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Bone powder as EPR dosimetry system for electron and gamma radiation

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Abstract. In this work bovine bone powder samples were irradiated at three different dose rates of 100, 260 and 630 kGy/min for the absorbed dose range of 3 to 110 kGy, using 10 MeV electron beam radiation. The samples were subjected to EPR measurement at room temperature in air. The variation of EPR signal intensities were constructed and evaluated base on quantitative data related to the absorbed doses. Moreover, they were compared with the obtained results from the samples irradiated by a ^{60}Co gamma-ray source with a dose rate of 2.65 kGy/h. The time and temperature effects on the EPR response of this dosimeter were also studied. The results indicated that the bone sample was a suitable dosimeter especially for electron beam at high doses.

Key words: bone powder dosimeter • EPR response • dose rate • electron beam • gamma ray

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Introduction

Electron paramagnetic resonance spectroscopy (EPR) is an established non-destructive method for the analysis of free radicals. The advantage of this method as a tool for control of irradiated food lies in its high sensitivity and accuracy [6], and, among other applications, EPR is employed in radiation dosimetry [1, 4, 7]. The problems that arise in the application of this technique is how many radiation induced paramagnetic species of the EPR measurements are sufficiently stable, and whether radiation induced long-lived EPR spectra differ in shape from the endogenous (native) EPR signals appearing in a non-irradiated bone [5].

In our previous work, the bovine bone powder and α-1-alanine crystalline powder were irradiated in the same conditions under a ^{60}Co gamma source and the dose value vs. the EPR signal intensity for both kinds of samples were constructed and compared [7]. In this work, a comparison was made of dose rate effect on the EPR responded signal of irradiated samples under electron and gamma rays. Furthermore, the time and temperature effects on the EPR response of this dosimeter were studied as well.

Experimental procedures

Sample preparation

The bovine bone samples were prepared according to the previous work [7] and adapted to the standards [2,

3]. The flesh and fat were removed from the bone as completely as possible by a cutter knife. Next, bone pieces were washed with warm water, to get the bone as clean as possible. In order to remove the bone marrow, the samples were sliced and washed in water. Finally, the bone pieces were crushed using a fraise, and the layer covering the bone was removed and placed in a methanol-ether mixture to dissolve the fat. Then, they were dried for about 3 h at approximately 60°C in an oven, and grounded to a powder form. The grain size of 35–50 mesh was separated.

Sample irradiation

The powder form samples of about 1 g, packed in a plastic package and shaped very thin and placed in a polystyrene phantom were irradiated along with a polystyrene calorimeter to measure accurately the absorbed dose. Irradiation was performed in the dose range from 3 to 110 kGy under different dose rates of 100, 260 and 630 kGy/min, using the 10 MeV electron beam of a Rhodotron TT200 type electron accelerator. Another set of the sample were irradiated using ^{60}Co gamma ray with a 2.65 kGy/h dose rate. To meet the electron equilibrium during irradiation, the samples were put in a cylindrically shaped polystyrene dummy with a wall thickness of 4 mm. Since polystyrene (1.046 g/cm^3) has approximately the same density as water, the dose values acquired became comparable to those of water.

EPR measurement

The samples (about 250 mg) were put into quartz, thin-wall EPR tubes (4 mm in diameter) and measured with a Bruker EMS-104 spectrometer operating in X-band. The EPR spectrometer parameters used for this study were: 0.402 mT modulation amplitude, 100 kHz modulation frequency, 5.0 mT scan width, 1024-point field resolution, 41 ms time constant, 21 s sweep time, 15 dB receiver gain, and 3 number of scans. The microwave power was 3.15 mW. The position of the samples inside the spectrometer cavity (10 mm) was the same for all measurements.

The EPR signal intensities were measured as peak-to-peak height for the most intense EPR lines (first derivative of the absorption spectra as shown in Fig. 1) per sample mass. In order to ensure reproducibility of the EPR signal intensity, the samples were examined at the same instrument settings. For each sample, the mean value from four EPR measurements was calculated and the standard deviation of the mean (SD) was estimated as listed in Table 1.

