Silicone-specific imaging using a single-echo Dixon technique

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Introduction: An estimated two million women in US have had silicone breast implants. The number is expected to increase substantially with the recent announcement by FDA that silicone breast implants are now re-approved for breast augmentation in women whose ages are 22 or older. In its decision, FDA concludes that an extensive body of scientific evidence exists for reasonable assurance of the benefits and risks of the silicone implants. However, FDA also requires a specific device labeling for the silicone implants that a woman should have an MRI three years after her initial implant surgery and then once every two years thereafter to check for implant rupture. Therefore, the number of the procedures for silicone breast implant MRI is expected to increase accordingly.

Currently, the standard of practice for silicone implant MRI relies on the use of selective saturation pulses to obtain silicone-specific images. As a result, magnetic field inhomogeneity that is often encountered in breast imaging can negatively impact the quality of the results. As an alternative, silicone-specific images can also be generated by using multiple-point Dixon methods (1-2), which can overcome the limitations due to the magnetic field inhomogeneity. Because silicone (S) constitutes a third chemical species in addition to water (W) and fat (F), previous efforts in using the multiple-point Dixon techniques for silicone-specific imaging have to either assume that the frequency separation between W and S is twice the frequency separation between F and S (so that the three component system can be treated as a two-component system in the postprocessing) (3), or to rely on using a preparatory inversion pulse to suppress F (so that the three-component system is reduced to a two-component system) (4), or to require additional data acquisition and extensive processing to directly decompose the three components (5-6). While these approaches are reported to be successful to some extent, they all require a minimum of three scans for proper processing. Furthermore, because an image with all the three components in-phase is usually required, most of these methods can only be implemented with a spin echo based pulse sequence, further limiting the minimum total scan time and the spatial resolution that is clinically achievable for these techniques.

In this work, we propose to use a single-echo Dixon technique with flexible echo times (7-8) for silicone breast implant imaging. The echnique does not need to make any assumption on the frequency separation between the three components and does not rely on using a preparatory inversion pulses to suppress fat. Furthermore, the method can easily be implemented with a gradient echo based pulse sequence (either 2D or 3D) for substantially superior scan time efficiency and spatial resolution.

Method: For a three-component system consisting of W, F and S, the complex signal after the Fourier transform at a given echo time (TE) can be expressed as:

$$S(x,y) = (W + F \cdot e^{i\omega_f \cdot TE} + S \cdot e^{i\omega_s \cdot TE}) \cdot e^{i\phi} \quad [1]$$

where ω_f and ω_s are the resonance frequency of F and S relative to W, respectively. ϕ is the overall phase error for all the three components due to the magnetic field inhomoneity and all other factors. If TE is chosen for W and F to be in-phase (e.g. at 360^o), Eq. [1] becomes:

$$S(x,y) = (W + F + S \cdot e^{i\omega_s \cdot TE}) \cdot e^{i\phi} = (T + S \cdot e^{i\omega_s \cdot TE}) \cdot e^{i\phi} \quad [2]$$

where T (= W + F) represents the tissue (either W or F or a combination of the two). Thus, for postprocessing purpose, the three-component system is reduced to a system with only two components (T and S) that have a relative phase angle of $\omega_s \cdot TE$. To separate the two components from Eq. [2], a single-echo Dixon method with flexible echo times that was originally developed for water and fat separation (7-8) can be used to determine the phase error ϕ . Afterwards, Eq.[2] can be phase-corrected, and T and S can be separated algebraically from the phase corrected complex signal.

Experiments and results: Phantom and in vivo data were acquired using the commercially available 2D and 3D fast gradient echo pulse sequences. The TE of the data acquisition was set to 4.6ms to make water and fat in-phase. From the phantom data, we determined that at this TE, the relative phase angle between S and W/F is approximately 230^o. This phase angle was then used for processing both the phantom and the in vivo data. The postprocessing algorithm was implemented in Matlab and was able to produce clean silicone-specific images in both phantom and in vivo. The figure below shows the results from the data acquired of a patient on a 1.5 Tesla scanner (GE Healthcare) with the 2D fast gradient echo sequence and an 8-channel HD breast coil. The acquisition parameters used for these images were TR/TE=300/4.6ms, flip angle = 60^o, acquisition matrix = 384x192, slice thickness/gap = 5/0mm, RBW= ±41.7kHz, NEX = 2, NPW = on, and total acquisition time = 1:58min for 30 slices. The image on the left shows the magnitude image before phase correction. The image in the middle and the image on the right show the tissue-specific (W+F) and silicone-specific images, respectively. These images are generated automatically from the same data as for the image on the left. Despite the large FOV used for bilateral coverage, the quality of the silicone-specific image is judged to be excellent.

Discussions: Among all the imaging modalities, MR provides **a** unique capability of producing silicone-specific images for evaluating the breast implant integrity. However, we find that the quality of the silicone-specific images obtainable in practice using the existing techniques is widely varying. Besides the magnetic field inhomogeneity which can not always be compensated with shimming, the level of the skills of the MR technologists (e.g. in correctly identifying and setting the center frequency) can also be a complicating factor. The technique proposed in this work has the advantages of overcoming the field inhomogeneity effects in postprocessing and of eliminating the need for manual prescan. In comparison to the other Dixon-based techniques, the proposed technique makes no assumption on the frequency separation between the three chemical species and offers a substantial improvement in scan time and spatial resolution. If implemented with a spin-echo based sequence, the technique can also include acquisition of an image with all three components in-phase to first remove the coil-dependent phase errors in Eq. [1].

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