Fat saturation and motion compensation using gating and reordering

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INTRODUCTION

Dynamic contrast enhanced (DCE) breast MRI is sensitive for the detection of breast cancer. However, the prone position with which DCE-MRI images are usually acquired is significantly different from that of the surgical setting, in which the patient is supine. The supine position can be used to image the patient during DCE-MRI to mimic the breast configuration in the operating room (OR). Registration of the resulting supine images will be useful in breast conserving surgeries to accurately determine the position and extent of the tumor in the OR.

Supine breast MRI was previously implemented with custom-built coils and fixture [1]. The zonal motion-adapted acquisition and reordering technique (ZMART) [2] was used to compensate for respiratory motion. ZMART is a combination of reordering and gating, which increases the scan time depending on the selected gating window. The addition of full fat saturation required for breast MRI will result in unacceptably long scan-times. Here, we present a method to achieve adequate levels of fat suppression with a minimal increase in scan-time by electively applying fat saturation to only the centric phase-encode regions [3,4]. This combination of ZMART with partial reordered fat saturation allows fast motion-compensated and fat-suppressed supine breast MRI.

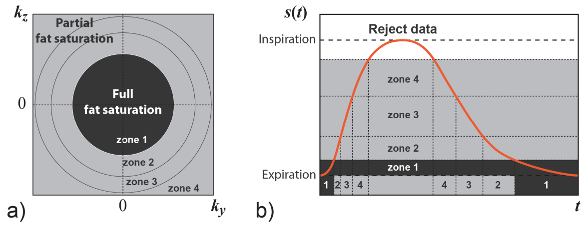

Figure 1: Principle of ZMART combined with partial fat saturation: (a) The k-space plane of the two phase-encoding directions (k_y-k_z) is segmented in circular zones around the k-space center. The two regions for partial fat saturation overlay the ZMART zones. (b) Similarly, the displacement range in the gating window during one respiratory cycle is divided into zones corresponding to the zones in k-space.

MATERIALS AND METHODS

All images were acquired with a whole body 1.5T MR scanner (GE Signa Excite) using a fast 3D spoiled gradient echo (fast 3D SPGR) sequence with the following modifications:

- Respiratory motion compensation using ZMART:
  The k-space-plane of the two phase-encoding directions (k_y-k_z) was segmented into circular zones around the k-space-center (fig.1). During the scan, the respiration state was monitored using a respiratory belt. No data were acquired if the detected displacement was above a given gating window (see fig.1b). The remaining displacement range within the gating window was segmented into zones corresponding to the k-space-zones. Thereby, the central k-space-zones corresponded to the zones in the respiratory cycle closest to expiration. The choice of k-space-zone was made in real-time during the scan based on the actual respiration state before acquiring the appropriate k-space-line.
- Combination with partial reordered fat saturation:
  A modification of the partial reordering technique [4] was necessary because the k-space-positions were dependent on the respiratory pattern and therefore unpredictable. For partial fat saturation, the k_y-k_z-plane was segmented in two circular zones overlaying the ZMART-zones (fig.1a). All k-space lines in the central zone (determined by the ratio of this zone area to the total area of all zones - $R_{central}$) were fat saturated, versus only a fraction of positions ($F_{periphery}$) in peripheral zone. Since fat saturation required a longer repetition time, the relative size of the zones in the respiratory cycle was adjusted to ensure that each zone was sampled an equal number of times during one cycle.

For all experiments the gating limit was set to 60% of the maximal displacement between expiration and inspiration. 32 zones were used for reordering.

- Periodic motion (amplitude: 3mm, time period: ≈6s) was manually applied to a phantom perpendicular to the chosen imaging plane (FOV=190×190×126mm^3, matrix=256×256×84) during the scan. Data sets were acquired without (T_E=4.2ms, T_R=6.5ms) and with (T_E=4.2ms, T_R=16.4ms) fat saturation; in each case without periodic motion, with uncompensated periodic motion and with ZMART-compensated motion. The partially fat-saturated and ZMART-compensated data set was acquired of the moving phantom with $R_{central}$=10% and $F_{periphery}$=1/10.
- Volunteer: Unilateral, slightly tipped coronal scans of a free-breathing volunteer were acquired with ZMART motion compensation as well as full fat saturation and partial fat saturation (FOV=180×180×90mm^3, matrix=192×192×36, T_E=4.2ms, T_R=6.0ms (no fat sat)/15.8ms (fat sat), $R_{central}$=50% and $F_{periphery}$=1/10).

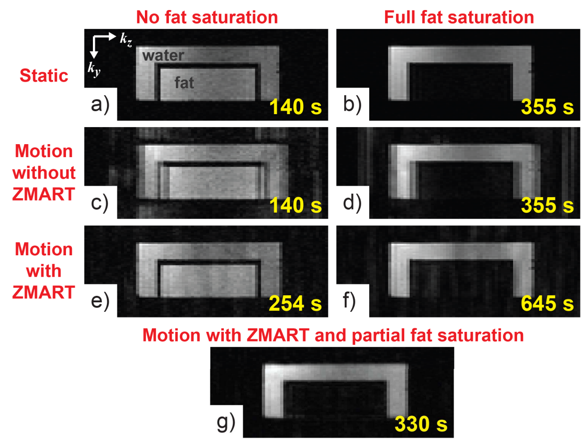

Figure 2: Reformatted slice in the phase encoding plane of a 3D data set through a part of the phantom containing fat surrounded with water.

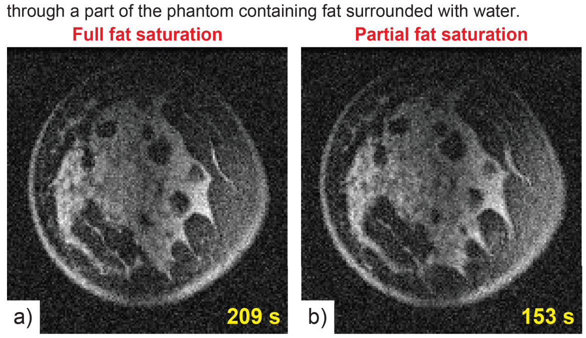

Figure 3: One slice of the motion compensated 3D data set of a volunteer acquired with (a) full fat saturation and (b) partial reordered fat saturation.

RESULTS

The results of phantom (fig.2) and volunteer (fig.3) experiments show that the combination of motion compensation with ZMART and partial fat saturation results in effective fat saturation without dramatic increases in scan-time. For example, with a moving phantom the use of partial fat suppression (fig.2g) added only 30% more scan-time to the strictly motion-compensated acquisition (see fig.2e). However, since the detailed structure of the breast requires a higher fat saturation ratio, the reduction in scan-time is less dramatic in volunteers.

DISCUSSION AND CONCLUSIONS

The high spatial resolution that is required for supine breast MRI to aid breast conserving surgeries leads to long scan-times. The use of the suggested combination of ZMART and partial fat-saturation achieves this without greatly sacrificing scan-time. Further time reductions might be possible with different ratio values $R_{central}$ and $F_{periphery}$ or ZMART parameter settings. In addition, fat suppression of only a fraction of the central region of k-space would still be effective, as fat has a relatively long T_1-relaxation. This would further accelerate the acquisition time.

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