Results and discussion

To investigate the time effect on the EPR response, the variation of EPR signal intensity of the samples, irradiated at the same dose rate were constructed as a function of dose for different time passages and presented in Fig. 2 (according to Table 1). Figure 3 shows the variation of the EPR signal intensity as a function

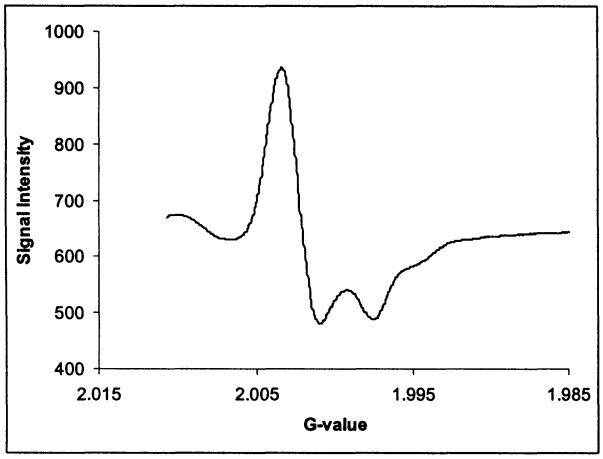

Fig. 1. The EPR signal of the bone powder samples (signal intensity is in arbitrary units).

of time for two sets of heated and unheated samples. The heated samples are those that were put in an oven at 60°C for 1 h after irradiation. The signal intensity for both samples seems to be time-dependent. For the heated samples, it is somewhat stable and decreases slowly with time. For the unheated samples, a rapid fall in early hours after irradiation is observed. After 4 months, the variation of EPR signal intensity for the heated and unheated samples were obtained to be

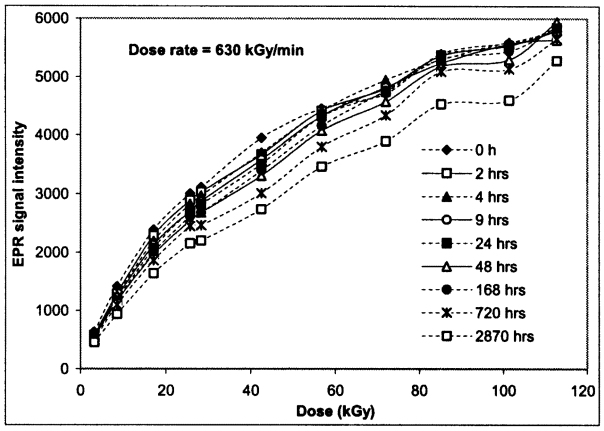

Fig. 2. Response curves of EPR signal of bone powder samples at different time after irradiation under the e-beam.

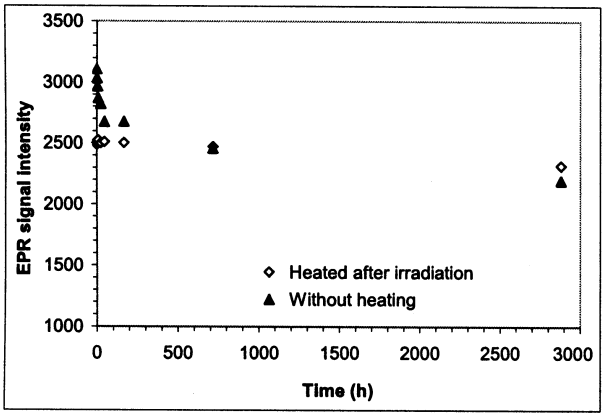

Fig. 3. Variation of EPR signal intensity after 4 months for heated and unheated samples, irradiated at ~29 kGy and 630 kGy/min under e-beam.

