WATER-FAT SEPARATION FOR FAST SPIN ECHO IMAGING IN AN INHOMOGENEOUS FIELD WITH PROGRESSIVE ENCODING

H. E. Avram[1], D. Kramer[1], I. Simovsky[1]

[1]Research & Development, Toshiba America MRI, South San Francisco, CA, United States

INTRODUCTION

In clinical applications where the water signal is chiefly of interest , it is imperative to attenuate the signal coming from fat which tend to reduce contrast in such areas as extremities and abdominal sections. The lost of contrast is also emphasized by the natural behavior of the FSE sequence that enhances the fat signal by a partial averaging of the J-coupling of the lipid protons [1]. Typical approaches for lipid signal reduction include: chemically selective radio frequency pulses, inversion recovery pre-pulse and multipoint Dixon techniques [2]. The first approach is very dependent of the homogeneity of the main magnetic field. Furthermore, at mid- and low field, the actual frequency difference is small which requires impracticably long RF pulse lengths. The typical problem with the inversion pre-pulse is the loss of signal from tissues other than fat. One way to avoid the above-mentioned pitfalls, in case of an inhomogeneous field, is to rely on phase sensitive methods [2,3]. The approach followed here is the progressive encoding of the sequence where the encoding time is measured from the point of the echo formation to the point where the first order interactions are cancelled out. An algorithm was designed to separate the water from the fat image based on the optimum choice of a set of water-fat phase increment angles.

METHODS

A FSE sequence was modified to run in dynamic mode such that during each dynamic study, a different time differential was used. The only requirement on the sequence was that the time differential the echoes are shifted, must preserve the CPMG condition and therefore, it has to maintain the symmetry such that all echoes (direct as well as indirect ones) are phase encoded the same way for the entirety of the echo train. solidly between refocusing RF pulses [1]. The scans were performed at 0.35T (Toshiba Ultra Open System) equipped with high performance gradient subsystem .

THEORY

Water-fat imaging is based on the mathematical model derived from [1,2],

$$(w + f*\exp(i\alpha_n))*\exp(i\alpha_n\beta) = I_n,\ n = 0,1,2, \ldots, N-1,$$

where w is the signal from the water component in the current voxel, f is the signal from the fat component, α_n is the n-th phase increment angle, β is the scalar magnetic field inhomogeneity coefficient and I_n is the complex signal, generated by the current voxel for the current phase increment angle. For each given β the real-valued least-square solution {w,f} can be found by the Moore Penrose pseudo inverse of the system:

$$\cos(\alpha_n\beta)*w + \cos(\alpha_n(1+\beta))*f = \mathrm{real}(I_n); \quad \sin(\alpha_n\beta)*w + \sin(\alpha_n(1+\beta))*f = \mathrm{imag}(I_n).$$

The residual for a given β is $R(\beta)$. Then w, f and β can be found by minimization of $R(\beta)$ over the interval β_{min},β_{max})[3]. Unfortunately for $w \neq f$ the function $R(\beta)$ has two very close local minima, which makes the minimization process unstable.

To avoid this problem we propose another less precise, but more robust method, conceptually similar to [10]. Suppose first that $N \geq 3$ and $\alpha_0 = 0$ (this is usual case). Then from 2 pairs of equations:

$$|w+f*\exp(i\alpha_n)| = |I_n|,$$

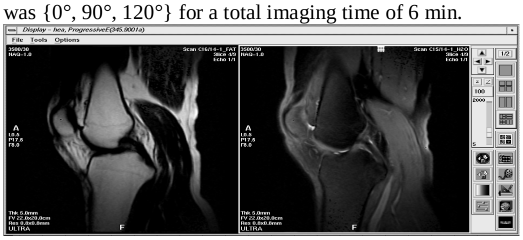
with n = {0, N-1} and n = {0,N-2} we can calculate two pairs of solutions for w and f, and from these two pairs of solutions for β : $\{\beta_1^1,\beta_1^2\}$ and $\{\beta_2^1,\beta_2^2\}$. To select the unique solution for β .We can use the following reasoning: suppose that the first pair corresponds to the largest between α_{N-1} and α_{N-2} increment angle. Then from β_1^1 and β_1^2 we choose the one with the minimum distance among: $|\beta_1^1 - \beta_2^1|$, $|\beta_1^1 - \beta_2^2|$, $|\beta_1^2 - \beta_2^1|$, $|\beta_1^2 - \beta_2^2|$. Again, as for minimization of $R(\beta)$ with the presence of noise, there is a certain possibility that the chosen solution for a particular voxel is wrong. But since β represents the magnetic field inhomogeneity, it should change very slowly from voxel to voxel and can be approximated with enough precision by a cubic polynomial function of the voxel position. Therefore it is natural to fit the solution for β with a cubic polynomial over the whole slice or volume. We made some numerical experiments for the two methods of the local solution for β, described above, and found that the tedious process of searching for two local minima in $R(\beta)$ in the presence of noise is giving results very similar to the direct solution [2].

RESULTS

SIMULATION: We created a 2D model, which consisted of 4 areas of different water/fat ratios: area1= 1/36, area2=9/4, area3=3.3/26.6 and area3=6.7/13.3. White noise of a certain level was added to $I_n(x,y)$. As expected [3], the water/fat separation quality depends very much on the noise level in the input data and the values of increment angles. It also depends on the water/fat ratio. It is also obvious that the bigger the water component in the total signal the better is the water/fat separation with respect to the water estimate. Acceptable results of separation with the presence of noise can be achieved with α_{max} of at least 120°, but it is not necessary to go much higher that this number. Simulation results (errors) of the separation for the case of 3 encoding angles, when a white noise of level equal to the water signal in area 1 was added, are the following:

	$\alpha_n = \{0^\circ,60^\circ,120^\circ\}$		$\alpha_n = \{0^\circ,90^\circ,120^\circ\}$	
Area	Water error %	Fat error %	Water error %	Fat error %
1	124.797	10.589	100.000	10.910
2	19.819	57.828	14.148	50.56
3	86.021	5.345	65.014	3.196
4	28.974	11.975	22.936	8.562

IN-VIVO: The knee image of a normal volunteer; on the left is the calculated fat image. The image on the right is the water image. The set of angles used for encoding was {0°, 90°, 120°} for a total imaging time of 6 min.



CONCLUSIONS

Water-fat separation, with good levels of snr for FSE, is feasible using the method of progressive encoding with a maximum value of phase increment angle of at least 120°.

REFERENCES

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3) Xiang QS, ISMRM, 2003;1130