Investigation of Cell Ratio Objects by Magnetic Resonance Imaging (MRI)

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Abstract: The physical model of cell ratio object is used for calculation of additional magnetic fields caused by the interaction of magnetic moments. There have been calculated the additional magnetic fields caused by the interaction of magnetic moments. The spatial density reconstruction of the modeled object with additional magnetic fields was obtained by MRI. The pseudo-inversion matrix method is used for spatial density reconstruction of investigated object. The calculation of additional magnetic fields while reconstruction of small objects gives more precise and full information about investigated objects.

Key words: MRI, reconstruction, spectrum, cell, spatial distribution, concentration.

1. Introduction

The use of nuclear magnetic resonance (NMR) as an analytical method for investigation of micro objects, different membranes is very common question today. There are many articles and works devoted to the optimization of NMR methods for possibility to use NMR for obtaining more accurate analytical information. The investigation of glycine (Gly) concentrations in low and high-grade gliomas based on ^1H MR spectroscopic [1-5]. In other papers authors work over the problems of reconstruction methods. A discrete Fourier based method for calculating field distributions and local magnetic susceptibility in MRI is carefully studied [6]. In Ref. [7] they are to demonstrate how the density matrix formalism is used to study spectral modulations induced by selected multipulse sequences for an AB system. The problem of image reconstruction from sensitivity encoded data is formulated in a general fashion and solved for arbitrary coil configurations and k-space sampling patterns [8]. A novel, fast entropy-minimization

algorithm for bias field correction in magnetic resonance (MR) images is suggested to correct the intensity inhomogeneity degradation of MR images that has become an increasing problem with the use of phased-array coils [9]. The problem of super-resolution reconstruction (SRR) in MRI is considered. Presented subpixel-shifted MR images were taken in several fields of view (FOVs). The algorithm can be applied locally and guarantees perfect reconstruction in the absence of noise [10]. Performed numerical simulations for various combinations of membrane permeability and intracellular diffusion coefficients using the finite-difference method. By minimizing the difference between signals obtained experimentally and those from numerical simulation, they could estimate membrane permeability ($76 \pm 9 \text{ mm}^2/\text{s}$ μm) and intracellular diffusion coefficient ($1.0 \pm 0.0 \text{ mm}^2/\text{s}$) for the human brain [11]. Diffusion-weighted single voxel experiments conducted at b-values up to $1 \times 10^4 \text{ s}/\text{mm}^2$ yielded biexponential signal attenuation curves for both normal and ischemic brain [12]. Water diffusion in neurological tissues is known to possess multicomponent diffusion behavior. The fractions of

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fast and slow apparent diffusion components have often been attributed to the volume fractions of extracellular space (ECS) and intracellular space (ICS) although diffusion fractions are at variance with the tissue compartment volume ratios. In Ref. [11], this puzzle was examined with a finite difference diffusion simulation model on the basis of optical images from sectioned rat spinal cord. Since the magnetic moments of the investigated object not only under the influence of permanent magnetic field and gradient but also under the influence of additional magnetic fields caused by the interaction of magnetic moments. This is because of each magnetic moment creates a magnetic field to be outside for other moments of investigated object. That field $\vec{H}_{aditinal}$ influences the accuracy of obtained analytical information of investigated object. When calculating and taking into account the meanings of $\vec{H}_{aditinal}$ while obtaining signal can give us more accurate and full information about concentration. Proposed method of pseudo-inverse gives the possibility to reconstruct the spin density based on redused sampled data [13].

2. Physical Model

When we investigate such small objects we are interested in a very accurate data which could give us information of molecule concentration, dynamic, structure. That is why the additional magnetic fields created by magnetic moments are important for taking into account while reconstruction. In simple case of MRT the object is under the influence of applied constant magnetic field and gradient. But in our case we have the following situation the investigated object is under influence of constant magnetic field gradient and the additional magnetic fields. For investigation we need a model of small object. For calculations the following model of cell ratio object is used. The model consists of 100 magnetic moments with radial distribution. The radials are the same distance from each other. The angles between magnetic moments on the radials are of the same value. The magnetic

moments are chaos oriented. We apply constant magnetic field at discovered object, under the influence of that field moments become oriented the way field is. Than we apply the field gradient and detect signal. Than we able to calculate the magnetic fields created by magnetic moments and the additional magnetic field created by all moments of the investigated system and under the influence of that is each single magnetic moment of the system.

