On shimming approaches in 3T breast MRI

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Introduction: Breast MRI exams at 3T are becoming increasingly common. In such exams, diffusion weighted imaging (DWI) is sometimes used, as it was shown to increase the specificity of cancer detection. Due to its typical long echo-planar imaging readout, however, DWI requires a very homogeneous B_0 field to produce non-distorted images, whose features can be easily traced back to anatomy. As previously reported [1], the inherently inhomogeneous, susceptibility induced B_0 distribution in the female torso makes choosing a shimming strategy difficult. In this work, 12 volunteers were initially scanned, and full 3D B_0 data were acquired over the breast area. Based on these input data, a number of shimming strategies were considered, in order to decide the best approach for shimming *in vivo*, and understand trade-offs associated with each of the choices.

Methods: All experiments presented in this work were performed on a 3T DVMR scanner (GE, Waukesha, WI). 3D B_0 data were first acquired in twelve volunteers using an IDEAL approach [2]; during the 60-second acquisition, 32 axial slices were acquired at x/y/z spatial resolutions of 3/3/6mm, respectively, covering the entire breast region. Linear shimming was performed offline, using (fractions of) the 3D B_0 data sets as input. Thirteen shimming strategies were considered here, based on either 3D input B_0 maps (cases 1, 3, 5, 8, 10 or 12 in Table 1), or 1-6 planes (interpolated from the initial 3D B_0 data (cases 2, 4, 6, 7, 9, 11 and 13 in Table 1)). The figure of merit computed for all shimming approaches was the standard deviation of the B_0 field (after shimming) over the 3D breast region (predicted std (B_0)).

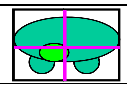
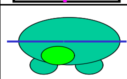
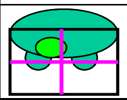
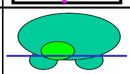
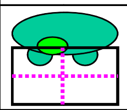
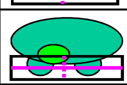
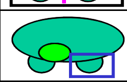
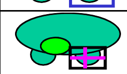
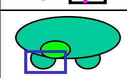
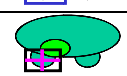
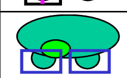
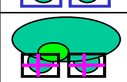
Case #	Shim strategy	Graphical description	Predicted std(Bo)	Shim rank
1	3D shim over entire FOV		70.9	13
2	3 plane shim over the entire FOV		68.0	12
3	3D shim avoiding the back (below the blue line)		52.6	10
4	3 (or 2) plane shim that avoids the back		54.6	11
5	3D shim over the breasts (below blue line)		35.8	1
6	1 plane (axial) shim		41.6	6
7	3 plane rectangular shim		38.9	3
8	3D shim over the right breast		39.0	4
9	3 plane shim over the right breast		51.0	9
10	3D shim over the left breast		40.8	5
11	3 plane shim over the left breast		46.3	8
12	Average 3D shims over 2 breasts		37.1	2
13	6 plane shim		42.3	7

Table 1: Shimming strategies considered, together with expected average standard deviation in the 12 volunteers studied

Results: Figure 1 presents a typical example of a volunteer who was shimmed over the entire FOV (case 1), or using a multi-plane, rectangular FOV (case 7). The strong anterior-posterior (A/P) gradient over the breasts [1] results in poor cross-sectional shimming (case 1). Multi-plane rectangular shimming (case 7) differs only to a minimal extent from case 5 (best case scenario), and results in good overall B_0 uniformity (at the expense of increasing the overall resonance frequency of the subject's back). Table 1 presents a summary of our results; here, the predicted std (B_0) is displayed for each of the 13 shim cases considered, averaged over the 12 volunteers (3rd column); a ranking of the shim strategies is also presented (4th column). A few interesting conclusions can be drawn from this table. First, the back or the heart of the subject should never be included inside the shim region for breast exams; they resonate at a different frequency than the breasts and will bias the shims towards values inappropriate for the breasts. While 3D shimming strategies result in the best overall B_0 homogeneity (cases 5 and 12), they come at the expense of increased prescan time for the acquisition of volumetric B_0 maps, and may never be practical. Among the timesaving, multi-plane shimming strategies, cases 7, 6 and 13 result in the best B_0 homogeneity. Interestingly, however, while case 5 is the best overall shimming approach for each of the volunteers studied, no single multi-plane shim strategy works best for all volunteers. Table 3 presents a ranking of multi-plane strategies for all our 12 subjects. While case 7 works very well on the average, it works less well, e.g. for volunteer 9; this is because there is residual, within-breast B_0 variability that may not be captured well by the few planes used as input to the shimming algorithm. Figure 2 presents a DWI image (acquired in a volunteer using case 7 shimming), overlapped on an anatomical image. Note the exquisite alignment of the two, requiring no additional correction through post-processing for image interpretation.

Discussion and Conclusions: A study was presented, investigating the best shimming strategy for breast exams at 3T. It was concluded that the back and the heart of the subject should be excluded from the shim region, as they bias shims towards values inappropriate for the breasts. Among the multi-plane approaches, the rectangular shim ROI (case 7) resulted in best overall results in our study, with a predicted std (B_0) only 8% lower than the best achievable std (B_0)-- case 5. Case 5 however, would require the acquisition of 3D B_0 maps for input to the shim algorithm (60 sec), while case 7 would only require 2-3 planes as input (acquisition time of 4-6 sec).

References: **1.** Maril et al., Magn Reson. Med 54: 1139 (2005) **2.** Reeder et. al., Magn Reson Med 54:586 (2005).
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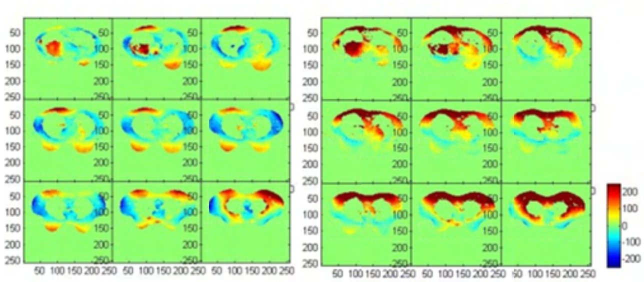

Figure 1: Example of a typical volunteer shimmed using case 1 (left) and case 7 (right)

	Case 2	Case 4	Case 6	Case 7	Case 9	Case 11	Case 13
vol 1	3	6	5	7	1	4	2
vol 2	1	3	7	6	2	4	5
vol 3	1	3	7	6	2	4	5
vol 4	2	1	5	6	3	7	4
vol 5	1	2	6	7	4.5	3	4.5
vol 6	2	1	3	7	4	5	6
vol 7	1	2	4	6	3	5	7
vol 8	1	4	3	6.5	6.5	2	5
vol 9	1	3	5	4	2	7	6
vol 10	1	2	3	5	4	7	6
vol 11	1	3	5	7	2	6	4
vol 12	1	2	5	6.5	3	4	6.5
Total	**18**	**35**	**64**	**81**	**41**	**59**	**66**
Stdev	**0.7**	**1.3**	**1.4**	**0.9**	**1.4**	**1.9**	**1.3**

Legend
Best=7 points; Worst=1 point; linear scale

Table 2: Performance of the multiple plane strategies in each of the volunteers studied

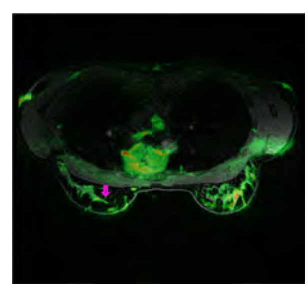

Figure 2: Overlap between a DWI and an anatomical image (case 7)