2024 International Nuclear Atlantic Conference – INAC 2024
Escola de Guerra Naval, Rio de Janeiro, RJ, May 6 - 10, 2024

ISBN: 978-65-594-1256-3

Optical Computed Tomography for Chemical Dosimetry with Fricke Xylenol Gel

Tavares, P.V.S. , Diniz, R.E., Rodrigues Jr, O. and Campos, L. L.

paulo.tavares@ipen.br, Radiation Metrology Center, Institute of Energetic and Nuclear Research
Av. Prof. Lineu Prestes,2242 – Cidade Universitária, São Paulo – SP, Brazil

1. Introduction

The three-dimensional dosimeter with Fricke solution was conceptualized in the 1980s by Gore et al. by adding a gel matrix to this solution to maintain its structure and reduce information loss due to diffusion [1]. The Fricke solution is a reference in chemical dosimetry that operates by analyzing the concentration of ferric ions (Fe3+) resulting from the oxidation reaction related to the absorbed dose by the material. The Fricke solution is initially composed of ferrous ions (Fe2+) [2]. To enable other methods of analysis, the addition of the xylenol orange ligand, a metal indicator, allows the Fricke gel solution to be evaluated through optical analysis. The binding of Fe3+ forms an FXO complex that enables analysis of a specific wavelength of the solution proportional to the concentration of Fe3+ ions [3]. Innovations in radiotherapy techniques aim to administer the dose in a conformal manner, reducing exposure to surrounding healthy tissues. To achieve this goal, a complex dosimetry system capable of providing dose results with a specific volume is essential [4]. One approach to analyzing the irradiated Fricke dosimeter is through optical computed tomography. Images are generated based on the variation in attenuation before and after irradiation. The application of mathematical algorithms for inverse problems is used to reconstruct the obtained images. These reconstructions enable the analysis of volumes of interest in the solution, correlating the attenuation variation with the deposited dose in the material [5]. This study presents the methodology and initial findings of the characterization of the Optical CT technique for a modified Fricke Xilenol Solution. The experiment involved irradiating FXG solution using a Gammacell source and a Theratron 780c system, both with a ^{60}Co source. Results involved analysis of the reconstruction image which is made by attenuation values of the difference before and after irradiation. To assess the impact of irradiation on attenuation and its correlation with dose lead filters were employed to induce radiation attenuation. This approach allows for discerning differences among regions within the irradiated volume, potentially informing the application of analysis in radiation therapy protocols involving irradiated volumes.

2. Methodology

For the preparation of the Fricke Xylenol gel solution, the following reagents are used: porcine gelatin, 270 Bloom (food grade) obtained from Gelita, Brazil; sulfuric acid (H_2SO_4) pro-analysis (PA) obtained from Merck; sodium chloride (NaCl) pro-analysis (PA) obtained from Merck; Mohr's salt / Ferrous ammonium sulfate $Fe(NH_4)_2(SO_4)_26H_2O$) pro-analysis (PA) obtained from Merck; xylenol orange ($C_{31}H_{28}N_2Na_4O_{17}S$) pro-analysis (PA) obtained from Merck. The first step of the experiment focused on characterizing the Optical CT system to confirm its appropriateness for use. Prior research on the Optical CT system identified artifacts stemming from the initial high attenuation value of the solution, leading to difficulties in analyzing the reconstruction images [6]. This problem is particularly common in radiochromic gels, resulting in a distinct artifact referred to as the cupping artifact [7]. After preparation, the solution is placed in a bottle with a diameter of 5 cm and a height of 7 cm and is kept refrigerated (4ºC ± 1°C) for 20 hours until the time of irradiation. Ten bottles of the solution were prepared, and they were irradiated using a Gammacell apparatus with a ^{60}Co source located at the Radiation Technology Center. The solutions were irradiated with doses from 1 to 10 Gy at intervals of 1 Gy. A characteristic of the Gammacell source is its ability to irradiate the entire solution, providing an effective method for detecting and verifying issues associated with artifacts in reconstructed images. After irradiation optical tomography analyses were conducted using the Vista 16 equipment (ModusQA) located in the High Dose Laboratory at the Radiation Metrology Center. The second part of the work was to irradiate the solution in a teletherapy equipment Theratron 780c system, located in the Instrument Calibration Laboratory. The FXG solution was placed inside a water phantom of 30 cm x 30 cm x 30 cm dimensions. Three flasks of the solution were irradiated with a dose of 5 Gy. Lead filters (14 mm diameter) were utilized in two flasks and the third flask without lead filters. In the first flask, the lead filters have central holes of 0.1 mm diameter, and it used 7 cm, 5 cm, and 2 cm of lead thickness. The lead filters in the second flask do not have holes and used 7 cm, 5 cm, and 2 cm of lead thickness.

