Simultaneous Quantification of Fat Fraction and Fatty Acid Composition Using MRI

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Introduction

The distinction between non-alcoholic fatty liver disease (NAFLD) and steatohepatitis is currently only possible using invasive techniques. Possibly, the fatty acid (FA) composition of hepatic fat may be able to discriminate between the two conditions [1]. MR spectroscopy (MRS) has been proposed as a non-invasive method of estimation of FA composition [1-3]. Hamilton *et al.* have recently suggested the use of theoretical knowledge of the chemical structure of FAs to achieve detailed information on the FA composition from ^{1}H-MRS measurements [2]. In addition, an MR-imaging technique would provide spatial information in case of a non-diffuse disease. In a previous work, we were able to use multi-echo imaging to quantify the fraction unsaturated FA (*UF)* [4]. However, not including water, this technique required the estimation of seven unknowns.

In this phantom study, we introduce a new reconstruction algorithm based on multi-echo imaging which uses theoretical knowledge to simultaneously quantify the fat content and the FA composition with a reduced number of estimates.

Theory

An iterative least squares procedure for separation of spectral components with frequency shifts Δf_i and estimation of off-resonance effects has previously been described by Yu *et al.* [5]. As suggested by Hamilton *et al.*, the amplitudes α_i of nine fat signal components can be expressed in terms of number of double bonds (*ndb*), number of methylene-interrupted double bonds (*nmidb*) and chain length (*cl*) [2]. This allows for a complete description of the fat (*F*) and water (*W*) signals with five estimates: *W*, normalized fat signal $f = F/\Sigma\alpha_i$, *ndb*, *nmidb* and *cl*. The equations below yields the estimates $\tilde{\mathbf{P}}_{5x1}$ from the N (≥ 6) acquired signals $\mathbf{S}_{Nx1}$ with echo times t_i and complex field map $\hat{\psi}$. For numbering of the fat resonances, see Figure 1. Using these estimates, the fat fraction (*FF*) and *UF* can be calculated as $FF = F/(F+W)$ and $UF = \alpha_5/2\alpha_4 = (ndb - nmidb)/3$, respectively [3].

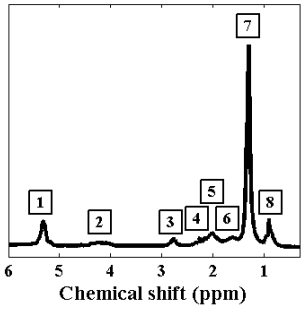

Figure 1. Rapeseed oil spectrum with peak assignments.

$$\tilde{\mathbf{P}} = (\mathbf{A}^{\mathbf{T}}\mathbf{A})^{-1}\mathbf{A}^{\mathbf{T}}\mathbf{S} \qquad \mathbf{A}_{N\times 5} = \begin{bmatrix} e^{\hat{\psi}t_1} & a(t_1)e^{\hat{\psi}t_1} & b(t_1)e^{\hat{\psi}t_1} & c(t_1)e^{\hat{\psi}t_1} & d(t_1)e^{\hat{\psi}t_1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ e^{\hat{\psi}t_N} & a(t_N)e^{\hat{\psi}t_N} & b(t_N)e^{\hat{\psi}t_N} & c(t_N)e^{\hat{\psi}t_N} & d(t_N)e^{\hat{\psi}t_N} \end{bmatrix}$$

$$\tilde{\mathbf{P}} = \begin{bmatrix} W \\ f \\ f \cdot ndb \\ f \cdot nmidb \\ f \cdot cl \end{bmatrix}$$

$$E_i(t) = e^{i2\pi\Delta f_i t}$$
$$a(t) = E_1(t) + 4E_2(t) + 6E_4(t) + 6E_6(t) - 24E_7(t) + 9E_8(t)$$
$$b(t) = 2E_1(t) + 4E_5(t) - 8E_7(t)$$
$$c(t) = 2E_3(t) - 4E_5(t) + 2E_7(t)$$
$$d(t) = 6E_7(t)$$

Method

Nine 50 ml vials with *FF*=10, 50 and 100 % and *UF*=8, 46 and 87 % were prepared and imaged in a 3 T Tim Trio Siemens scanner (Siemens Medical Solutions, Erlangen, Germany). The FA compositions of the used oils were provided by the Swedish National Food Administration. The parameters used in the gradient echo sequence were: TR=1000 ms, flip angle=30º, TE_1=1.63 ms, echo spacing=3.5 ms and number of echoes=12. From the acquired images, *W*, *f*, *ndb*, *nmidb* and *cl* were estimated and *FF* and *UF* calculated.

Results

The results from the simultaneous quantification of *FF* and *UF* are presented in Figure 2, both as images and compared to the true values. Both *FF* and *UF* were successfully quantified, although estimated values of *UF* were overestimated at low *UF*. The estimation of *FF* was accurate for all tested FA compositions.

Discussion and conclusion

The investigated multi-echo imaging technique enables quantification of both the fat content and the FA composition. The overestimation of *UF* at low values with *FF*=10 % and 50 % is likely caused by a spectral overlap of the water and olefinic signals (peak 1). These results clearly show the ability of our proposed multi-echo imaging technique to simultaneously quantify both the fat content and FA composition.

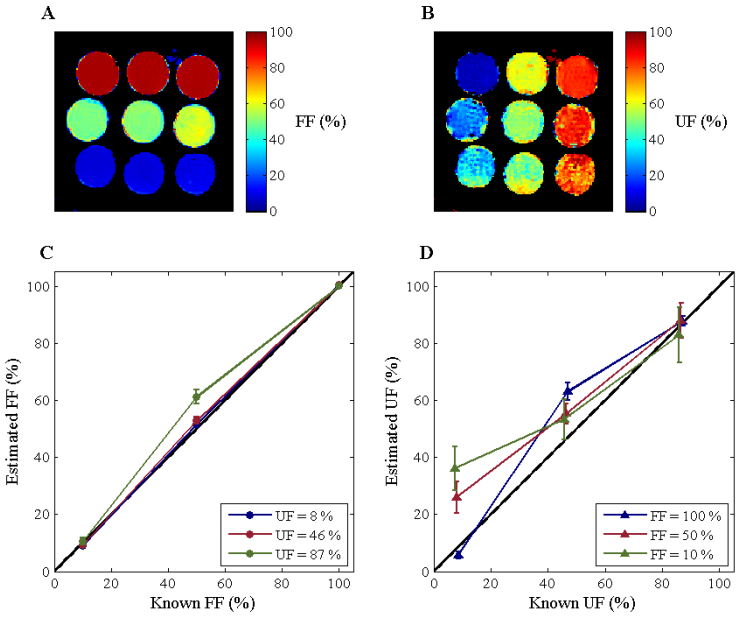

Figure 2. Estimated FF (A,C) and UF (B,D) compared against known values. In A and B, FF is kept constant in rows and UF in columns showing the highest FF on top and the highest UF to the right. Error bars represent one standard deviation.

References

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