Stability and Influence of Dose Rate in the Signal Response of the Alanine Gel Dosimeter

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Abstract. Nowadays, the three dimensional (3D) dosimetry has been studied by many researchers for application in radiotherapy and radiosurgery treatments, because this kind of dosimeter enable to evaluate the 3D dose distribution. The alanine gel dosimeter was developed at IPEN to be applied to 3D dose evaluations using magnetic resonance imaging. This dosimeter is a gel material based on the transformation of the ferrous ions in ferric ions, which presents significant improvement on previous alanine systems developed by Costa (1994). The DL-Alanine (C$_3$H$_7$NO$_2$) is an amino acid tissue equivalent that improves the production of ferric ions in the solution. The ferric ions concentration can be measured by spectrophotometry technique. This work aims to analyse the stability and influence of the dose rate in the optical signal response of alanine gel dosimeter, since these two properties are very important for characterization and standardization of any dosimeter.

1. Introduction
In current days, an useful tool for the verification of radiation treatments in water-equivalent tissues is the gel dosimetry, because the determination of absorbed dose is very important in the delivered dose quality control to the interest volume. 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 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 (1994) [5] using spectrophotometry and electronic paramagnetic resonance – EPR evaluation techniques and improved by Mizuno (2007) [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. In this dosimeter the production of ferric ions radiation induced in the solution is improved with addition of the alanine and, consequently, the dose response signal is higher than Frick gel dosimeter dose response.

This work aims to analyze the stability and influence of dose rate in the signal response of the alanine dosimeter developed by Mizuno (2007) [5] irradiated with $^{60}$Co gamma radiation, because these dosimetric properties are of crucial importance for characterizing and standardizing a dosimetric system [7]. The concentrations of ferrous ($\text{Fe}^{2+}$) and ferric ($\text{Fe}^{3+}$) ions radiation induced in the dosimetric system were measured by means of spectrophotometry technique.
2. Materials and Methods

2.1 Alanine gel solution
The method described by Mizuno (2007) using 300 Bloom gelatin was followed to prepare the dosimetric solution. The table 1 shows the chemical composition of the studied solution.

After preparation the solution was conditioned in plastic cuvettes ($1 \times 1 \times 4.5 \times 10^{-6} m^3$) and optical path of $10^{-2} m$.

| Table 1: Chemical composition of Alanine gel solution. |
|--------------------------------------------------------|
| Compound C (mol/L)                                      |
| Ferrous Ammonium Sulfate 0.001                          |
| Xylenol 0.0002                                          |
| Sulfuric Acid 0.2375                                    |
| DL-Alanine 0.6735                                       |
| Tri-distilled water 5.55                                |
| Gelatin (300 Bloom) 10 % of the tri- distilled water volume |

2.2 Gamma Irradiation
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 gamma irradiations were performed in air and electronic equilibrium conditions with doses between 0.5 and 50 Gy.

2.3 Spectrophotometric evaluation
According to Gore (1984), the absorbed dose is proportional to the variation on the optical density (OD) given by equation 1:

$$D = \frac{N_A \epsilon}{\rho l G(Fe^{3+}) \epsilon_m} \cdot \frac{OD(D) - OD(0)}{\epsilon_m}$$

where $D$ is the absorbed dose, $G(Fe^{3+})$ is the chemical yield of Fe$^{3+}$ (expressed in ions produced per 100 eV), $\rho$ is the density in kg/L, $N_A$ is Avogadro’s number, $e$ is the number of Joules per electron volt, $l$ is the optical path length (width of the cuvette holding the solution), OD(D) and OD(0) are the optical densities at 585 nm of the irradiated and non-irradiated dosimeter, respectively, and $\epsilon_m$ is the molar extinction coefficient for Fe$^{3+}$ [8].

The optical density was measured using a Shimadzu UV-2101 PC spectrophotometer using the following set up parameters, see the table 2:

| Table 2: Spectrophotometer set up 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 2nm interval) |
| Precision (nm) 0.1                           |
To study the stability the measures were always performed in regular time intervals after irradiation during 25 days, which the alanine gel response presents saturation.

To study the dose rate dependence each batch was composed of 24 cuvettes filled with alanine gel solution, separated in 6 groups; each group was irradiated with same dose (5 Gy) and different dose rates between 21,8 and 250 Gy/h, except one that was not irradiated, considered as reference (background).

The measures were always performed 1 h after irradiation. Each presented value is the average of 5 measures.

3. Results and Discussion

3.1 Dose Rate Response
According to the obtained results, the alanine gel solution presents a dose rate dependence better than 1.8 % (1σ), while the Fricke Gel developed at IPEN presents 10 % (1σ) described by Cavinato [9], indicating that the signal response can be considered independent of the dose rate.

![Figure 1. Dose rate response of alanine gel solution to $^{60}$Co gamma radiation](image1)

![Figure 2. Signal response of alanine gel solution as a function of storage time after irradiation](image2)

3.2 Stability Test
The optical response is stable between approximately 1 to 2 h after irradiation. After this time, it presents an increasing linear behavior until 8th day, a sublinear behavior between 8th and 25th days and saturation in 25th day, see the figure 2. It was considered as day zero the measurement performed two hours after irradiation.

4. Conclusion
It was observed that the optical response is stable between approximately 1 to 2 h after irradiation, so the measures should be performed in this period to obtain reproducible results. After this time, it is necessary to correct the obtained response, while the signal response can be considered dose rate independent. The obtained results 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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