Dynamic Frequency Drift Correction for Binomial Water Excitation

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Introduction

Fat suppression is a fundamental technique applied in routine musculoskeletal magnetic resonance (MR) imaging used to improve the dynamic range for water containing structures, such as cartilage, in particular when used in conjunction with T1-weighted sequences. The most widely used methods are frequency-selective fat saturation (FatSat) and inversion-recovery (STIR). However, in low field systems (< 0.5T), spectral fat saturation cannot be used due to the too small frequency offset by the chemical shift between the fat and water resonance frequencies, while the STIR technique results in low signal to noise ratio (SNR). In [1] an alternative fat suppression method has been proposed, binomial water excitation by means of a spectral spatial pulse. By section-selective composite rf-pulses, water is excited, while the lipid nuclei magnetization is kept in the longitudinal axis and hence will not contribute to the MR imaging signal. Still, consistent and reliable fat suppression in low field systems can be challenging because of as main magnetic field (B_0) inhomogeneities and drift. B_0 inhomogeneity induced frequency offsets are usually compensated by a frequency scout, to improve the fat suppression within the region of interest (ROI), yet this method can not compensate for drifts of the magnetic field. In this work, a dynamic frequency measurement and correction based on a 1D navigator is introduced to improve the fat suppression for binomial water excitation pulses.

Methods

Sequence: A 3D gradient echo sequence with the simplest binomial pulse (1-1) consists of two α° flip angle pulses with an inter pulse delay time τ chosen to allow for an 180° phase evolution between the water and fat spins (τ = 10 ms at 0.35 T). A 1D navigator without partition and phase encoding gradients is inserted into the image scans at an interval of 16 TRs during the acquisition, to measure the frequency change $\Delta f(n)$. The initial phase of the second RF pulse is updated after a new $\Delta f(n)$ is measured. Equation (4) gives the phase $\varphi(n)$ while Fig. 3F shows the evolution of magnetization vectors. The initial phase of the first RF pulse is kept constant along the *x* axis.

$$S(0,k_x)=\int\rho(x,y)\cdot e^{-j2\pi k_x x}dxdy \quad (1) \qquad S(n,k_x)=\int\rho(x,y)\cdot e^{-j2\pi k_x x}\cdot e^{j2\pi\int_0^{TE}\Delta f(n)dt}dxdy \quad (2)$$

$$\Delta f(n)=\frac{angle\left(\sum_{k_x}\left(S(n,k_x)\cdot conj\left(S(0,k_x)\right)\right)\right)}{2\pi\cdot TE} \quad (3) \qquad \varphi(n)=\Delta f(n)\cdot\tau \quad (4)$$

Here $S(0,k_x)$, $S(n,k_x)$ are the first and the *n*-th navigator, respectively, $angle(\bullet)$ is the phase operator and $conj(\bullet)$ is the conjugate operator.

Human Study at 0.35T: Volunteer knee images in the coronal plane were acquired on a Siemens MAGNETOM C! 0.35T scanner. The parameters of the 3D gradient echo sequence were: FOV=172mm×172mm, matrix size=384×384×20, TE=12.5ms, TR=40ms, slice thickness=3.5mm, flip angle=15, band width=50 Hz/pixel.

Evaluation: The fat suppressed images using binomial water excitation with and without the dynamic frequency drift correction are compared and shown in Fig. 1.

Results

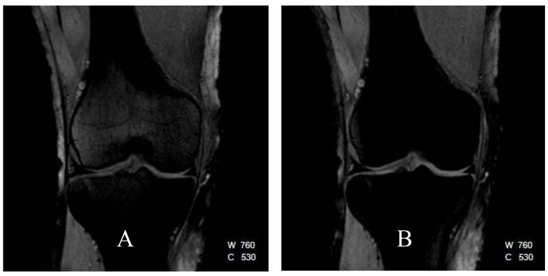

Fig. 1: Fat suppressed images w/o & w correction.

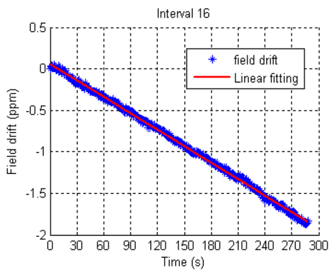

Fig. 2: Magnetic field drift.

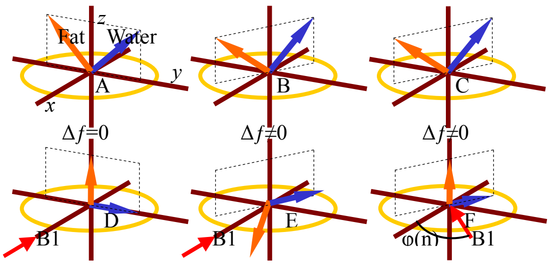

Fig. 3: Water and fat spins evolution.

Fig 1.A displays the fat suppressed image without dynamic frequency drift correction, while in Fig 1.B the dynamic frequency drift correction was applied. The windowing and central values are identical for both images. Using the dynamic frequency correction (Fig 1.B) the bone marrow fat signal is suppressed better than without (Fig 1.A), while the water signal in the muscle in Fig 1.B is brighter than in Fig 1.A. Fig 2 shows the magnetic field drift of about 2ppm during the scan time of 285 seconds.

Discussion & Conclusion

A dynamic frequency drift correction method for binomial water excitation has shown to substantially improve the performance of the fat suppression effect. Fig. 3 shows the temporal evolution of the magnetization from water and fat nuclei before and after the second RF pulse. Fig 3.A is the ideal situation with $\Delta f(n)=0$, the water magnetization is tipped to *y* axis by the second RF pulse while the fat magnetization is kept along the *z* axis as shown in Fig 3.D [1]. According to the measured magnetic field data showed in Fig 2, $\Delta f(n)$ changes during the scan due to temperature drifts of the permanent magnet. As a consequence, the water and fat spins are not always in *zy* plane (Fig 3.B, C). If the second RF pulse is still applied along *x* axis, the water and fat spins will not be tipped exactly to the *y* and *z* axes (Fig 3.E) respectively, therefore, the image will be contaminated by the residual fat signal (Fig 1.A). If the initial phase of the second RF pulse is adapted according to $\Delta f(n)$ so that the direction of B1 is perpendicular to the plane formed by water and fat spins, the fat spin will be tipped to *z* axis (Fig 3.F) and will not contribute to the MR signal (Fig 1.B). Thus, the performance of fat suppression by binomial water excitation can be improved via initial phase adaption according to a dynamic frequency measurement. The important note is that the proposed method can be combined with a frequency scout to address frequency drifting and field inhomogeneity problems.

References

[1] Schick F *et al*. MRM, 38:269-274 (1997).