Appl. Radiat. Isot. Vol. 42, No. 7, pp. 617–619, 1991
Int. J. Radiat. Appl. Instrum. Part A
Printed in Great Britain

0883-2889/91 $3.00 + 0.00
Pergamon Press plc

Estimation of the Absorbed Dose in Radiation-processed Food—2. Test of the EPR Response Function by an Exponential Fitting Analysis

M. F. DESROSIERS

Center for Radiation Research, National Institute for Standards and Technology,
Gaithersburg, MD 20899, U.S.A.

(Received 17 October 1990; in revised form 4 December 1990)

The use of electron paramagnetic resonance spectroscopy to accurately evaluate the absorbed dose to radiation-processed bones (and thus meats) is examined. Additive re-irradiation of the bone produces a reproducible dose response function which can be used to evaluate the initial dose by back-extrapolation. It was found that an exponential fit (vs linear or polynomial) to the data provides improved accuracy of the estimated dose. These data as well as the protocol for the additive dose method are presented.

Introduction

Detection and dosimetry of radiation-processed foods is a growing concern to numerous government regulatory agencies worldwide. In response, a sensitive and reliable dosimetry method for meats (containing bone) has been advanced using electron paramagnetic resonance (EPR) spectrometry (Dodd *et al.*, 1988). The method is based on the measurement of stable radiation-induced EPR signals in the bones of irradiated meats. Additive re-irradiation of a bone sample generates a dose response which is used to estimate the initial dose. One of the details of the procedure yet to be established is the proper mathematical expression used to describe the dose response in terms of the EPR signal intensity as a function of the absorbed dose.

In the preceding article, Desrosiers and co-workers examined the use of a linear fit to the EPR response. It was concluded that this approach provided good estimates for bone irradiated at doses below 2 kGy, but inaccurate estimates for doses above 4 kGy. The failure of the method at higher doses was attributed to the trend toward saturation of the EPR response in this dose range. The EPR signal intensity is known to vary with the age of the bone (Gray *et al.*, 1990), and other factors (Ostrowski and Dziedzic-Goclawska, 1982). The EPR saturation characteristics of bone would be expected to vary accordingly. These sample-dependent parameters could be compensated for by using a mathematical function which describes completely the entire dose response. Recent publications applying EPR to the dosimetry of irradiated foods have used linear (Desrosiers and Simic, 1988; Desrosiers, 1989; Gray *et al.*, 1990) and polynomial fits (Dodd *et al.*, 1989) to the response. However, it was demonstrated previously (Houben, 1971) that the EPR response of irradiated bone tissue can be described by an exponential function, namely,

$$S = a[1 - \exp(-bD)], \qquad (1)$$

where the EPR signal intensity, S, is expressed as a function of the dose, D (a and b are constants). Equation (1) would account for the saturation effect observed at the higher doses. In the present study, the use of an exponential fit to estimate the absorbed dose for previously irradiated chicken bones is evaluated.

Experimental*

Gamma-ray doses were delivered at ambient temperature using a ^{60}Co Gammacell 220 (absorbed dose rate in water = 7.5 kGy/h).

EPR spectra were recorded at ambient temperature with a Bruker ESP300 spectrometer. The spectrometer settings were: modulation amplitude 1.6 G,

---

*The mention of commercial products does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

