Water-Fat Separation in Rat by MRI at High Field (9.4T)

R. Korinek, K. Bartusek, Z. Starcuk

ASCR, Institute of Scientific Instruments, Královopolská 147
612 64 Brno, CZ
Email: radim.korinek@gmail.com

Abstract. *High fields yield benefits such as higher sensitivity along with specific problems - water-fat shift in the image or stronger susceptibility artifacts. Measurement in small animals is more problematic than in humans because the high field necessary to reach better sensitivity causes stronger susceptibility artifacts and requires shortening of specific time intervals used for encoding of the specific phase shift between water and fat. This article illustrates water and fat separation in rat at high fields. The data were acquired by a FSE-based 3-point Dixon technique employing iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) algorithm. The rat was measured in a standard volume coil. The fat/water fraction (FF, WF) map was calculated from the separated water and fat images. The results presented here show a FF map characterizing the fat distribution in a coronal slice of abdomen/pelvis region of a rat.*

Keywords: fat, rat, high field, IDEAL, Dixon

1. Introduction

One of the interesting domains in MRI is water and fat separation/suppression. The first articles describing various approaches for separation/suppression water and fat appeared almost 30 years ago. Methods for water and fat separation are based on either of two physical principles: difference in their longitudinal relaxation T_1 or chemical shift (CS). Methods for water and fat separation/suppression are very useful for diagnosis in liver diseases [1], [2], [3], cardiology [4], [5] [6] and other clinical applications. The methods can be divided into four main categories: Inversion recovery (IR), Fat-Sat, spectral-spatial excitation, and finally Dixon techniques. Besides the application in humans, these methods can be used in preclinical research involving small animals such as mice, rats, rabbits or others mammals. The fat in the tissue can be used as a biomarker in specific diseases of liver (e.g., NAFLD) or heart [7].

Of all the above mentioned categories of water-fat separation/suppression techniques, which are all used in clinical and pre-clinical imaging, the Dixon separation methods, utilizing the chemical shift difference between the water and the major lipid signal, have several advantages: the frequency difference is a well-defined, stable and known parameter (unlike T_1), and no narrow-bandwidth excitation is necessary, which makes these methods immune to static field inhomogeneity. The original method was introduced by Thomas Dixon [8] in 1984. Several modifications of this technique have been proposed; these derived techniques can be classified as one-, two-, three- or multi-point methods. The big challenge for Dixon techniques is the removal of phase errors for correct separation of water and fat signals. Removing the phase errors is crucial for the success of these techniques. Several methods have been proposed for the phase correction (post-processing algorithms, data acquisition or combination of both) [9], [10], [11], [12].

Subject and Methods

For the acquisition of experimental data by a 3-point Dixon (3PD) technique with water-fat phase shifts of $(0, \pi, 2\pi)$, a modified FSE technique was used because FSE [13] is relatively insensitive to B_0 field inhomogeneities and provides useful T_2-weighted (T2W) images. The measurements were performed with a 9.4T MRI system (Bruker Biospec 94/30 USR) at Institute of Scientific Instruments of the ASCR, v. v. i. in Brno.

All measurements on animals were approved by the local ethics committee. The rat was anesthetized and placed into an 86-mm inner-diameter volume coil. All measurements were synchronized to breathing for reducing respiratory motion artifacts. The measured data were processed by iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) [12] algorithm. The algorithm was implemented in Matlab. The resulting water and fat images were used for the calculation of the FF map [14]

$$FF = \frac{|F|}{|F| + |W|} \cdot 100, \qquad (1)$$

where |F| is magnitude of fat image,
|W| is magnitude of water image,
FF is fat fraction [%].

The basic parameters of the measurement were: repetition time T_R = 3000 ms, echo time: T_E = 4.774 ms, effective echo time ETE = 9.548 ms, matrix = 192 × 192, field of view FOV = 70 × 70 mm and bandwidth BW = 150 kHz. The chemical shift between water and fat was 1400 Hz.

2. Results

The calculated water and fat coronal images of rat abdominal and pelvis region are shown in Fig. 1 (B, C) and the calculated FF maps in Fig. 2 B.

