Feasibility Study of parallel image-acquisition in CW-EPR Imaging

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Target Audience: Biomedical researchers and dermatologists using electron paramagnetic resonance (EPR) imaging.

Purpose: The purpose of this work was to perform proof-of-concept experiments for the multiplexing of EPR detection in the frequency domain. Fast image-acquisition of EPR is required for target free radical molecules in small animals, since exogenously injected imaging agents, free radical molecules, are rapidly metabolized or reduced in living animals. The visualization of a wider area should also be desirable for future EPR imaging in large animals or large organs in a human subject. To extend the area of visualization, a surface coil array that enables the sequential switching of individual coils for CW-EPR imaging have been reported [1,2]. However, the acquisition time increased with the number of coils under sequential acquisition. Instead of sequential acquisition by the multiplexing of EPR detection in the time domain, parallel image-acquisition requires a different approach, such as multiplexing of EPR detection in the frequency domain, which has not been used in CW-EPR imaging previously.

Methods: The principle of parallel detection is to excite electron spins by the use of multiple RF frequencies and multiple coils in a polarizing magnetic field. This approach involves the multiplexing of EPR detection in the frequency domain. Fig. 1 presents an overview of the laboratory-built 750-MHz CW-EPR imager for parallel detection of the surface coil array. The resonant frequencies of the individual surface coil resonators were different from each other to suppress mutual inductive coupling between two coils. To demonstrate the parallel detection capability with the two-channel surface coil array, EPR spectra were obtained when RF waves were fed to both resonators simultaneously. We used a glass cell filled with 2 mM 4-oxo-2,2,6,6-tetramethylpiperidine-1-oxyl (Tempone) aqueous solution to obtain first-derivative EPR absorption spectra. In addition, we measured 3D EPR images of a phantom that consisted of two quartz tubes (outer diameter 5 mm, inner diameter 4 mm) placed in parallel with a gap of 6 mm.

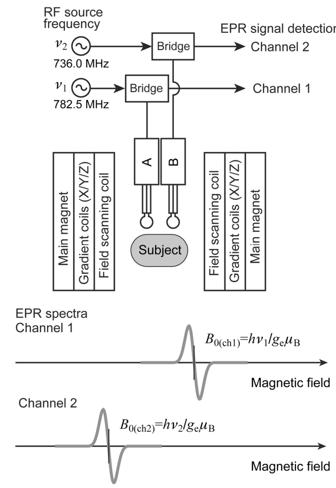

Fig. 1. Schematic diagram of the experimental setup for parallel EPR image-acquisition using a surface coil array.

Results and Discussion: Fig. 2 shows the reflection (S_{11} and S_{22}) and transmission characteristics (S_{21} and S_{12}) of the surface coil resonators. Based on Figs. 2A and 2B, the resonant frequencies of the two resonators were 782.5 MHz (resonator A) and 736.0 MHz (resonator B), respectively. In both traces, in addition to the main peak of the resonant frequency, a peak of less than -1 dB appeared at the frequency around the resonant frequency of the other resonator. While small peaks appeared at the resonant frequency of the other resonator (Figs. 2A and 2B), the EPR spectra shown in Fig. 3 were not affected by the resonant peak of the resonator connected to the other receiver system. In addition, the transmission coefficients were -16 dB and -21 dB at the resonant frequencies. These results show that decoupling between coils was reasonably achieved by shifting the resonant frequencies of the resonators. However, the SNR achieved by simultaneous acquisition was decreased to approximately 40% of that under single-resonator feeding. Fig. 4 shows the arrangement of the tube phantom and the resulting 3D EPR images. Figs. 4B and 4C were obtained with individual resonators. The image shown in Fig. 4D was created by combining the two images in Figs. 4B and 4C. Figs. 4E-4G show slice-selective images generated from the 3D combined image in the YZ-, XZ- and XY-planes. The threshold of surface rendering for all 3D images was set to 50% of the peak signal intensity.

Conclusion: We have demonstrated the feasibility of parallel EPR image-acquisition with a surface coil array. For decoupling between the two coils, the two different resonant frequencies were set to individual channels, and we suppressed mutual coupling of the two coils. Although the problem of degradation in SNR has been remained, the concept of the multiplexing of EPR detection in the frequency domain was proved in CW-EPR imaging.

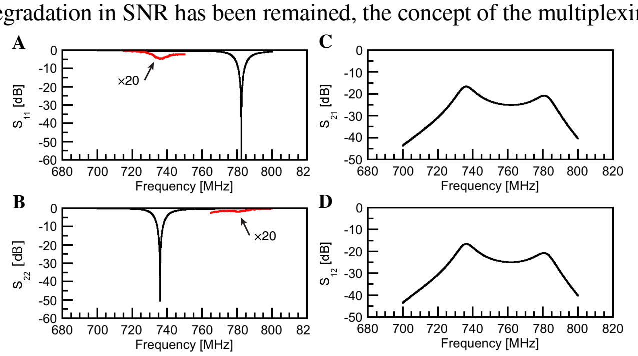

Fig. 2. Scattering-matrix parameters (S_{11} and S_{22}) of each resonator and the transmission characteristics for both directions (S_{21} and S_{12}) when resonator A is connected to port 1 and resonator B is connected to port 2 of the RF network analyzer.

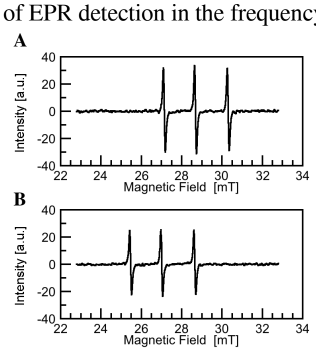

Fig. 3. EPR spectra obtained by the individual resonators when RF waves were fed to the individual resonators simultaneously.

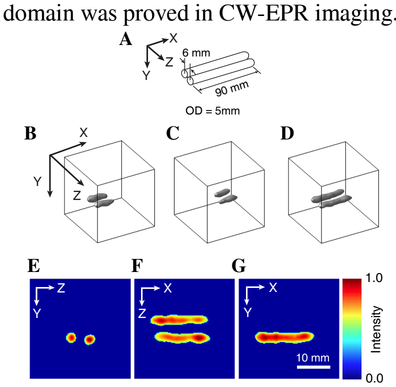

Fig. 4. 3D EPR images measured by parallel data-acquisition.

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References: [1] A. Enomoto, H. Hirata, *J. Magn. Reson.* **209** (2011) 244–249. [2] A. Enomoto, M. Emoto, H. Fujii, H. Hirata, *J. Magn. Reson.* **234** (2013) 21–29.