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Optical and energy dependent response of the alanine gel solution produced at IPEN to clinical photons and electrons beams

Reações óptica e dependente de energia da solução gel de Alanina produzida no IPEN para fótons clínicos e feixes de elétrons

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Abstract

The DL-Alanine ($C_3H_7NO_2$) is an amino acid tissue equivalent traditionally used as standard dosimetric material in EPR dosimetry. Recently, it has been studied to be applied in gel dosimetry, considering that the addition of Alanine in the Fricke gel solution improves the production of ferric ions radiation induced. The spectrophotometric evaluation technique can be used comparing the two spectrum wavelengths bands: 457 nm band that corresponds to ferrous ions and 588 nm band that corresponds to ferric ions concentration to evaluate the dosimetric properties of this material. The performance of the Alanine gel solution developed at IPEN has been firstly studied using the spectrophotometric technique aiming to apply this material to 3D clinical doses evaluations using MRI technique. In this work, the optical and the energy dependent response of this solution submitted to clinical photons and electrons beams were studied. Different batches of gel solutions were prepared and maintained at low temperature during 12 h to solidification. Before irradiation, the samples were maintained during 1 h at room temperature. The photons and electrons irradiations were carried out using a Varian 2100C Medical Linear Accelerator of the Radiotherapy Department of the Hospital das Clínicas of the University of São Paulo with absorbed doses between 1 and 40 Gy; radiation field of 10 x 10 cm^2; photon energies of 6 MeV and 15 MeV; and electron with energies between 6 and 15 MeV. The obtained results indicate that signal response dependence for clinical photons and electrons beams, to the same doses, for Alanine gel dosimeter is better than 3.6 % (1σ), and the energy dependence response, to the same doses, is better 3% (1σ) for both beams. These results indicate that the same calibration factor can be used and the optical response is energy independent in the studied dose range and clinical photons and electrons beams energies.

Keywords: Alanine, dosimetry, high-energy radiotherapy, instrumentation.

Resumo

A DL-Alanina ($C_3H_7NO_2$) é um tecido de aminoácido equivalente, tradicionalmente utilizado como material dosimétrico padrão em dosimetria por EPR (ressonância paramagnética eletrônica). Recentemente, estuda-se aplicar tal material em dosimetria por gel, considerando que a adição de Alanina na solução Frickle gel melhora a radiação induzida pela produção de íons férricos. A técnica de avaliação espectrofotométrica pode ser usada comparando as duas bandas de comprimentos de onda do espectro: banda de 457 nm que corresponde aos íons férricos e a de 588 nm que corresponde à concentração de íons férricos, para avaliar as propriedades dosimétricas desse material. O desempenho da solução gel de Alanina desenvolvida no IPEN foi primeiramente estudado usando a técnica de espectrofotometria, com o objetivo de aplicar esse material em avaliações de doses clínicas 3D usando a técnica da ressonância magnética. Neste trabalho, as reações óptica e dependente de energia de tal solução, submetida a fótons clínicos e feixes de elétrons, foram estudadas. Diferentes lotes de soluções por gel foram preparados e mantidos em baixa temperatura durante 12 horas para solidificação. Antes da irradiação, as amostras foram mantidas durante 1 hora em temperatura ambiente. As irradiações de fótons e elétrons foram realizadas usando um acelerador linear médico Varian 2100 C do Departamento de Radioterapia do Hospital das Clínicas da Universidade de São Paulo, com doses absorvidas entre 1 e 40 Gy; campo de radiação de 10 x 10 cm^2; energias de fóton de 6 e 15 MeV; e elétron com energias entre 6 e 15 MeV. Os resultados obtidos indicam que a dependência da reação do sinal por fótons clínicos e feixes de elétrons, às mesmas doses, para o dosímetro gel de Alanina é maior do que 3,6% (1σ), e a reação de dependência de energia, às mesmas doses, é maior que 3% (1σ) para ambos os feixes. Tais resultados indicam que o mesmo fator de calibração pode ser utilizado, e a reação óptica é independe de energia na variação da dose estudada e dos fótons clínicos e energias dos feixes de elétrons.

Palavras-chave: Alanina, dosimetria, radioterapia de alta energia, instrumentação, reação óptica.

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Introduction

Nowadays, the three-dimensional mapping of the absorbed dose distribution in the volume of interest has become a very important tool to check if the radiation treatment was properly applied, considering the absorbed dose delivered to the tumor, since with a lower dose the treatment has no effect, and a larger dose puts at risk healthy tissues around the tumor. It is, therefore, extremely important to create techniques that can be used to check the distribution of absorbed dose to the tumor and tissue around it. Among these radiation dosimetry techniques, the gel dosimetry has been largely studied.