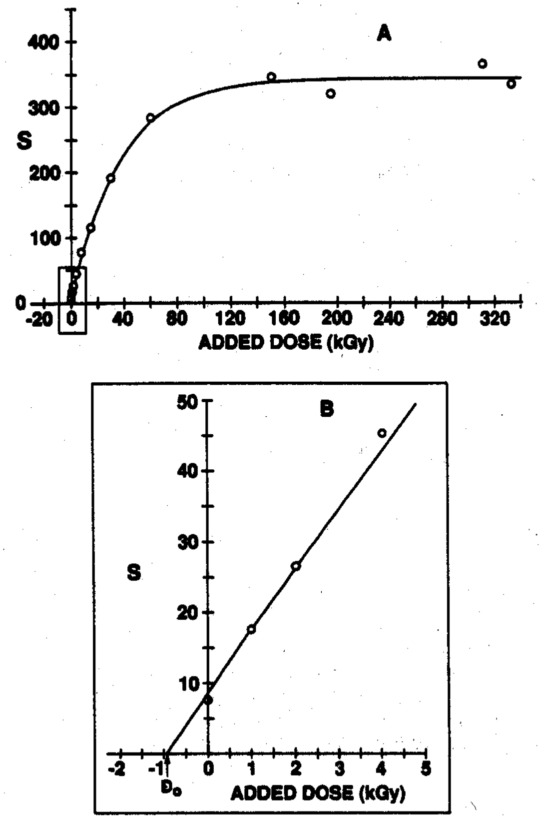

Fig. 1. The amplitude, *S*, of the radiation-induced EPR signal (in relative units) plotted against the added dose (in kGy). The associated curve A is a computer best fit to the data using equation (2) from the text. The boxed region of curve A is expanded in (B) to view the low-dose data and curve, as well as the estimated dose, $D_0 = 0.95$ kGy, obtained by back-extrapolation (actual $D_0 = 1.00$ kGy).

microwave frequency 9.7 GHz, microwave power 1 mW.

Chicken thigh bones from a local market were scraped of excess meat, fractured to expose the marrow and freeze-dried overnight. The bone was again scraped clean of soft tissue and marrow with a metal scalpel. Two bone fragments were cut to approx. 15 mm long by 3 mm wide. On these bone fragments a mark was placed at one end so that it could be configured, oriented, and measured reproducibly in the EPR cavity.

One bone fragment was irradiated to 1.00 kGy and the other to 7.00 kGy. The EPR spectrum of each bone fragment was recorded and the peak-to-peak amplitude of the radiation-induced signal measured (see preceding paper for discussion of spectral features). An additional dose of radiation was administered to each bone fragment and the EPR measurement repeated. For each initial dose the same bone fragment was used throughout. Additive administration of dose to each bone fragment, with measurement of the EPR signal at each interval, continued until the EPR signal intensity appeared to saturate.

Results and Discussion

The saturation of the EPR signal intensity at high absorbed dose (>60 kGy) is clearly evident for the bone fragments, as shown in Figs 1 and 2. This saturation effect is predicted by equation (1). However, to adapt this function to one that can be used for previously irradiated bone tissues, equation (1) would have to be modified to account for the pre-existing EPR signal intensity at zero added dose. Equation (2) was derived for this application

$$S_D = S_\infty[1 - \exp(-(D_0 + D')/D_{37})] \qquad (2)$$

where S_D = EPR signal intensity at dose D; S_∞ = EPR signal intensity at saturation; D_0 = initial dose; D' = added dose; D_{37} = dose at 63% of the saturation value.

When equation (2) is applied to the dose response for the bone fragment irradiated to 1.00 kGy, the function correlates well with the data. When the function is extrapolated to the negative dose axis (abscissa), a reasonably good agreement is obtained between the extrapolated dose value, 0.95 ± 0.70 kGy, and the administered dose of 1.00 kGy.

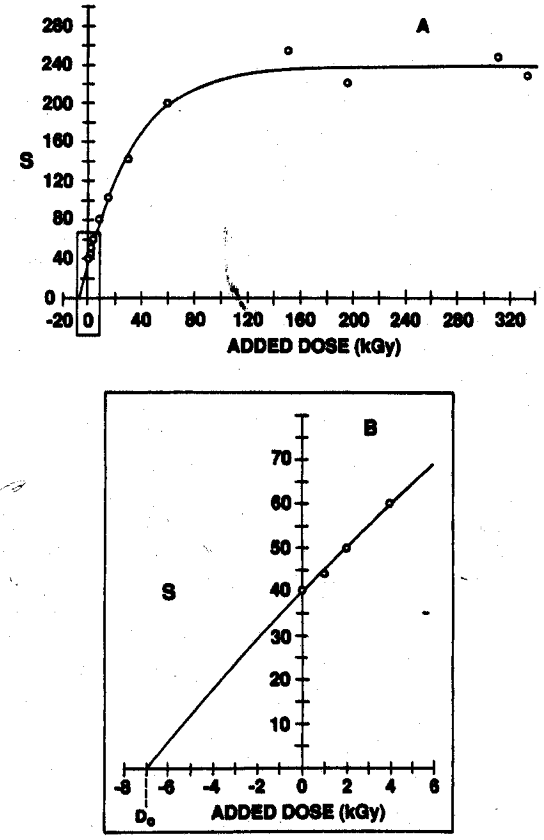

Fig. 2. The amplitude, *S*, of the radiation-induced EPR signal (in relative units) plotted against the added dose (in kGy). The associated curve is a computer best fit to the data ($D_0 = 7.00$ kGy) using equation (2) from the text (actual $D_0 = 7.00$ kGy). The boxed region of curve A is expanded in (B) to view the low-dose data and curve, as well as the estimated dose.

