NOWOTWORY Journal of Oncology • 2005 • volume 55
Number 6 • 448–451

In vivo dosimetry in electron beam teletherapy using electron paramagnetic resonance in L-alanine

Katarzyna Schultka[1], Bartłomiej Ciesielski[1], Barbara Wysocka[2]

Aim. The aim of this study was to compare radiation doses measured in vivo with the use of ERP/alanine dosimetry with doses calculated using the CadPlan R.3.1.2 treatment planning system.
Materials and methods. The doses were measured in vivo using electron paramagnetic resonance (EPR) in L-alanine. The detectors consisted of small polyethylene bags filled with crystalline L-alanine. Clinical research was performed on a group of patients undergoing radical and palliative treatment at the Department of Oncology and Radiotherapy of the Medical University of Gdansk. The planned doses were calculated by the CadPlan R.3.1.2 radiotherapy treatment planning system.
Results. The average difference between the measured doses and those calculated by the treatment planning system was, for all 50 fields, 0.6% with a data scatter of 6.3% (standard deviation of a single measurement).
Discussion and conclusions. The results of in vivo dosimetry showed apt concordance between the prescribed and the actually delivered doses. The 0.6% average difference may be considered satisfactory in routine radiotherapy treatment.

Dozymetria *in vivo* w teleterapii wiązkami elektronowymi z wykorzystaniem elektronowego rezonansu paramagnetycznego w L-alaninie

Cel pracy. Celem pracy była ocena dokładności dawek promieniowania podczas teleterapii nowotworów z wykorzystaniem wiązek elektronowych.
Materiały i metody. Pomiarów in vivo dokonano metodą spektroskopii elektronowego rezonansu paramagnetycznego (EPR) w L-alaninie. Badania kliniczne obejmowały grupę pacjentów leczonych radykalnie i paliatywnie w Katedrze i Klinice Onkologii i Radioterapii Akademii Medycznej w Gdańsku. Zastosowano dozymetry w postaci niewielkich saszetek polietylenowych wypełnionych krystaliczną L-alaniną. Porównano wyniki pomiarów in vivo z wartościami dawki planowanej przez komputerowe systemy planowania.
Wyniki. Odchylenie średniej dawki zmierzonej od zaplanowanej wynosiło 0,6%. Odchylenie standardowe pojedynczego pomiaru wynosiło ±6,3%.
Wnioski. Uzyskane wyniki wykazały zgodność między dawkami zmierzonymi a obliczonymi. Średnie odchylenie pomiędzy obydwiema dawkami na poziomie 0,6% można uznać za zadowalająca dla rutynowo prowadzonej radioterapii.

Key words: alanine, EPR, dosimetry, radiotherapy, electron beams
Słowa kluczowe: alanine, EPR, dozymetria, radioterapia, wiązki elektronowe

Introduction

Properties of EPR/alanine dosimetry have been well documented in numerous reports [1-6]. The recent development of experimental techniques has allowed to improve the accuracy and reliability of the method in low-dose regions (0.5-50 Gy). This allows to perform accurate measurements in a range of clinical applications [2-6], such as in phantom dose measurements, external beam therapy or brachytherapy. EPR/alanine dosimetry is characterized by high signal stability, tissue equivalence of energy absorption, flat energy response, applicability to both photon and particle radiation and nondestructive readout which render this technique a useful tool in clinical conditions. Present radiotherapy dosimetric protocols stress the important role of *in vivo* dosimetry to assess the concordance between planned and actually delivered doses. This is an essential issue in radiotherapy and determines the final therapeutic effect of this modality. Discrepancies between prescribed and delivered doses may increase the risk of complications in case of overdosing, or reduce the probability tumor control in case of underdosing. According to ICRU and WHO recommendations [7-8], the acceptable difference

[1] Department of Physics and Biophysics
[2] Department of Oncology and Radiotherapy
Medical University of Gdansk, Poland

between delivered and planned doses is 5%. Such accuracy requires individual treatment planning and verification of the calculated doses by direct *in vivo* measurements.

