

A dosimetric evaluation of tissue equivalent phantom prepared using 270 Bloom gelatin for absorbed dose imaging in Gamma Knife radiosurgery

C C Cavinato¹, O Rodrigues Jr¹, J H Cervantes², S R Rabbani² and L L Campos¹

¹ Radiation Metrology Centre, Instituto de Pesquisas Energéticas e Nucleares – CNEN/SP, Sao Paulo, Brazil

² Physics Institute, University of Sao Paulo, Sao Paulo, Brazil

E-mail: ccavinato@ipen.br

Abstract. Tissue equivalent gel phantoms have been widely studied in radiation therapy for both relative and reference dosimetry. A Fricke xylene gel (FXG) spherical phantom was evaluated by means of magnetic resonance image method (MRI) to measure absorbed dose distribution resulted from gamma knife irradiation. The FXG phantom was prepared using 270 Bloom gelatin. The gelatin is a tissue equivalent material, of easy preparation, can be used to mold phantoms into different shapes and volumes, is commercially available and inexpensive. The results show that the Fricke gel phantom prepared with 270 Bloom gelatin satisfy the requirements to be used for the quality control in stereotactic radiosurgery using Gamma Knife technique and may constitute one more option of dosimeter in radiation therapy applications.

1. Introduction

Among the high-precision techniques used in stereotactic radiosurgery for treatment of intracranial lesions, which they use narrow ionizing radiation beams [1], the Gamma Knife is the most precise modality currently available [2]. This technique allows obtaining a local energy release in tumors saving the surrounding health tissues. Therefore there is the necessity of getting the three-dimensional (3-D) images of in-phantom absorbed dose, achieving high precision and the most reliable resolution [3].

Gel dosimetry is a technique for dose imaging based on water-equivalent gels. Phantoms can easily be obtained and used as dosimeter to obtain 3-D dose distribution. Different kinds of gel dosimeters have been developed, the two main investigated groups are the aqueous gels, the Fricke gel dosimeters [4,5,6,7,8,9] and the based on radiation-induced polymerization and cross-linking of acrylic monomers, the polymer gels [3,10,11,12,13]. Imaging techniques such as spectrophotometry and MRI scanning, have been proposed [14,15,16,17]. Compared with other imaging methods, magnetic resonance imaging (MRI) presents superior properties for planning, guiding, monitoring and controlling therapeutic interventions, including minimally invasive procedures [16,17,18]. Applied in radiation therapy, the main advantages of MRI are the high spatial resolution and the direct acquisition of multiplanar and 3-D imaging data.

The Fricke gel dosimeter has been studied for determine both dose and dose distribution with accuracy and precision [12,13] in radiation treatments. Oxidation of ferrous ions (Fe^{+2}) to ferric ions (Fe^{+3}) occurs when the dosimeter is exposed the ionizing radiation [14] with the oxidation yield proportional to the absorbed dose and the absorbed dose distributions can be imaged by MRI. The studied Fricke gel solutions have been prepared using 300 Bloom gelatin [8,14,19,20] that is imported and very expensive in Brazil.

The purpose of this work is to make the dosimetric evaluation of a FXG spherical phantom prepared using 270 Bloom gelatin to measure absorbed dose distribution resulted from gamma knife irradiation.

2. Materials and methods

2.1. Spherical phantom preparation

The spherical glass housing (1 mm thick wall, 12.5 mm diameter and 1.0 L volume) was filled with Fricke xylenol gel solution (FXG) in order to simulate the human brain. The FXG solution was prepared with 1 mM ferrous ammonium sulphate [$\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$], 1 mM sodium chloride (NaCl), 0.1 mM xylenol orange dye ($\text{C}_{31}\text{H}_{28}\text{N}_2\text{Na}_4\text{O}_{13}\text{S}$), 50 mM sulphuric acid (H_2SO_4), tri-distilled water [4] and 5% by weight 270 Bloom porcine gelatin.

2.2. Phantom irradiation and calibration

The phantom positioned at the headframe was irradiated to a prescription dose of 40 Gy and 50% isodose surface using a Leksell Gamma Knife system model B.