The first publication in Gel Dosimetry area was in 1984 by Gore et al[1], when the Fricke solution was incorporated into a gel matrix and this system was combined with magnetic resonance imaging (MRI) to make possible three-dimensional radiation dosimetry. Therewith, it was born the modern gel dosimetry[2]. Gel dosimeters have been studied using different compositions of the dosimetric solution and gel materials such as organic gels or polymer gels[3,4]. The High Dose Laboratory of IPEN developed a alanine gel dosimeter based on the alanine dosimetric solution proposed by Costa[5], using spectrophotometry and electronic paramagnetic resonance (EPR) evaluation techniques, and improved by Mizuno[6] with the addition of gelatin at the dosimetric solution and using spectrophotometry as evaluation technique aiming to obtain a gel dosimeter enable to evaluate 3D dose distribution using MRI technique. The DL-Alanine ($C_3H_7NO_2$) is an amino acid tissue equivalent that improves the production of ferric ions radiation induced, which can be estimated through spectrophotometric technique to measure the ferric ions concentration, aiming to evaluate the dosimetric properties of this material.

Table 1. Chemical composition of Alanine gel solution.

Compound	C (mol/L)
Ferrous Ammonium Sulfate	0.0010
Xylenol	0.0002
Sulfuric Acid	0.2375
DL-Alanine	0.6735
Tri-distilled water	5.5500
Gelatin (300 Bloom)	10 % of the tri- distilled water volume

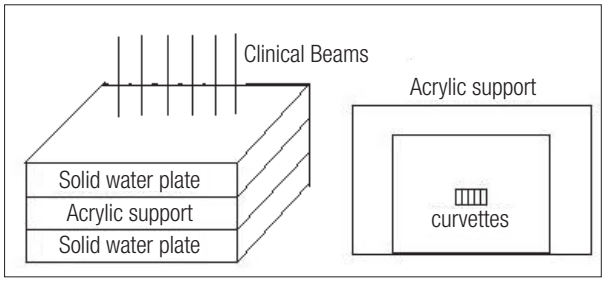

Figure 1. Irradiation set up to photons and electrons irradiations.

In this work, the optical and energy dependent response of this solution submitted to clinical photons and electrons beams were studied, considering that these dosimetric properties are of crucial importance for characterizing and standardizing a dosimetric system[7].

Materials and methods

Alanine gel solution

The dosimetric solution was prepared following the method described by Mizuno[6] using 300 Bloom gelatin. The solution was conditioned in cuvettes 1 cm x 1 cm x 4.5 cm with optical path of 10^{-2} m and maintained at low temperature during 12 h to solidification. Before irradiation, the samples were maintained during 1 h at room temperature. The chemical composition of the dosimetric system is shown in Table 1.

Samples irradiation

The samples were always positioned on a specially designed acrylic support in a solid water RW3 phantom that consists of 30x30x30 cm^3 plates positioned on and under the acrylic support for guaranteeing the desired depth and backscattering conditions, presented in Figure 1.

Photon and electron irradiations

The photons and electrons irradiations were performed using a Varian 2100 C Medical Linear Accelerator of the Radiotherapy Department of the Hospital das Clínicas of the University of São Paulo with doses between 1 and 40 Gy, radiation field of 10x10 cm^2, photon energies of 6 and 15 MeV, electron energies of 6, 9 and 15 MeV, and dose rate of 320 cGy/min.

Each batch was composed of 35 cuvettes filled with gel solution, shared in 7 groups; each group was irradiated with one different dose, except one that was not irradiated, considered as background.

Spectrophotometric evaluation

The optical response (absorbance) was measured using a Shimadzu UV-2101 PC spectrophotometer using the following setup parameters. See the Table 2.

Table 2. Spectrophotometer setup parameters.

Parameters	
Wavelength range (nm)	400 ~ 700
Light source	Tungsten and Deuterium
Slit width (nm)	2
Absorbance (%)	-9.999 ~ +9.999
Transmittance (%)	-999.9 ~ +999.9
Scan speed (nm/min)	1600 (fast and 2 nm interval)
Precision (nm)	0.1

Each presented value is the average of 5 measures, and the error bars are the standard deviation of the mean.

Results

Absorbed dose response

The Alanine gel dose response curves for clinical photon (6 MeV) and electron (6 MeV) beams are showed in Figures 2 and 3 respectively.

Energy response

The Alanine gel energy response curves for clinical photons and electrons beams are showed in Figures 4 and 5 respectively.

Discussion

Dose response

In the dose range studied, between 1 and 40 Gy, the optical response presents a linear behavior for both clinical beams. The optical response to the same doses of the Alanine gel solution for photons and electrons radiation is better than 3.6%, indicating that the sensitivity can be considered independent of the radiation type for the studied energies.

Energy response

The energy response of the Alanine gel solution to the same doses is better than 3% (1σ), indicating that the optical response can be considered independent of beam energy in the studied energy range.

