Respiratory and cardiac motion induced B0 fluctuations in the breast: implications for PRFS-based temperature monitoring

N. H. Peters[1], L. W. Bartels[2], F. Lalezari[1], K. L. Vincken[2], J. L. Verwoerd[3], W. P. Mali[1], C. J. Bakker[1]

[1]Radiology, University Medical Center Utrecht, Utrecht, Netherlands, [2]Image Sciences Institute, University Medical Center Utrecht, Utrecht, Netherlands, [3]Philips Nederland BV, Medical Systems, Eindhoven, Netherlands

INTRODUCTION:

Accurate thermometry is a prerequisite for the safe and reliable application of focused ultrasound (FUS) in a clinical setting. Proton resonance frequency shift-based (PRFS) MR temperature mapping is currently considered the best method for achieving this goal. However, phase shifts due to field disturbances caused by respiratory and cardiac motion can be mistaken for phase shifts induced by temperature elevation. In preparation of the application of MR-guided FUS for the treatment of breast tumors, we thought it relevant to first study the effect of B_0 fluctuations on PRFS-based thermometry in this region. This study was performed at 3 T because of the higher signal to noise ratio (SNR) and the larger phase shift per degree temperature change at higher field strengths, which allow for more accurate thermometry. We postulate a method for measuring field disturbances in the breast due to respiration and cardiac motion and describe the implications for PRFS-based thermometry.

MATERIALS & METHODS:

Modulus and phase images were reconstructed from gradient echo scans on a 3-T whole body system (Intera Achieva, Philips, Best, The Netherlands). Subjects were placed in prone position. Signals were acquired with a bilateral open breast array coil (MRI devices, Würzburg, Germany). The scan protocol included a transverse time resolved single slice scan through the center of the breast to monitor the phase shifts due to regular respiration ((TE/TR 2.3/5.9 msec; flip angle 10º; FOV 269×384 mm, acquired voxel size 1.5x2.5x10.0 mm3, reconstructed voxel size 1.5x1.5x10.0 mm3; temporal resolution 0.64 sec); two low resolution 3D scans, one during the maximum inspiration state and one during the maximum expiration state, both in breath hold, to study the effect of maximum capacity respiration on the field disturbance in the breast (TE/TR 4.6/8.4 msec; flip angle 15º; FOV 300x375 mm, acquired matrix 154x192, acquired voxel size 1.95x1.95x8.0 mm3, reconstructed voxel size 1.46x1.46x4.0 mm3; number of reconstructed slices 25 (overcontiguous), scan duration 16.4 sec); a cardiac triggered sequence in breath hold to determine the effect of cardiac motion on homogeneity of the field (TE/TR 1.8/3.7 msec; flip angle 10º; FOV 320x320 mm, acquired voxel size 2.0x2.0x8.0 mm3, reconstructed voxel size 1.25x1.25x8.0 mm3; 20 heart phases). From the phase images, phase changes were calculated. The phase changes were converted to field changes using:

$$\Delta B = \Delta\varphi / (\gamma \cdot T_E)$$

where $\Delta\varphi$ is the change in phase in radians, γ is the gyromagnetic ratio for protons in radians per second per Tesla and T_E is the echo time in seconds. Subsequently, ΔB was expressed in parts-per-million (ppm) of B_0 (1 degree Celsius corresponds to 0.01 ppm).

Field disturbances were calculated for each pixel in all three series. For the regular respiration and cardiac series a maximum intensity projection of phase and a minimum intensity projection of phase were made along the time axis. The minimum intensity projection was subtracted from the maximum intensity projection in order to obtain a phase change map in time. The breasts were segmented on the modulus images using thresholding and a brush-tool to obtain segmented phase change maps. The phase change maps were converted to field disturbance maps, and subsequently a color scale overlay was superimposed (figure 1). For the maximum capacity respiration series, the phase image from the maximum expiration state was subtracted from the phase image from the maximum inspiration state. The resulting phase difference image was converted to a field difference map and a color overlay was superimposed.

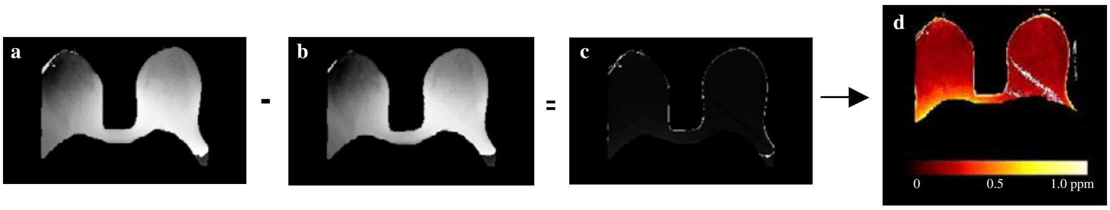

Figure 1. illustration of the creation of a field disturbance map for each pixel: the minimum phase per pixel over time (b) is subtracted from the maximum phase per pixel over time (a). The resulting subtraction image (c) is converted to a field disturbance map (in ppm) using equation 1 and a color overlay is superimposed (d).

RESULTS:

A typical example of field disturbance due to regular respiration is shown in figure 2, for maximum capacity respiration in figure 3 and for cardiac motion in figure 4. From these images we conclude that the field disturbances were approximately 0.15 ppm (+/- 15˚C) for the regular respiration series, 0.25 ppm (+/- 25˚C) for the maximum capacity series, and less than 0.03 ppm (+/- 3˚C) for the cardiac motion series.

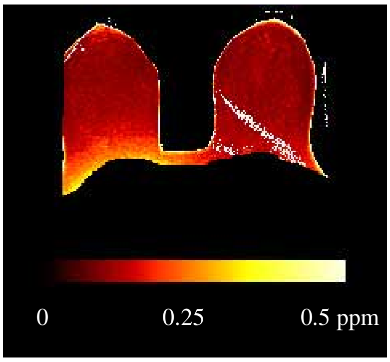

Figure 2 Field disturbance (ppm) in the breast due to regular respiration

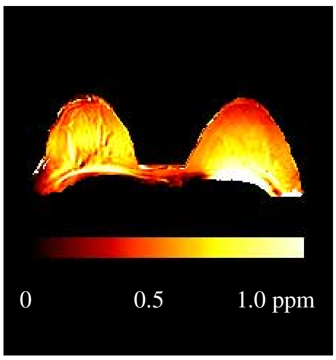

Figure 3 Field disturbance (ppm) in the breast due to maximum capacity respiration

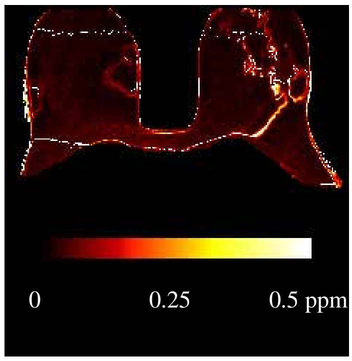

Figure 4 Field disturbance (ppm) in the breast due to cardiac motion

CONCLUSION:

Respiration-induced field disturbances cause significant phase shifts in the breasts that need correction for accurate thermometry during MR-guided focused ultrasound.