A rapid and accurate automated in-vivo shimming application integrated with the Siemens 1.5T and 3T consoles

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INTRODUCTION

High field MRI is known to suffer from severe susceptibility artifacts and distortions. A more homogenous static magnetic field (B0 field) reduces these artifacts and distortions. Shimming improves static field homogeneity by finely adjusting the current for each shim coil. The shim fields on almost all NMR magnets are designed to generate the spherical-harmonic basis functions [1]. Several methods (too numerous to list here) have been developed to map and fit the static magnetic field, calculate the correction for each shim coil. The goal of this project was to develop a fast and accurate 3D volume-selective high order *in-vivo* shimming application that can be integrated into Siemens scanners consoles, using the development tools supplied with the Siemens research environment. The shimming application is developed for improving field homogeneity in brain, cardiac and other organs imaged at 1.5T and 3T, and to be exported to our 7T scanner.

MATERIALS AND METHODS

This new application has been developed on the Siemens 1.5T (Sonata) and 3T system (Trio). The shimming application includes four major components: (1) a fast frequency mapping sequence which combines a symmetric spin echo (SE) EPI and an asymmetric spin echo (ASE) EPI; (2) an image reconstruction program to create field maps from the phase differences of two acquisitions (SE, ASE) and intensity images in real time and send them to patient database for further viewing, analysis and shim fitting; (3) a Windows based user interface (UI) that can import and view the shimming dataset, analyze the frequency linewidth (FWHM), fit the spherical harmonics to the acquired shimming dataset (both field maps and intensity images) and calculate the change in the field for each shim coil; and (4) a shim current adjustment interface provided by Siemens Medical Solutions. Echo shift value of the asymmetric spin echo can be set from a special card on sequence protocol UI. Users can also draw target ROIs to define a 3D shimming volume and select any combinations of shim terms for the shim fitting and correction. Nine shim terms are available on the current Siemens 3T Trio system: Z0, first order (X, Y, Z) and second order (Z2, ZX, ZY, XY, X2-Y2). Each shimming pixel within the selected volume has 5 attributes: pixel intensity, frequency and X, Y, Z location in the physical gradient or equipment coordinate system. Each pixel is processed for distortion correction along phase encoding axis [2] and then least square fitted with a spherical harmonic mathematical model to obtain the correction for each shim coefficient. This shim fitting process is based on our method for automated shimming using EPI frequency maps [3].

Preliminary studies, focused on brain imaging, have been performed on four volunteers on the Siemens 3T (Trio) system. Imaging parameters were: TR 1000 ms, TE 43 ms, FOV 240x240, matrix 64x64, 8 slices, slice thickness 5 mm, echo spacing 0.43 ms, echo shift for ASE 2.2 ms (± 227Hz frequency dynamic range for field map). Images and frequency line width (FWHM) have been compared before and after the application of our shimming tool.

RESULTS

As illustrated in Table 1, brain scans on all of four volunteers showed great improvement after shimming with our application. Compared with the pre-shimming scan (tune up setting), the FWHM (calculation performed by our linewidth analysis tool) has improved from 72 - 108 Hz to 13 – 16 Hz for all 4 volunteer brain scans within 1-2 iterations. In all cases, a second iteration with our method provides, at most, 2-5 Hz improvement. Figure 1 shows the sample intensity images, field maps and frequency line width analysis from one volunteer before and after shimming. In comparison, the shimming algorithm supplied with the Siemens console required 3-4 iterations to achieve a similar result and its acquisition time for field maps is longer, as shown in the last row of Table 1. Lorentzian line shape and narrow FWHM indicate a good shimming outcome and a more homogenous static field.

	Tune up (pre-shimming)	Best shimming with our application		Best shimming with built-in tool	
	FWHM	FWHM	Iteration	FWHM	Iteration
Volunteer 1	77 Hz	14 Hz	2	15 Hz	4
Volunteer 2	108 Hz	16 Hz	2	14 Hz	3
Volunteer 3	72 Hz	15 Hz	1	12 Hz	3
Volunteer 4	83 Hz	13 Hz	1	14 Hz	3
Scan time of each shimming		2 seconds		35 seconds	

Table 1:comparison of frequency linewidth (FWHM) and shimming scan time on 3T

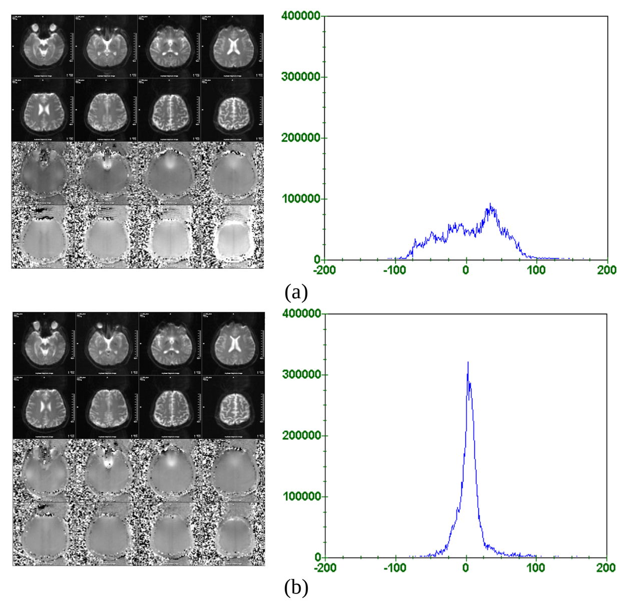

Figure 1: intensity images, frequency maps and intensity weighted frequency linewidth
(a) pre-shimming with tune-up setting (b) after shimming (one iteration)

DISCUSSION

In this study, an in-vivo shimming application using SE-ASE EPI for fast frequency mapping was implemented and evaluated. The resulted linewidth with this application has shown comparable to vendor-equipped tool using a relatively slower frequency mapping sequence. In addition, this shimming application provides a rapid, accurate and easy-to-use tool to perform higher order *in-vivo* shimming. Users can draw arbitrary ROIs on the Windows based UI to define a 3D shimming volume and click a single-button to run the whole shimming procedure, including shimming data pre-processing, shim mapping and fitting and shim coil current correction. The flexibility of this shimming application also allows users to process field maps acquired with fast sequences other than the default SE-ASE EPI sequence. This application can be installed on any Siemens Numaris scanner console and expanded to include higher order shim (3rd order and higher). Because the application can use any frequency mapping sequence the user might develop, all sequence capability can be supported. For example, the built-in Siemens shimming method currently does not support ECG gating, making cardiac shimming ineffective. One goal of this project is to extend our current application to support effective cardiac shimming with ECG gating. We also plan to export the shimming application to our 7T scanner, equipped with shim currents of 1st, 2nd and 3rd orders and operating with a Siemens console.

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REFERENCES

1. Anderson WA, Rev Sci Instr, 32: 241– 250, 1961
2. Sekihara K, et al., Phys Med Biol, 29:15 – 24, 1984
3. Reese TG, et al., *J Magn Reson Imaging*, 5: 739 – 745, 1995