Table 1. The EPR measurement results for samples irradiated under electron beam at a dose rate of 630 kGy/min (SI is EPR signal intensity and SD is standard deviation)

Dose (kGy)	Time after irradiation (h)																	
	0		2		4		9		24		48		168		720		2870	
	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD	SI/mg	SD
3	634	18	576	13	566	15	555	8	540	10	545	9	523	15	487	15	450	8
9	1411	41	1287	38	1256	28	1223	15	1172	20	1162	10	1158	22	1092	14	934	15
17	2382	59	2281	17	2191	30	2125	58	2070	19	1958	61	1994	38	1856	70	1636	11
26	3003	423	2890	93	2826	41	2707	14	2705	59	2535	19	2609	55	2442	59	2147	65
28	3108	129	3032	66	2967	97	2870	84	2820	40	2674	39	2676	32	2458	46	2195	31
29*	2513	28	2486	24	2510	23	2524	26	2498	27	2510	24	2503	26	2472	27	2317	26
43	3950	162	3670	108	3696	97	3581	75	3504	91	3305	32	3395	67	3005	98	2733	41
57	4454	126	4415	80	4416	97	4325	84	4316	97	4071	121	4157	96	3798	67	3458	66
72	4706	164	4800	133	4943	114	4820	121	4738	104	4572	38	4762	84	4337	60	3892	54
85	5395	202	5361	209	5294	196	5232	161	5370	243	5173	227	5306	61	5086	70	4529	121
101	5586	50	5535	74	5590	87	5561	53	5534	89	5293	104	5441	139	5132	99	4597	116
113	5791	123	5792	88	5631	97	5642	130	5844	108	5948	176	5838	66	5650	81	5277	146

* Data are related to the heated samples (others are related to the unheated ones).

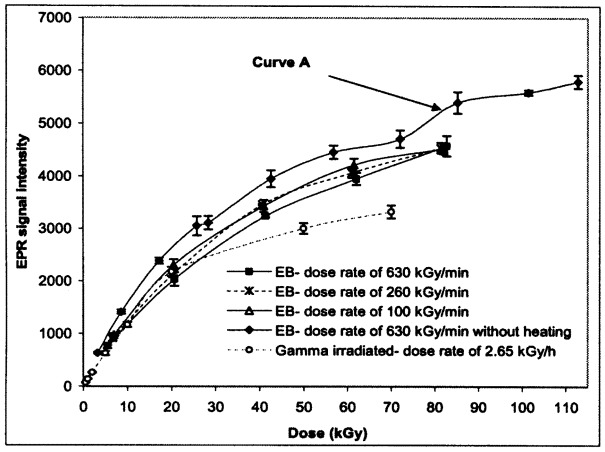

Fig. 4. Response curves of EPR signal of bone powder samples electron-irradiated with different dose rates and gamma--irradiated (the indicated curve A shows the unheated sample results for comparison).

5% and 30%, respectively. Similar behavior has been found for all other samples irradiated with gamma rays and e-beam to different dose rates. This is due to the recombination of the lower leaving radicals in the heated samples.

Figure 4 shows the variation of EPR signal intensity of the bone samples irradiated under the 10 MeV electron beam as a function of dose with various dose rates. All samples were heated in oven in the mentioned conditions, except the one which is indicated as curve A. Moreover, they were compared with the obtained results from the samples exposed to ^{60}Co gamma rays. The results show the same responses for the bone samples irradiated at different dose rates of the e-beam, while the signal of gamma irradiated samples starts to saturate at doses above 20 kGy. This is probably because of the dose rate of gamma rays which, in comparison with the e-beam, is too low. In fact, due to the low dose rate of gamma rays, the formed radicals in a long irradiation time have a chance to diffuse away or have enough time to recombine in the bulk of the sample. Whereas, irradiation under a high dose rate from the applied electron beam occurs in a very short time and thus, the EPR response shows a considerable difference in comparison to the ones irradiated with gamma rays.

Conclusion

The EPR signal intensity of the irradiated bone decreases with time. To improve the stability of EPR response, the irradiated bone powder samples have been subjected to thermal treatment at 60°C. The EPR signals as a function of dose from gamma irradiated samples can be used as a calibration curve for doses below 40 kGy. Whereas, the results related to the electron beam irradiated samples are applicable for higher dose ranges. The bone dosimeter is not sensitive to dose rates in the practical range of industrial electron accelerators. Therefore, it is concluded that the bovine bone sample could be a suitable and readily available dosimeter especially for an electron beam at high doses. This can be practical when the base of bone type was calibrated against the radiation doses.

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