Dose Estimation by ESR on Tooth Enamel from Two Workers Exposed to Radiation due to the JCO accident

KUNIO SHIRAISHI1*, MIDORI IWASAKI2, CHYUZO MIYAZAWA2, HIDENORI YONEHARA3, MASAKI MATSUMOTO1

ESR / Tooth enamel / JCO accident / Dosimetry

ESR dosimetry is useful to estimate the external dose for the general population as well as for occupational workers in a nuclear emergency. Three teeth were extracted from two exposed workers (A and B) related to the JCO criticality accident. Tooth enamel was carefully separated from other tooth parts and subjected to ESR dosimetry. Doses equivalent to the γ-ray dose of 60Co were estimated as follows: for worker A, the buccal and lingual sides of the eighth tooth in the upper right side, 11.8 ± 3.6 and 12.0 ± 3.6 Gy, respectively; for worker B, the buccal and lingual sides of the fourth tooth in the upper right side and the fifth tooth in the upper left side, 11.3 ± 3.4 and 10.8 ± 3.3 Gy, 11.7 ± 3.5 and 11.4 ± 3.4 Gy, respectively. The estimated doses were found to be similar and not dependent on the tooth positions, whether the buccal or lingual sides in each tooth.

INTRODUCTION

Dose estimation by electron spin resonance (ESR) has been applied in past radiation accidents, and is recognized to be an effective method1). Many kinds of organic materials, such as sugar, amino acids, and tooth enamel, have been used to measure radicals produced by radiation2–4). ESR dosimetry of human tooth enamel has been applied to atomic-bomb survivors, inhabitants affected by the Chernobyl accident, and to other radiation workers5,6). Furthermore, both basic and applied research on ESR dosimetry using human tooth enamel has been carried out since the early 1990’s7–11). Occupational workers use a personal dose monitor, and work near monitoring systems. However, the general population does not have personal monitors in an emergency. Therefore, ESR dosimetry is especially useful to estimate the external dose for the general population. In this study, teeth from two occupational workers, who did not put on a personal monitor and were exposed during the JCO accident12), were used for dose estimations.

MATERIALS AND METHODS

Materials

Three occupational workers were initially exposed in the JCO accident. One tooth (the eighth tooth on the upper right side) was obtained from worker A. Two teeth (the fourth tooth in the upper right side and the fifth tooth in the upper left side) were obtained from worker B. The fourth tooth in the upper right side had an amalgum filling. Some other teeth were also treated with amalgum or crowns in workers A and B13). Tooth enamel was separated mechanically from other tooth parts using a disk-shaped diamond cutter.
(Φ100 mm and 250 µm blade width). The enamel of each tooth was removed as two sides, buccal and lingual sides, and crushed to grain sizes of 500–1400 µm without any chemical treatment. The total weight of each crushed enamel sample was 60–140 mg.

**ESR measurements**

The enamel of each tooth was weighed into a quartz ESR tube (outer diameter, 5 mm). The same ESR tube was used for all measurements. A commercial ESR spectrometer, JEOL-RE-1X (Japan Electron Optics Laboratory Co. Ltd., Tokyo), was used. The enamel samples were measured at room temperature. Measurements were performed at a microwave power level of 5 mW with a 100 kHz modulation unit. The ESR absorption spectra of the free radicals were observed with a 0.32 mT modulation width, 328 mT center magnetic field, and ±5 mT scanning magnetic field. The time constant and scanning time were 0.1 s and 16 min, respectively.

ESR sample measurements were made simultaneously with a Mn$^{2+}$ standard sample (a manganese digital marker, ES-DM1 type) set in the same resonator. The measured values were then processed and arranged by a computer.