For dose response calibration, gel samples were irradiated at predefined ^{60}Co gamma dose levels between 1 and 90 Gy.

2.3 MR Imaging

The evaluation technique employed was the Magnetic Resonance Imaging (MRI) using the PHILIPS GYROSCAN S15/ACS scanner.

MR scans of the calibration gel samples were used to establish a dose response curve as a function of the calculated relaxation rates R_1 . This curve is the reference curve for dose readings in the phantom.

Before and after gamma knife irradiation the phantom MR images were acquired, the T_1 weighted multi-slice of the phantom were also obtained and, using localized spectroscopy, T_1 was measured at the irradiated volume and far from it in order to correlate the pixel intensity with the irradiation dose. The standard Z orientation slices were used in image acquisition (transaxial section image).

A MATLAB program was created to calculate the pixel T_1 values and reconstruct the dose in 3D to the patient from the measured gamma knife images.

3. Results and discussions

The calibration curves, R_1 and NMR signal intensity as a function of the dose are presented in figure 1. The 3D phantom representation is present in figure 2. A 33 MRI slices (zSlices in figure 2) were processed in Matlab program. The dose colormap in figures 2, 3, 4 and 5 were reported as percentage of the prescription dose (% PD). Selected MRI slices are presented in figure 3.

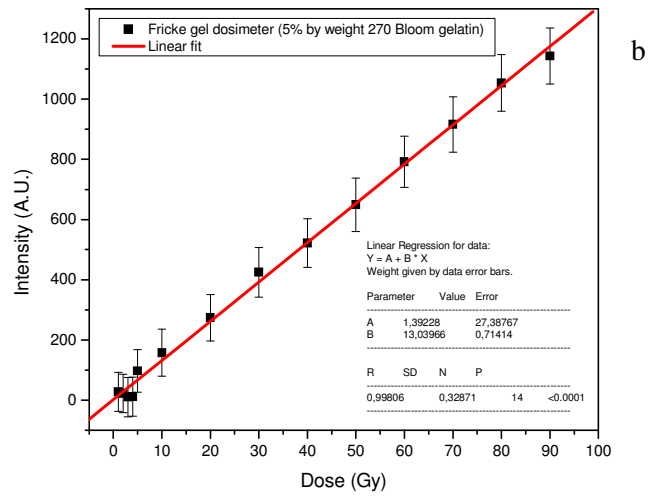
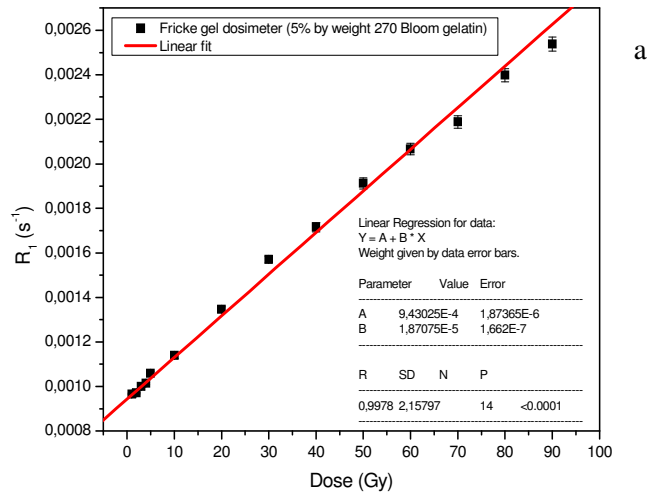


Figure 1. Dose-response curves calculated using R_1 (a) and NMR signal intensity (b).

