Comparative Study of the 3DCRT Dosimetric Response of Head Fricke Xylenol Gel Phantoms with and without Human Bone

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Abstract—In this preliminary comparative study, the dosimetric response of two different head Fricke xylenol gel (FXG) phantoms, with and without human bone, prepared using 270 Bloom gelatin and irradiated with 6 MV photon beams using 3DCRT treatment, were evaluated employing magnetic resonance imaging (MRI) technique, in order to verify the difference of ionizing radiation absorption in head phantom due to the presence of human skull, to make a more reliable dosimetry. This study presents good results for 6 MV photons and 3DCRT treatment technique and no significant influence was observed due to the human skull presence. The obtained results encourage future studies using other complex treatment techniques, such as IMRT.

Index Terms—Clinical photon beams, FXG phantom, magnetic resonance imaging, three-dimensional conformal radiotherapy.

I. INTRODUCTION

An failure in treatment planning for head tumors may result in intellectual impairment of the patient or drastically affect the functionality of other body parts [1]-[4]. That is why, increasingly, studies are carried out to maximize the effect of radiation on the tumor and minimize damage surrounding tissues. Complex radiation treatment techniques, such as three-dimensional conformal radiation therapy (3DCRT) and intensity modulated radiation therapy (IMRT), are used for this purpose [5], [6]. The greater the complexity of the treatment technique, the more accurate should be the quality control of treatment planning, and for this application, different dosimetric systems have been studied [7]-[9].

In this comparative study, the dosimetric response of two different head Fricke xylenol gel (FXG) phantoms, with and without human bone, prepared using 270 Bloom gelatin from porcine skin (made in Brazil) and irradiated with 6 MV photon beams using 3DCRT treatment technique, were evaluated employing magnetic resonance imaging (MRI) evaluation technique, in order to verify the difference of ionizing radiation absorption in head phantom due to the presence of human skull, to make a more reliable dosimetry.

II. MATERIALS AND METHODS

A. FXG Solutions Preparation

The FXG solutions were prepared as in [10], at High Doses Laboratory (LDA) of Nuclear and Energy Research Institute (IPEN) using 5% by weight 270 Bloom gelatin from porcine skin, ultra-pure water, 50 mM sulphuric acid (H_2SO_4), 1 mM sodium chloride (NaCl), 1 mM ferrous ammonium sulphate hexahydrate [Fe(NH_4)_2(SO_4)_2·6H_2O] and 0.1 mM ferric ions indicator xylenol orange (C_13H_26N_2Na_4O_12S).

B. FXG Solutions Conditioning

The FXG solution was conditioned in polymethyl methacrylate (PMMA) cuvettes (10 x 10 x 45 mm^3) (Fig. 1) to obtain calibration curves. Sets of three samples each were prepared and packed with polyvinyl chloride (PVC) film to prevent evaporation of the water contained in the FXG solution and to ensure the reproducibility of the dosimetric response of the three FXG samples.

The dosimetric solution was also conditioned in a spherical glass balloon of 2000 mL (156 mm internal diameter and 2 mm wall thickness) (Fig. 2) and a PMMA rectangular box with separate lid (17 x 20 x 16 cm^3 and 3 mm wall thickness), containing a adult human skull (Fig. 3), in order to conform two different head FXG phantoms, without and with human bone.

The PMMA cuvettes and head phantoms were maintained under low temperature ((4 ± 1) °C) and light protected during about 12 hours after preparation.
C. Treatment Planning

To perform the 3DCRT treatment planning, computed tomography (CT) scans were obtained from head phantoms without and with human bone filled with water, instead of Fricke xylenol gel solution, using a Philips® Brilliance CT 64-channel scanner of the Diagnostic Image Department of Sao Paulo Hospital (HSP) of Federal University of Sao Paulo (UNIFESP).

The Eclipse® External Beam Planning system version 7.3.10 was used for axial CT images slices processing. These CT images corresponding to the head phantoms without and with human bone are presented in Fig. 4.

D. Irradiation

The cuvettes and phantoms were stored in a Styrofoam box (with lip) containing ice reusable in order to keep them under low temperature and light protected to be transported to the irradiation site. They were maintained at room temperature and light protected for 30 minutes before irradiation.

The irradiations were carried out in the Radiotherapy Service of HSP/UNIFESP.

PMMA Cuvettes

To obtain the calibration curves, the PMMA cuvettes sets were positioned at source-surface distance (SSD) of 80 cm in a PMMA phantom (30 x 30 cm\(^2\) plates 1.5 cm thick), 40 x 40 cm\(^2\) radiation field size and irradiated with different photon doses ranging from 2 to 30 Gy and dose rate of 74.98 cGy.min\(^{-1}\), using a GENERAL ELECTRIC COMPANY® Alcyon II \(^{60}\)Co gamma radiation therapy machine. All cuvettes sets were positioned together in the PMMA phantom and each set was removed when the radiation exposure time needed to obtain the desired absorbed dose was completed.

The \(^{60}\)Co gamma radiation was applied to the cuvettes filled with FXG solution, considering: the homogeneity and precision of absorbed dose delivery of \(^{60}\)Co gamma sources and that the effective photon energy of 6 MV photon beams is approximately 2 MeV.

Head FXG Phantoms

The head phantoms were irradiated with 6 MV clinical photon beams, absorbed dose of 20 Gy, dose rate of 300 cGy.min\(^{-1}\), SSD of 91.9 cm, using multiple static radiation fields of a VARIAN® Clinac 600C linear accelerator. The other irradiation parameters and experimental set-ups for phantoms irradiations are presented in Table 1 and Fig. 5, respectively.

