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The Sensitivity Analysis of Tooth Enamel to The Absorbed Dose for The Application to EPR Dosimetry

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ABSTRACT

Electron Paramagnetic Resonance (EPR) spectroscopy is one of the methods applicable to retrospective dosimetry. The retrospective dosimetry is a process that is a part of dose reconstruction for estimation of exposed dose occurred years before the estimation. Many techniques can be used to the retrospective dosimetry. As a physical method, EPR analysis of biological material measures the quantity of free radicals generated in the material from the interaction of radiation and material. Since the later 80s, in many countries, EPR dosimetry with tooth enamel has been studied and applied for the retrospective dosimetry. In the consideration of the biological materials for EPR dosimetry, human fingernail, hair, bone and tooth are generally considered. The tooth can be separated as enamel, dentine and cementum. Among the three parts, enamel shows the best sensitivity to the absorbed dose and is most widely used. In this study, the characteristics of tooth enamel for EPR dosimetry is examined and experimented. At the experiment, for easy separation, tooth was cut into 4 parts and then each part is treated by ultrasonic vibration in NaOH liquid to reduce mechanically induced noise in the corresponding signal. After the separation of the enamel from dentine, background EPR signal is measured and then radiation-induced EPR spectrum is estimated.

1. Introduction

Nowadays, radioactivity becomes widely used in industry, medicine, power generation and etc. So, it is necessary to measure dose for usual monitoring and accidents. For usual monitoring situation, normal dosimeter is enough to check the radiation exposure to workers. However, in case of accident, for personnel and the general public not equipped with such devices, an alternative approach should be provided.

The retrospective dosimetry is a process that is a part of dose reconstruction for estimation of exposed dose occurred years before the estimation. The dose reconstruction may be required in a variety of situations such as acute accidental exposure, suspected chronic overexposure and reassessment of occupational exposure. Among the techniques applicable to dose reconstruction, EPR dosimetry using tooth enamel is considered as the most promising technique for its merits.

In this study, the characteristics of tooth enamel for EPR dosimetry is examined and analyzed. For those objectives, teeth are collected and pure enamel is separated from each tooth. And the factors affecting EPR spectrum are examined and the linearity of EPR spectrum to absorbed dose is assessed.

2. Characteristics of EPR dosimetry

Electron Paramagnetic Resonance (EPR) or Electron spin resonance (ESR) spectroscopy is one of the methods applicable to retrospective dosimetry. The phenomenon of paramagnetic absorption was discovered by Zavoisky in 1945. The history of accurate EPR dosimetry however is only little more than 20 years old.

Techniques for retrospective dosimetry can be divided as a biological and a physical techniques. If possible, retrospective dosimetry based on the measurement on a biological sample drawn from every individual of concern will give the most satisfactory result. But the accident dosimetry using biological systems in which the quantification of chromosome aberrations or the ratios between different blood proteins can give an indication of exposure, is hampered by the individual characteristics of the victim (i. e., general health, diet etc.) and by the complexity of the techniques[1].

In contrast to other biological dosimetry systems, EPR spectroscopy is not subject to these limitations. If the EPR signals are sufficiently stable, and a direct relationship exists between radical concentration and radiation dose, the material may be useful as a dosimeter. Measurements are made directly on the sample and very small amounts of material can be used [1].

When a material of concern interacts with radiation, free radicals are generated in the material. If the radicals are trapped and do not react with environment, it can remain for a long time. EPR dosimetry is based on the measurement of free radicals by microwave absorption spectroscopy.

3. Tooth enamel for EPR dosimetry

The use of tooth enamel for the assessment of individual doses was first described by Ikeya et al. for the atomic survivors of Hiroshima and Nagasaki, later for victims of the Chernobyl accident, for

the nuclear workers of the Mayak, and for residents of the Techa river valley also in the Southern Ural region.