The aim of the present work was to verify the alanine dosimetry and its accuracy in clinical *in vivo* measurements of single fraction radiotherapy doses in patients treated with high energy electron beams. The measured doses were compared with those calculated using routine computer treatment planning systems.

Material and methods

The detectors consisted of small polyethylene bags (16 x 16 mm, 1-3 mm thick) filled with powdered crystalline L-alanine. They were taped directly to the patients' skin. Some of the detectors were covered by buildup material (0.5-1 cm layer of tissue-equivalent gel) and some measured the "skin dose" directly. The measured one-fraction doses varied from 0.88 Gy to 2.78 Gy. Two detectors measured doses under lead shields. The measurements included doses from the following fields: post mastectomy chest wall irradiation, boost to tumor bed, internal mammary lymph nodes, inguinal lymph nodes and spinal cord.

EPR measurements were performed with Varian E-4 using 1.25 mT modulation amplitude, 5 mW microwave power, 3 s time constant, 16 min scan.

The detector readings were corrected for variations in SSD and converted to the reference dose at the maximum dose point (d_{max}), using experimentally determined "buildup factor" BF (Figure 1). Additionally, the detector readings were corrected to allow for the deviation between the temperature of irradiation and that during calibration procedure, according to a previously described protocol [9]. Due to the variations of the average detector temperature in time, determination of the effective correction factor k(t) was based on the graphical integration shown in Figure 2 [9]. Conversion of the corrected EPR signal

