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

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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 ATE 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: α = 10º, TE1 = 1.53 ms, TEn+1 = TEn+ΔTE, ATE = 60 μs, 1.6 x 1.3 x 5 mm³ 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 α1, α2, ..., αN (Σαi = 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/W (F: Fat signal amplitude, W: Water amplitude) and assuming F/W = Σαi (where fi 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. In particular, 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].


**Figure 1:** Measured and predicted signal time course from a SVD-MP signal analysis from a ROI 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 (ATE = 60 μs, ATE = 120 μs, ATE = 600 μs). Measured and predicted signal from a ROI on subcutaneous adipose tissue for a 5 mm³ 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 α1, α2, ..., αN (Σαi = 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/W (F: Fat signal amplitude, W: Water amplitude) and assuming F/W = Σαi (where fi are the relative amplitudes of the fat components).

**Figure 3:** Maps of amplitudes of various fat peaks. Average in the indicated ROI: α1(420 Hz)=0.60, α2(318 Hz)=0.14, α3(-94 Hz)=0.09, α4(470 Hz)=0.07, α5(234 Hz)=0.02, α6(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.