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Effect of Tooth Positioning on EPR Dosimetry

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Abstract: L-band electron paramagnetic resonance (EPR) tooth dosimetry is a technique which could estimate the whole body irradiation dose by quantifying the amount of radiation induced radicals in intact tooth enamel. However, the positioning of the tooth would strongly affect the signal amplitude. In this study, we acquired microCT-scanned images from tooth samples to generate 3D model. Then, the variations of simulated EPR signal were calculated with variations of tooth model position by HFSS. The signal decreased rapidly with increasing distance within few mm and varied significantly with angles respect to y-axis. Therefore, immobilization and minimizing motion during in-vivo measurement would be effective to reduce uncertainties in estimated dose.

1. Introduction

When human tooth is irradiated to ionizing radiation, radicals are formed and remain stable in tooth enamel. Electron paramagnetic resonance (EPR) dosimetry mainly quantifies the amount of CO_2^- radicals using magnetic resonance phenomenon and the amplitude of EPR signal is linearly proportional to the absorbed dose. [1] It has been widely used in retrospective analyzing to estimate exposed dose. [2-4] However, extracted tooth and extra sample preparation is required to use X-band EPR spectroscopy which has been widely used.

L-Band EPR spectroscopy was developed for in-vivo measurement. [5] Tooth positioning would strongly affect measured amplitude of EPR signal. Distribution of magnetic energy is perturbed when the position between tooth and surface coil is varied. Long-time measurement of in-vivo EPR spectroscopy could induce discrepancy due to the variation of location of tooth.

In this study, we investigated the effect with variation of tooth position to use as a guidance for development for acquisition of consistent EPR signal during in vivo measurements. We generated 3D models based on microCT-scanned images from tooth samples. Then, we calculated the variations of simulated EPR signal with variations of tooth position respect to angle and distance with surface loop of resonator.

2. Methods and Results

2.1 Instrumentation

The overall configuration of this EPR spectrometer is shown in Figure 1. [6] Homebuilt continuous-wave EPR spectrometer was developed in our institution.
The resonator is a key component to detect the signal in EPR spectroscopy. In our homebuilt spectrometer, reflective surface coil design was adopted to facilitate in-vivo measurement.

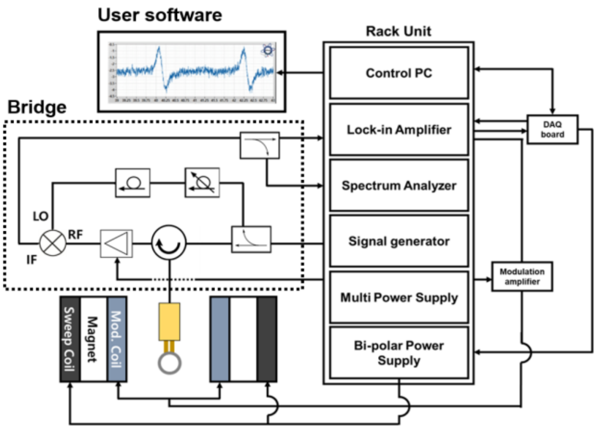

Figure 1. Simplified block diagram of homebuilt in-vivo CW EPR spectrometer for tooth dosimetry.

2.2 3D model for simulation

As shown in Figure 1, the spectrometer was composed of many components. However, only resonator affects the amplitude of the signal and the other components only generate, transport and analyze the microwave. Therefore, only resonator is needed to be modeled in simulation to calculate the amplitude of EPR signal.
The resonator was modeled in ANSYS High Frequency Structure Simulator (v18, HFSS) based on previous studies (Figure 2). [6] The parameters for simulation were assigned according to electromagnetic properties of each material. The detection and internal loop were made of 1.2 mm diameter high purity silver wire, transmission line was consisted of PTFE and copper, and resonator box was composed of brass. Simulation boundary was set as perfectly conducting box and sufficiently far from resonator to avoid interactions with the resonator loop. In real resonator, the resonator contains extra coil to control coupling which we skipped. It is because we proceeded the simulation in eigenmode which automatically find resonance point.
Ten incisor samples were used in this study. 3D images of tooth models were acquired using micro CT scanner (skyscan1275). These 3D enamel images are decimated

and smoothed to decrease calculation time and imported to resonator model. Each enamel model was rotated to set anterior face parallel to detection loop. Then the origin of the coordinate system was defined as a mean value of maximum and minimum in each coordinate axis to define tooth positioning. (Figure 3)

