Model-Free Spectral Fat Analysis Based on Ultra-Dense Echo Sampling Using a Singular Value Decomposition Matrix Pencil Method

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TARGET AUDIENCE: Physicists working on water-fat imaging and hepatologists.

INTRODUCTION: Quantification of the spectral composition of fat is of main clinical interest for various diseases, such as for muscular dystrophy [1] or non-alcoholic fatty liver disease (NAFLD) [2]. In originally introduced water-fat separation methods and up to today in most clinical protocols, only the main peak of fat is considered [3]. Recently, the standard has started to shift towards multi-peak fat spectrum analysis [4, 5, 6]. Here, we make use of sequentially shifted echo times (TEs) of a 2D multi-contrast spoiled gradient echo (GRE) technique [7] to achieve an ultra-dense signal sampling in the tens of microseconds regime leading to hundreds of contrast images. Signal modulations are subsequently analyzed to extract multi-peak fat information based on singular value decomposition matrix pencil method (SVD-MP) [8], as previously introduced for water-fat imaging [7].

METHODS: Multi-contrast in vivo 2D GRE imaging of the calf was performed at 3T on a clinical scanner on healthy volunteers. An ultra-dense echo spacing ΔTE of 60 μs was achieved by a sequential shift of echo times [5], leading to as much as 400 contrast images with a TR of 40 ms. Scan parameters were: $\alpha = 10°$, $TE_1 = 1.53$ ms, $TE_{n+1} = TE_n + \Delta TE$, $\Delta TE = 60$ μs, $1.6 \times 1.3 \times 5$ mm^3 resolution, bandwidth = 1302 Hz/Pixel, total scan time ~ 4 min (2 averages). The signal time course of each voxel was analyzed based on the SVD-MP approach, proposed by Lin et al. [8]. Complex data were processed and the results were analyzed as a function of the echo spacing using a predefined number of spectral components M (i.e., one for water and N for fat, M = N+1), which is necessary as input for the signal decomposition method. The normalized amplitudes of the N fat components α_0, $\alpha_{1, \ldots,} \alpha_{N-1}$ ($\Sigma\alpha_i = 1$) were estimated with the SVD- MP method. Finally, fat fraction (FF) maps were calculated by predetermining different N, using the signal component amplitudes as FF= F/ (F+W) (F: Fat signal amplitude, W: Water amplitude) and assuming $F = \Sigma_1^N \alpha_i f_i$ (where f_i are the relative amplitudes of the fat components).

RESULTS: A representative signal time course for fat is shown in Fig. 1 in combination with the SVD prediction results for one and six spectral fat components. N=6 results in the best signal prediction. Respectively, in Fig. 2 the effect of the echo spacing is analyzed. Reducing the echo time by a factor of 10, the predicted signal cannot fit properly the fat signal oscillations. Estimated assuming N=6 peaks for the fat spectrum, the amplitude maps of the different fat spectral peaks are presented in Fig. 3 and are in agreement with literature [3]. Finally, in Fig. 4 FF maps are calculated for N=6, 4 and 1. It is observed that reducing the preset signal components results in an underestimation of the fat percentage.

DISCUSSION & CONCLUSION: Sequential shifting of echo times within a multi-echo GRE technique is able to provide an ultra-dense echo sampling in the tens of microseconds regime to resolve the multi-peak fat spectrum within clinically feasible scan times using a SVD-MP approach. The proposed method offers a new and promising fast model-free analysis of spectral fat content and composition that can be used for optimization of iterative water-fat imaging [4] or analysis of the fatty acid composition [6].

REFERENCES: 1. Huang et al. jMRI 1994 (4), 2. Browning et al., Hepatology 2004, 3. Dixon et al. Radiology 1984, 4. Yu et al. MRM 60 (2008), 5. Lee et al. JMRI 33 (2011), 6. Peterson et al. MRM 69 (2013), 7. Deligianni et al. ISMRM 12 #4032, 8. Lin et al. J. Magn. Res. (128) 1997.

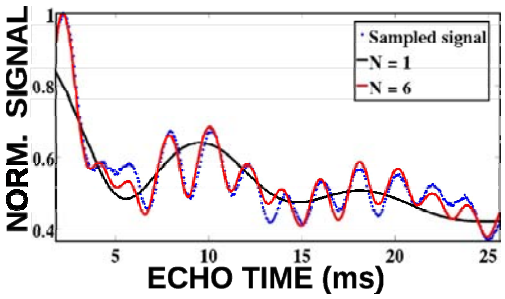

Figure 1: Measured and predicted signal time course from a SVD-MP signal analysis from a ROI (see Fig.3&4) on subcutaneous adipose tissue for a predefined number of spectral components M 2 and 7 (i.e., N = 1 vs. 6).

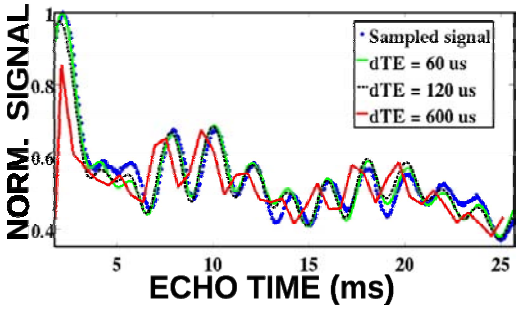

Figure 2: Effect of echo spacing (ΔTE = 60 μs, ΔTE = 120 μs, ΔTE = 600 μs): Measured and predicted signal from a ROI on subcutaneous adipose tissue (see Fig.3&4).

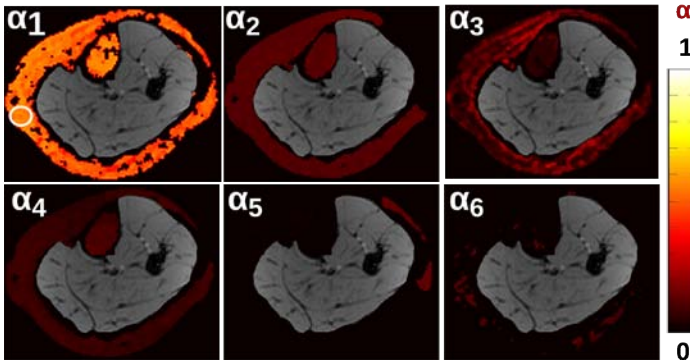

Figure 3: Maps of amplitudes of various fat peaks. Average in the indicated ROI: α_1(*420 Hz*)≈0.60, α_2(*318 Hz*)≈0.14,α_3(*-94 Hz*)≈0.09),(α_4(*470 Hz*)≈0.07),(α_5(*234 Hz*)≈0.02) ,(α_6(*46 Hz*)≈0.07).

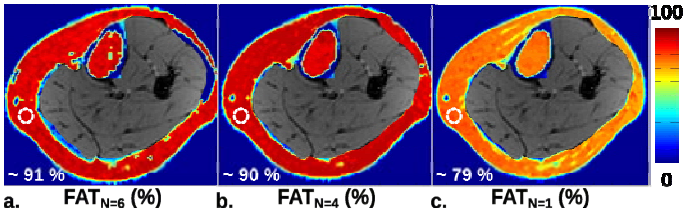

Figure 4: Fat fractions maps for different pre-settings of signal spectral components N: a. 6, b. 4, and c. 1.