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Analysis of Dose in Teeth for Estimation of Effective Dose by the Electron Spin Resonance (ESR) Dosimetry Using Dental Enamels

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Abstract

Dose in teeth was studied to develop a method that can predict effective dose from results by the Electron Spin Resonance (ESR) dosimetry using dental enamels for external photon exposure. Absorbed dose in teeth and effective dose were calculated by the Electron Gamma Shower Code Version 4 (EGS4). In the Monte Carlo calculations, a region for teeth was newly added to a mathematical human model. Experiments were carried out with a head phantom, which is made of tissue equivalent materials. ESR dosimetry was made with dental enamels irradiated at teeth-part in the head phantom. The absorbed dose in a mouth was also measured with TLDs exposed to gamma rays as the teeth. The Monte Carlo calculation and the experiment gave a quantitative relationship between absorbed dose in teeth and effective dose. The obtained data are considered to be useful for the retrospective individual dose assessment with ESR dosimetry using dental enamels.

1 Introduction

Retrospective assessments of exposures to ionizing radiation have been performed to evaluate past radiation events, where no useful information can be taken from a dosimeter or a radiation monitor. The Electron Spin Resonance (ESR) dosimetry with teeth is based on measurements of radiation-induced CO33- radicals in hydroxyapatite and one of the methods to assume past exposure[1, 2]. Since the hydroxypatite crystal in the dental can easily trap free electrons and the signal in exposed dental enamel remains stable for a long time, this method has been applied to retrospective dose assessments in atomic-bomb survivors[3, 4], residents affected by the Chernobyl accident[5, 6] and accumulated individual dose of workers in Russian nuclear facility "Mayak"[7, 8].

The ESR signal has been related to the dose accumulated in teeth[9, 10, 11, 12, 13]. For an estimation of individual dose, the ultimate quantities are organ or tissue dose and effective dose, risk-weighted average of organ dose over a whole body. The intensity of ESR signal resulted from the radicals, however, can directly indicate only absorbed dose in teeth. Then, the retrospective individual dose assessment requires the information for conversion from the measured quantities to organ dose of interest. In this work, Monte Carlo calculations with the Electron Gamma Shower Code Version 4 (EGS4)[14] and experiments with a realistic head phantom were carried out to correlate quantitatively dose in teeth with effective dose for external photon exposure.

2 Computation

EGS4 Code in conjunction with user's code UCGEN[15, 16] was used to calculate absorbed dose to organ or tissues including teeth. A mathematical human model used in the calculations was an adult MIRD-5 type phantom designed by Cristy[17] and teeth-part was newly added in the head of the phantom, where facial skeleton had been already defined. Figure 1 shows an overview of the MIRD-5 type phantom and a cross section of the head at the level of newly defined teeth region. The teeth were grouped into five parts to examine the distribution of absorbed dose to teeth (teeth-dose) in the mouth. A soft tissue area was also attached on the chest surface to assess a dosimeter reading.

Photon parallel beams were assumed to be incident on the phantom. Calculations were performed for 12 incident angles with 30 degrees interval to study the angular characteristics of the teeth-dose and effective dose. The track length estimator was applied to calculate energy differential fluences in each organ or tissue and the kerma approximation to convert them into absorbed dose.

3 Experiment

Experiments were made with a realistic head phantom, which is made of tissue-equivalent plastic and contains human skull. The head phantom was placed on the trunk of an Alderson RANDO phantom. The phantom was set at 2.0 m distant from a ^{137}Cs or a ^{60}Co source. Teeth were inserted in the upper and lower jaws of the phantom. After the irradiation, dental enamels were separated mechanically from other parts of the teeth and subjected to ESR measurements[18]. In addition to the teeth, the absorbed dose in the mouth was measured with thermo-luminescence dosimeters (TLDs) located at the teeth-part in the head phantom. The TLD is made of a $CaSO_4$ crystal and has a diameter of 4mm (UD-110s, Matsushita). The measured dose by the TLD could be directly compared to the teeth-dose obtained by the calculations, since the energy absorption coefficient for tooth enamel is closed to that for a $CaSO_4$ crystal with the energy of photons emitted from a ^{137}Cs or a ^{60}Co source.

