The potentialities of implantable micro-coil for detection of brain's proton metabolites by NMR micro-spectroscopy

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Introduction:

Analyzing a small volume (about a microlitre) by Nuclear Magnetic Resonance Spectroscopy (MRS) requires a new generation of NMR instruments. In order to detect such small volumes we should be able to reach a sufficient sensitivity, so we propose two strategies: The improvement of spatial localization by implanting the micro-coil in the region of interest, and secondly, the improvement of the filling factor by miniaturization of the probe [1]. The feasibility to use this new generation of in vivo implantable micro-coils was presented in a recent study [2] and brain tissue response to a chronically implantation was studied [3]. The aim of this work is the investigations of B1 radiofrequency (RF) field distribution of planar micro-coil, by simulation correlated with NMR imaging to define the region of maximal sensitivity. The micro-coil sensitivity in terms of limits of detection (LOD) as defined in [1] was also estimated and validated by a comparative study of performances of the micro-coil and a commercial surface-coil for cerebral metabolites MRS detection and determining the gain factor defined as GF = LOD surface-coil/LOD micro-coil.

Materials and methods:

The planar homemade micro-coil of ellipsoidal geometry (1000x500µm²) had four concentric turns, (20µm trace width, and 22µm spacing between turns, quality factor Q=24) Figure 1(I). The 2D map of B1 radiofrequency field distribution was obtained by Matlab simulation at a distance of 10 µm from the top of the copper strip to take into account the biocompatible layer on the micro-coil. For signal distribution by NMR imaging the micro-coil was immersed in a water sample and MR images were acquired using a MSME sequence(FOV = 1.19 cm, TR/TE = 1000/14 ms, in plane isotropic digital resolution 172 µm/pixel, slice thickness 0.3 mm, 8 slices). MRS acquisitions, for comparison study, were carried out using a commercial surface-coil (~3.5cm diameter, designed for ^{1}H rat brain) was set on a phantom containing ten metabolites. The planar micro-coil was immersed in the solution. Both coils were used for signal detection only at same depth. RF transmission was performed using a birdcage coil (7.2cm diameter) in active decoupling mode. Spectra were obtained using PRESS sequence (TR/TE=5000/20ms, excited voxel size 1.5x1.5x1.5mm^3, depth ~10mm, 256 accumulations, experiment duration 20mn). Observations and comparisons were focused on Choline (Cho), N-Acetyl-aspartate (NAA), lactate doublet (Lac) and Creatine (Cr) with concentrations of 25, 50 and 100mM in buffered aqueous solutions. MRI and MRS experiments were performed using a 4.7T-Bruker Biospec System.

Results:

Figure1: (II: a, b, c) shows the micro-coil's spatial sensitivity of the B1 radiofrequency (RF) field map in three directions, simulated using a routine based on Biot-Savart law implemented in Matlab. The simulation results were correlated with the corresponding MR images. As we can see in Figure1: (III: a`, b`, c`). There is a good agreement between measured and simulated spatial sensitivity distribution. Active volume estimated from the MR images is about V_{active}= 2.07±0.06 µl, calculated from the MR signal intensity (70 % of the maximum observed intensity). Figure 2: (a), shows a spectrum obtained using the micro-coil. Spectra were quantified using Bruker Top spin and also with jMRUI software and AMARES method [4]. The performances of the micro-coil were also studied by measuring the sensitivity and estimating limits of detection function of concentration LODc determined in all cases from signal to noise ratio measurement from spectra. The results were compared to those obtained with the commercial surface-coil. The GF (for Cho, NAA, Lac and Cr) using different concentrations 25, 50 and 100mM, showed that the micro-coil approach can provide a more important sensitivity and a lower LOD_c than the surface-coil. GF values are reported between 2 and 2.4, see Figure 2:(b).

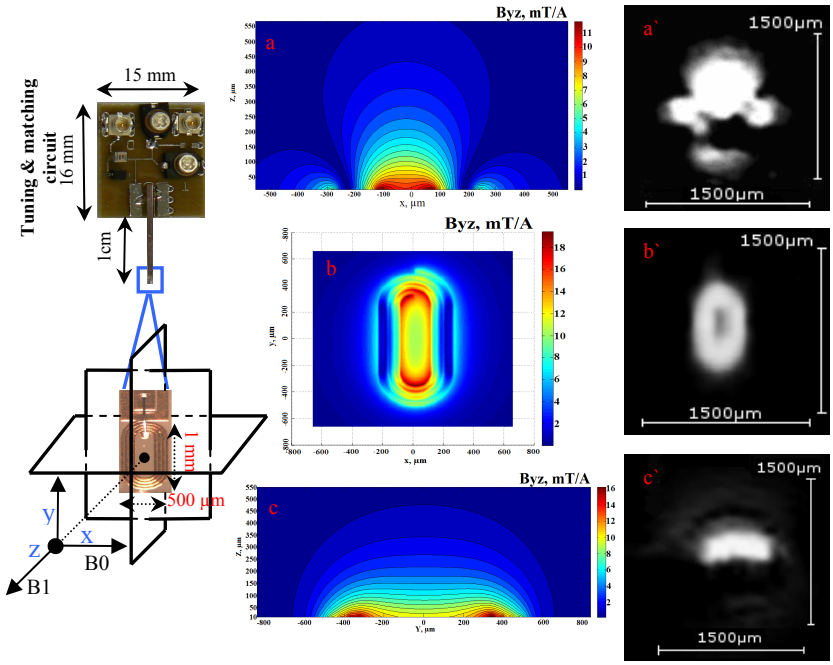

Figure 1: (I) Micro-coil with a focus on the active part with the three directions slices, (II: a, b, c) 2D map of B1 radiofrequency field sensitivity distribution, (III: a`, b`, c`) signal distribution obtained by NMR imaging.

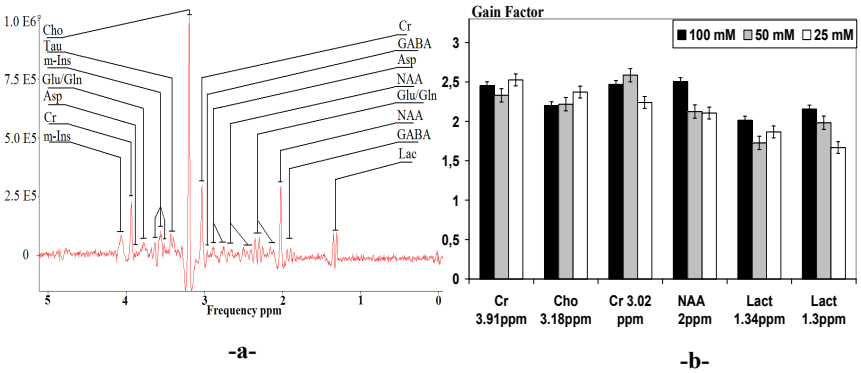

Figure 2: -a- Spectrum of 10 metabolites with 50mM concentration, **-b-** Gain factor for Cr, Cho, NAA and Lac with concentration 25 (white), 50 (grey), 100 (black) mM.

Conclusion:

The planar micro-coil investigation results, obtained first by simulation and then by MRI analysis, are in good concordance. The simulation of intensity shows that the maximum of the signal is localised next to the first and the second loops. An active volume of 2 µl was estimated from MR images. The values of sensitivity, LOD_c and GF show the advantage of the micro-coil, in spite of its smaller active volume, to detect and to analyze small metabolite concentration, opening thus, the way to a new kind of highly spatially resolved explorations on animal model.

Reference:

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