were created from 32 axial slices acquired with the spiral pulse sequence in a separate 0.5 second scan. 2D and 3D abdominal scans of a normal volunteer were acquired with ASSET using a 4-channel torso coil and a reduction factor of 2.

Results

Fig. 1 shows a typical spiral calibration slice and images reconstructed using the spiral calibration. Initial results show that a spiral scan is fast enough and has adequate image quality for use as a navigated calibration in these examples. Even at higher field strengths, where more interleaves would be necessary to minimize fat blurring, (e.g. 8 interleaves at 3 T), the resulting scan time is still within our target of 1 second. More testing with a variety of applications is needed to verify the adequacy of spiral image quality.

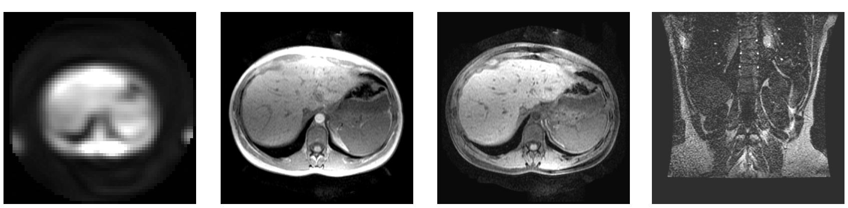

Fig. 1. Left to right: spiral calibration slice (TE/TR/flip = 1/132/45, 32x32, +/-125 kHz, 48 cm FOV, 10 mm slice), 2D axial gradient echo (TE/TR/flip = 4.4/180/75, 256x128, +/-62.5kHz, 32x32 cm FOV, 5mm slice), 3D axial gradient echo (TE/TR/flip = 4.2/7.8/15, 256x128, +/-32kHz, 32x32 cm FOV, 5mm slice), 3D coronal gradient echo (TE/TR/flip =1/5.3/40, 256x192, +/-62.5 kHz, 38x30 cm FOV, 3mm slice).

Conclusions

A navigated sensitivity measurement combines benefits of a separate scan and self-calibration, including minimal scan time penalty, robustness to patient motion and calibration pulse sequence and protocol flexibility. A 2D spiral pulse sequence is an attractive candidate for the calibration acquisition because of its speed and because the moderate blurring artifacts are not detrimental. With a 2D spiral, calibration of the complete scan volume in 0.5 to 1 second is possible.

References

1. Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P. Magn Reson Med 1999;42:952.
2. Sodickson DK, Manning WJ. Magn Reson Med 1997;38:591.
3. McKenzie CA, Yeh EN, Ohliger MA, Price MD, Sodickson DK. Magn Reson Med 2002;47:529.
4. Ehman RL, Felmlee JP. Magn Reson Imaging 1989;173:255.
5. Griswold MA, Jakob P, Heidemann R, Nittka M, Wang J, Kiefer B, Haase A. Proc. 9th ISMRM, 2001, 446.