RF pulse design for MRI of samples including conductive implants

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Abstract

Magnetic resonance imaging (MRI) of patients having a conductive implant causes interference with internal RF magnetic fields. The interference results in a signal loss around the implant. In this study, we propose an MRI acquisition method to recover the signal loss using the RF pulse for spatially designed excitation. Based on the measured distribution of RF magnetic field, the Bloch equation was inversely solved to design the waveform of RF pulse for improving the homogeneity of flipped magnetization. MRI acquisitions were performed with phantoms including metallic implants made from copper and aluminum. The results show that the designed waveform of RF pulse improves the homogeneity of signal intensity in MRI, and the signal loss around the metals was recovered.

1. Introduction

There are many patients have to be supported by medically implanted components and devices such as a pacemaker, stimulating electrode, and so on [1]. However, most of these medical implants include metallic parts, and MRI acquisition is difficult due to interference between RF pulse and metallic parts [2-3]. One of the reasons is inhomogeneous proton excitation in subject due to induced eddy current of metallic parts by radio frequency (RF) pulse [4]. In this study, we developed a MRI acquisition method to recover the signal loss around metallic implants in MRI by using an optimized RF pulse for spatially patterned excitation in subject.

2. Design method of RF pulse

The behavior of protons in MRI system is described by Bloch equation as shown in equation (1).

$$M_{xy}(\mathbf{r}) = \mathrm{i}\gamma M_0 \int_0^T B_1(t) e^{-i\gamma \mathbf{r}\cdot\int_t^T \boldsymbol{G}(s)ds} dt \tag{1}$$

where M_{xy} is the transverse magnetization, r is position vector, M_0 is the magnetization by static magnetic field, B_1 is the magnetic field associated with RF pulse, $\boldsymbol{G}$(s) is the function of gradient, and T is the wave length of RF pulse. It needs to solve equation (1) for designing convenient wave form of RF pulse. In order to calculate equation (1) numerically, it was rewrite to matrix form as following of equation (2).

$$\mathbf{m} = \mathbf{DAb} \tag{2}$$

where **m** is the desired excitation pattern, **D** is distribution of magnetic field associated with RF pulse, **A** is the external magnetic field, and **b** is wave form of RF pulse. The wave form of RF pulse **b** can be determined by calculating equation (2) inversely.

3. MRI acquisition using conductive samples

We prepared 2 kinds of phantom samples as shown in Fig.1 (a) with a nonmagnetic material of copper and a paramagnetic material of aluminum in 1% agarose gel. The dimension of phantom samples is shown in Fig.1 (b).

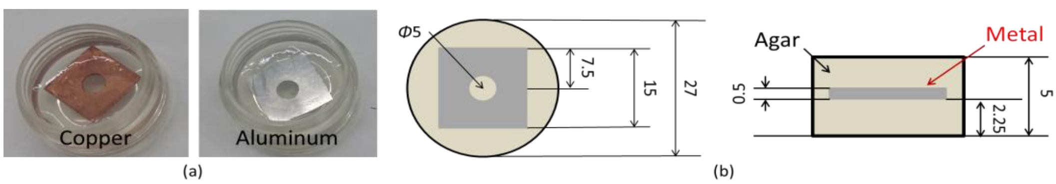

Fig.1 (a) 1% of Agarose gel including metal (b) Dimension of phantom samples

Interference of RF magnetic field intensity due to existence of metal causes inhomogeneity of MR signals around metallic parts. In order to improve the homogeneity of MR signal intensity around metallic parts, wave form of RF pulse was calculated based on measured distributions of RF magnetic field associated RF pulse. Figure 2 shows an example of designed wave form of RF pulse. The wave length was 8ms, and the number of pulse steps was 2000. The transmission directions of RF pulses were x-axis and y-axis.

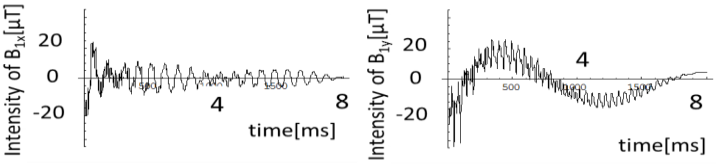

Fig.2 RF pulse for recovery of signal intensity

We performed MRI acquisition using designed RF pulse to improve the homogeneity of MR signal intensity for the samples including conductive metal. Fig.3 (a) and (b) are MR images of the sample including copper. Fig.3 (a) was acquired by FLASH method with conventional hermite wave form of RF pulse, and Fig.3 (b) was acquired with designed wave form of RF pulse. Vertical stripes and signal loss in Fig.3 (a) due to inhomogeneous RF field were recovered in Fig.3 (b). Fig.3 (c) and (d) are MR images of the sample including aluminum. Compared with MR images of copper, the area of signal loss in MRI became wide due to magnetism of aluminum. However, the recovery of MR signal intensity and homogeneity was also observed in MR image of aluminum. These results indicate the designed RF pulse is sufficiently useful for recovering RF signal intensity and homogeneity for conductive subjects.

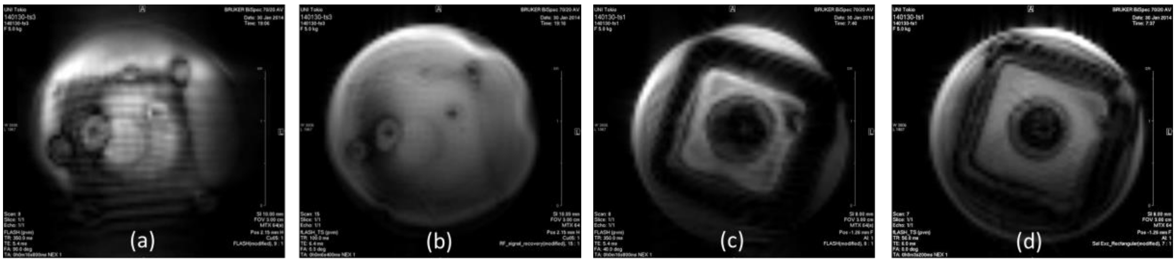

Fig. 3 MR image of agarose gel including copper by (a) FLASH (b) the designed RF pulse
MR image of agarose gel including aluminum by (c) FLASH (d) the designed RF pulse

4. Conclusion

We proposed a MRI accusation method to recover inhomogeneous RF field due to metal in MRI using designed wave form of RF pulse. The designed RF pulse was valid for nonmagnetic material (copper) and paramagnetic material (aluminum). Signal loss and inhomogeneous RF field near metal are recovered by applying the designed RF pulse compared with conventional method. However, Signal loss around metallic part of paramagnetic material was not recovered completely by the reason of inhomogeneity of static magnetic field around paramagnetic material. The use of designed wave form of RF pulse improves the uniformity of MRI signal intensity and reduces the signal loss around metallic parts. And this method is most useful for a conductive subject including metals of nonmagnetic material.

5. References

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