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Measurement of magnetic relaxation in intratumor magnetic nanoparticles

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Abstract

The magnetization response such as magnetic relaxation of magnetic nanoparticles was affected by the intratumor multiple environments. In this study, the intratumor magnetic relaxation was measured, and the magnetic relaxation time was analyzed to evaluate the environment of a living tumor. The estimated distribution of the magnetic relaxation time in tumor was different from those in the non-biological samples such as magnetic nanoparticle dispersed in liquid and solidified conditions. The evaluation of the magnetic relaxation time particularly determined by the Brownian relaxation associated with the particle physical rotation of intratumor magnetic nanoparticles develops a low-invasive tissue imaging technique based on the magnetic particle imaging.

I. Introduction

In the magnetic particle imaging (MPI) [1], the signal derived from magnetic nanoparticles (MNPs) was influenced by the magnetic relaxation properties. Multicolor MPI has been demonstrated as the method for the constant mapping of magnetic relaxation time in MNPs [2]. The magnetic relaxation was divided into the Néel and Brownian relaxations associated with the magnetization and particle physical rotations, respectively. Particularly, the Brownian relaxation was influenced by the conditions of surroundings such as the viscosity of the medium.

In this study, the magnetic relaxation of MNPs in living tumor was measured by constructing an *in vivo* measurement system [3] as shown in Fig. 1. The tumor environment was estimated from the measured magnetic relaxation process by analyzing the magnetic relaxation time, which contributes the development of the tissue imaging technique by MPI.

II. Methods and materials

The time evolution of the magnetization response of MNPs was observed under a pulsed magnetic field to measure the magnetic relaxation [4]. Carboxydextran-coated iron oxide nanoparticles, Resovist® (PDR pharma Co. Ltd, Tokyo, Japan), was measured. The rise time of

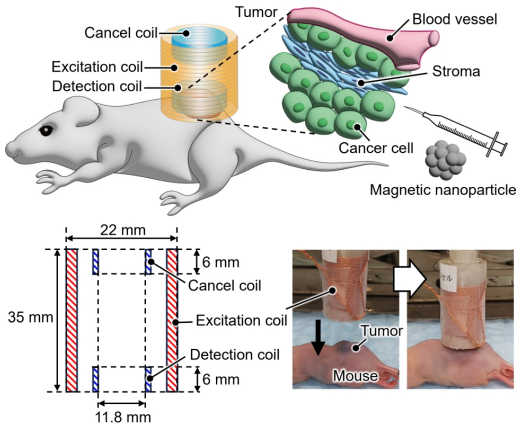

Figure 1: Measurement system of magnetic relaxation of MNPs injected into living tumor on a mouse body [3].

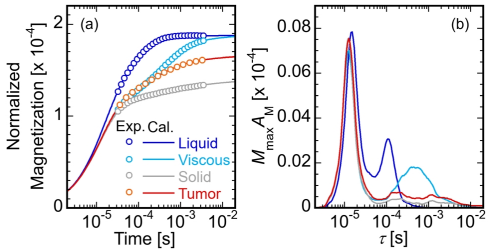

Figure 2: (a) Magnetic relaxation process and (b) magnetic relaxation time τ distribution of MNPs dispersed in diluted water, viscous liquid, fixed with epoxy resin, injected into living tumor, respectively.

the applied magnetic field was 25 µs, determined at 90% of its amplitude of 1.68 mT.

The distribution of the magnetic relaxation time τ was estimated by minimizing the mean square error between the experimental magnetization and calculated magnetization M_{cal} with time t given by

$$M_{\mathrm{cal}} = \sum_i \left(1 - e^{-t/\tau_i}\right) \times A_{\mathrm{M},i}. \quad (1)$$

M_{cal} is the calculated from the estimated τ. A_M is the magnetization fraction, whose summation with respect to each distributed τ indexed by i is 1. The magnetic relaxation process was fitted in 40 µs–4 ms. For the tumor samples, human fibrosarcoma HT1080 and pancreas adenosarcoma BxPC3 cells were implanted subcutaneously into the right hip of BALB/c nu/nu male mice.

III. Results and discussion

Figure 2 shows the measured magnetic relaxation and estimated τ distribution of MNPs dispersed in diluted water, viscous liquid, fixed by epoxy resin, and injected into the living BxPC3 tumor as liquid, viscous, solid, and tumor samples, respectively. The viscosities measured by a viscous meter in the liquid and viscous samples adjusted by mixing diluted water with glycerol were 0.87 and 7.7 mPa·s, respectively.

The largest peaks in the shortest τ distribution were derived from the magnetization response along with the transitional increase of the applied pulsed magnetic field. The magnetic relaxation process was characterized by the second and third largest peaks. The magnetization in liquid was larger than that in solid where the particle physical rotation was restricted. In the viscous sample, τ in the second largest peaks was longer than that in the liquid sample due to high viscosity, which indicates that the second largest peaks in liquid and viscous samples were associated with the Brownian relaxation. τ distribution in tumor was different from other samples, because of the multiple environments in the tumor, which was minutely characterized by magnetization response in the viscous liquid of 0.89–47 mPa·s and solid as non-biological samples in Ref. [3].

IV. Conclusion

The magnetic relaxation process characterized the complex environment of the living tumor affected by the intratumor compartments such as cancer cells, stroma, and blood. The potential of tissue imaging technique by the characterization of the tumor microenvironment as the non-biological viscous samples based on MPI holds promise for advancing cancer diagnostics and treatment monitoring.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] B. Gleich, J. Weizenecker, *Tomographic imaging using the nonlinear response of magnetic particles.* Nature, vol. 435, pp. 1214–1217, 2005.

[2] J. Rahmer, A. Halkola, B. Gleich, I. Schmale, J. Borgert, *First experimental evidence of the feasibility of multi-color magnetic particle imaging*, Physics in Medicine and Biology, vol. 60, pp. 1775–1791, 2015.

[3] S. Ota, H. Kosaka, K. Honda, K. Hoshino, H. Goto, M. Futagawa, Y. Takemura, and K. Shimizu, *haracterization of microscopic structures in living tumor by in vivo measurement of magnetic relaxation time distribution of intratumor magnetic nanoparticles*, Advanced. Materials, vol. 36, 2404766, 2024.

[4] S. Ota, Y. Takemura, *Characterization of Néel and Brownian relaxations isolated from complex dynamics influenced by dipole interactions in magnetic nanoparticles*, The Journal of Physical Chemistry C, vol. 123, pp. 28859—28866, 2019.

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