In dose reconstruction using tooth, EPR analysis is based on the detection of radiation induced free radicals in hydroxyapatite($Ca_{10}(PO_4)_6(OH)_2$), the mineral component of enamel. Due to the crystalline structure of tooth enamel, these free radicals are very stable. As a dosimeter, tooth enamel has a high sensitivity for ionising radiation and since the tooth follows the carrier in all situations, it can act as a lifetime-dosimeter.

For the dose determination, only small amount of enamel is sufficient. So, with only one tooth without caries, it is possible to make one or two samples for dose reconstruction.

One drawback is that the tooth must be extracted to be analysed on, but, on the other hand, often individuals need to have teeth extracted for other reasons during their life times[2]. Moreover, Motoji Ikeay [3] developed new EPR apparatus to determine the radiation dose of a tooth *in situ* without extraction.

A tooth can be divided into three parts of tissue : enamel, dentine and cementum. Each tissue has different chemical composition and hydroxyapatite content. In addition to the difference of chemical composition, contents of hydroxyapatite are diverse. Hydroxyapatite constitutes 95-97% by weight of tooth enamel, 70-75% of dentine and 60-70% of compact bones. In addition to the hydroxyapatite content, organic components and impurities, various level of carbonisation, as well some peculiarities of the crystal structure are also different. The latter results in different radiation sensitivities of enamel, dentine, and cementum. The results of experimental investigations of radiation EPR sensitivity with ^{60}Co show 7:3:1 for enamel, dentine and cementum respectively[4]. So, among the three parts of tooth, enamel is generally used for the dosimetry.

Enamel is acellular in its adult state and is composed of hydroxyapatite needle crystallites with lengths of approximately 500 – 600nm dispersed in an aqueous organic gel. The aqueous-organic gel is about 2% water and 1% organic component (mostly protein). Because many other impurities are present in enamel, this description of tooth enamel is a rough approximation ; however, it remains sufficient for the aims of EPR dosimetry[5].

4. Factors affecting EPR dosimetry using tooth enamel

EPR dosimetry using tooth enamel can be affected by some factors. At high-level dose, these factors can be negligible, but at lower detectable level, these factors can be significant for application of EPR dosimetry. Each factor and method to control the effect caused by factor are briefly described.

Light effects

When exposed to UV irradiation or sunlight, a large signal in enamel near g=2.0018 is observed. This phenomenon may be a real problem for EPR dosimetry, since at present time it is not possible

to distinguish between the radiation and sunlight induced fractions of the signal at $g_{\perp}$ = 2.0018, $g_{\parallel}$ =1.9985. One possible solution is to exclude the incisors from dosimetry studies as these are the teeth most affected by sunlight. However, such an approach seems to be oversimplified. In certain cases not only the incisors, but the canines and even the molars may be exposed to sunlight. In addition, exposure to UV light is increasingly used as a medical/dental procedure[6].

Grain size effects

The effect was not only grain size dependent, but also a function of whether the sample was irradiated before or after the tooth had been reduced to a powder for analysis. Samples which had been irradiated after crushing showed a different sensitivity to radiation compared to those irradiated prior to crushing[7]. It is assumed that the finer grains have undergone greater mechanical stress than their larger gains. The grain size range of 250 to 600μm was shown to minimize the effect.

Transient radiation induced signals

After irradiation, a transient signal is induced. That is significant on the g=2.0018 signal normally used for dosimetry[7]. The signal may decrease to near background levels after approximately 1 month and can be removed quickly by annealing process.

Dental X-rays[8]

For the EPR dosimetry, a tooth with disease is normally pulled out from individual of concern. During the process, the tooth can be exposed to dental X-rays at least one time. This dental X-ray can form a native signal at tooth. As sensitivity of 100mGy and lower dose levels, the contribution from dental x-rays will become increasingly important. Dental x-ray doses to the general population have been examined in Japan and it would be useful to have a similar data set for x-rays in the U. S. as well as exposed regions of Russia and Ukraine.