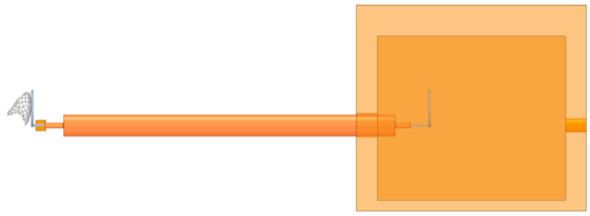

Figure 2. 3D model of resonator

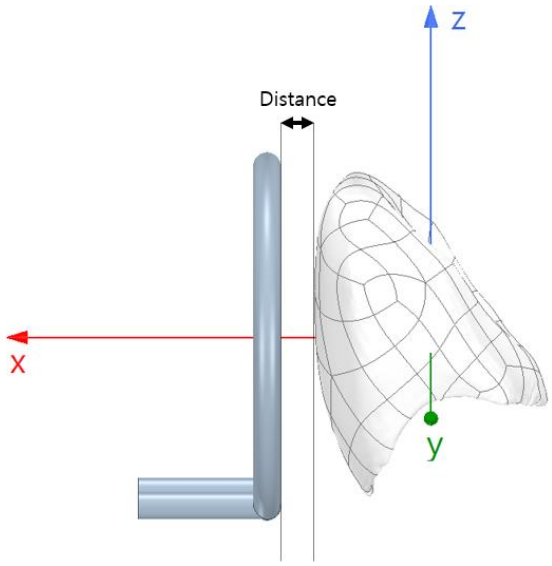

Figure 3. Simulation setting for HFSS simulation

2.3 Relative radiation induced signal calculation

The EPR signal (S) is proportional to the product of the quality factor (Q), the filling factor of sample (η), the magnetic susceptibility of the sample (x), and incident microwave power (P_{in}).

$$S \propto xQ\eta P_{in} \quad (1)$$

In this study, we assumed that the measurement setting was consistent excluding tooth position respect to resonator. Relative radiation induced signal (RIS) was assumed as the product of Q and η. The simulation was proceeded in eigenmode and delta F was set as 2. The quality factor and the filling factor of each simulation set was calculated using field calculator.

2.4 Effect due to distance

We changed the distance between anterior face of enamel and detection loop from 0 mm to 4.8 mm with 0.3 mm interval for each tooth sample.

The results of ten tooth samples were described in Figure 4. The relative RIS amplitude was rapidly decreased for all samples. The signal decreased to approximately 50% at 0.9 mm, and approximately 22% at 2.1 mm.

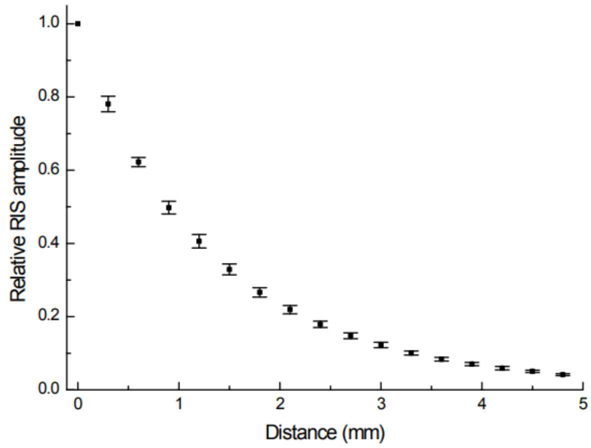

Figure 4. Variation of RIS amplitude with distance.

2.5 Effect due to angular displacement

As shown in Figure 3, we defined the coordinate axis. The distance was fixed to 1mm while the enamels are rotated from -15˚ to 15˚ respect to y-axis and z-axis.
The results were described in Figure 5. Relative RIS amplitude increased linearly with y axis angular displacement increased. However, no tendency was found according to angle with respect to z-axis. For y-axis, relative RIS amplitude was decreased 9.8% at -6˚ and decreased 20.2% at -15˚. And also, the signal increased 11.5% at 6˚, and the signal increased 30.8%. However, for z-axis, signal amplitude changed less than 3%.

