$B_1^{(+)}/B_1^{(-)}$-asymmetry unbalances calibration of MR spectra at high fields

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Introduction

It is well known that absolute calibration of NMR signals which accounts for B1-inhomogeneities and coil loading can exclusively be obtained by using the principle of reciprocity [1]. Unfortunately, at high-magnetic fields the wave-like propagation of electromagnetic fields inside the human body causes a pronounced asymmetry between the clockwise and counter-clockwise rotating transversal B1 field components resulting in an imbalance between the transmitting and receiving sensitivities of a MR coil. Hence, exploitation of the principle of reciprocity for quantitative MR, in particular for absolute quantitation of MRS(I) data, is complicated substantially [2]. To address this issue for clinical 3 tesla MRS we compared the B1-corrected water signal measured by a PRESS sequence in the left and right hippocampus of 20 patients. Further, $B_1^{(+)}$-distributions were measured in a healthy volunteer and complementary FDTD electromagnetic field simulations were performed.

Methods

All measurements were performed on a 3T whole body scanner (MEDSPEC30/100, BRUKER) utilizing the standard 12 rung circularly polarized head coil. Within a MRS study of 20 neurological healthy patients we deduced the water amplitude and B_1–correction factor from PRESS spectra of the left and right hippocampus (voxel size 2x3x2 cm^3). At a given voxel position the transmit sensitivity of a coil is proportional (by convention) to the circularly polarized component $B_1^{(+)}$ which generally differs from the receive sensitivity determined by $B_1^{(-)}$ [1]. By assuming $|B_1^{(-)}/B_1^{(+)}| = 1$ absolute calibration of the in vivo MR spectra is achieved by a volume selective in vivo measurement of $B_1^{(+)}$ and the use of the principle of reciprocity. In the case of an imbalance of the ratio $|B_1^{(-)}/B_1^{(+)}|$ absolute calibration of MR spectra is affected accordingly. In a healthy volunteer we determined the distribution of $|B_1^{(+)}|$ per square root of unit power (1kW) in an axial slice through the centers of the two hippocampus voxels using a MR-based technique described in [3]. For this purpose we recorded 8 images of the head using a standard gradient echo sequence preceded by a 1ms long rectangular preparation pulse with 8 different RF powers. For each voxel the power required for a $\pi/2$ pulse was calculated by fitting the dependence of the theoretical voxel intensity on RF power of the preparation pulse to the measured data. All numerical simulations were performed using the program XFDTD (Remcom Inc.) to solve Maxwell's wave equations by the Finite Difference Time Domain method in conjunction with a Visible Human based head model. The model was implemented on 0.5 – 1 cm grids with 8 perfectly matched layers surrounding the simulation space to assure an infinite space behavior. At each position of the imaged slice the complex steady state field values for B_{1x} and B_{1y} were evaluated. According to [1] $|B_1^{(+)}|$ is determined by $|B_1^{(+)}|=|B_{1x} + iB_{1y}|/2$.

Results

Both the simulation and the in vivo measurement show similar asymmetries (see figure) of the $|B_1^{(+)}|$ distributions whereas the product $|B_1^{(-)}B_1^{(+)}|$ is always symmetric with respect to the head. The imbalance $|B_1^{(-)}/B_1^{(+)}|$ for the left hippocampus voxel determined by an integration over the corresponding box (see figure) was measured to be 1.097. An absolute measurement of brain metabolites or brain water by using the principle of reciprocity and by assuming $|B_1^{(-)}/B_1^{(+)}| = 1$ would result in a 10% higher concentration in the left voxel compared to the right one. This was confirmed by the MRS measurements of water content in the hippocampi of 20 patients. The average water concentration in the left hippocampus voxel was 11% higher than the water concentration in the right hippocampus ($p = 0.00004$). Since the product $|B_1^{(-)}B_1^{(+)}|$ should be always symmetric with respect to the left and right hippocampus voxel we tried to calibrate the water signal crosswise, i.e. we used the individual B_1–correction factor of the left voxel for calibration of the right voxel MRS signal and vice versa. In this way the pretended difference of water concentration vanished ($p = 0.4$).

Conclusion

We have shown that at high fields a significant imbalance between $B_1^{(+)}$ and $B_1^{(-)}$ occurs even when using a highly symmetric rf coil. As a consequence MRS measurements may result in wrong conclusions with respect to left/right differences of metabolite concentrations. To compensate for those artifacts a crosswise correction scheme may be utilized or a reliable simulation of the RF fields generated by the coil in the object has to be performed.

References:
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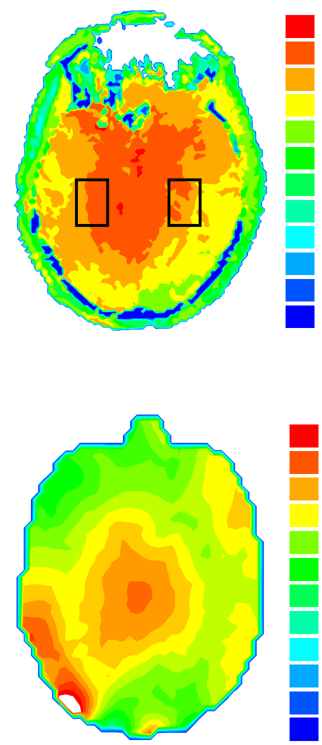

top: measured $|B_1^{(+)}|$in $\mu T/(kW)^{0.5}$ of an axial slice through the hippocampi, the boxes indicate the hippocampus voxels measured by MRS
bottom: calculated distribution of $|B_1^{(+)}|$ in $\mu T/(kW)^{0.5}$ of an corresponding slice using the Visible Human based head model