5. Experimental process

The experiment process for the evaluation of EPR spectrum of exposed dose is shown in Fig. 1. In this section, the apparatus and each step of the experiment are briefly described.

Experimental apparatus

For the experiment, ultrasonic cleaner made by Branson is used. The cleaner generates ultrasonic of frequency of 4.2kHz. The EPR spectrum of background and irradiated enamel sample are measured by EPR spectrometer in KAERI(Korea Atomic Energy Research Institute). The spectrometer is EMX model made by Bruker in Germany. In the measurement of EPR signal, X-band cavity at room temperature is used.

For the irradiation of samples, irradiator in Radiation Health Research Institute of Korea Hydro & Nuclear Power Co., LTD is used. As a blood irradiator, it is designed for the irradiation of blood

products and biological samples. It was IBL 437C model, made by SCHERING(CIS bio international). The source nuclide is Cs-137, and the absorption rate is (8.95 ± 6%) cGy/sec. the absorbed dose will be (8.95 ± 6%) cGy/sec.

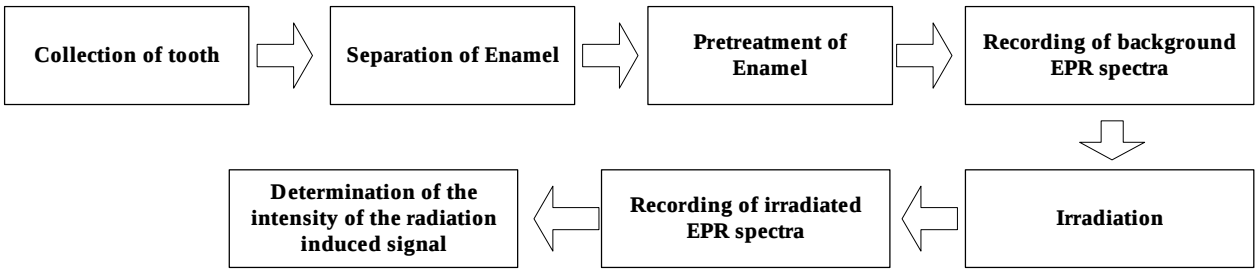

Fig. 1. Block diagram of the procedure of the experiment

Preparation of teeth

In this study, 8 teeth are used among those gathered by School of Dentistry in Wonkwang University. The gender or age of donor is not identified. All teeth are molar or pre-molar stored in ethanol from the collection time until the cleaning and drying for the experiment. Among 8 teeth, four are healthy teeth and the others are with caries.

Separation of enamel

After drying, each tooth is cut into root and crown by dental diamond saw. Again the separated crown is cut into 4 pieces. Each pieces of tooth are ultrasonic treated in 2N NaOH solution. Every 2 times of ultrasonic treatment of 60 minutes, each part is washed with distilled water and then dried in oven for the examination of condition of enamel and dentine.

Depending on the conditions of enamel and dentine, parts of dentine is scrapped off by dental drill. As the exposure time to NaOH solution is increased, the color of dentine turns into white and then, this part of dentine is removed easily by dentinal drill. This process was repeated until all dentine is removed and only the pure enamel is remained.

The weight of each sample enamel is listed in Table 1. As shown, the weight of enamel from each tooth is various depending on the original tooth weight, size and condition.

Table 1. Weight of enamel separated from each tooth

	1	2	3	4	5	6	7	8
Weight[mg]	247.4	446.2	293.6	323.3	385.1	503.0	494.0	416.7

Sample preparation

After weighing, enamels from 8 teeth are divided into 2 groups. One is a group of enamels from healthy tooth and the other is a group of enamels from teeth with yellow colors and caries. Again each group of enamels is divided into 4 samples. One sample is used for the estimation of native

or background EPR spectrum and the others are used for the analysis of radiation-induced EPR spectrum.

