Dose rate response analyses of FXG solution using spectrophotometric technique

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Abstract. The aim of this paper is to investigate the response of FXG solution developed at IPEN as a function of dose rate using 9 MeV electrons from 2 Clinac 2100-C (Varian) accelerators and dose rates of 0.013, 0.027, 0.040, 0.053 and 0.067 Gy/s. Groups of 5 spectrophotometric cuvettes filled with FXG were irradiated in the centre of a 10 x 10 cm^2 field at the depth of maximum dose in the solid water phantom. The dose delivered at the depth of dose maximum was 5 Gy. The irradiations were repeated five times for five different batches in five different days. The cuvettes were evaluated four hours after irradiation by the spectrophotometric technique. Results showed that the absorbance values obtained do not vary more than 1% for the same batch and 2% for different batchs. In other words, the electron dose response of the Fricke gel solution can be considered dose rate independent.

KEYWORDS: Electron Bean; Dose Rate; NMR; Fricke Xylenol Gel; Spectrophotometry.

1. Introduction

The evolution of radiotherapy and the increase in the number of clinical electron beam linear accelerators have encouraged the substitution of low energy radiotherapy and mould brachytherapy that are still being used on Radiotherapy Centres nowadays. Certain new radiotherapeutic procedures require special attention in the treatment planning, what demands the performance of accurate dosimetric mesurements of dose distribution [1].

To possibly deliver a high dose of radiation to the tumor with these new treatments options, while preserving normal surrounding tissues, the development of new dosimetric techniques to evaluate the dose distribution of untypical fields on irregular surfaces is mandatory.

Gel dosimetry gives three-dimensional (3D) information that allows determining the dose distribution on anthropomorphic phantoms [2] [3] [4] [5]. The Fricke Xylenol Gel (FXG) is a chemical tissue equivalent gel dosimeter which is based on the Fe^{2+} to Fe^{3+} transition after irradiation resulting in optical absorbance changes [6]. These measurable changes can be useful for radiotherapic electron beans dosimetry [7]. This material has been mainly studied to gamma dosimetry using ^{60}Co radiation sources in IMRT, gamma knife and conventional radiotherapy. The dosimetric characteristics of FXG solution developed at IPEN to electrons beans were not studied and explained [8].

Previous study [9] shown that the FXG solution presents dose response linear behaviour from 0.2 to 40 Gy of clinical electrons in the energy range from 4 to 15 MeV, the interest dose range of radiotherapy.

The objective of the present work is to determine the dose rate response of FXG solution developed at IPEN using spectrophotometric technique, aiming to use this material for 3D dose distribution evaluation.

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2. Materials and Methods

2.1 FXG Solution Preparation

The FXG solution was prepared with 300 Bloom gelatin and tri-distilled water, at room atmosphere and temperature as described by Bero [10] and Cavinato [11]. The FXG solution was prepared approximately 12h before irradiation and was conditioned on standard spectrophotometric cuvettes (1 x 1 x 4.5 cm^3 with 1 cm of optical length and acrylic wall 1 mm of thick).
Up till 1 h before irradiation the dosimeters were maintained under refrigeration at 6 ºC, being kept at room temperature (20 ºC) and in the dark environment. The chemical composition of the studied solutions is presented at Table 1.

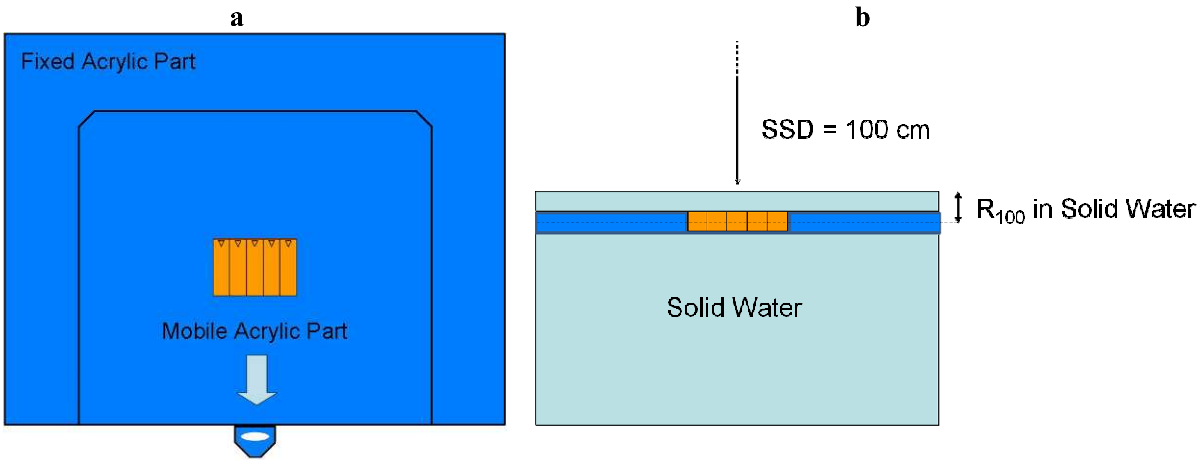
Table 1: Chemical composition of FXG solution

Compound	C (mol/L)
Ferrous Ammonium Sulfate	$1.0\ 10^{-3}$
Sodium chloride	$1.0\ 10^{-3}$
Xylenol	$1.0\ 10^{-4}$
Sulfuric Acid	$5.0\ 10^{-2}$
Tri-distilled water	5,6
Gelatin (300 Bloom)	10 % of the tri-distilled water mass

2.2 Irradiation

The cuvettes were fixed, in groups of 5 per irradiation, in a PMMA mould especially designed to this purpose as shown by **Figure 1a** and **Figure 1b** and positioned in solid water (SW) simulator.

