

Characteristics of modified radiochromic gel Turnbull-Blue

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Abstract. This work presents a dosimetric characterization of the modified radiochromic gel Turnbull-Blue (TB). Formaldehyde a cross-link agent was added to the composition. This modification raised the melting point of agarose gel to 55°C, 22°C above the agarose gel matrix. For this new gel formulation the energy, dose-rate dependence and Diffusion coefficient were verified. The modified TB gel showed higher sensitivity in the 6 MV than 15 MV beam. Dose rate dependence was evaluated from 100 to 500 cGy/min using a 15MV linear accelerator. The results show variations in sensitivity for dose rate dependence. The addition of formaldehyde does not affects the diffusion coefficient for the modified Turnbull-Blue.

1. Introduction

Turnbull-Blue is a radiochromic gel proposed by Solc and Spevacek, it is a gel with low diffusion rate [1] that can be used to perform tridimensional dosimetry [2]. This gel is based on the formation of the Turnbull-Blue (TB) compound when submitted to radiation. The gelatin matrix of TB gel is filled with a ferric salt and potassium ferricyanide. Upon radiation water radiolysis reduces the ferric ions to ferrous ions, which reacts with potassium ferricyanide forming TB complex [3].

Gelling matrices usually have a low melting point what could compromise the use of some gels. Porcine gelatin and agarose matrix have a temperature of 25°C and 33°C of melting point, respectively. In warm environments these kind of gel matrix start to melt and the irradiated gel loses tridimensional dose distribution information. To solve this problem in gel matrix our group proposed the addition of a cross-link agent to the gel matrix. In a previous work the addition of formaldehyde to MAGIC gel [4] formulation increase the dosimeter melting point to 69°C [5, 6]. The new formulation was named MAGIC-f and several studies were performed aiming clinical QA applications [9-11]. Following the same rationale, this work added formaldehyde to the TB's agarose gelling matrix. The cross-linking of agarose and formaldehyde resulted in an increase of the melting point, which allowed us to perform gel dosimetry using the radiochromic TB gel. The aim of this work is the modified TB gel characterization by measuring its, absorbance peak, energy dependence, dose-rate dependence and diffusion coefficient.

2. Materials and Methods

2.1 Gel Preparation and storage

Gel preparation follow the same steps proposed by Solc [7]. It starts with the agarose powder (Uniscience® - electrophoresis agarose) added to water. The solution is heated to 92°C ± 2°C, the fixation point of agarose to dissolution, under continuous stirring. The solution was cooled down to



40°C, when, ferrous chloride solution and potassium ferricyanide were added. After homogenization, formaldehyde was added. Table 1 shows modified turnbull-blue compounds. Gel solution was storage into plastic cuvettes of 1.0 x 1.0 x 5 cm³ and stored in to refrigerator at 5°C for 12 hours. The original TB formulation was also prepared, but it melted so fast that was not possible to use it for comparison with the modified TB gel.

Table 1. Modified Turnbull-Blue Compounds

Mili-Q water	93.4 w/w%
Agarose	0.6 w/w%
Potassium ferricyanide	1.0 w/w%
Ferrous Chloride solution	1.0 w/w%
Formaldehyde	4.0 w/w%

2.2 Gel Irradiation

Irradiations were performed at Radiotherapy Service of the Hospital das Clinicas de Ribeirão Preto, FMRP - University of São Paulo using a dual energy selection, 6MV and a 15MV, linear accelerator Siemens ONCOR Impression Plus linear accelerator. A SSD of 100 cm was used and the gel dosimeter were irradiated at the depth of the maximum doses. To guarantee the necessary buildup and backscattering for both energies acrylic plates were used. Doses of 3, 6, 9, 12 and 15 Gy were delivered to evaluate the energy dependence with the 6 MV and 15 MV beams. To evaluated dose rate dependence, the same doses were delivered with the 15 MV beam using, 100, 200, 300, 400 and 500 cGy/min.

2.3 Gel scanning.

Optical absorbance measurements were performed few hours after the irradiation process using an Utrospec 2100 pro spectrophotometer. The absorbance of the gel samples scanning band selected were 530 nm to 900 nm for the modified Turnbull-blue samples. Plastic cuvettes of 1cm of optical path were used.

2.4 Diffusion measurements

Gel diffusion measurements were performed in a HP scanner 3707 using an imaging acrylic cuvette, specially constructed to fit the scanner with 1mm of optical path and (5 x 10 cm²) of area. This cuvette was irradiated with a nominal dose of 18Gy by a 50kv x-ray tube at 5 cm of distance of the tube. The diffusion coefficient was evaluated using the Kron method, [8] for TB gel, described in solc and Spevacek 2009 [1].

