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The use of human hair as biodosimeter

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HIGHLIGHTS

- Applied electron spin resonance spectroscopy to human hair used in biodosimetry.
- Showed the limitations of hair samples using as a biological dosimeter.
- Provided more systematic information on radiation-induced radicals in hair.
- Found at least 3 different contributions in the RIS. That is the major finding of this work.

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ABSTRACT

The potential use of human hair samples as biologic dosimeter was investigated by electron spin resonance (ESR) spectroscopy. The hair samples were obtained from female volunteers and classified according to the color, age and whether they are natural or dyed. Natural black, brown, red, blonde and dyed black hair samples were irradiated at low doses (5–50 Gy) and high doses (75–750 Gy) by gamma source giving the dose rate of 0.25 Gy/s in The Sarayköy Establishment of Turkish Atomic Energy Authority. While the peak heights and *g*-values (2.0021–2.0023) determined from recorded spectra of hair were color dependent, the peak-to-peak line widths were varied according to natural or dyed hair (ΔH_{pp}: 0.522–0.744 mT). In all samples, the linear dose–response curves at low doses saturated after ~300 Gy. In black hair samples taken from different individuals, differences in the structure of the spectrum and signal intensities were not observed. The EPR signal intensities of samples stored at room temperature for 22 days fell to their half-values in 44 h in black hair, 41 h in blonde and brown hairs, 35 h in dyed black hair and in 17 h in red hair. The activation energies of samples annealed at high temperatures for different periods of time were correlated well with those obtained in the literature. In conclusion, hair samples can be used as a biological dosimeter considering the limitations showed in this study.

1. Introduction

Application of ionizing radiation in many different fields is constantly increasing, including the use for energy and medical purposes, so it becomes very important to monitor people exposed to radiation. In case exposed people do not wear a personal dosimeter, a rapid and accurate method to meet the needs for effective and efficient triage after a large-scale radiation exposure event is required. But in this case, it is needed to be able to assess doses about 1 Gy, whereas in the case of an accident, doses can locally reach several Gy up to tens of Gy. Therefore, this paper describes the potential use of human hair as a physically-based biodosimetry method that uses electron paramagnetic resonance spectroscopy (EPR) for a large scale radiological/nuclear event. The usefulness of this method has been reported several times in the case of serious accidents (Clairand et al., 2006; Schauer et al., 1993, 1996; Desrosiers, 1991). In the EPR technique, depending on the material, a single measurement can take between some minutes up to a few hours. The readout is non-destructive, allowing for repeated measurements on the same sample. The EPR signal intensity is directly proportional to the amount of free radicals specifically generated by ionizing radiation. But in case of a sample that has fast radical decay after irradiation (Müller and Streffer, 1991), the EPR method should be applied immediately. The biological tissues that have been proposed for EPR dosimetry should have some criteria such as ubiquity, noninvasiveness and ease of sample collection, presence of a post-irradiation EPR signal, negligible background signal, linearity of dose–response relationship,

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minimum detection limit and post-irradiation signal stability (Trompier et al., 2009a).

Human hair has a broad non-negligible background signal, due to the melanin content of hair (Herrling et al., 2008). The signal stability is unfortunately limited to several hours (Çolak and Özbey, 2011). Nevertheless, in a detailed study, the conditions of human hair to provide alternative biologic dosimeter in case of an emergency overexposure were investigated (Tepe Çam, 2011). There are studies investigating the dosimetric potential use of human hair (Nakajima, 1982; Trivedi and Greenstock, 1993; Kudynski et al., 1994; Alexander et al., 2007; Çolak and Özbey, 2011) and still there is a need to study the dose–response curves, activation energies, decay constants and biological variability for each color of hair samples. In this sense in the present investigation, we provide more systematic information on radiation-induced radicals in hair using the EPR technique.

2. Materials and methods

2.1. Hair samples

The hair samples were obtained from young female volunteers (20–30 years old) and classified according to the color and whether they are natural or dyed. The samples were used without any treatment except for one cut sample and all were stored in small locked bags in the dark. Measurements were carried out on natural dark (three sample; DS N1, DS N4 and cut sampled N7), brown, red, blonde and dyed black hair (BS) samples obtained each from the same donors. The EPR spectra were measured prior to irradiation at room temperature and within 10 min after the irradiation. The samples were bent by hand, then inserted into the EPR tubes along the active cavity region and fixed by using iron filled rod from the top of the tube.