Irradiation of sample

At the irradiation, sample size of 0.5mm~0.1mm are used. The enamel sample is contained in the glass vial and then exposed to γ-ray from Cs-137 in the middle of irradiator.

For the radiation-induced signal evaluation, the spectrum subtraction method is used. In that method, the EPR spectrum of unirradiated reference sample is subtracted from the spectrum of the actual irradiated samples.

Measurement background EPR spectrum

The parameters used for measuring the EPR spectrum is listed in Table 2. Based on those parameters, Fig. 2 shows the background EPR spectra are shown. In the figure, EPR spectra of blank quartz tube are plotted with native EPR spectra of enamels from rotten tooth and healthy tooth. As shown, EPR spectrum is induced at tooth enamel without irradiation. This signal can be caused by free radicals in the hydroxyapatite and organic materials in enamel. Those free radicals can be created by dental X-ray, UV-light or mechanical work during sample preparation.

Table 2. Parameters for the measurement of EPR spectrum

Parameter	Value
Temperature	300.0K
Number of scans	5
Receiver Gain	5.02×10^{4}
Mod. Frequency	100kHz
Mod. Amplitude	5.00G
Sweep width	80.00G
Microwave power	6.362mW
Microwave frequency	9.621GHz

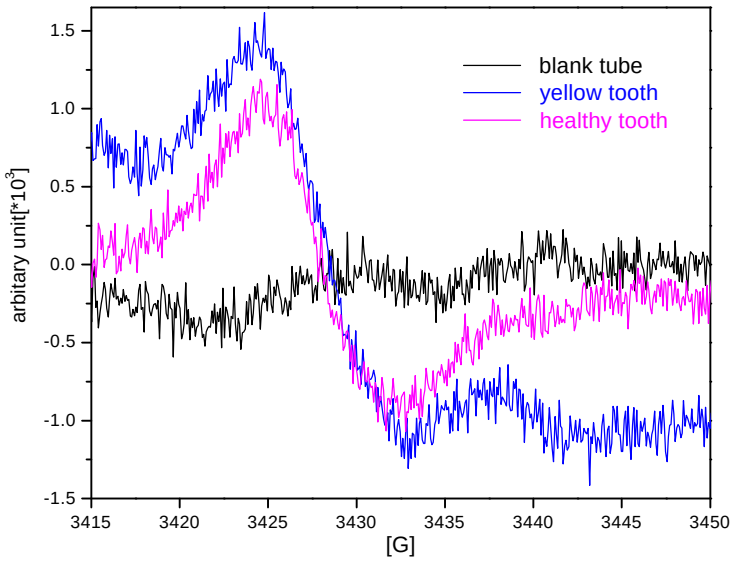

Fig. 2. Native EPR signal of blank tube and tooth enamel samples

6. Results

EPR spectrums caused by absorbed dose are shown in Fig. 3 & 4 for the each group of sample enamel respectively. As the native signal is subtracted from actual irradiated sample, each spectrum represents radiation-induced signal only.

In Fig. 5, linearity analysis for the EPR spectrum of irradiated enamel is shown. For the linearity analysis, peak-to-peak amplitude is measured for the signal near g=2.0018. The maximum value is measured at g=2.004 and the minimum is measured at g=2.0015. The linearity of EPR spectrum to absorbed dose is compared for the enamel from rotten tooth and healthy tooth. As shown, the linearity of is similar but the enamel from healthy tooth shows more sensitivity than the enamel from rotten one.

