Development of fast CW-EPR imaging

H. Sato-Akaba[1], H. Fujii[2], and H. Hirata[1]

[1]Division of Bioengineering and Bioinformatics, Hokkaido University, Sapporo, Hokkaido, Japan, [2]School of Health Sciences, Sapporo Medical University, Sapporo, Hokkaido, Japan

INTRODUCTION

Visualization of nitroxyl spin probes can provide valuable information regarding the environment surrounding spin probes in living organisms and biological tissues. To visualize the distribution of free radical molecules in biological samples, continuous-wave electron paramagnetic resonance (CW-EPR) imaging can be used, and is a non-invasive magnetic resonance technique. To date, five-membered nitroxyl radicals, which have a longer lifetime than six-membered nitroxyl radicals, have been intensively used in biomedical applications (1-3). This is because the sensitivity of EPR detection and the acquisition time for a multi-dimensional distribution of targeted free radicals limit the temporal resolution of CW-EPR imaging. To visualize the distribution of free radicals with a short lifetime, the temporal resolution of three-dimensional (3D) EPR imaging should be several times shorter than the lifetime of the free radicals being measured. The purpose of the present work was to further reduce the acquisition time for 3D EPR imaging to improve the temporal resolution. We optimized the performance of the instrument to obtain the maximum sensitivity for EPR detection.

METHODS

To improve the temporal resolution of 3D CW-EPR imaging, we must reduce the data acquisition time and improve the sensitivity of EPR detection. Reduction of the acquisition time was pursued as follows: (i) reduction of the duration of field scanning that is used to obtain EPR spectra for each projection by adopting triangular waves for field scanning, (ii) reduction of the communication time between the computer and hardware, and (iii) reduction of the number of projections by using a uniform distribution of projections. To improve the sensitivity of the EPR spectrometer, we used a multi-coil parallel-gap resonator (MCPGR) with a higher quality factor (4). The detection circuits were optimized for the gain of the amplifiers and the level of the reference signal.

To decrease the effects of signal decay on a reconstructed image, signal averaging was not performed during data acquisition for 3D EPR imaging. A triangular signal with a frequency of 9 Hz, which was generated from a function generator, controlled the output current from a bipolar power supply to the Helmholtz coil that was used for magnetic field scanning. First, the zero field-gradient EPR spectrum was measured for deconvolution of the spectra obtained under a field gradient. After the spectrum was measured, the amplitudes of currents flowing into the field gradient coils were set to acquire the next projection. The duration of the half-cycle of field scanning was used to stabilize the field gradient. The directions of the projections were pre-calculated from the vertices of a geodesic sphere of an icosahedron (5).

RESULTS

Figure 1 shows a surface-rendered 3D image of the letters 'NO' filled with 2 mM triarylmethyl (TAM) radicals in the plastic phantom. This result indicates that 3D imaging with 46 projections can give reasonable image quality for the phantom we used. The total acquisition time for 3D projection data was 5.8 s for 46 projections. The field-of-view (FOV) of the image was 18.8 x 18.8 x 18.8 mm.

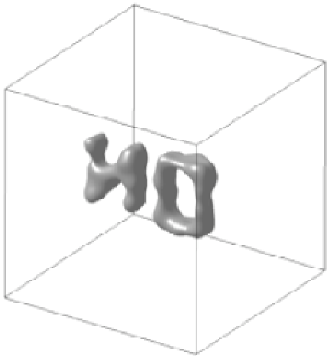

Fig. 1. Surface-rendered 3D image of a phantom that has the letters 'NO' filled with 2 mM TAM radicals. The total acquisition time was 5.8 s for 46 projections.

DISCUSSION

The duration of field scanning was 40 ms, but this is in the portion of field scanning with a triangular signal, which has a period of 0.111 s. More than a half-cycle was used to stabilize the field gradient. Therefore, the total time of field scanning for 46 projections and one zero-gradient spectrum should be 5.2 s. Since the experimental acquisition time was 5.8 s, the difference of 0.6 s was the overhead time used for the computer to communicate with slaved hardware and the time needed to save the obtained data on the computer.

CONCLUSION

An acquisition time of 5.8 s was achieved under conditions of 46 projections and a field-scan frequency of 9 Hz. This is 5 times faster than that previously reported for a 650-MHz CW-EPR imaging apparatus, which makes it possible to acquire 3D projection data in 30 s with a uniform distribution of projections (5).

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