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The sensitivity variation of the radiation induced signal in deciduous teeth to be used in ESR tooth enamel dosimetry

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HIGHLIGHTS

- ESR signals were examined in individual deciduous tooth enamel samples.
- The RIS sensitivity of deciduous teeth are similar with that in permanent teeth while its variation is larger.
- The BGS intensity of deciduous teeth are also similar with that in permanent teeth while its variation is also larger.
- The average of the line width of BGS in deciduous and permanent teeth are indistinguishable due to variation.
- The line position (g factors) of BGS in deciduous teeth is at slightly higher field than in permanent teeth.
- With these similarities and differences, ESR dosimetry with deciduous teeth will be also useful as with permanent teeth.

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ABSTRACT

The sensitivities to dose of the radiation induced signal observed in tooth enamel were examined by electron spin resonance (ESR) for individual deciduous and permanent teeth. The sensitivities in deciduous teeth are in agreement with those in permanent teeth within the statistical error while the variation is larger in deciduous teeth than in permanent teeth. While the intensities of the interfering background signal are also similar, the average value of the line widths of the background signal are larger but statistically indistinguishable due to larger variations in deciduous teeth than in permanent teeth. The position of the background signal (g factor) in deciduous teeth is slightly different from that in permanent teeth. With these similarities and differences, the ESR dosimetry with deciduous teeth will be useful as with permanent teeth using the same experimental procedures. The obtained dose will have larger statistical error in deciduous teeth than in permanent teeth when the calibration line method is applied, as the variation in sensitivity of deciduous teeth is larger.

1. Introduction

The determination of individual radiation doses is an important issue in assessing the accidental retrospective radiation risks, which have been estimated by ESR (electron spin resonance) (or EPR, electron paramagnetic resonance) by measuring the intensities of the radiation induced signal (RIS) in tooth enamel. This method has been applied to cases of various radiation accidents (e.g. Ikeya et al., 1984; Romanyukha et al., 1996; Chumak et al., 1999; Ivannikov et al., 2006; Shiraishi et al., 2002; Zhumadilov et al., 2006; Degteva et al., 2015; Bailiff et al., 2016). The techniques have been improved as shown in the results of intercomparison studies (Chumak et al., 1996; Wieser et al., 2000, 2006; Hoshi et al., 2007; Ivannikov et al., 2007; Fattibene et al., 2011), and so that an ISO standard for this method (ISO, 2013) was published. While the method was established for permanent teeth, there are much more chances for deciduous teeth to be provided for measurements than for permanent teeth, in actual radiation accidents, especially, in the accidents of Fukushima Dai-ichi Power Plants.

In spite of such an advantage, there are only a few papers studying deciduous teeth for the use for the ESR dosimetry. Wieser

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and El-Faramawy (2002) first examined the characteristics of the dosimetric and native signals in deciduous teeth and have shown that deciduous teeth would be useful for retrospective dosimetry. El-Faramawy and Wieser (2006) investigated the sensitivity of the pooled enamel extracted from deciduous molars in the dose range up to 10 Gy and concluded that the sensitivity of the dosimetric signal is more or less similar with permanent teeth and that the shape of the interfering organic signal is slightly different.

In the present paper, the variation of the sensitivities of the dosimetric signal to gamma rays of the tooth enamel of individual deciduous teeth are examined as well as the signal intensity and the line width of the interfering organic signal, which are necessary to establish the protocol to measure the doses given to the deciduous teeth for practical use of deciduous teeth for ESR dosimetry.

2. Samples and experimental procedures

Six naturally fallen deciduous teeth from three children (2 each) were provided by their parents, and 5 permanent molar teeth extracted because of medical reason were provided by Department of Dentistry, Ohu University, as shown in Table 1.

After roughly removing dentine of these deciduous teeth with a dental drill, they were gently crushed by a mortar and pestle until the grains pass the 1 mm sieve. The samples were, then, treated with 20% KOH solution at 60 °C in an ultrasonic bath for 2 h. If after rinsing with deionized water and drying, remaining dentine was found microscope, then the above KOH solution treatment was repeated once more to remove dentine completely. The roots of the permanent teeth were cut off and the crowns were vertically cut in half. The dentine in the crowns were roughly removed by a dental drill. After treating the crowns with 20% KOH solution at 60 °C in an ultrasonic bath for 5 h, remaining dentine was again removed by a dental drill. They were gently crushed by a mortar and pestle until the sample pass the 1 mm sieve. The samples were, then, treated with 20% KOH solution at 60 °C in an ultrasonic bath for 2 h. The last procedure was repeated twice before rinsing with deionized water.