Figure 1: -a Superior view of the acrylic mould with the cuvettes
-b Horizontal slice of irradiation setup



The irradiation setup agrees with the recommendation of IAEA-TRS398 [12] for dosimetry on SW simulator excepting that the center of the cuvettes be placed at depth dose maximum (R_{100}).
Two Clinac 2100-C (Varian) accelerators, from Hospital das Clínicas/SP and Hospital A. C. Camargo, were used to generate the 9 MeV electrons beans. The available dose rates were 0.013, 0.027, 0.040, 0.053 and 0.067 Gy/s (80, 160, 240, 300 and 400 monitor units (M.U.) per minute respectively). All cuvettes groups were irradiated with electron dose of 5 Gy (500 M.U.).
The irradiations were repeated five times for five different batches in five different days.

2.4 Dosimeter Assessment System

The optical densities at 585 nm band before (OD(D)) and after (OD(0)) irradiation was used to evaluate the absorbed dose at FXG solution [13].

The absorbed dose is given by [14]:

$$D = \frac{N_A . e}{\rho . l . G(Fe^{3+})} . \frac{OD(D) - OD(0)}{\varepsilon_m} \quad (1)$$

where D is the absorbed dose, $G(Fe^{3+})$ is the chemical yield of Fe^{3+} (expressed in ions produced per 100 eV), ρ 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), and ε_m is the molar extinction coefficient for Fe^{3+}.
Is more practice to use a calibration curve to determine a unknowing dose at a dosimeter from the same batch than determine the chemical yield $G(Fe^{3+})$ to each batch [6], considering that the variation on the optical densities is proportional to the absorbed dose.
The optical absorption values were measured using a spectrophometer Shimadzu UV-2101PC, using the setup parameters presented at 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

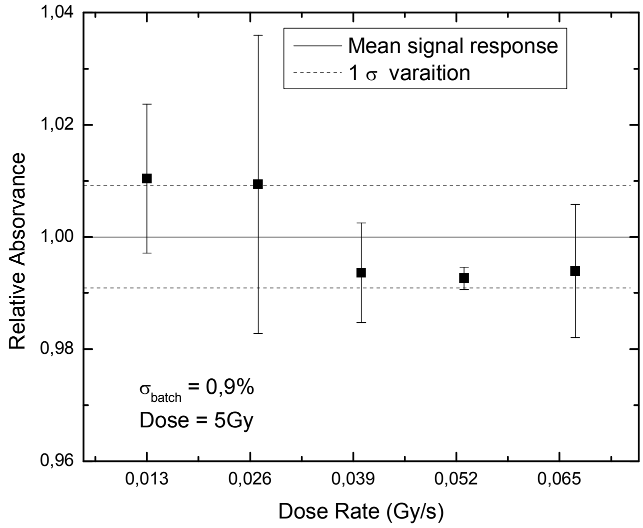
2.5 Dosimetric System

In the present work the dosimetric system was considered as not only the sensitive material (constituted by FXG solution + cuvettes) but also the assessment system.
Each presented value is the average of 25 cuvettes (5 cuvettes in each 5 irradiation per dose rate) and the error bars the standard deviation of the mean.

3. Results and Discussion

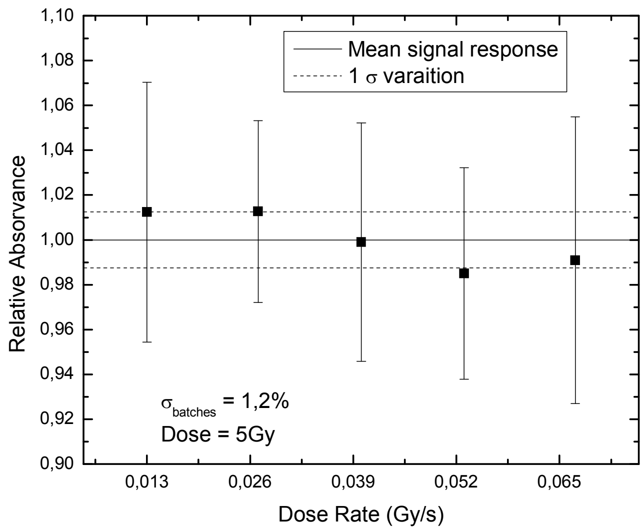
All obtained absorbance values were normalized to the mean absorbance from analysed data.
The dosimeter response, relative to the mean signal to each group of 5 cuvettes, as a function of the dose rate to FXG solution due to electron radiation in a same batch is shown by **Figure 2**.

Figure 2: Dose rate optical response of same batch FXG solution irradiated with 9 MeV electron beam



The optical response (absorbance) of samples of the same batch do not presents significant dose rate dependence, considering the imprecision on measurements, but a tendency of reducing the signal when the dose rate increases was noted.

Figure 3: Dose rate optical response of FXG solution irradiated with 9 MeV electron beam of different solution batches



It can be observed that the FXG solution does not present significant dose rate dependence. A significant increase of uncertainness was observed, it may be explained due to the low reproducibility of chemical dosimeters [6] and due to the use of 2 accelerators, that presents a small differences on setup position, effective energy and dose rate.

4. Conclusion

The FXG dosimetric system presents dose rate independence behaviour to 9 MeV electron beam to dose rates between 0,013 and 0,067 Gy/s, considering the uncertain. These results can be improved by improving and standardizing the preparation method to electron measurement.
This results indicate that FXG solutions can be used to electron 3D dose distribution using MRI technique.

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