Dynamic Bo Shimming at 7 Tesla

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Introduction

Dynamic Shimming is a technique for obtaining optimal Bo field homogeneity over a volume by updating the shim coil and gradient currents for every slice in a multislice acquisition in real time [1, 2]. Dynamic shimming can produce better field homogeneity within each slice than global volume shimming methods. It can therefore reduce signal losses and geometric distortions and can be especially useful in fast T_2* weighted imaging sequences such as EPI and in multislice spectroscopic imaging. We have implemented dynamic shimming on a human 7T system. Results with human brain imaging and an evaluation of the improvements made are presented.

Methods

Our studies were performed on a Philips 7 Tesla Achieva human imaging system. The system is equipped with a Resonance Research Inc shim power supply (RRI Inc, MA, USA MXH 10 Amps) with an actively shielded Z2 shim coil (Z2D) for dynamic operation in addition to the unshielded Z2 coil (Z2). For the 1st order slicewise corrections, modifications were made to the shimming pulse program software. For higher order corrections, an additional hardware module (MXH 14R Real Time Shim System, RTS, RRI Inc), was connected to the auxiliary input of the higher order shim supplies. 64x64 pixel resolution field maps were acquired for FFE and single shot EPI (7 slices, 2/10 mm, thick/gap) imaging. For dynamic shimming, slice specific shims were determined by multilinear least squares fitting of a three-slice volume from the Bo field map centered on the slice of interest. During scanning, first order shim corrections were loaded slice wise through the sequence gradient control and higher order corrections were loaded from the RTS system triggered by the pulse program. Slice wise base frequency correction was implemented to correct for shim induced frequency offset changes, including Z2 –Z0 compensation. Results were compared with the existing pencil beam based global shimming method [3] available on the scanner in terms of fieldmap standard deviations, histogram line widths, EPI image edge pixel displacement from reference FFE and the similarity index [4]. We also characterized the 2nd order shim induced eddy currents by the method outlined in Terpstra et al [5].

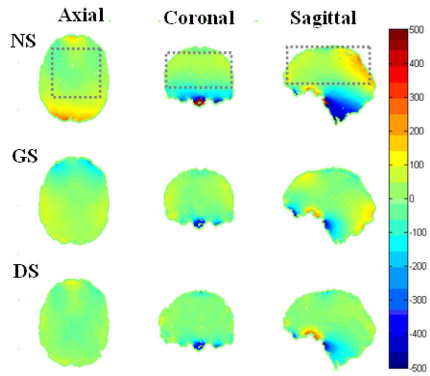

Fig 1: Slice 4 Fieldmaps.

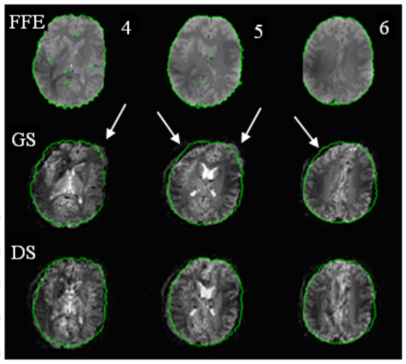

Fig 2: SS EPI with different shim types, slices 4 -6.

Results and Discussion

Fig 1 and Table 1 show results of 2nd order dynamic shimming (DS) compared to global shimming (GS) and no shim (NS) in the FFE scans. The static field standard deviation within the shim ROI (dotted boxes, Fig 1) in most slices was significantly lower with DS than with GS in all orientations (Table 1). This improvement in Bo homogeneity was reflected in lower image distortion with DS compared with GS in the EPI images (arrows, Fig 2, Table 1). One of the effects of switching shims in real time is the generation of eddy current related ghosting, seen in Fig 2, slice 4, DS image. Our experiments suggested that the bulk of these effects could be attributed to the unshielded Z2 shim coil. This conclusion was corroborated by the results of our higher order shim eddy current characterization (Eddy Current related Bo shifts induced by Z2 switching) and by the improved image quality when using the shielded Z2 coil in the same sequence.(Fig 3). Current work is focused on integrating dynamic shimming into regular anatomic and functional imaging and spectroscopy as well as incorporating temporal Bo correction linked to respiration.

FFE Fieldmap Measures	Slice	Axial		Coronal		Sagittal	
		DS	GS	DS	GS	DS	GS
Fieldmap Standard Deviation, within ROI (Hz)	1	67.17	105.35	45.32	69.94	24.92	69.81
	2	57.75	91.24	44.31	58.93	21.43	50.05
	3	29.36	63.54	31.06	41.26	23.05	39.12
	4	17.01	41.79	17.26	27.89	28.22	44.78
	5	16.50	28.89	20.58	36.90	21.82	40.74
	6	27.52	20.09	25.67	40.94	22.63	53.27
	7	34.77	26.02	24.15	37.09	22.25	60.90
Line Width at 10% of Maximum Value within ROI (Hz)	1	251.02	364.26	102.42	266.85	89.55	109.26
	2	212.03	348.27	90.67	186.02	77.02	145.76
	3	119.16	235.80	93.44	143.87	76.65	120.42
	4	67.22	145.41	58.56	112.09	88.98	135.84
	5	68.58	116.00	58.68	126.78	78.12	145.80
	6	106.66	73.09	75.09	131.28	81.27	168.50
	7	140.81	108.35	94.52	125.71	96.15	175.84

EPI Distortion Measures.	Slice 4		Slice 5		Slice 6	
	DS	GS	DS	GS	DS	GS
RMS Edge Pixel Shift (pixels)	6.164	8.538	4.136	8.925	4.740	6.515
Similarity Index (DICE Score)	0.955	0.943	0.974	0.946	0.967	0.950

Table 1: Measures of fieldmap deviation and EPI image distortion.

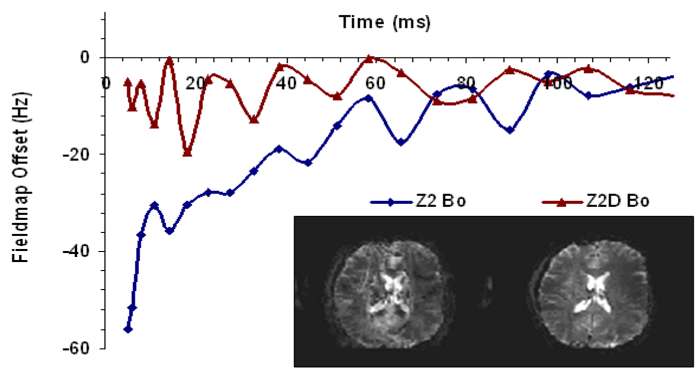

Fig 3: Eddy current induced Bo shift with 1Amp step change in Z2 and Z2D shim; EPI image ghosting seen with Z2 vs. Z2D for same shim change. (inset)

Conclusion

Dynamic shimming has been implemented on a human 7T scanner leading to considerable improvements in Bo homogeneity and image distortions, inherent to high field strength imaging. The use of actively shielded Z2 shim coil is also shown to be necessary for maintaining image quality with dynamic shimming.

Reference

[1] Blamire AM et al, MRM. 36:159, 1996. [2] Zhao Y et al, JMR, 173, 10-22, 2005. [3] Gruetter R et al, JMR, 96,323-334, 1992. [4] Zijdenbos AP et al, IEEE Trans Med Imaging, 13, 4, 716-724, 1994 [5] Terpstra M et al, JMR, 131,139-143, 1998.