Evaluation of Effective Regions in Deep Brain Stimulation using MR-based Current Density Imaging (MRCDI): *In Vivo* Canine Brain Study

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Target audience

This study provides information for the evaluation of current density and current pathways during the excitation of deep brain stimulation (DBS). It might be helpful to the people who are interested in the clinical applications of electromagnetic tissue property mapping.

Purpose

The purpose of this study is to evaluate the potential of MR-based current density imaging (MRCDI) for the quantitative assessment of effective brain regions during the deep brain stimulation (DBS).

Methods

The injection current through the DBS electrode induces current density, voltage, and magnetic flux density (B_z) which are determined by the internal conductivity distribution, boundary geometry, and electrode configurations. Based on such a relationship, we implanted DBS electrode (Fig. 1a) into the canine head and measured B_z using a multi-gradient echo sequence (Fig. 1b). The imaging parameters were as follows: TR/TE = 1000/45 ms, FOV = 140×140 mm^2, matrix size = 128×128, slice thickness = 3 mm (16 slices), NEX = 4, and total imaging time = 15 min. The injection current amplitude was 3 mA with the total pulse width of 45 msec. We designed the DBS electrode configuration with mono-polar (anodic) and bi-polar mode. The DBS electrode marked as 1 was used for mono-polar excitation. For the bi-polar excitation, we defined electrode 1 as source and 2 as sink (Fig. 1a). Using the projected current density, optimal current can be recovered from the one component of the measured B_z data.[1] During the *in vivo* measurement, the target imaging slice often contains low SNR region due to the short T_2 or T_2^* relaxation time, low proton density, and presence of the lower conductive region such as skull, sinus. Therefore, while estimating the projected current density, the noise from the defected region is spread over the whole imaging domain and results in poor estimation as described in Sajib et al.[2] To minimize it, we applied the projected current density method to the limited local region.[2] The estimation of local projected current density is given by $J^{P,R} = \nabla \upsilon + (-\partial\beta/\partial y, \partial\beta/\partial x, 0)$; where, $J^{P,R}$ represent the estimated current density in a given ROI and α, υ, β is given by equation (1)-(3).

$$\begin{aligned} &\nabla^2\alpha = 0 \quad \textit{inside} \quad \Omega \\ &\nabla\alpha.\hat{n} = -I \quad \textit{on} \quad \partial\Omega \quad \textit{and} \quad \int_{\partial\Omega} \nabla\alpha.\hat{n} d\Omega = 0 \end{aligned} \qquad (1)$$

$$\begin{aligned} &\nabla^2\upsilon = 0 \quad \textit{inside} \quad \Omega_R \\ &\nabla\upsilon.\hat{n} = (-\nabla\alpha + \frac{1}{\mu_0}(\frac{\partial(B_z - B_z^0)}{\partial y}, -\frac{\partial(B_z - B_z^0)}{\partial y}, 0)).\hat{n} \quad \textit{on} \quad \partial\Omega_R \end{aligned} \qquad (2)$$

$$\begin{aligned} &\tilde{\nabla}^2\beta = \frac{1}{\mu_0}\nabla^2 B_z \quad \textit{inside} \quad \Omega \\ &\beta = 0 \quad \textit{on} \quad \partial\Omega \end{aligned} \qquad (3)$$

Results and Discussion

Figure 2(a) shows MR magnitude images obtained from two different imaging slices. The dark MR signal in the brain indicates the position of implanted DBS electrode. Two images on the left side of Fig. 2(b) shows the acquired B_z images from the mono-polar and right two images are from the bi-polar excitation. To select local ROI, we manually segmented the brain region avoiding the defected area which included the electrode part. Using the method described above, we estimate the current density within the given ROI. Figure 3(a) and (b) show the magnitude of the estimated current density in mono-polar case, (c) and (d) represent the bi-polar excitation, respectively. Comparing to bi-polar excitation, mono-polar shows more current flow inside the brain region. Moreover, currents are widely spread out to the neighboring brain areas. This stem from the fact that the outer boundary of mono-polar stimulator acts as a ground path, while one electrode of bi-polar excitation acts as a source and the other acts as sink. Hence, the bipolar excitation shows more concentric excitation and less current flow to the neighboring area. Based on our finding, we suggest bi-polar configuration method for the better therapeutic effect and less tissue damage.

Conclusion

This study demonstrates the potential of MR-based current density imaging in deep brain stimulation by predicting the current pathway and volume tissue activation. It might be a useful tool for the diagnosis and prognosis in neuronal surgical operation.

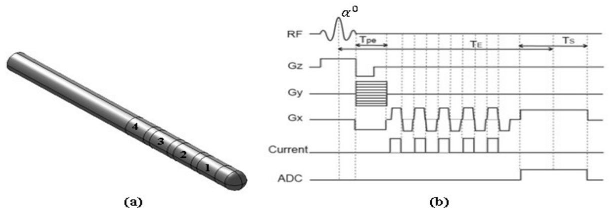

Fig.1. (a) Electrode configuration for DBS and (b) multi-echo gradient pulse sequence for imaging experiment.

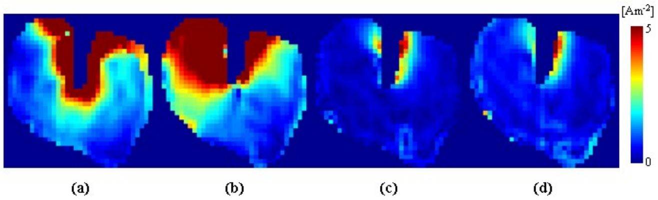

Fig.3. Magnitude of estimated current density images. (a) and (b) are results of mono-polar excitation, (c) and (d) are bipolar excitation.

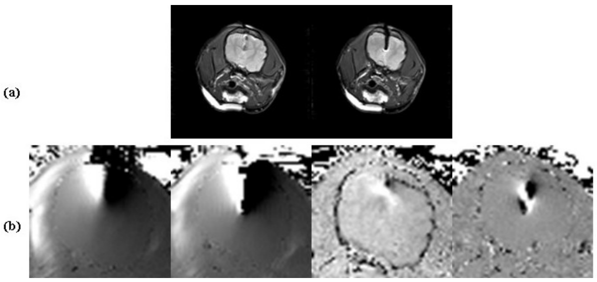

Fig.2. (a) MR magnitude and (b) respective B_z images from two different imaging slices.

References

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2. Sajib ZKS et al. Regional absolute conductivity reconstruction using projected current density in MREIT. Phy. Med. Biol. 2012;57:5841-5859.