論　文　内　容　要　旨

Behavior of the electron spin resonance signals in X-ray irradiated human fingernails for the establishment of a dose reconstruction procedure

（X 線被曝した人の爪の電子スピン共鳴信号の挙動について–遡及的線量評価手順確立に向けて–）

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Investigating electron spin resonance (ESR) signals from human fingernails after a radiation accident can be helpful in retrospective dosimetry. However, the previous studies lacked much-needed information when the focus was on X-ray irradiation, while X-rays are the most commonly used technique for diagnosis and treatment these days. Our papers investigated X-ray-induced ESR signal behaviors under realistic conditions, proposed a new procedure based on practical handling, and evaluated its limitations.

One of the most significant issues to establish the realistic procedure of fingernail ESR dosimetry is the difficulty of separating the radiation-induced signal (RIS) from the mechanically induced signal (MIS) and the background signal (BKS). The MIS is generated by cutting. The BKS is a residual component caused by ambient radiation after erasing RIS and MIS, generating radicals in the equilibrium state. In the previous studies, researchers tried to remove them by physical and chemical means. The previously suggested protocols are too complicated for nail ESR to be widely used in actual radiation accidents because some chemical treatment or equipment such as a freezer are required in sample collection and transportation. To develop our procedure that requires people onsite to cut the nails and pack them with silica aerogel keeping low humidity during transportation to avoid signal fading, we measured RIS characteristics in X-ray irradiation, MIS, and BKS quantitatively relative to RIS, and signal change under low humidity. During the observation of signal change, we found an increase in RIS for the first time in the world. To estimate the effect of build-up phenomena of the absorption energy in the nail sample, specifically in X-ray irradiation, we also simulated the energy absorption using PHITS.

For this study, we collected fingernails from 12 Japanese donors, ranging in age from their 30s to 60s, for X-ray irradiation, mechanical stimulation, and background measurements. We also collected ten toenails from one of these donors for comparison to check whether they can be used as a reference for irradiated fingernails. We also prepared 15 samples from two donors to compare the signals generated by γ-rays to those by X-rays. Additionally, to investigate the signal change, we collected 40 nail samples from the fingers and toes of three donors in their thirties, forties, and fifties. We X-ray irradiated samples using a commercial device (Cabinet X-ray system model CP-100, Faxitron Bioptics LLC., Tucson, USA). The peak photon energy of photons was around 60 keV, and the dose rate was 1.2 Gy/min. For γ-ray irradiation, we used a Gamma-cell40 Exactor Low Dose-Rate Research Irradiator (Best Theratronics Ltd., Ottawa, Canada) equipped with Cesium-137 sources. The dose rate was 0.79 Gy/min. The air-absorbed dose was monitored using Dose Ace GD-352M and GD-302M (Chiyoda Technol Corporation, Tokyo, Japan) glass dosimeters respectively for X-rays and γ-rays. The ESR measurements were conducted on a JES-FA100 instrument (JEOL Ltd., Japan) with an X-band microwave generator (9.4 GHz).

We confirmed the linear-dose response for X-ray irradiation as well as γ-ray and found that sensitivity to X-ray was the same as γ-rays. The inter-individual variation of the sensitivity was no more significant than the intra-individual variation of that. There was a tendency for the sensitivities of the toenails to be smaller than those of the fingernails. The effect of build-up phenomena is small because nail samples, the average was 0.5 mm, were thinner than the thickness of the build-up region, 8 mm. Moreover, the energy increase due to build-up is only 6 % at maximum. The actual absorbed dose in nail samples was possible to be from 1.4 to 2 times larger than the air-absorbed dose. The resolution of the air-absorbed dose was 1.7 Gy.

In MIS measurements, the increment of the signal intensity showed a linear response with the summation of the additional cutting cross-sections. When we assumed that typical fingernail thickness,0.5 mm, and the width, 1 cm, the size of the MIS generated at harvest is comparable to the size of the RIS by 20 Gy X-ray irradiation. We erased all the signals, including the RIS and MIS, by soaking samples in water to estimate BKS. The sizes of the BKS were different in samples from the same donor. The average was the same size as the RIS obtained with 21 Gy of X-rays. The results of observation of RIS under the 11% humidity at 20 ℃ shows that the extent of signal intensified after irradiation was proportional to the given dose for the first few days after the subtraction of increase of MIS from non-irradiated samples. This result seemed to contradict previous studies, reporting signal fading. The signal fading was due to humidity, and in reality, the convolution of both the increasing and fading intensity determines the maximum increment size. Taking this into account, the entire excess of the RIS was approximately 50% of the initial RIS at 11% humidity. According to the model taking both the decay and increase into consideration we constructed based on the literature and our data, at humidity levels over 40%, the fading was dominant; therefore, we can suppose that, at these humidity levels, the increase we observed remained undetected in previous studies. This fact should be taken into account for practical use because RIS should increase during sample transport.

Based on the experimental results obtained in this work, we propose the following procedure for X-band fingernail ESR: 1. After the accident, the sample was packed with silica aerogel under 40% humidity and sent to the laboratory. 2 Measure the weight and cutting cross-section and initial ESR signal. 3. Irradiate and measure the sensitivity. 4. Observe the signal increase under transport conditions. 5. Erase all RIS and MIS, then measure BKS, 6. Add new cuts and measure the sensitivity of MIS. 7. Observe the increase of MIS for the same period of transport. 8. Subtract the BKS, MIS, and its increase during transport from the initial ESR signal and then divide it by the RIS increase ratio during the transport period.