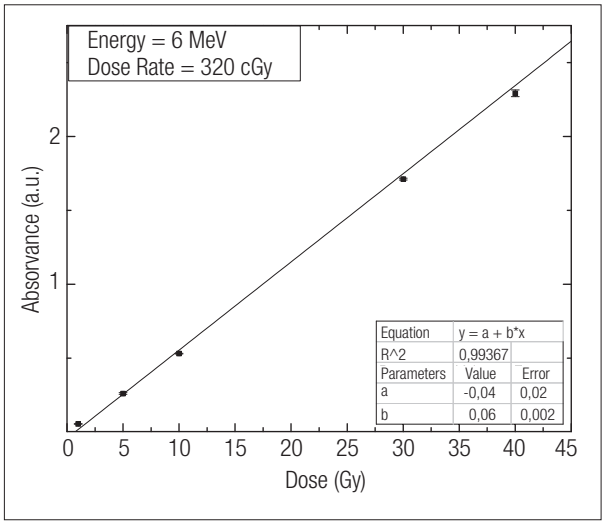

Figure 2. Photon dose response curve of Alanine gel solution.

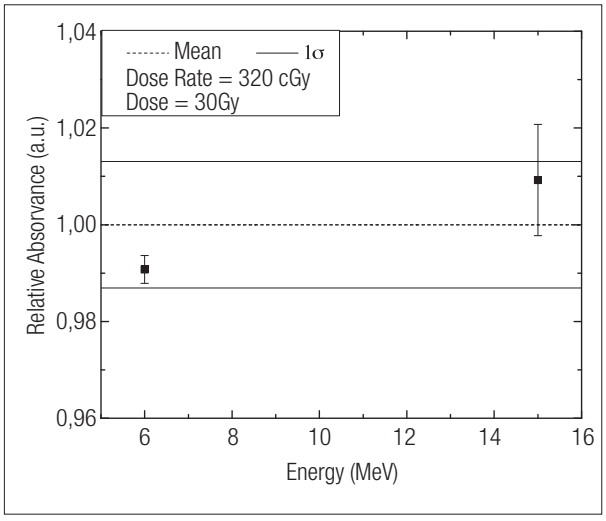

Figure 4. Photon energy response curve of Alanine gel solution.

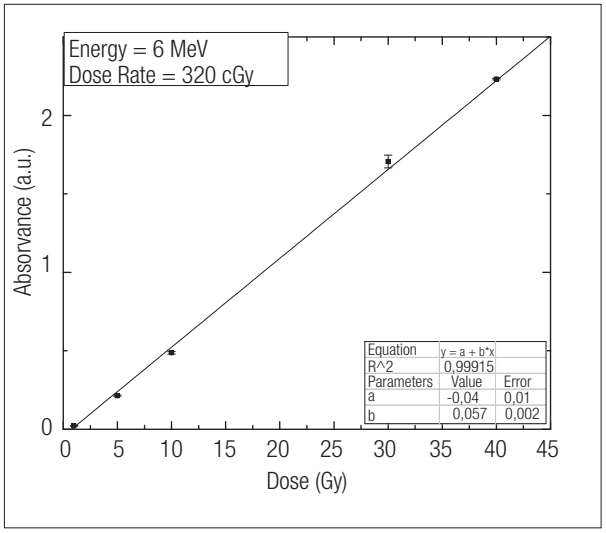

Figure 3. Electron dose response curve of Alanine gel solution.

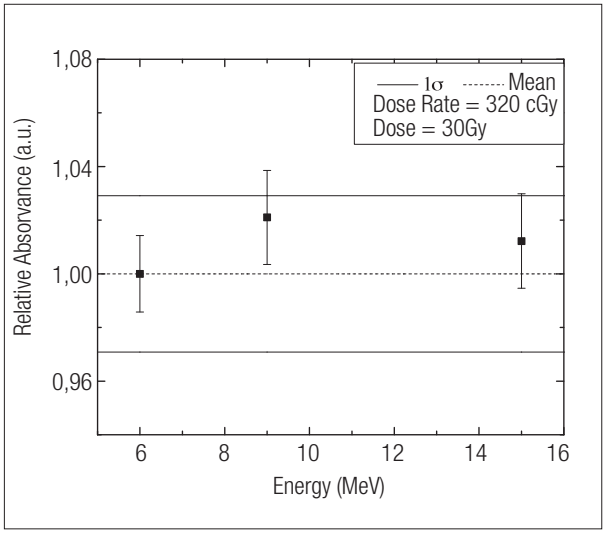

Figure 5. Electron energy response curve of Alanine gel solution.

Conclusions

The obtained results indicate that it is possible to evaluate the absorbed doses for both clinical photons and electrons radiation beams using the same calibration curve for different energies.

The obtained results also indicate that the Alanine gel dosimeter presents good performance and can be useful as dosimeter in the radiotherapy area using MRI technique for 3D dose distribution evaluation.

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