Table 1. Estimated values of D_0 (in kGy) for different mathematical fits to the bone EPR dose response

	Estimated D_0		
D_0	Linear*	Polynomial†	Exponential‡
1.00	0.83 ± 0.55	0.67 ± 0.05	0.95 ± 0.70
7.00	7.78 ± 0.94	5.98 ± 0.35	7.00 ± 1.52

*Data fit to a function of the form $S = aD + b$. Data from 0–4 kGy added dose were used for D_0 estimate. Estimated uncertainty limits are expressed at the 95% confidence level.

†Data fit to a function of the form $S = aD^2 + bD + c$. Data from 0–15 kGy added dose were used for D_0 estimate. Uncertainty limits were determined from the standard deviation of the regression coefficients. These were estimated at the 95% confidence level.

‡Data fit to a function of the form described in equation (2). All data were used for D_0 estimate. Estimated uncertainty limits are expressed at the 95% confidence level.

Furthermore, when the same approach is used to estimate the dose of the 7.00 kGy bone fragment (Fig. 2), the calculated initial dose, 7.00 ± 1.52 kGy, is in excellent agreement with the actual dose of 7.00 kGy. In contrast to the approach used in the preceding publication, where a linear function fails to yield good estimates for bones irradiated >4 kGy, the use of an exponential function accurately assesses the initial dose for bone fragments irradiated to high and low dose (7.00 and 1.00 kGy).

In order to compare the use of different mathematical fits to the observed dose response both linear and polynomial functions were applied to the data. The range of data chosen for each fit was based on the operative dose ranges previously reported for linear (Desrosiers and Simic, 1988) and polynomial (Dodd *et al.*, 1989) functions. The results are summarized in Table 1. Improved estimates of D_0 are given for the linear regression compared to the previous work of Desrosiers and co-workers. This may be due to the use of a bone fragment in the present study vs bone powder in the latter; the same bone fragment reproducibly placed in the EPR cavity and measured throughout the process would not be subject to the sample-to-sample variability of multiple bone powder samples. Polynomial regressions introduced by others to account for a curved dose response give even less acceptable estimates of D_0 in this study. Although reasonable evaluations are supplied by both the linear and polynomial fits, clearly the exponential function, equation (2), best assesses the dose response and the initial dose.

More extensive tests are necessary to verify this approach and confirm that it is applicable to commercial radiation processing conditions. However, recent results of an international blind test involving four laboratories and three different meats (chicken, pork and frog legs) have demonstrated that the method can be applied to different foods successfully (Desrosiers *et al.*, 1990).

References

Desrosiers M. F. (1989) γ-Irradiated seafoods: Identification and dosimetry by electron paramagnetic resonance spectroscopy. *J. Agric. Food Chem.* **37**, 96.

Desrosiers M. F. and Simic M. G. (1988) Postirradiation dosimetry of meat by electron spin resonance spectroscopy of bones. *J. Agric. Food Chem.* **36**, 601.

Desrosiers M. F., McLaughlin W. L., Sheahen L. A., Dodd N. J. F., Lea J. S., Evans J. C., Rowlands C. C., Raffi J. J. and Agnel J.-P. L. (1990) Co-trial on identification and estimates of gamma-ray and electron absorbed doses given to meat and bones. *Int. J. Food Sci. Tech.* **25**, 682.

Dodd N. J. F., Lea J. S. and Swallow A. J. (1988) ESR detection of irradiated food. *Nature, London* **334**, 387.

Dodd N. J. F., Lea J. S. and Swallow A. J. (1989) The ESR detection of irradiated food. *Appl. Radiat. Isot.* **40**, 1211.

Gray R., Stevenson M. H. and Kilpatrick D. J. (1990) The effect of irradiation dose and age of bird on the ESR signal in irradiated chicken drumsticks. *Radiat. Phys. Chem.* **35**, 284.

Houben J. L. (1971) Free radicals produced by ionizing radiation in bone and its constituents. *Int. J. Radiat. Biol.* **20**, 373.

Ostrowski K. and Dziedzic-Goclawska A. (1982) The quality of bone mineral evaluated by the electron spin resonance spectrometry. *Acta Med. Pol.* **23**, 209.