2.2. Irradiation

The samples were irradiated with ^{60}Co gamma rays at ambient conditions using gamma cell with an air kerma rate of 0.25 Gy/s at the Sarayköy Establishment of the Turkish Atomic Energy Authority in Ankara. The radiation doses between 5 and 50 Gy were named as low doses and doses between 75 and 750 Gy were named as high doses in order to obtain the dose–response curve. The uncertainty in radiation doses was nearly 3%. The absorbed dose at the sample location was checked by a Fricke chemical dosimeter. An unirradiated hair (control) sample was also prepared for comparison purposes. The samples were protected from light during irradiation and transported to the measurement laboratory and then stored in closed bags in the dark.

2.3. EPR measurements

EPR measurements were carried out using a Bruker e-scan X-band EPR spectrometer operating at 9.8 GHz. Samples were placed in standard pyrex tubes with inner diameter 4.0 mm not exhibiting any EPR signal. The EPR spectra were recorded at room temperature (open to air) under the following spectrometer operating conditions: sweep width 10 mT, microwave power 0.5–1 mW, modulation frequency 86 kHz, modulation amplitude 0.3 mT, and gain 1.5×10^2. Each measurement was repeated three times. Signal intensities were calculated from the first derivative spectra and were normalized to sample mass. A strong pitch sample was used as a standard sample to determine the g-factors.

All EPR measurements were carried out at normal laboratory conditions (about 21 ± 2 °C and 25 ± 3% relative humidity) about 10 min after the irradiation to observe the radiation-induced free radicals. For each color, the sample was placed in the cavity three times and at each time the EPR spectra of the sample were recorded separately. The mean value of the signal intensities was taken in order to minimize the error from the cavity-filling factor. A long term radical decay feature at room temperature was performed over a storage period of 22 days using a sample irradiated at a dose of 12 kGy. Decay kinetics of the radiation-induced radicals at three different temperatures [40, 50 and 60 °C] was performed using the samples irradiated at a dose of 12 kGy. The kinetic experiments were begun immediately after the irradiation to avoid the radical decay at room temperature. The hair samples were transferred to water baths at temperatures mentioned above, and then their EPR spectra were recorded regularly over a time interval of 0–90 min after cooling them to room temperature following the predetermined heating times (3, 6, 10, 15, 20, 25, 30, 35, 45, 55, 65, 75, and 90 min). The activation energies of the involved radical species were calculated from Arrhenius plots.

3. Results and discussion

3.1. EPR spectra of unirradiated human hair samples

The background EPR spectra of human hair samples that have not been washed, irradiated or mechanically damaged except one cut sample were recorded. To determine the optimum sample mass to be used in EPR measurements, the variation in the EPR peak height (I_{pp}) with sample mass was examined. The EPR peak height (Fig. 1) varied linearly up to 30 mg and then began to saturate above this mass value. Hence, in all experiments, the sample mass falling into this linear region was used.

Untreated hair samples, except dyed dark, were observed to exhibit a sharp EPR singlet. For dyed dark sample, a weak resonance line also appeared at the right side of the central resonance signal (~346.5 mT) (Fig. 2). As shown in Table 1, the background spectra recorded for hair samples indicated that the g-factor and peak-to-peak line width are color and structure (natural or dyed) dependent.

The origin of the EPR spectra of background human hair is known mainly due to the presence of melanin which is a pigment that determines the color of both human skin and hair (Commoner et al., 1954; Swartz et al., 1972). The characteristic of melanin is the

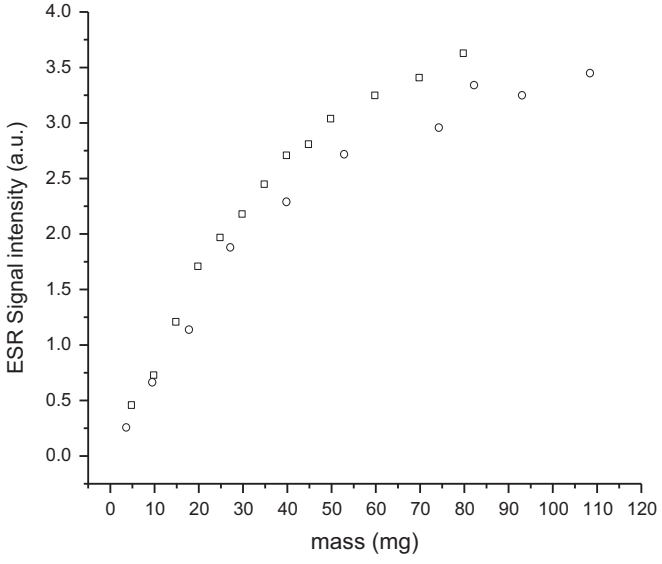

Fig. 1. Variations of ESR signal intensity with sample mass: □ (natural dark); ○ (brown).