4 Results and Discussion

Figure 2 shows calculated photon energy dependences of dose in front-teeth, dose in back-teeth, effective dose and dose on chest surface in anterior-posterior (AP) and posterior-anterior (PA) geometries. The values of dose are given in the unit of mSv/R, the ratio of equivalent dose or effective dose to exposure in free air. The equivalent dose of teeth was obtained with multiplying the absorbed dose in teeth by radiation weighting factor (wR) for photons[19]. The teeth-dose indicates different behavior from the effective dose for low photon energies, because tooth contains element with a higher atomic number such as Ca and P than those of soft tissue and can receive higher dose due to energy absorption through photoelectric effect. On the other hand, the teeth-dose is near to effective dose in the energy region above 300 keV, where the Compton scattering process is dominant interaction with tissues.

Figure 3 shows dependences of teeth-dose in the mouth on incident direction of 50 keV and 1250 keV photons. The teeth-doses are more strongly dependent upon the incident direction of the photon for 50 keV than for 1250 keV, because low-energy photons cannot penetrate materials with heavy elements as high-energy photons. The angular dependence of teeth-dose changes apparently according to the part of teeth for 50 keV photons.

Figure 4 depicts angular dependences of teeth-dose, effective dose and dose on chest surface for incidences of 1250 keV photons. The results suggest that the teeth-dose can be thought as the effective dose for the incidences of photons from the front of a human body within 60 degrees. The teeth-dose, however, can underestimate the effective dose for the photons from the back of a human body, because the photon can be absorbed in the red-bone marrow in the spine. On the other hand, the teeth-dose is more than the effective dose for the geometry of lateral photon irradiation, because the organs in the trunk principally contributing to the effective dose are well shielded by the human body tissues.

The obtained teeth-doses and effective doses are summarized in Table 1 with some cases of photon irradiations. The values of dose in the rotational (ROT) geometry are average of the calculated doses over all horizontal incident angles for each photon energy. It can be concluded from the results that we can interpret the teeth-dose as effective dose for more than 1 MeV photons in the AP and the ROT geometries. These conversion coefficients from the teeth-dose to the effective dose are to be essential for the retrospective individual dose assessment by ESR dosimetry with teeth. However, it should be mentioned that these data are obtained with a mono-energetic field. The teeth-dose can remarkably overestimate the effective dose for low energy photon as shown in 50 keV photons, so the measured dose with ESR dosimetry is to be larger than the teeth-dose of 1250 keV in Table 1 for a retrospective assessment of exposure with photons from a ^{60}Co source.

Table 2 summarizes distributions of the teeth-dose in the mouth by the ESR dosimetry, the measurements with TLDs and the calculations for a ^{60}Co source. Since relationship between intensity of the ESR signal and tooth-dose has not been determined yet, the signal intensity or the dose in teeth at the middle- and the back- part are given with relative values to those at the front part, which are normalized to 1.0. The values in the calculations are based on the result of 1250keV photons. The results by the ESR dosimetry agreed with the measurements by TLDs and the calculations for both of the AP and PA geometries.

Table 3 shows the comparison of the teeth-dose by the calculations and the experiments with TLDs. The calculated teeth-doses are less than the measured doses for the PA geometry, whereas the measured teeth-doses are valid to the results by the calculations for the AP geometry. The disagreements in the PA geometry are due to the difference of the head part between the modified mathematical human models for the calculations and the phantom used for the experiments. .

5 Construction of a Voxel type phantom (Verification of Experiments)

Since the calculated teeth-doses were less than the measured doses with TLDs ($CaSO_4$) located in the head phantom as shown in Table 3, the Monte Carlo calculations are to be performed for a verification of the experiments. The computational human model for the verification is called as "voxel (Volume-pixel) type" phantom[20].

A Voxel type phantom was developed based upon a computed topography (CT) image of the head phantom, which had been taken with 1mm interval. The CT image having 512x512 pixels was segmented into soft tissue, bone, teeth and air according to CT values as shown in Figure 4 (a). Figure 4 shows that the teeth-part defined in the Voxel type phantom is quite similar to the teeth-part added to the MIRD type in the already performed calculations. Since CT images of the RANDO phantom in the experiments were not taken, the trunk of the phantom is to be replaced by other human model. These images are now being piled up to construct the computational mathematical model for the calculations.