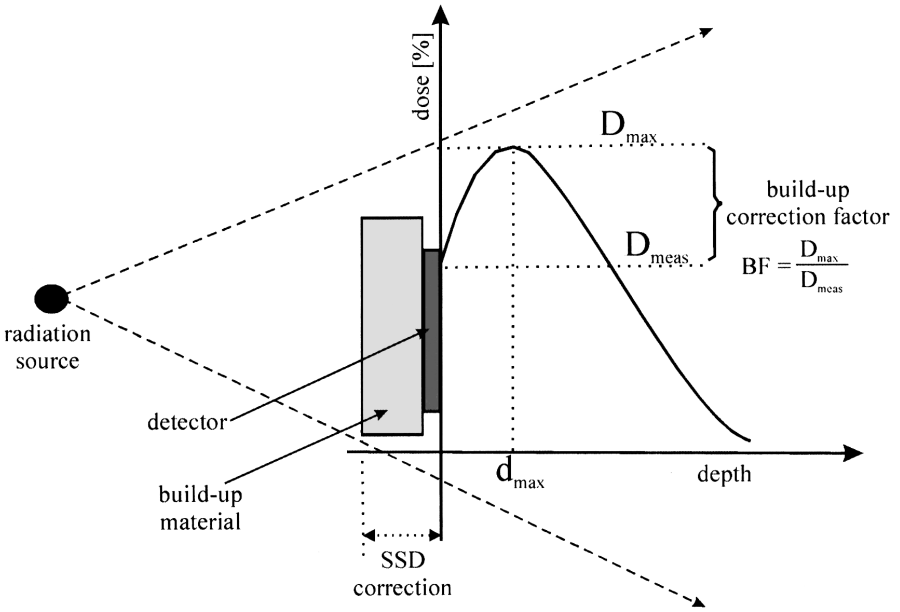

Figure 1. Buildup and SSD correction factors applied in data analysis

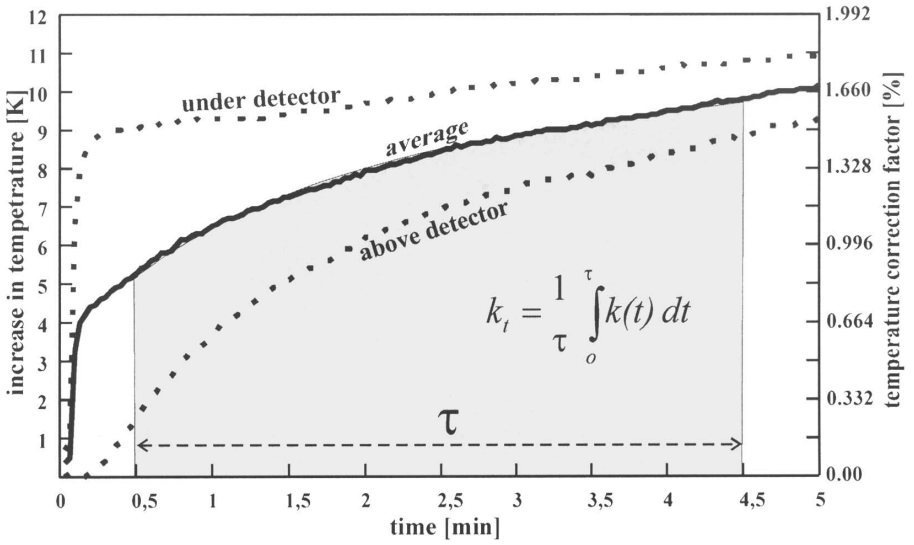

Figure 2. Determination of temperature correction factor k(t) as a function of irradiation time. The detector temperature was assumed to be equal to average of thermocouple readings from probes located below and above the detector attached to patient's skin

Table I. The results of *in vivo* dosimetry. The last row ("Total") shows the data calculated collectively for all 50 fields

Energy	Number of fields	Mean deviation	SD of the mean	Data scatter (SD)
6 MeV	11	+0.3%	1.7%	5.5%
9 MeV	19	+0.5%	1.3%	5.5%
12 MeV	14	-3.4%	2.6%	9.7%
16 MeV	3	-2.5%	3.7%	6.5%
20 MeV	3	+7.9%	2.7%	4.7%
Total	50	+0.6%	0.9%	6.3%

intensity into the absorbed dose was based on calibration of the alanine detectors using ^{60}Co radiation. Due to the differences (1) in radiation quality between the calibration beam and the measured electron beams and (2) in the composition of the alanine detector and tissue, we performed an additional conversion of the measured doses and the final dose was obtained using the following formula:

$$D^{el}_{tissue} = (S/\rho)^{tissue}_{ala} \cdot (\mu/\rho)^{ala}_{water} \cdot D^{ref}_{water} \cdot (I_{el} / I_{ref})$$

where D^{el}_{tissue} is the dose absorbed in tissue material from the electron beam, $(S/\rho)^{tissue}_{ala}$ stands for the ratio of stopping powers of tissue and alanine calculated at the actual electron energy at the measurement point, $(\mu/\rho)^{ala}_{water}$ is the ratio of mass absorption coefficients of alanine and water, D^{ref}_{water} is the dose to water in the calibration setup, and I_{el}/I_{ref} is the ratio of EPR intensities in the detector and in the reference (calibration) sample. The sensitivity of alanine detectors to the dose absorbed from electrons was shown to be constant in the 6-20 MeV energy range [6]. The total accuracy of dose measurements was 3.2%, accounting for the precision of EPR measurements (3%) and the accuracy of the calibration dose (1%). The doses measured *in vivo* were compared with the doses calculated at d_{max} by the CadPlan R.3.1.2 radiotherapy treatment planning system. (Varian INC.).

Results

The measured one-fraction doses varied from 0.88 Gy to 2.78 Gy. The results are given in the table as follows: third column – mean deviation from the planned dose (averaged over all measured fields for given energy), fourth column – the standard deviation of the mean values from third column, fifth column – the scatter of data reflected by the standard deviation of a single data point.

The measurements were performed on 50 fields with +0.6% mean deviation from the RTP dose with a standard error of a mean value of ±0.9%.

