Shim component analysis for dynamic shimming of the breast

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Introduction

Respiratory motion can induce fluctuation of magnetic field causing artifacts in magnetic resonance spectroscopy (MRS) and proton resonance frequency shift (PRFS) MR thermometry in the breast [1, 2]. It has been reported that the magnitude of respiratory-induced B_0 shift in the breast is ten times greater than in the brain, typically on the order of 0.10 ppm, and varies in location [1]. It is therefore important to determine the regional and temporal variation of B_0 fluctuation during respiration. Even though the amount of frequency shifts during respiration has been reported, a 3D visualization and analysis of its temporal changes have not been well studied. The aim of this study is to estimate and analyze the respiratory-induced temporal B_0 fluctuation in different location of breast in a three dimensional volume. The ultimate objective would be to use dynamic shimming for breast imaging.

Methods

Experimental studies were executed on a 3T MRI scanner (Siemens, Tim Trio). Three dimensional gradient echo images at maximum inspiration and maximum expiration from a breast-mimicking phantom (res = 2.8x2.8x5, TE1 /TE2 = 2.46/4.92ms, TR = 6.6ms) and the breast of a healthy volunteer (res = 4x4x5, TE1/TE2 = 2.46/4.92ms, TR = 6.6ms) were acquired to obtain static B_0 fieldmap of each respiration stage. Images with TE1 were used to create maps of phase difference ($\Delta\phi$) between inspiration and expiration, then the $\Delta\phi$ map was converted into a frequency-shift map $\Delta\nu = \Delta\phi/(2\pi TE1)$ [1]. Next, a least-squares linear fitting of the 3D data to spherical harmonics was performed to estimate the combination of shim terms. The x-axis is defined as subject right-left, the y-axis as anterior-posterior, and the z-axis as superior-inferior direction. Also, free induction decays (FIDs) of three region of interest (ROI) along y-axis in the right breast were acquired using point-resolved spectroscopy (PRESS) pulse sequence to assess the dynamic frequency-shift in different region of the breast (volume size = 1.5x1.5x1.5cm^3, TR/TE = 300/30ms, BW = 1200Hz, vector size = 256, NEX = 256). The frequency-shift ($r\Delta B_0$) at each TR was calculated as the slope of a least-square linear fit of the phase of FIDs. Only the first 20ms of the FIDs were used for least-square fitting.

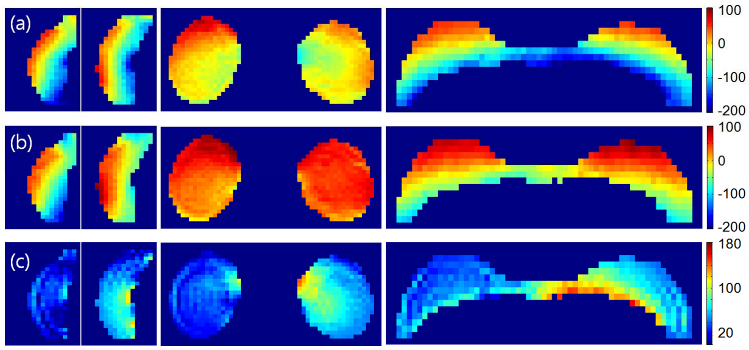

Figure 1. 3D visualization of the fieldmaps at (a) maximum inspiration and (b) maximum expiration (in Hz), and (c) difference of (a) and (b). Note that the scale of (a) and (b) are -200 to 100Hz, but (c) is 0 to 180Hz.

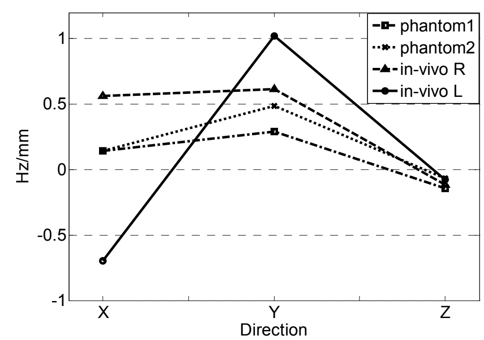

Figure 2. Plot of fit terms X, Y and Z in Table 1.

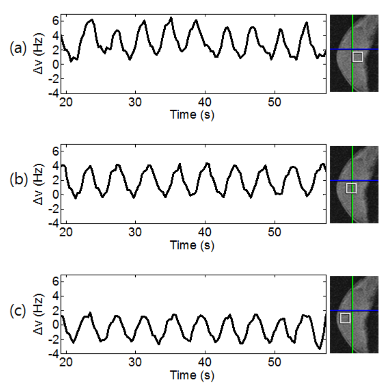

Figure 3. Time-courses of frequency-shift obtained from three ROI in the right breast.
(a) Near the chest wall (mean/std = 3.0314/1.619),
(b) mid region (mean/std = 1.9381/1.4979),
(c) near the nipple (mean/std = -0.4925/1.3446)

Results and discussion

Sagittal, coronal and transverse views of the fieldmaps of 3D volume at maximum inspiration and maximum expiration show severe B_0 offset in the regions near the air-tissue interface, near the chest wall and also near the surface of breasts (Fig 1(a) and (b)). But in the frequency-shift map between minimum and maximimum respiration (Fig 1(c)), we can see that the offset of the region near the chest wall is much greater than near the nipples, and also higher in the left breast than the right due to the cardiac motion. There is a tendency to increase the offset in the posterior-anterior (AP) direction thus we have high Y term in the fitting result of the frequency shift map (Table 1). The results of all experiments are highly correlated each other (r>0.9). However, there is important difference between the phantom data and in-vivo results, the X terms which represent the right-left gradient. This is due to the presence and motion of cardiac that we could not realize in the phantom. As shown in the frequency-shift map in Fig 1(c), the amount of offset is varying along x direction and it has larger value in the left than the right (the sign is opposite). Fig 2 shows the tendency of fit terms.

Fig 3 shows the dynamic changes of respiration induced frequency-shift at the ROIs along the y-axis. The ROI nearest the chest wall has highest mean value and standard deviation. This implies that there exist not only the static offset but time-varying component is also considerably dominant. These results suggest that dynamic shimming in the breast, especially in AP (and secondly RL) direction is most affected by the respiratory motion.

	Phantom1	Phantom2	In-vivo (R)	In-vivo(L)
X	0.1419	0.1423	0.5613	-0.6982
Y	0.2924	0.4852	0.6136	1.0206
Z	-0.1443	-0.0672	-0.1142	-0.0777

Table 1. Fit of frequency-shift map data to the linear terms, X, Y and Z basis. Note that in the in-vivo data, the X term of the left breast has opposite sign but similar magnitude to that of the right.

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References

[1] Bolan et al. MRM 2004;52:1239-1245, [2] Peters et al. JMRI 2009;29:731-735.