3. Results and Discussion

A Python script was developed to facilitate visualization, generating a colormap. The initial results are showcased in Figure 1, displaying the reconstructed images of the FXG solution after irradiation in Gammacell. Notably, there is a visible increase in the attenuation depending on the increase in dose. The image displays transversal slices of the reconstruction, demonstrating the absence of any artifacts.

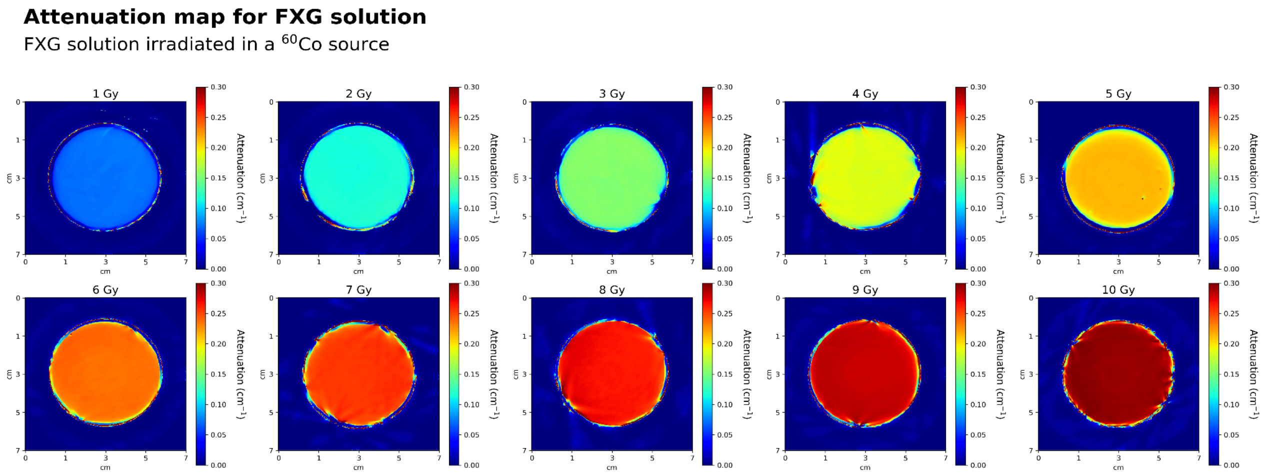

Figure 1: Slices Z of the reconstruction images of FXG solution with respective attenuation as colormap.

The Optical CT system produces images showing attenuation values after Theratron 780c irradiation. Correlating attenuation with dose allows representation in percentage values. Figure 2 shows the coronal slice of the gel.