<table>
<thead>
<tr>
<th>Radiation Fields</th>
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<td>Treatment Couch Position (º)</td>
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The evaluation techniques used in this study were the optical absorption (OA) spectrophotometry and magnetic resonance imaging (MRI).

The OA measures were performed immediately after FXG solution preparation and approximately 30 minutes after irradiation, using a SHIMADZU® UV2101-PC spectrophotometer (LDA/IPEN) and wavelength range of 190 to 900 nm. The absorbance values presented correspond to dosimetric wavelength of 585 nm [11]. This evaluation technique was used only as reference system.

The PMMA cuvettes and head phantoms MRI images were acquired approximately 30 minutes after irradiation using a SIEMENS® MAGNETOM® Sonata Maestro Class 1.5 T MRI scanner of the Resonance Magnetic Service at Diagnostic Image Department of HSP/UNIFESP, on cranium protocol-T1. The MRI images acquisition parameters are presented in Table 2. To MRI images processing, the softwares syngo fastView® version VX57F24 and ImageJ® version 1.42q were used.

Both the OA and MRI calibration curves, each presented value corresponds to the average of the measurement of three samples and the error bars the standard deviation of the mean. The background values corresponding to the optical and magnetic measurements of non-irradiated Fricke gel samples were subtracted from all values presented.

The Python scripts were used for post-processing the following tasks: identifying of the information in DICOM files and calibration curve fitting. The images were generated using custom software written in MATLAB. Isodose curves were calculated as a percentage of the dose to the central axis slices of MR images.

III. RESULTS AND DISCUSSION

A. Dose-Response Curves

The optical dose-response curve of the Fricke xylenol gel solution irradiated with $^{60}$Co gamma radiation, absorbed dose range from 2 to 30 Gy, is presented in Fig. 6.

![](https://example.com/fig6.png)

Fig. 6. Optical dose-response curve of the FXG solution irradiated ($^{60}$Co gamma radiation).

The coronal PMMA cuvettes MRI image slice of the FXG solution non-irradiated and irradiated with $^{60}$Co gamma radiation (2 to 30 Gy), is presented in Fig. 7.

![](https://example.com/fig7.png)

Fig. 7. Coronal PMMA cuvettes MRI image slice of the FXG solution non-irradiated and irradiated with $^{60}$Co gamma radiation.

The MRI signal intensity curve in function of absorbed dose, obtained from PMMA cuvettes MRI images presented in Fig. 7, is presented in Fig. 8.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>MRI IMAGES ACQUISITION PARAMETERS</th>
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<tr>
<td>Parameters Description</td>
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The calibration curves presented linear behavior in the clinical interest dose range (2 to 20 Gy) for both evaluation techniques (OA and MRI), tending to optical saturation to doses ≥ 20 Gy.

B. MRI Slices Images: FXG Phantoms

The coronal, sagittal and axial MRI image slices of the head FXG phantom without human bone, irradiated with 6 MV photons and 20 Gy, are presented in Fig. 9, 10 and 11, respectively.

The coronal, sagittal and axial MRI image slices of the head FXG phantom with human bone, irradiated with 6 MV photons and 20 Gy, are presented in Fig. 12, 13 e 14, respectively.
The irradiated target volume can be defined in the MRI images slices at coronal, sagittal and axial orientations. In the axial and coronal MRI image slices (Figs. 11 and 12) can also be seen the imput and the overlap of multiple radiation fields.

C. Isodose Curves

The isodose curves determined for coronal, sagittal and axial MRI image slices of the head FXG phantom without human bone, irradiated with 6 MV photons and 20 Gy, are presented in Fig. 15, 16 e 17, respectively.

The isodose curves determined for coronal, sagittal and axial MRI image slices of the head FXG phantom with human bone, irradiated with 6 MV photons and 20 Gy, are presented in Fig. 18, 19 and 20, respectively.

Fig. 14. Axial MRI image slice of the head FXG phantom with human bone (6 MV photons and 20 Gy).

Fig. 15. Isodose curves determined for coronal MRI image slice of the head FXG phantom without human bone (6 MV photons and 20 Gy).

Fig. 16. Isodose curves determined for sagittal MRI image slice of the head FXG phantom without human bone (6 MV photons and 20 Gy).

Fig. 17. Isodose curves determined for axial MRI image slice of the head FXG phantom without human bone (6 MV photons and 20 Gy).

Fig. 18. Isodose curves determined for coronal MRI image slice of the head FXG phantom with human bone (6 MV photons and 20 Gy).

Fig. 19. Isodose curves determined for sagittal MRI image slice of the head FXG phantom with human bone (6 MV photons and 20 Gy).
In both head FXG phantoms (with and without human bone) the irradiated target volume received the maximum percentage of the dose as expected. The high percentage of the dose in imput of multiple radiation fields can also be observed.

IV. Conclusion

The preliminary comparative study of the different head FXG phantoms with and without human bone presents good results for 6 MV photons and 3DCRT treatment technique. No significative influence was observed due to the human skull presence and the obtained results encourage future studies using other complex treatment techniques, such as IMRT.

Acknowledgment

The authors thanks to the staffs of the Radiotherapy Service and Resonance Magnetic Service of the Diagnostic Image Department of the HSP/UNIFESP to allow the FXG irradiations and MRI evaluations, respectively.

References