3. Results and Discussion

3.1 Absorbance peak

The absorption peak for modified Turnbull-blue gel is around 740 to 750nm (figure 1a), this value differs from the original formulation, that presents the absorption peak at 690 nm [7]. However in this work formulation the molar concentration of potassium ferricyanide and ferrous chloride were increase, both to 1mM and that change the absorption peak.

The gaussian fit analysis, $y = y_0 + A \cdot \sqrt{(2/\pi)/w} \cdot e^{(-2 \cdot ((x-x_c)/w)^2)}$, shows a $R^2=0.99$ in all samples plot, y is the absorbance, A is the Area, w the width, x is the wavelength, x_c is the wavelength center. Figure 1b presents the polynomial behavior of the wavelength peak in function of the absorbed dose. The displacement of the wavelength absorption peak as a function of dose, shows absorption peak is dose-dependent with a polynomial function $\lambda = 739.4 + 149.17D - 324.49.D^2$, with Pearson's correlation coefficient $R^2 = 0.99$, where λ is the wavelength and D is the absorbed dose. This wavelength displacement is according with the Turnbull-blue complex formation. The non-irradiated gel is yellow,

upon radiation changes to green and blue, so the when irradiated gel changes the absorption peak in the red visible spectra wavelength region.

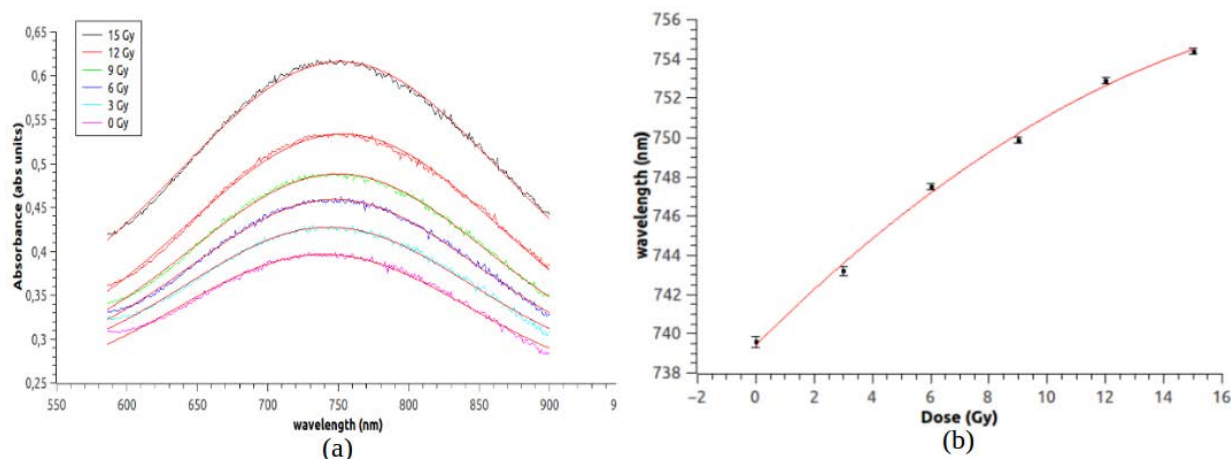


Figure 1. (a) Absorption spectra of modified TB gel. Irradiated samples 0 to 15 Gy, steps of 3 Gy in a 6 MV beam. (b) Wavelength absorption peak in function of the absorbed dose.

3.2 Energy and dose rate dependence

Figure 2a shows the energy dependence for the two calibration curves achieved when irradiating the dosimeters with 6 MV and 15 MV beams.

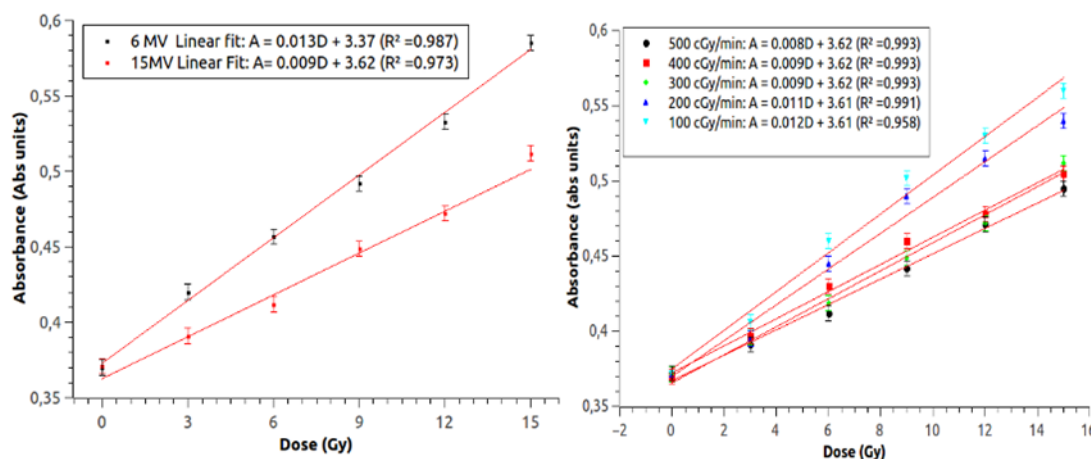


Figure 2. (a) Energy comparison between 6 MV and 15 MV beams. (b) Dose Rate comparison from 15 MV beam, from 100 cGy/min to 500 cGy/min.