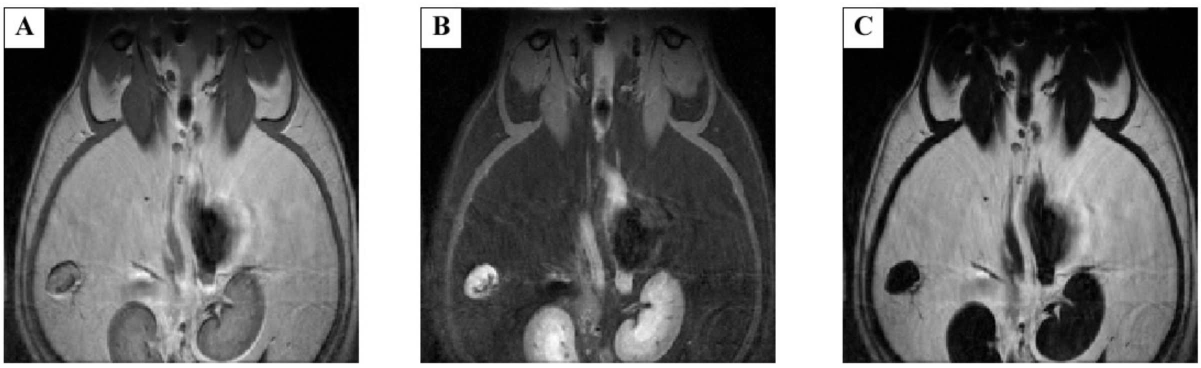

Fig. 1. A: water + fat image. B: calculated water image. C: calculated fat image.

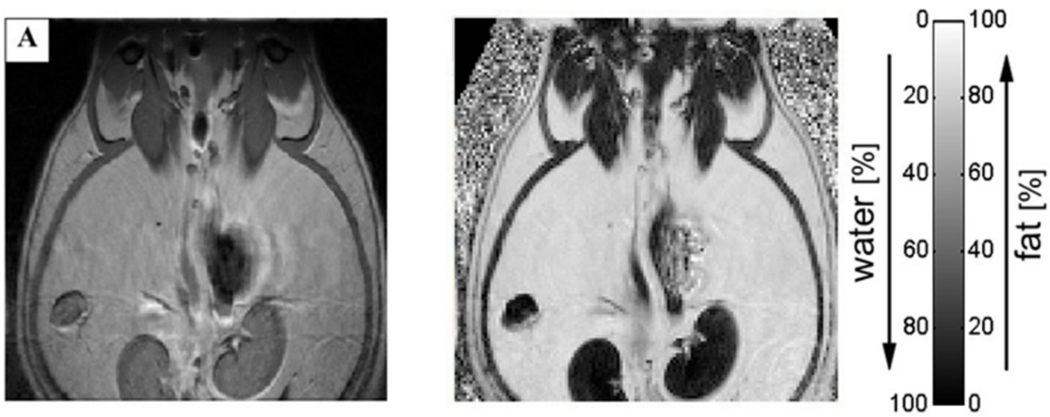

Fig. 2. A: T2W coronal image of rat abdomen and pelvis region (kidneys). B: calculated fat fraction map.

3. Discussion

The 3PD method based on modified FSE sequence with echo asymmetry was successfully implemented and tested in rat at 9.4 T MRI system. The measurement at such a high field is accompanied by specific problems. One of them are the consequences of inhomogeneity of magnetic susceptibility: considerable local static field inhomogeneity may lead, in some voxels, to considerable resonance line broadening, which may complicate the separation of water and fat components. The 3PD technique assumes a relatively simple signal model where water and fat have a single resonance frequency, in spite of the fact that fat has several spectral peaks. The inaccuracy of the simple signal model leads to incompletely separated water and fat images, as can be seen in Fig. 1B. Despite all this, we acquired water and fat images with good quality. For more accurate water-fat separation, multi-frequency fat spectrum modelling can be used. A more accurate signal model might yield better water and fat separation. However, in case of the FSE-based Dixon technique, the multi-point acquisition is more time consuming in comparison with the 3PD technique.

In high fields, the chemical shift between water and fat is increased, and to achieve small chemical shift displacement, strong gradients and large acquisition bandwidths must be used, with possible consequences such as non-negligible eddy currents or reduced SNR. In our case, gradients of 50 mT/m were sufficient to limit the chemical-shift displacement to 0.65 mm; with the pixel size of 0.365 mm, it still represents a 2-pixel displacement. If such a displacement was a problem for a specific application, increased gradients are technically feasible, but at the expense of lower SNR and hence increased risk of post-processing failure. Transfer of the implemented 3PD method to a lower magnetic field is possible.

