Dynamic BOLD Contrast in the Breast Using Heart Saturation

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Introduction: BOLD contrast applied to breast imaging has great potential to provide additional diagnostic information as a supplement to that collected with DCE-MRI. A recent paper by Gilad et al. [1] indicates in a mouse tumor model that while conventional DCE-MRI provides data on the permeability of a tumor, BOLD contrast reports on the tumor's vascular maturity. Rapidly growing vessels in tumors often do not develop the musculature for a vasoreactive response. Thus, BOLD contrast can differentiate the healthy vessels that respond to a vasoreactive stimulus and those tumor vessels that do not. From our group's past experience, measuring BOLD contrast in the breast has been extremely challenging due to two main factors: motion artifacts from the nearby beating heart and motion of the patient in response to a hypercapnic stimulus such as breath holding. Previous studies have measured BOLD contrast in the breast, but results are conflicting [2,3]. A more robust method for measuring BOLD contrast in breast may help provide more consistent results. The method presented in this paper significantly improves BOLD contrast by using a new pulse sequence that selectively saturates the MRI signal of the heart and induces contrast by having the volunteer breathe pure oxygen in a time jittered approach.

Methods: A dedicated gradient echo spiral pulse sequence was designed for this study. This pulse sequence selectively saturates a cylinder encompassing the heart. The user controls the position and dimensions of the saturated signal and thus the cylinder can be adjusted according to each patient's anatomy. The pulse sequence also saturates fat. The resultant image is of the glandular tissue of the breast and part of the chest wall with most heart signal eliminated. The BOLD contrast stimulus used for this study consisted of three one-minute blocks of pure oxygen interleaved with room air for a total of seven minutes. The oxygen was administered through a nasal cannula, and the onset of each oxygen block was jittered to optimize the contrast (cross-hatched boxes in Fig. 1). This GRE-2D spiral sequence, was tested on the left breasts of two healthy volunteers with the jittered stimulus, once with heart saturation and once without heart saturation (1.5T -- GE Healthcare, Waukesha, WI, breast coil -- MRI Devices, Waukesha, WI, TE = 30 ms, TR = 1 s, Flip Angle = 75, Bandwidth = 125 kHz, matrix size = 64 x 64, FOV = 20, Slice Thickness/Spacing = 5 mm/ 5 mm, 1 interleave, 9 slices, 420 time frames/slice).

The BOLD signal time series for each voxel was cross-correlated to the jittered block design after convolution with an exponential Hemodynamic Response Function (HRF) [4] with a 30 s time constant (i.e. blue trace in Fig. 1). Maps of correlation coefficients were overlaid on T1 weighted anatomic maps with a threshold range of 0.1 – 0.3 (Fig. 2).

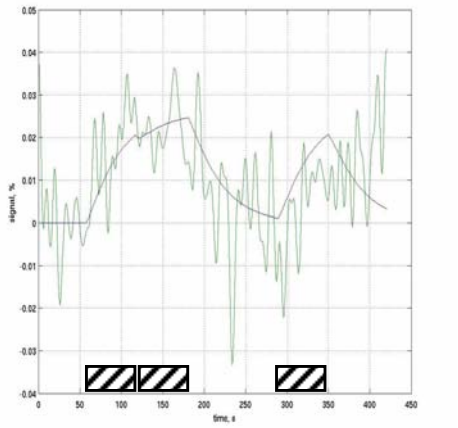

Figure 1. The green trace is the negative of the measured BOLD signal. The blue trace is the modeled HRF with a 30 s time constant. The cross hatched boxes represent the times when the volunteer breathed pure oxygen during the scan acquisition.

Results: Saturating the signal from the heart significantly improved the measured BOLD contrast. In figure 2, the left image is the BOLD signal when the heart was not saturated and the right image is the BOLD signal with heart saturation. The red mapping represents negative correlation. This means that the jittered oxygen stimulus correlated with an increase in deoxyhemoglobin in healthy breast vasculature. Data from both volunteers produced a significant negative correlation to the stimulus. The measured BOLD contrast in figure 1 is the inverted time series taken from a large region of interest (selected from the right image of Fig. 2) plotted against the modeled HRF. The good agreement between the two curves demonstrates the reliability of this measurement.

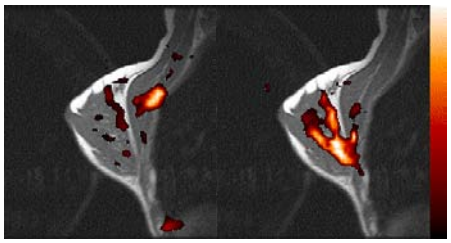

Figure 2. The left image is the BOLD contrast image without heart saturation. The right image is the BOLD contrast with heart saturation.

Conclusion: The method presented in this abstract allows for greater exploration of BOLD contrast in breast tissue. Saturation of signal from the heart reduces motion artifacts, enabling robust BOLD contrast in the breast induced by blocks of oxygen inhalation. Breathing of pure oxygen is also advantageous because it is comfortable for the volunteer (unlike inhaling hard-to-breathe carbogen) and does not involve stimulus-correlated motion (unlike breath holding). With an effective imaging method now in place, future studies will focus on measuring BOLD contrast in tumors, and better understanding the negative correlation of BOLD contrast in breast tissue.

REFERENCES: [1] Gilad et al., Int. J. Cancer. 117:202-211 (2005). [2] Padhani, et al. ISMRM Proceedings #90, 2005. [3] Taylor, et al. J Magn Reson Imag. 14:156-163 (2001). [4] Jezzard. Functional MRI: an introduction to methods. Oxford Univ. Press (2001). Funding provided by NIH P41-RR09784.