The influence of RF inhomogeneity on the metabolite signals measured by volume pre-selected spectroscopic imaging sequences

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Introduction:

High magnetic fields provide a possibility to achieve higher signal/noise or resolution in the given measurement time. However, due to pronounced interactions between magnetic fields and examined tissues to reach homogeneous static and radio frequency fields (RF) is more difficult. Several studies have reported significant RF variations in the human brain measured at 3T [1, 2]. Such variations represent an issue especially for quantitative spectroscopic imaging where signals from large areas are compared. The aim of this study is to assess the impact of the RF inhomogeneity on the metabolite signals measured by volume pre-selected (PRESS and STEAM) spectroscopic imaging sequences in the human brain at 3T.

Methods:

A spatially variable RF exhibits as flip angle variations within the examined sample. As a result, spins in individual voxels are subject to the different degree of excitation, refocusing and saturation. To evaluate effects of inhomogeneous RF distribution the solution of Bloch equations (within a hard pulse approximation) for the signals $S_{PRESS}(r)$ in PRESS and $S_{STEAM}(r)$ in STEAM sequences was derived:

$$SAT_{PRESS}(r) = \frac{\cos^2(B(r)\cdot\pi)\cdot(1-e^{-t1/T1})\cdot e^{-(TR-t1)/T1} + \cos(B(r)\cdot\pi)\cdot(1-e^{-TE/2T1})\cdot e^{-(TR-t1-TE/2)/T1} + 1 - e^{-(TR-t1-TE/2)/T1}}{1-\cos(B(r)\cdot\pi/2)\cdot\cos^2(B(r)\cdot\pi)\cdot e^{-TR/T1}}$$

$$SAT_{STEAM}(r) = \frac{\cos^2(B(r)\cdot\pi/2)\cdot(1-e^{-TE/2T1})\cdot e^{-(TR-TE/2)/T1} + \cos(B(r)\cdot\pi/2)\cdot(1-e^{-TM/T1})\cdot e^{-(TR-TM-TE/2)/T1} + 1 - e^{-(TR-TM-TE/2)/T1}}{1-\cos^3(B(r)\cdot\pi/2)\cdot e^{-TR/T1}}$$

$$S_{STEAM}(r) = SAT_{STEAM}(r)\cdot\sin^3(B(r)\cdot\pi/2) \quad \text{and} \quad S_{PRESS}(r) = SAT_{PRESS}(r)\cdot\sin^5(B(r)\cdot\pi/2)$$

where B(r) describes RF inhomogeneity (B(r)=1 for perfectly homogeneous RF), T1 represents the T1 value of the given metabolite, t1 is the distance between the first and the second pulse in the PRESS sequence and TM is the distance between the second and the third pulse in the STEAM sequence.
In equations above it is assumed that the profiles of 90° and 180° pulses are ideal and that all flip angle deviations are ascribed to RF variations exclusively. The RF distribution was measured in a healthy volunteer using 3D RF mapping technique described previously [2]. The measurement was performed on whole body 3T MR scanner using head array coil. The parameters used for simulations were as follows: TE/TR=30ms/1500ms; t1=10ms (PRESS only); TM=10ms (STEAM only).

Results:

The dependences of the saturation factors SAT_{PRESS}, SAT_{STEAM} and of the signals S_{PRESS}, S_{STEAM} on the flip angle (α=R(r)·π/2) are shown in Fig.1 and Fig. 2, respectively. For each case the dependences for two T1 values T1=1170ms and T1= 1570ms corresponding to the lowest T1 value for choline and the greatest value for NAA at 3T [3] are shown. As apparent from Fig. 1 the dependence of the saturation factors for STEAM sequence is for the flip angles ranging from 70° to 110° almost a constant unlike the dependence for PRESS. The maximal signal difference ΔS for two T1 values reaches about 15% (both STEAM and PRESS). To asses the influence of typical RF inhomogeneities present at 3T on the acquired signal, the artificial PRESS (S_{PRESS}) image was calculated based on the above equations and on the RF distribution measured in the human brain at 3T. The calculated PRESS image is shown in Fig. 3, where the signal variations up to 34% can be observed as a consequence of the RF inhomogeneity. In the STEAM image (not shown) variations up to 16% were observed.

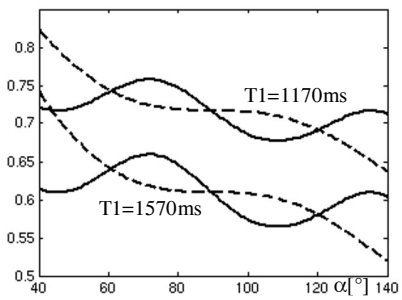

Fig.1 Dependence of SAT_{PRESS} (solid line) and SAT_{STEAM} (broken line) on the flip angle α

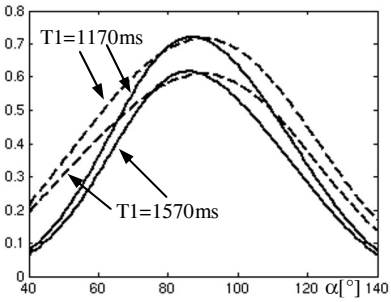

Fig.2 Dependence of S_{PRESS} (solid line) and S_{STEAM} (broken line) on the flip angle α

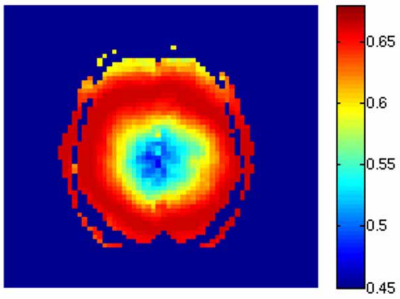

Fig.3 S_{PRESS} image calculated using the RF map measured from the slice through the basal ganglia

Conclusion

The different behavior of STEAM and PRESS sequences with respect to RF inhomogeneity has been shown. The performed analysis revealed significant signal variations in PRESS and STEAM sequences as a consequence of inhomogeneous RF. The hard pulse approximation assumed in the analysis does not take off-resonance effects and different pulse shapes into account. Therefore, the detailed signal dependence may differ from the one presented. However, within this approximation the simulations imply that the significant signal variations has to be taken into account when interpreting SI results at high field strengths (>=3T).

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References:

[1] Alecci M, Collins CM, Smith MB, Jezzard P. Radio frequency magnetic field mapping of a 3 Tesla birdcage coil: experimental and theoretical dependence on sample properties. Magn Reson Med. 2001 Aug;46(2):379-85.
[2] Jiru F, Klose U. Fast 3D radiofrequency field mapping using echo-planar imaging. Magn Reson Med. 2006 Nov 6; [Epub ahead of print]
[3] Ethofer T, Mader I, Seeger U, Helms G, Erb M, Grodd W, Ludolph A, Klose U. Comparison of longitudinal metabolite relaxation times in different regions of the human brain at 1.5 and 3 Tesla. Magn Reson Med. 2003 Dec;50(6):1296-301.