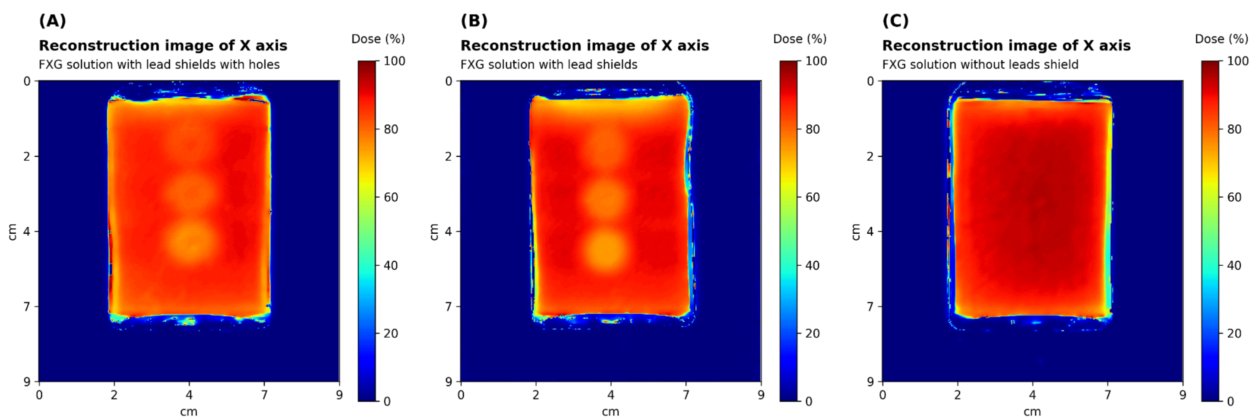

Figure 2: Reconstruction images of the X-axis. A) The FXG solution with 5, 7, and 9 mm lead filters with 0.1 mm central hole; (B) The FXG solution with 5, 7, and 9 mm lead filters without hole; (C) The FXG solution without lead filters.

The regions where the lead filters were placed in each FXG flask are evident. Figure 2.A shows a prominent dot with a high percentage dose value at the center of the lead filter. Figure 2.B clearly illustrates the fluctuating percentage dose relative to the thickness of each lead filter. Additionally, Figure 2.C indicates that the radiation field irradiated all flasks.

4. Conclusions

In conclusion, this study demonstrates the efficacy of the Optical CT system in characterizing radiation-induced attenuation in FXG solutions. The methodology employed, including irradiation with Gammacell and teletherapy apparatuses, combined with optical tomography analyses, provided valuable results into attenuation patterns and the effects of lead shielding. These initial findings show the potential of Optical CT analysis for further research in radiation 3D dosimetry for radiation therapy protocols and quality assurance measures. Future research will investigate the mechanisms of Optical CT analysis in FXG solutions and their clinical applications.

Acknowledgments

Acknowledgments to the funding agencies FAPESP under process number 2017/50332-0, CAPES under process number 88887.704665/2022-00, and CNEN for supporting this project and providing scholarships.

References

[1] Schulz, R. J., A. F. deGuzman, D. B. Nguyen, and J. C. Gore. “Dose-Response Curves for Fricke-Infused Agarose Gels as Obtained by Nuclear Magnetic Resonance.” Physics in Medicine & Biology 35, no. 12 (1990)

[2] Macchione, Micaela A., Sofía Lechón Páez, Miriam C. Strumia, Mauro Valente, and Facundo Mattea. “Chemical Overview of Gel Dosimetry Systems: A Comprehensive Review.” Gels 8, no. 10 (2022)

[3] Olding, T., G. Salomons, J. Darko, and L. J. Schreiner. “A Practical Use for FXG Gel Dosimetry.” Journal of Physics: Conference Series 250, no. 1 (2010)

[4] Rousseau, Alice, Christel Stien, Jean-Marc Bordy, and Valentin Blideanu. “Fricke-Xylenol Orange-Gelatin Gel Characterization with Dual Wavelength Cone-Beam Optical CT Scanner for Applications in Stereotactic and Dynamic Radiotherapy.” Physica Medica 97, pp. 1–12 (2022).

[5] Tavares, Paulo Victor dos Santos. “Padronização do dosímetro Fricke gel aplicado em dosimetria 3D em radioterapia utilizando um CT óptico.” Dissertação, Universidade de São Paulo (2021).

[6] Kelly, R. G., K. J. Jordan, and J. J. Battista. “Optical CT Reconstruction of 3D Dose Distributions Using the Ferrous–Benzoic–Xylenol (FBX) Gel Dosimeter.” Medical Physics 25, no. 9 (1998)

[7] Takanashi, Takaoki, Kazuya Hayashi, Mikio Nemoto, Hiraku Kawamura, Shin-Ichiro Hayashi, and Hiroaki Gotoh. “Cause of Cupping Artifacts from Radiochromic Micelle Gel Dosimeters Used in Optical CT Scanner Measurement.” Journal of Physics: Conference Series 1305, no. 1 (2019)