The absorbance of the modified TB gel show linear behavior with dose for both energies, but an energy dependence was found with a higher sensitivity for the 6 MV, ($S = 0.013 \text{ abs.Gy}^{-1}$) than for the 15 M beam, ($0.009 \text{ abs.Gy}^{-1}$), corresponding to an absolute difference of 0.004. Figure 2b shows the dose rate dependence of the modified TB gel. The gel shows dose rate dependence, differing 33% in the sensibility, when varying the dose rate from 100 cGy/min to 500cGy/min, 0.008 and $0.012 \text{ abs.Gy}^{-1}$. However, considering only the range of 300 cGy/min to 500 cGy/min, the dose rate dependence is much smaller, varying 12.5% for the sensitivity of the modified TB gel.

3.3 Diffusion measurements

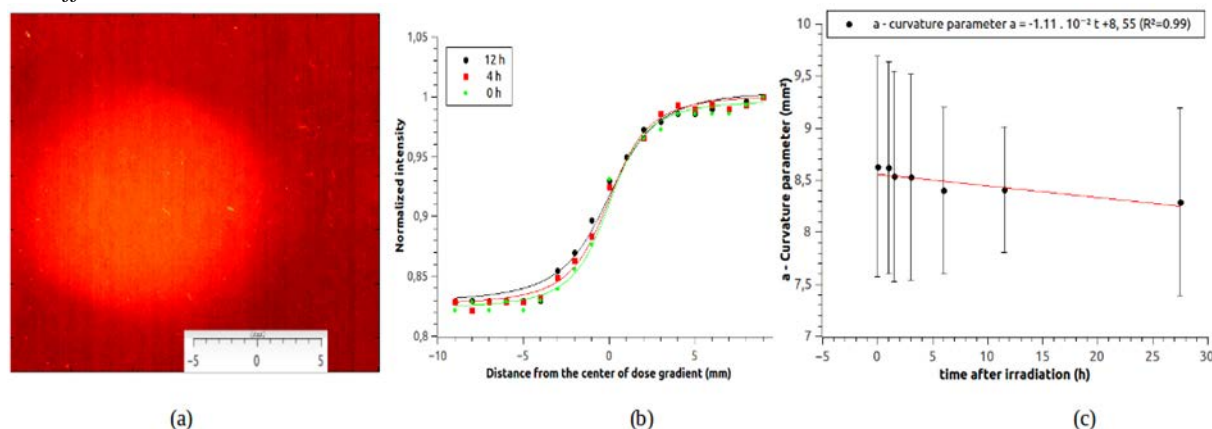


Figure 3. (a) Image of the cuvette containing the gel irradiated with a dose of 18Gy by a 50kV x-ray source. (b) Normalized intensity profile distance from center of gradient dose. (c) Curvature parameter function of time after irradiation.

Figure 3 show the measurements for the evaluation of diffusion coefficient. Figure 3a show the irradiated gel with a dose of 18 Gy in a 50kv x-ray source. Fitting the normalized intensity (figure 3b) in profile along 10 mm (range of -5mm to 5mm), as shown by a scale in figure 3a, using the inverse of square root function (ISQR) described in [1], it is possible to determinate $a(t)$ parameter. The graph in figure 3c evaluated the slope as a function of parameter $a(t)$, $a = -1.11 \times 10^{-2} t + 8.55$ is used to determinate the diffusion coefficient D , by the formula $D = 0.2119 \cdot a/t$, resulting in $D = 2.3 \times 10^{-3} \text{ mm}^2 \cdot \text{h}^{-1}$. This diffusion coefficient corresponds to the same evaluated in the original TB formulation [1, 7], meaning that the addition formaldehyde does not compromise the diffusion effects in the TB gel dosimeter.

4. Conclusions

The present work shows some important dosimetric properties of the modified TB gel dosimeter. The addition of formaldehyde to Turnbull-blue gel dosimeter increased its melting point to 55°C. The displacement of the wavelength absorption peak shows a dependence of the wavelength peak with the absorbed dose. The gel shows a higher sensitivity for a 6 MV beam than 15 MV beam and varying 12.5% in sensitivity of dose rate dependence from when varying from 300cGy/min to 500 cGy/min. The evaluation of diffusion coefficient [12] shows the same result that the original TB formulation, therefore the addition of formaldehyde does not affect the diffusion in the dosimeter. The results in this work shows the dosimetric characteristics of the modified TB gel and gel behavior seems promising to perform tridimensional dosimetry.

5. References

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