Each sample of permanent tooth was separated into 4 aliquots. While one aliquot was left unirradiated, the other three were irradiated by gamma rays from a ^{60}Co source at Takasaki Advanced Radiation Research Institute of National Institutes for Quantum and Radiological Science and Technology with a dose rate of 480 mGy/h to doses up to 400 mGy (the dose and the dose rate are quoted as to enamel). As the amount of enamel extracted from deciduous teeth was too small to make several aliquots, ESR measurements and gamma ray irradiation were repeated for each sample. After ESR measurements were performed with the conditions described below, the samples were irradiated with the same gamma ray source described above with a dose rate of 180 mGy/h. ESR measurements and irradiation were repeated until the dose reaches 440 mGy.

The ESR measurements were performed with an X-band ESR spectrometer, JEOL JES-PX2300 at Okayama University of Science equipped with a cylindrical cavity of TE_{011} mode. The conditions of the measurements were; microwave power of 2 mW, the modulation frequency of 100 kHz and amplitude of 0.2 mT, scan range of 10 mT with a MgO:Mn standard marker to have two hyperfine lines at the both end of the spectrum, scan time of 30 s with accumulating scans of 40 times, and the time constant of 0.03 s. After the data files are converted to text files of 1024 points per spectrum, they were processed with a software, ER0906 (Ivannikov et al., 2001, 2010) to obtain the RIS intensities and the organic radical intensities by fitting Gaussian lines where the position (g factors) and the linewidth of RIS (radiation induced signal) are fixed while those of BGS (native background signal) are variable.

3. Results

The observed ESR spectra are shown in Fig. 1a and b. The intensity of the radiation induced signal (RIS), due to CO_2^- radical, increase with dose both in deciduous and in permanent teeth. Using a simulating program, ER0906 (Ivannikov et al., 2001, 2010), the signal intensities of the RIS and the native background signal (BGS), due to an organic radical, were obtained.

Typical examples of the dose response of the RIS intensities in deciduous and in permanent teeth are shown in Fig. 2. The slopes of the regression lines, obtained by the least squares method, correspond to the sensitivity of the RIS signal intensities to gamma ray dose. In the present paper, the slopes, hence, the sensitivity was examined for the individual teeth.

These obtained sensitivities normalized by the average of the permanent teeth, are plotted as shown in Fig. 3 and in Table 1. The solid line represents the average value, and the dotted line represents the standard deviation in Fig. 3. As results, the average value of the sensitivity of the dosimetric signal in deciduous teeth is smaller by 18% of that of the permanent teeth while the variation (the standard deviation) of the sensitivity in individual samples was obtained to be 25% for the deciduous teeth while 15% for the permanent teeth. Within the statistical variation the sensitivity of deciduous and permanent teeth was similar, being consistent with the results by El-Faramawy and Wieser (2006). The sensitivity variation obtained in the present study for permanent teeth, which is 15% is close to the variation of 10% previously obtained for

Table 1
The samples and the measurement results of the present study. The RIS sensitivities (the slopes in the dose responses) and the BGS intensities are normalized by the averages for the permanent teeth. The BGS line positions are quoted as the difference in the magnetic field to the lower magnetic field of RIS ($H_\perp$). As for the positions for deciduous teeth, C denotes incisor and D and E are molars.

Sample	Position		RIS sensitivity		BGS intensity		BGS line Width (mT)		BGS line Position (mT)	
Deciduous teeth										
ED1	E	Child A	1.01	0.82 ± 0.21 (average)	0.61	1.08 ± 0.33 (average)	0.25	1.61 ± 0.99 (average)	−0.25	−0.26 ± 0.02 (average)
ED2	E		0.88		0.96		2.42		−0.27	
No.18	D	Child B	0.49		0.95		2.42		−0.28	
No.19	C		1.01		1.14		2.59		−0.25	
No.21	E	Child C	0.87		1.22		0.94		−0.29	
No.22	E		0.65		1.59		1.06		−0.24	
Permanent teeth										
No.3	Molar	Adult A	0.80	1.00 ± 0.15 (average)	0.74	1.00 ± 0.20 (average)	1.01	1.21 ± 0.27 (average)	−0.32	−0.31 ± 0.01 (average)
No.5	Molar	Adult B	0.98		0.96		1.65		−0.31	
P3	Molar	Adult C	0.99		1.09		1.26		−0.31	
P4	Molar	Adult D	1.21		0.94		1.02		−0.31	
P5	Molar	Adult E	1.03		1.27		1.11		−0.31	

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