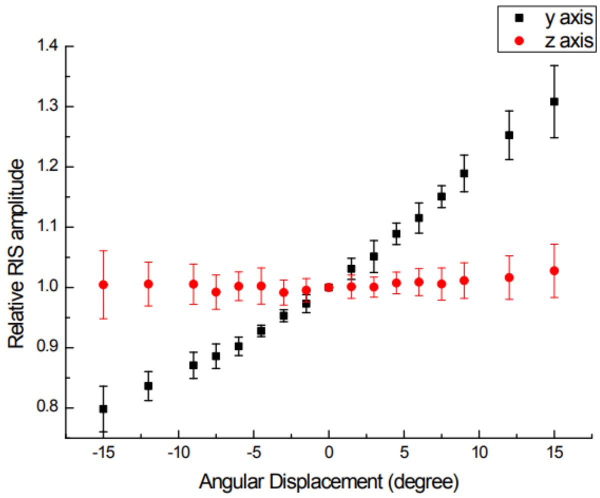

Figure 5. Variation of RIS amplitude with angle respect to y-axis and z-axis

2.6 Effect due to displacement

The distance was fixed to 1mm while the displacement varied from -3 mm to 3 mm respect to y-axis and z-axis. The results were described in Figure 6. Relative RIS amplitude changed parabola shape tendency in both case. For y-axis, relative RIS amplitude was decreased 3.4% and 27.7% at 1 mm and 3 mm, and decreased 3.9%, 29.5% at -1 mm and -3 mm. And also, for z-axis, relative RIS amplitude was decreased 4.0%, 26.2% at 1 mm and 3 mm, and decreased 1.4%, 13.0% at -1 mm and -3 mm.
In addition, the maximum change rate of the signal for each tooth sample shows correlation with the labial volume of the enamel. For both axes, the enamel sample which has bigger labial enamel volume shows smaller maximum change rate of the signal. (Figure 7)

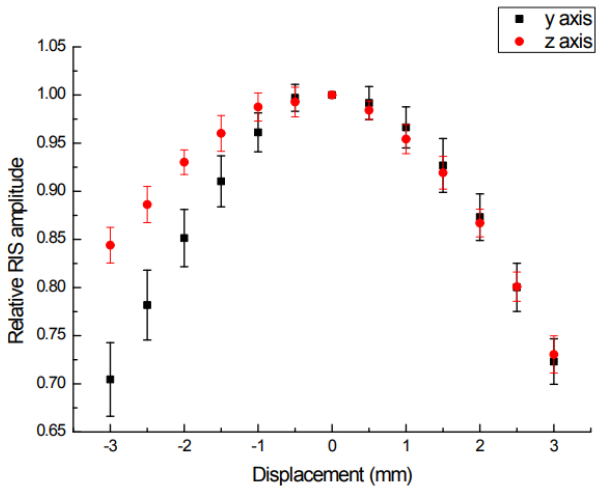

Figure 6. Variation of RIS amplitude with displacement respect to y-axis and z-axis

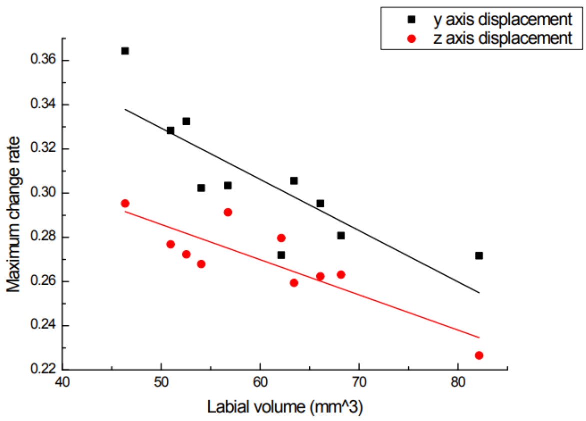

Figure 7. Correlation between the maximum change rate of the signal and the labial volume of the enamel.

3. Conclusions

We investigated the effects of tooth positioning with respect to the loop of resonator on EPR signals. Relative RIS amplitude was rapidly decreased with increasing the distance within few mm. Relative RIS amplitude significantly varied with angles with respect to y-axis. Measurement setup should be maintained consistent for acquisition of stable EPR signals.
Therefore, immobilization and minimizing motion during in vivo measurements would reduce uncertainties in estimated dose.

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