Dixon Fat Suppression for Off-resonant Water Imaging of Superparamagnetic Iron Oxide Nanoparticles

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Purpose

The demonstration that cells labeled with magnetic nanoparticles (MNPs) can be detected non-invasively by MRI, made MNPs popular MRI contrast agents[1]. Superparamagnetic contrast agents introduce magnetic field inhomogeneities due to their strong magnetic moment which lead to shorter T_2^* relaxation times[2]. This causes hypointense contrast on T_2^*-weighted sequences. In order to improve detectability of MNP labeled cells, positive contrast imaging techniques have been developed such as Inversion Recovery with ON-resonant water suppression (IRON)[3]. A suppression pulse with a specific frequency offset, bandwidth and flip angle is being used to allow only the display of off-resonant protons. IRON can be combined with a spectral pre-saturation pulse (SPIR) to achieve fat suppression. Here we sought to investigate the feasibility of the Dixon water–fat separation method as an alternative to SPIR fat supppression in combination with the IRON positive contrast imaging technique and to compare both methods in terms of their fat suppression ability.

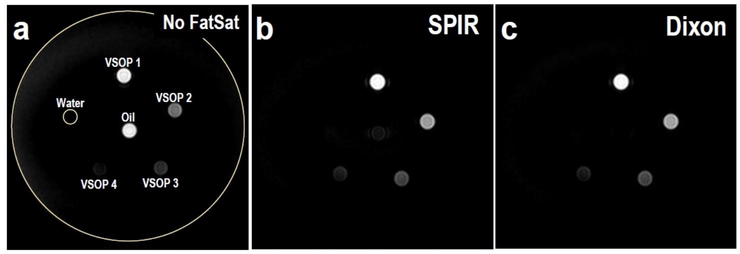

Figure 1: Water phantom with four MNP concentrations and a vial with olive oil. a) IRON without any fat saturation techniques (the contour of the phantom is shown), b) IRON with SPIR, c) IRON with Dixon.

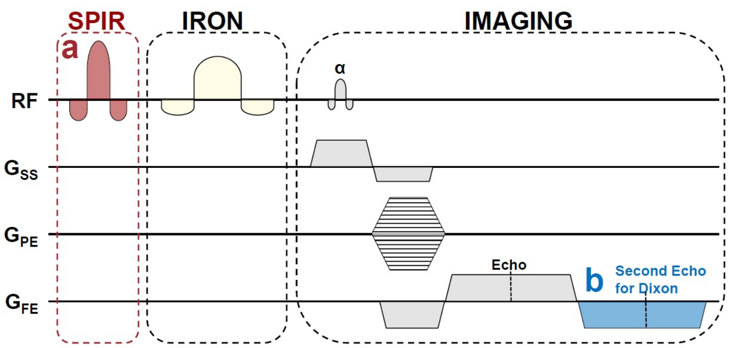

Figure 2: Sequence diagram: a) Gradient-echo sequence with SPIR pre-pulse followed by a frequency-selective IRON pre-pulse. One echo is acquired in the imaging part. b) Only one pre-pulse (IRON) but two echoes are acquired to generate in and out of phase images (Dixon).

Methods

We used a Water phantom with four different MNP concentrations (1.2 mM, 0.6 mM, 0.3 mM, and 0.15 mM) and a tube containing olive oil. In addition, the phantom also contained an Eppendorf tube filled with water to assess the effect the tube has on the signal creation. We used a multishot fast gradient echo sequence with 10 startup echoes, 1000 ms shot interval, 0.53 mm in-plane resolution, 1.36 ms echo time, 10 ms repetition time and 18° flip angle. The IRON pulse was selected with an offset of 135 Hz, a bandwidth of 679 Hz, and an angle of 120°. For the Dixon fat suppression technique we acquired two echoes to generate in and out of phase images (figure 2). Otherwise, both sequences had identical scan parameters. All experiments were performed using a medium sized extremity flex coil on a clinical 3T Achieva scanner (Philips Healthcare, Best, NL).

Results

All four MNP solutions can be seen on the phantom images of figure 1 with the brightest signal belonging to the MNP solution with the highest iron concentration. Water and oil signals are well suppressed on both images with the fat signal suppression of the olive oil tube being superior on figure 1c where Dixon was used. These results were quantified in figure 3 where we plotted signal-to-noise ratio (SNR) for each vial over the iron concentration. It can be seen that the data points follow a linear relationship with similar R^2 values. Fat suppression was superior with the DIXON compared to the SPIR technique resulting in SNRs of 3.29 ± 0.42 and 37.37 ± 0.84, respectively. IRON produced the best contrast at a frequency offset of the on-resonant water suppression pulse of 249 Hz.

Discussion

From figure 1 it is obvious that very good water suppression was achieved with the IRON technique as signal from the water phantom was efficiently nulled. At the same time, a very bright signal was achieved for the highest MNP solution. The signal of the MNP solutions increased linearly with increasing MNP concentration both for the SPIR and Dixon IRON sequence as demonstrated in figure 3. IRON imaging with Dixon fat suppression produced a much better suppression of the olive oil vial as can be seen in figure 1 and by the very low SNR value of 3.29 ± 0.42 compared to 37.37 ± 0.84 with SPIR. The quality of the linear fits of figure 3 are comparable with both having an R^2 value of higher than 0.98. Finally, the proposed Dixon fat suppression could be also combined with other positive contrast imaging techniques that require effective fat suppression.

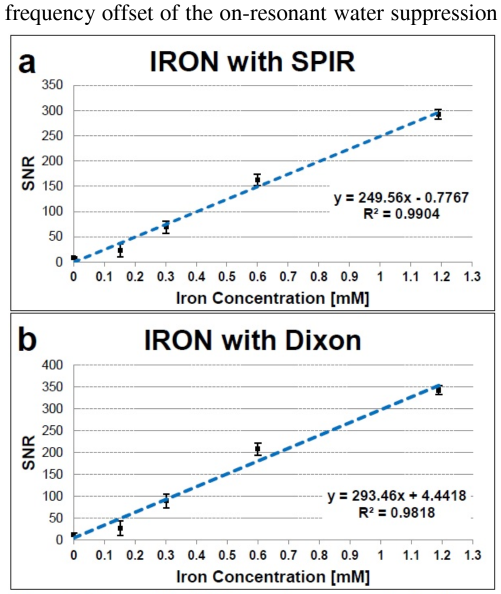

Figure 3: Linear fit of SNR over iron concentration for IRON sequence with SPIR (a) and Dixon (b).

Conclusion

IRON is an off-resonant water imaging technique that produces positive contrast images with magnetic nanoparticles. As the ultimate goals of contrast agent MR imaging are in vivo applications, a strong and reliable fat suppression technique is imperative. We have shown that the Dixon fat suppression in combination with the IRON technique produces superior fat suppression compared to SPIR and IRON while maintaining the image quality of positive contrast in vitro and providing slightly improved sensitivity.

References

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