Beside the abdominal application this method can be used elsewhere, e.g., in cardiac imaging.

Acknowledgements

This work was financially supported by the Ministry of Education, Youth and Sports, Czech Republic, in Program "National Programme of Sustainability I" (NPU I) (LO 1212) (Grant no. MSMT-34807/2013).

References

[1] Qayyum A, Goh JS, Kakar S, Yeh BM, Merriman RB, Coakley FV. Accuracy of liver fat quantification at MR imaging: comparison of out-of-phase gradient-echo and fat-saturated fast spin-echo techniques-initial experience. *Radiology,* 237 (2): 507-511, 2005.

[2] Kim H, Taksali SE, Dufour S, Befroy D, Goodman TR, Petersen KF, Shulman GI, Caprio S, Constable RT. Comparative MR study of hepatic fat quantification using single-voxel proton spectroscopy, two-point dixon and three-point IDEAL. *Magnetic Resonance in Medicine,* 59 (3): 521-527, 2008.

[3] Peng XG, Ju S, Qin Y, Fang F, Cui X, Liu G, Ni Y, Teng GJ. Quantification of liver fat in mice: comparing dual-echo Dixon imaging, chemical shift imaging, and 1H-MR spectroscopy. *The Journal of Lipid Research,* 52 (10): 1847-1855, 2011.

[4] Liu CY, Redheuil A, Ouwerkerk R, Lima JA, Bluemke DA. Myocardial fat quantification in humans: Evaluation by two-point water-fat imaging and localized proton spectroscopy. *Magnetic resonance in medicine,* 63 (4): 892-901, 2010.

[5] Kellman P, Hernando D, Shah S, Zuehlsdorff S, Jerecic R, Mancini C, Liang ZP, Arai AE. Multiecho dixon fat and water separation method for detecting fibrofatty infiltration in the myocardium. *Magnetic resonance in medicine,* 61 (1): 215-221, 2009.

[6] Farrelly C, Shah S, Davarpanah A, Keeling AN, Carr JC. ECG-gated multiecho Dixon fat-water separation in cardiac MRI: advantages over conventional fat-saturated imaging. *American Journal of Roentgenology,* 199 (1): 74-83, 2012.

[7] Lu M1, Zhao S, Jiang S, Yin G, Wang C, Zhang Y, Liu Q, Cheng H, Ma N, Zhao T, Chen X, Huang J, Zou Y, Song L, He Z, An J, Renate J, Xue H, Shah S. Fat deposition in dilated cardiomyopathy assessed by CMR. *JACC: Cardiovascular Imaging,* 6 (8): 889-898, 2013.

[8] Dixon WT. Simple proton spectroscopic imaging. *Radiology,* 153 (1): 189-194, 1984.

[9] Glover GH, Schneider E. Three-point Dixon technique for true water/fat decomposition with B0 inhomogeneity correction. *Magnetic resonance in medicine*, 18 (2): 371-383, 1991.

[10] Glover GH. Multipoint dixon technique for water and fat proton and susceptibility imaging. *Journal of Magnetic Resonance Imaging,* 1(5): 521-530, 1991.

[11] Yu H, Shimakawa A, McKenzie CA, Brodsky E, Brittain JH, Reeder SB. Multiecho water-fat separation and simultaneous R2* estimation with multifrequency fat spectrum modeling. *Magnetic resonance in medicine,* 60(5): 1122-1134, 2008.

[12] Reeder SB, Pineda AR, Wen Z, Shimakawa A, Yu H, Brittain JH, Gold GE, Beaulieu CH, Pelc NJ. Iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL): application with fast spin-echo imaging. *Magnetic resonance in medicine,* 54 (3): 636-644, 2005.

[13] Hennig J, Nauerth A, Friedburg H. RARE imaging: a fast imaging method for clinical MR. *Magnetic resonance in medicine,* 3(6): 823-33, 1986.

[14] Buxton RB, Wismer GL, Brady TJ, Rosen BR. Quantitative proton chemical-shift imaging. *Magnetic resonance in medicine,* 3(6): 881-900, 1986.