6 Conclusion

The Monte Carlo calculations and the experiments have provided the quantitative relationship between the teeth-dose and effective dose for photon external exposure with 9 energies between 20 keV and 2500 keV. The obtained results are to be useful for the individual dose assessment by the ESR dosimetry with teeth. To get the final goal of this work, Monte Carlo calculations should be performed to verify the experiments with a Voxel type phantom based upon the head phantom used in the experiments.

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Table 1 Teeth-dose and Effective dose for some cases of photon external photon exposures.

1. 1250keV	(A) Teeth-dose (mSv/R)	(B) Effective dose (mSv/R)	(B)/(A)
AP Geometry	9.2	8.8	0.96
PA Geometry	5.4	7.9	1.46
LLAT Geometry	8.2	6.4	0.78
ROT Geometry	7.8	7.4	0.95
2. 50keV	(A) Teeth-dose (mSv/R)	(B) Effective dose (mSv/R)	(B)/(A)
AP Geometry	53	9.2	0.17
PA Geometry	6.5	5.3	0.82
LLAT Geometry	32	3.5	0.11
ROT Geometry	30	5.5	0.18

Table 2 Teeth-dose distributions in the mouth by the ESR dosimetry, the TLDs and the calculations (^{60}Co source).

1. AP geometry	Relative value*		
	Front	Middle	Back
ESR dosimetry	1.0	1.0	0.9
TLDs	1.0	1.0	1.0
Calculation	1.0	1.0	0.9
2. PA geometry	Relative value*		
	Front	Middle	Back
ESR dosimetry	1.0	1.1	1.1
TLDs	1.0	1.1	1.2
Calculation	1.0	1.1	1.2

*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.

Table 3 Comparison of Teeth-dose by the TLDs and the calculations (^{60}Co source).

1. AP geometry	Teeth-dose (mSv/R)			Effective Dose (mSv/R)
	Front	Middle	Back	
TLDs	9.4	9.7	9.1	—
Calculation	9.4	9.4	8.8	8.8
2. PA geometry	Teeth-dose (mSv/R)			Effective Dose (mSv/R)
	Front	Middle	Back	
TLDs	6.2	6.5	7.1	—
Calculation	4.8	5.2	5.9	7.5

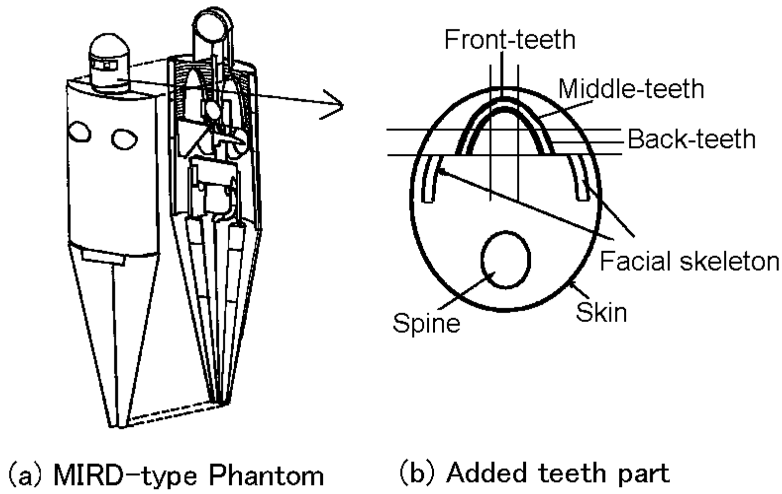


Figure 1 Schematic view of a MIRD-type phantom and the cross section of head at the level of newly defined teeth-part.