3. Reconstruction

Since the magnetic moments under the influence not only the permanent magnetic field and gradient but also under the influence of additional magnetic fields. This is because each magnetic moment creates a magnetic field to be outside for other moments. Therefore, we have the following fact that the total field that influences magnetic moment is we can obtain the information about the concentration of atoms in the molecule having found appropriate value correction of the magnetic field that is created by all other magnetic moments and influences each separate point $\vec{H}_{aditinal}$ when a constant magnetic field $\vec{H}_{const}$, and the attached magnetic field H_{grad} and recorded signals $S(t_1, t_2)$ are known. So the sum field:

$$\vec{H}_{\Sigma} = \vec{H}_{const} + \vec{H}_{grad} + \vec{H}_{aditinal} \quad (1)$$

$$S(t_1, t_2) = \sum_{x,y} \rho(x, y) e^{ik_x x t_1 + k_y y t_2} \quad (2)$$

The calculation of $H_{aditinal}$ is held according to next assumption $k_x = \gamma G_x$ and $k_y = \gamma G_y$ the Eq. (2) can be represented like:

$$S(t_1, t_2) = \sum_{x,y} \rho(x, y) e^{i\gamma \tilde{G}_x x t_1 + i\gamma \tilde{G}_y y t_2} \quad (3)$$

where, $\tilde{G}_x = G_x + G_x^{aditinal}$, and $\tilde{G}_y = G_y + G_y^{aditinal}$.

For further calculations, it is more convenient to change spherical coordinate system to Cartesian coordinate system. Than we calculate the field each magnetic moment exposed using following equation:

$$\vec{H}(\vec{r}) = \frac{1}{r^3} (-\vec{m} + \frac{3\vec{r}(\vec{r} \cdot \vec{m})}{r^2}) \quad (4)$$

where, $\vec{H}(\vec{r})$ magnetic; $\vec{r}$, spherical coordinates; $\vec{m}$, magnetic moment. The next step is to reconstruct the spatial density distribution of modeled object. For that inverse task we use pseudo-inversion reconstruction method.

4. Reconstruction Method

For reconstruction, the pseudo-inversion method is used in Ref. [13]. It stands for reconstruction of spatial distribution of spin density or relaxation characteristics based on reduced sampled data. The method has been modeled the next way. The sampled tomography signal may be represented like the one-dimension signal:

$$S(t) = \sum_i \rho_i e^{ikx_i t} e^{-\frac{t}{T_{2i}}} \quad (5)$$

For further calculations, we neglect the relaxation term $e^{-t/T_{2i}}$ and reconstruction of the signal comes to the solution of the system of equations:

$$\underbrace{\begin{pmatrix} e^{ikx_1 t_1} & e^{ikx_2 t_1} & \dots & e^{ikx_n t_1} \\ e^{ikx_1 t_2} & e^{ikx_2 t_2} & \dots & e^{ikx_n t_2} \\ \dots & \dots & \dots & \dots \\ e^{ikx_1 t_n} & e^{ikx_2 t_n} & \dots & e^{ikx_n t_n} \end{pmatrix}}_A \underbrace{\begin{pmatrix} \rho_1 \\ \rho_2 \\ \dots \\ \rho_n \end{pmatrix}}_{\hat{\rho}} = \underbrace{\begin{pmatrix} S(t_1) \\ S(t_2) \\ \dots \\ S(t_n) \end{pmatrix}}_{\hat{S}} \quad (6)$$

Fig. 1 The reconstruction of spatial density distribution of the investigated object.

where A , matrix of angle coefficients; $\hat{\rho}$, matrix of spatial density; $\hat{S}$, matrix of signals. In simple form it can be represented like following

$$A \cdot \hat{\rho} = \hat{S} \quad (7)$$

$$kx_i t_n = \varphi_i \Rightarrow e^{i\varphi_i}, 0 < \varphi_i < \frac{\pi}{2} \quad (8)$$

Having made the substitution Eq. (8) in Eq. (6) we get the following system of linear equations:

$$\underbrace{\begin{pmatrix} e^{i\varphi_1} & e^{i\varphi_2} & \dots & e^{i\varphi_n} \\ e^{i\varphi_1} & e^{i\varphi_2} & \dots & e^{i\varphi_n} \\ \dots & \dots & \dots & \dots \\ e^{i\varphi_1} & e^{i\varphi_2} & \dots & e^{i\varphi_n} \end{pmatrix}}_A \underbrace{\begin{pmatrix} \rho_1 \\ \rho_2 \\ \dots \\ \rho_n \end{pmatrix}}_{\hat{\rho}} = \underbrace{\begin{pmatrix} S(t_1) \\ S(t_2) \\ \dots \\ S(t_n) \end{pmatrix}}_{\hat{S}} \quad (9)$$

The inverse task solution can be represented by next equation :

$$\hat{\rho} = (A^H A)^{-1} A^H \cdot S \quad (10)$$

where A^H is conjugated transposed matrix .

5. Results

The obtained result of the reconstruction of spatial density distribution of modeled object can be represented like Fig. 1.

6. Conclusions

Results show that reconstructed spatial density distribution of the modeled object is corresponding to one of our model except some central solutions. The pseudo-inversion method of reconstruction allows to obtain reconstruction when the structure is not regular. The Fourier reconstruction method could be used for regular structures. The additional gradient fields caused by interaction of magnetic moments let us obtain more accurate diagnostic information (concentration, structure) of investigated objects. The obtained results are to be typical in average for each micro-object.

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