Relation between Teeth-dose and Effective Dose for External Photon Exposure.

F. Takahashi1, Y. Yamaguchi1, M. Iwasaki2, C. Miyazawa2 and T. Hamada3
1 Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki, 319-1195, Japan
2 School of Dentistry, Ohu University, Tomita-machi, Koriyama-shi, Fukushima, 963-8611, Japan
3 Nuclear Safety Research Association, 5-18-7, Shinbashii, Minato-ku, Tokyo, 105-0004, Japan

INTRODUCTION

Electron spin resonance (ESR) dosimetry using dental enamel is expected to be applicable to individual dose assessments, in the case where no dose information can be obtained from dosimeters, such as radiation accident. This method is based on the assumption of the linear relation between intensity of ESR signal induced by CO3³⁻ radicals and the absorbed dose in dental enamel. The ESR signal has been related to the dose accumulated in teeth for external photon irradiation1-5). Since the hydroxypatite crystal in the dental can easily trap free electrons in the defects in the crystal lattice and the signal in exposed dental enamel remains stable for a long time6), ESR dosimetry using dental enamel has been applied to retrospective dose assessments in atomic-bomb survivors7-9), residents affected by the Chernobyl accident10,11) and accumulated individual doses of workers in Russian nuclear facility “Mayak”.

The ultimate quantity is organ or tissue dose and effective dose, risk-weighted average of organ doses over a whole body for an estimation of individual dose. In this context, the retrospective dose assessment by ESR measurement requires a quantitative relationship between the effective dose and the dose in teeth. In this work, Monte Carlo calculations and experiments with a realistic head phantom were carried out to correlate quantitatively dose in teeth with effective dose for external photon exposure.

COMPUTATION

The Electron Gamma Shower Code Version 4 (EGS4)12) in conjunction with user’s code UCGEN13) was used to calculate absorbed dose to organ or tissues including teeth. A mathematical human model used in the calculation was an adult MIRD-5 type phantom designed by Cristy14) and teeth-part was newly added in the head to calculate dose. The composition and density of teeth were taken from the data of a reference man in ICRP Publ.2315) and an Asian reference man in Tanaka’s model16), respectively. Figure 1 shows an overview of mathematical phantom and a cross section of the head at the level of newly defined teeth part. The teeth were grouped into five parts: front, left-middle, right-middle, left-back and right-back parts to examine the distribution of the teeth-dose in the mouth. The track length estimator was used to calculate energy-differential fluences in each organ or tissue and the kerma approximation to convert them into absorbed dose.

The parallel beams of energies from 20keV to 2.5MeV were assumed to be incident on the body. Dose calculations were performed for 12 incident angles with 30 degrees interval to study the dependence of the teeth-dose and effective dose on the incident direction of photons. A soft tissue area was also attached on the chest surface to assess a dosimeter reading.

EXPERIMENT

Experiments were carried out with a head phantom, which is made of real human skull and polyurethane-based soft tissue substitute. The phantom was set at 2.0m distant from a ¹³⁷Cs or ⁶⁰Co source and exposed to gamma rays. Absorbed dose at the position of teeth were measured with thermoluminescence dosimeters (TLDs) : CaSO₄:Tm with a diameter of 4mm (UD-110s, Matsushita). Teeth-doses were directly estimated with the doses measured with the TLDs, since the difference in energy absorption coefficient is negligible between tooth enamel and CaSO₄ crystal for the photons of 662keV and 1250keV. In addition to this experiment, authentic dental enamels located at the teeth part in the phantom were irradiated with a ⁶⁰Co source. ESR measurement was performed for irradiated dental enamel samples separated mechanically from other part of the tooth and crushed into appropriate grain size1-4).

RESULTS AND DISCUSSION

Figure 2 shows comparisons of dose in teeth, effective dose and dose on the chest surface for the AP and PA irradiation geometries as a function of incident photon energy. In the figures, values are given in the unit of mSv/R, the ratio of equivalent dose or effective dose to exposure in free air. The fractional standard deviation of dose in teeth at each part was within 4% in the energy region above 50keV and within 6% for the photons of
20keV or 30keV. No dose was absorbed in some teeth parts for 20keV photons. The tooth receives very higher doses than other tissues, because it contains elements with higher atomic numbers such as Cs and P than those of soft tissue. For photons less than 100keV, the teeth-dose increases due to energy absorption through photoelectric effect. On the other hand, for photons more than 200keV, dose in teeth is near to effective dose, because Compton scattering process is dominant interaction with tissues in this energy region and energy absorption through this process does not significantly depend on the element.

Figure 3 shows the angular dependence of dose in teeth, effective dose and dose on chest surface for photons of 1250keV. For incidence of photons from the front with an extent of -60 and +60 degrees, the dose in tooth is close to effective dose. The dose in tooth can overestimate the effective dose for the incidence of 1250keV photons from the lateral of a human body, because the organs principally contributing to the effective dose are well shielded by the human body tissues. On the contrary, the effective dose is larger than dose in tooth for posterior incidence of 1250keV photons, since teeth are located at the front part in the head and the photons are absorbed in the red bone marrow in the spines contributing to effective dose.

Figure 4 shows the average of calculated doses over all the incident angles as a function of incident photon energy (ROT geometry). The dose in teeth and effective dose are 7.53mSv/R and 7.57mSv/R for 1250keV photons, respectively. This result suggests that the measured dose in tooth by ESR can be interpreted as the effective dose in the case where photons more than 1MeV are uniformly incident on the body from the horizontal angles.

Table 1 summarizes comparisons of the results by the calculation, the experiment with TLDs and the ESR dosimetry using tooth enamels for irradiation with a 60Co source. In the table, the obtained teeth-doses and the signal intensities at the middle- and back-parts are relative values to those at the front part, which are normalized to unity. The uncertainty in the experiment was within 5%. No significant difference can be seen in the degree of the distribution of teeth-dose in the mouth between the calculation or the experiment and the ESR dosimetry.

![Figure 1](image_url)  
(a) Mathematical phantom  
(b) Added teeth part

Figure 1  Schematic view of a mathematical phantom and cross section of the head at the level of added teeth part.
Figure 2  Teeth-doses, dose on the chest surface and effective dose per exposure in free air as a function of photon energy for the (a) AP and (b) PA geometries.
Figure 3  Angular dependence of teeth-dose, dose on the chest surface and effective dose for 1250keV photons. Teeth-dose is given as an average for five parts.

Figure 4  Teeth-dose, dose on the chest surface and effective dose per exposure in free air as a function of photon energy for the ROT geometry. Teeth-dose is given as an average for five parts.
Table 1 Teeth-dose distribution in the mouth determined by ESR dosimetry, calculation and experiment with TLDs.

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<table>
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</table>

* The signal intensities or teeth-doses at middle- and pack-parts are relative values to those at front-part, which are normalized to 1.0.

CONCLUSION

The relationship between the teeth-dose and effective dose for photon external exposure was analyzed by the Monte Carlo calculations and the experiment. Energy and angular dependence of dose in tooth were obtained by the Monte Carlo calculation. Experimental results agree with the calculations for some photon incidence cases. Whereas the result suggests that the dose in tooth can be directly interpreted as effective dose without any transformation for some cases, it also suggests that dose in teeth depends more significantly on photon energy than the effective dose. The obtained results can be directly applied only to a dose assessment at an ideal field of monoenergetic photons. The consideration of energy spectral distribution of incident gamma rays is needed for a more precise dose assessment.

REFERENCES