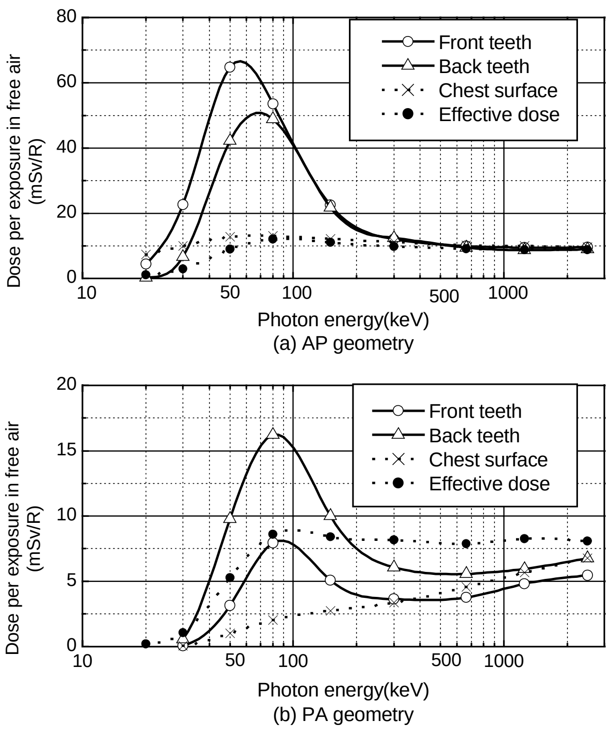


Figure 2 Teeth-dose, dose on chest surface and effective dose per unit exposure in free air as a function of photon energy for AP (a) and PA (b) geometries.

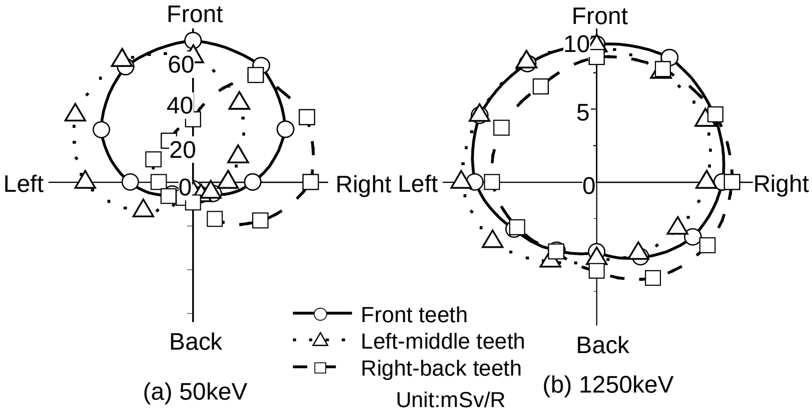


Figure 3 Angular dependence of teeth-doses for 50keV and 1250keV photons.

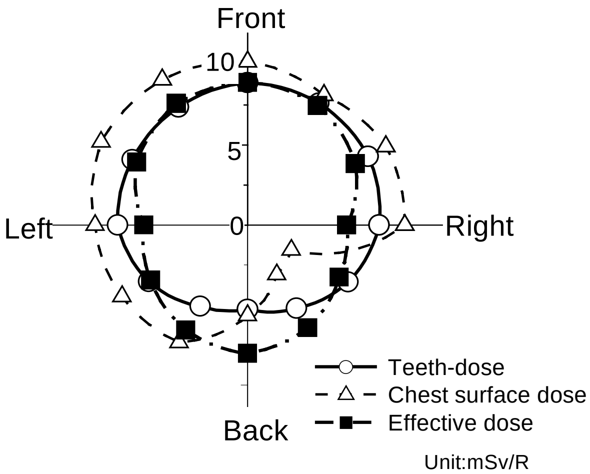
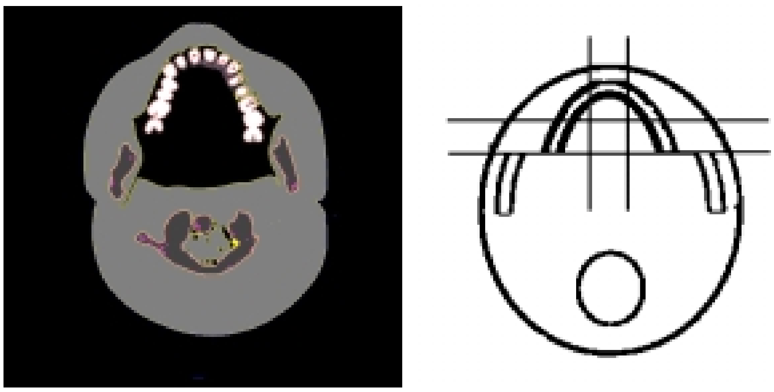


Figure 4 Angular dependence of teeth-dose, dose on chest surface and effective dose.



(a) Voxel-type phantom (b) MIRD-type phantom

Figure 5 Teeth-part in the two mathematical human models.