Discussion

The presented results confirm the applicability of ERP/alanine dosimetry for *in vivo* monitoring of radiotherapy doses. The observed 3.2% accuracy at the single fraction dose level allows for *in vivo* verification of actual doses within the recommended 5% accuracy limit [7, 8]. This dosimetric method hardly affects the treatment course – the shift in isodose distribution is approximately 1-3 mm, and occurs only in the field region below the detector. The application of the detector prolongs the time for which the patient occupies the therapeutic table by approximately 10 sec. When considering the EPR measurement uncertainty and the scatter of the *in vivo* measured data, the dosimetry did not reveal any systematic variations between the planned and the delivered doses with beam energy (Table I). This observation is concurrent with the previously observed flat energy response of alanine detector in the 4-20 MeV energy range [6]. Despite other sources of deviations, typical to all *in vivo* dosimetric methods (e.g. limited repetition of patient setup), the differences between theoretical and actual doses observed in the course of the study can be attributed to the effects related to nonperpendicular orientation of the beam with regard to the detector plane, which has not been accounted. Measurements of "skin dose" are particularly sensitive to such effects. ERP/alanine dosimetry applied for *in vivo* measurements showed similar quantitative results to other *in vivo* methods; for example, the reported deviations between the calculated doses and those measured with diodes were: in patients undergoing radiation therapy for head and neck cancer – 0.7% with 2.4% SD and in patients with prostate cancer +1.4% with 3.5% SD [10].

Acknowledgements

The authors would like to thank Dariusz Rompa from the Department of Oncology and Radiotherapyof the Medical University of Gdansk, for his help in the in vivo application of detectors and professor Jacek Jassem, M.D, Ph.D. from the Department of Oncology and Radiotherapy of the Medical University of Gdansk, for his helpful comments and suggestions.

Katarzyna Schultka MD
Department of Physics and Biophysics
Medical University of Gdansk,
Dębinki 1, 80-211 Gdansk, Poland
e-mail: kschult@amg.gda.pl

References

1. Regulla DF, Deffner U. Dosimetry by ESR Spectroscopy of alanine. *Int J Appl Radiat Isot* 1982; 33: 1101-14.
2. Olsen KJ, Hansen JW,. Waligórski MPR. ESR dosimetry in calibration intercomparisons with high-energy photons and electrons. *Appl Radiat Isot* 1982; 40: 985-8.
3. Kuntz F, Pabst JY, Delpech JP et al. Alanine-ESR *in vivo* dosimetry: a feasibility study and possible applications. *Appl Radiat Isot* 1996; 47: 1183-8.
4. De Angelis C, Mattacchioni A, Onori S et al. Electron arc therapy treatment planning verification with alanine/EPR dosimetry. *Appl Radiat Isot* 2000; 52: 1203-7.
5. Schaeken B, Scalliet P. One year of experience with alanine dosimetry in radiotherapy. *Appl Radiat Isot* 1996; 47: 1177-82.
6. Ciesielski B, Schultka K, Kobierska A at al. *in vivo* alanine/EPR dosimetry in daily clinical practice: a feasibility study, *Int J Radiation Oncology Biol Phys* 2003; 56: 899-905.

7. CRU Report 24. *Determination of absorbed doses in a patient irradiated by beams of X or gamma rays in radiotherapy procedures*. Washington D.C: International Commission on Radiation Units and Measurements; 1976.
8. WHO, World Health Organization. Quality assurance in radiotherapy. Geneva: WHO; 1988.
9. Schultka K, Ciesielski B, Szewczyk P. *In vivo* dosimetry in ^{60}Co teletherapy using electron paramagnetic resonance in L-alanine, *Nowotwory J Oncol* 2004; 54: 470-3.
10. Malicki J, Kierzkowski J, Kosicka G at al. The dose accuracy during radiotherapy. Ana-lysis of the dose *in-vivo* checks in a group of 700 patients. *Nowotwory J Oncol* 2002; 52: (Supll. 4) 53.

Paper received: 27 June 2005
Accepted: 28 October 2005