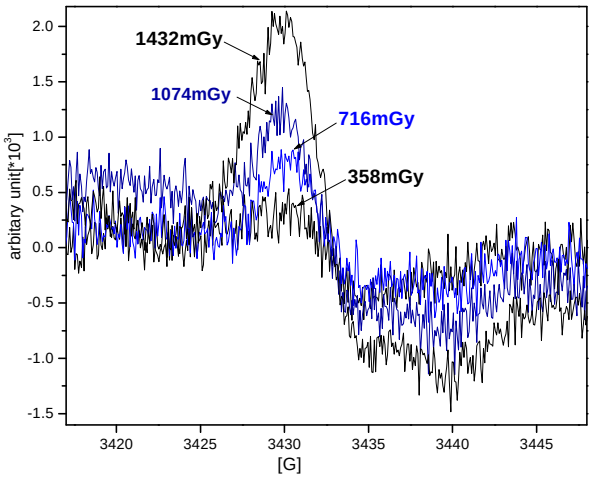

Fig. 3. EPR spectrum depending on absorbed dose (healthy tooth)

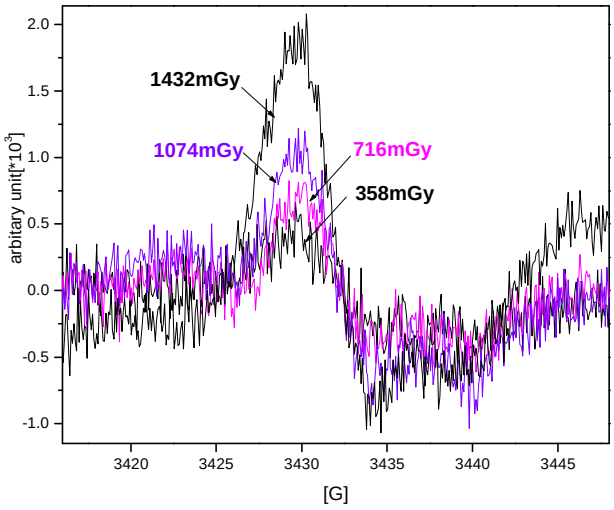

Fig. 4. EPR spectrum depending on absorbed dose (tooth with caries)

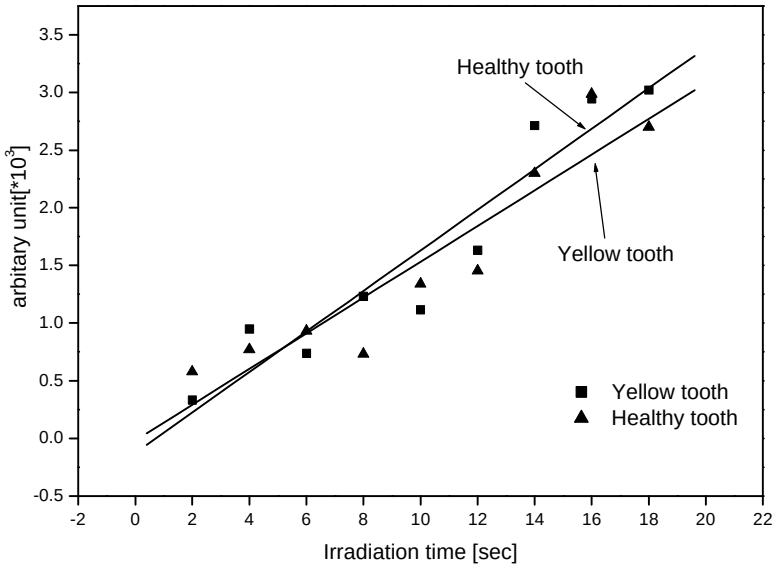

Fig. 5. Linearity of EPR spectra to absorbed dose of tooth enamel

7. Conclusion

In this study, the characteristics and the factors affecting EPR dosimetry are introduced. And EPR dosimetry using tooth enamel is experimented. At the experiment, molar tooth are used for tooth enamel separation for minimizing UV light effect and size of 0.1mm~0.5mm is used for minimizing the size effect. The results show a linearity of EPR spectrum of tooth enamel to absorbed dose. And the linearity is little bit different depending on the sample condition although the number of sample was not big. So, for the more reliable results, the more samples are needed.

8. References

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