**RESULTS AND DISCUSSION**

The ESR spectrum of irradiated enamel is due to CO$_2^-$ radicals induced by radiation; these CO$_2^-$ radicals are stable for a long time. For worker A, the CO$_2^-$ signals with Mn$^{2+}$ internal standard are shown for enamel of the buccal and lingual sides of the eighth tooth in Fig. 1. For worker B, the signals of the buccal sides of the fourth and fifth teeth are shown in Fig. 2. The signal intensities were changed to the doses by using a calibration curve prepared using $\gamma$-rays from a $^{60}$Co source and by using the weight-correction method. The results are given in Table 1. The estimated doses were found to be similar and not dependent on the teeth positions, whether they were for the

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**Fig. 1.** ESR spectra of teeth enamel for worker A.
buccal or lingual sides. The relative standard deviation of the ESR signals for one tooth enamel was 5%, while that for all teeth taken from each subject was less than 10%. Furthermore, the difference among the individuals was reported to be within $\pm 20$ to $30\%^{11}$. Therefore, the standard deviations were calculated using the maximum coefficient of variation ($\pm 30\%$) either for an individual or more subjects. They are reported in Table 1.

In the JCO accident, neutrons and $\gamma$-rays were emitted continuously during 19 hours due to fission reactions$^{12}$. Because of radiation by neutrons, specific radioactivities of $^{24}$Na in hair near to teeth were reported as $6.36 \times 10^4$ and $3.69 \times 10^4$ Bq/g for workers A and B, respectively$^{14}$. The average absorbed doses by $\gamma$-rays on whole bodies were estimated using the neutron/ $\gamma$-ray ratio of the ambient dose equivalent, the dose equivalent per unit fluence of $\gamma$-rays, the air kerma per unit $\gamma$-ray fluence, and the absorbed dose per unit air kerma to be 8.5 and 4.5 Gy, respectively$^{15}$. Another estimation of the $\gamma$-ray doses using a numerical-simulation technique, followed by normalization with specific radioactivity of $^{24}$Na, resulted in 11.7 and 5.0 Gy for workers A and B, respectively$^{16}$. Doses

| Worker | Tooth position | Estimated dose (Gy) |
|--------|----------------|---------------------|
|        |                | Buccal side | Lingual side |
|        |                | Mean $\pm$ error* | Range | Mean $\pm$ error* | Range |
| Worker A | 8th tooth in the upper right side | 11.8 $\pm$ 3.6 | 8.2 – 15.4 | 12.0 $\pm$ 3.6 | 8.4 – 15.6 |
| Worker B | 4th tooth in the upper right side | 11.3 $\pm$ 3.4 | 7.9 – 14.7 | 10.8 $\pm$ 3.3 | 7.5 – 14.1 |
|         | 5th tooth in the upper left side | 11.7 $\pm$ 3.5 | 8.2 – 15.2 | 11.4 $\pm$ 3.4 | 8.0 – 14.8 |

* The standard deviations were calculated using the coefficient of variation between individual differences ($\pm 30\%$) of human teeth.
estimated from chromosome aberration analyses were found to be 20 Gy-equivalent or more, and approximately 8 Gy-equivalent for workers A and B, respectively. The estimated doses showed differences of ca. 2 times between the two workers. The present result based on tooth enamel measurements indicated almost similar doses for the two workers. This may be because the positions of the heads of the two workers were almost equal distance from the reaction tank. The postures of the two workers were assessed by witnesses after the accident, as shown in Fig 3.

However, if the dose of worker A was the maximum value, 15.4 Gy, and that of worker B the minimum value, 7.9 or 8.2 Gy, the A/B ratios (1.9 or 2.0) would be close to the other reported values. These results were only estimated using the ESR sensitivity of $\gamma$-rays from a $^{60}$Co source. Therefore, many issues exist to resolve this estimated dose difference based on the results of other methods, e.g. 1) effects of neutrons, 2) effects of repair metal fillings in tooth samples, 3) the number of tooth samples used in this study, and 4) individual differences in sensitivity for induction of the ESR signal by radiation. Especially, the neutron-radiation share was bigger than that of $\gamma$-ray radiation in the JCO accident. The ESR sensitivity for neutron irradiation of teeth is under investigation.

In conclusion, the application of ESR dosimetry to human tooth enamel could provide important information for a dose estimation of workers exposed to heavy doses of radiation in the JCO accident.

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