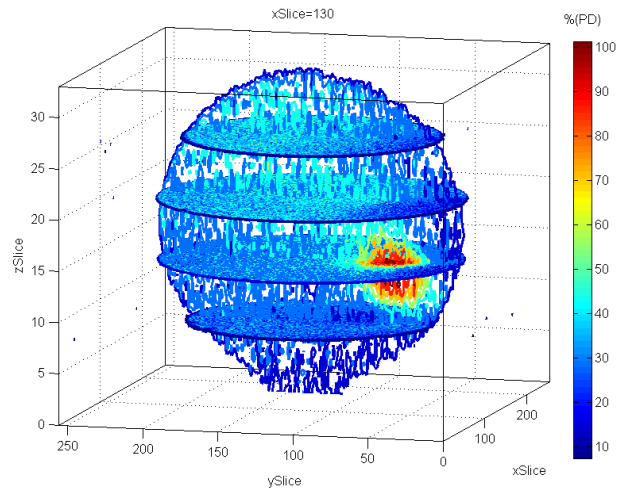


Figure 2. 3D phantom representation showing MRI slices orientation.

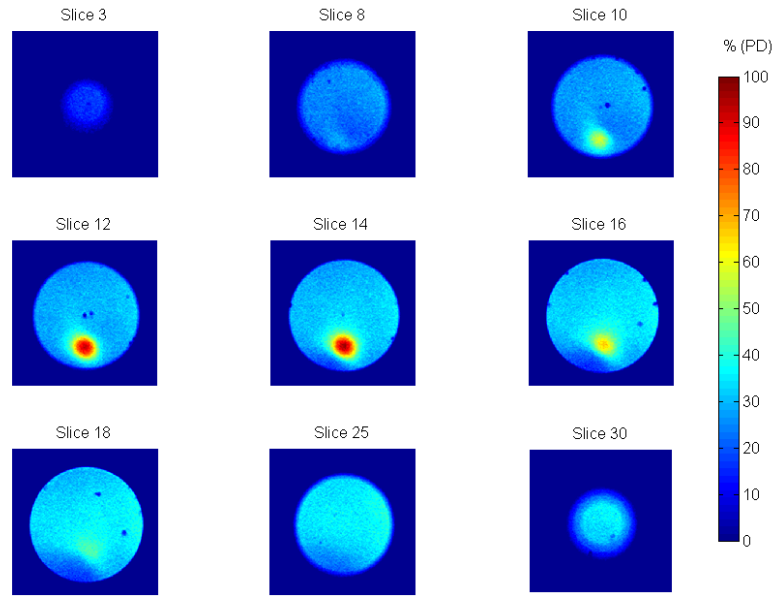


Figure 3. Selected MRI zSlices.

A reconstructed three-dimensional phantom image is presented in figure 4.

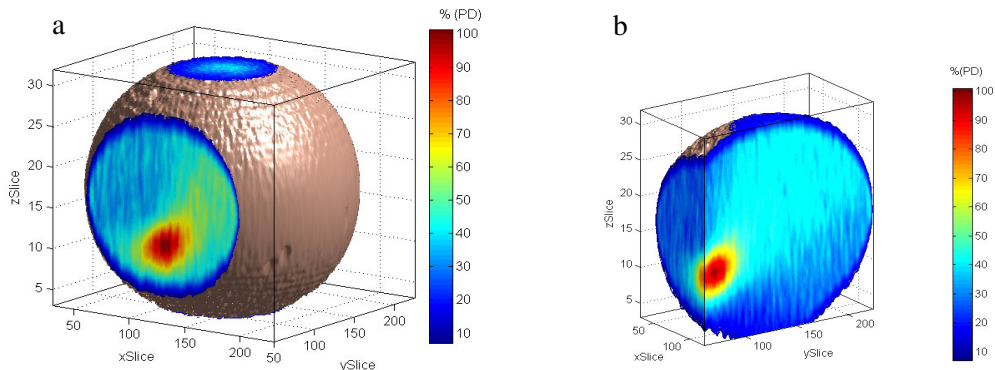


Figure 4. A reconstructed three-dimensional phantom image: cut in ySlice = 50 to highlight the centre of the irradiated volume (a); cut in ySlice = 60 and xSlice = 120 showing irradiation cone projection (b).

4. Conclusions

The obtained results show that the Fricke gel phantom prepared with 270 Bloom gelatin satisfy the requirements to be used for the quality control in stereotactic radiosurgery using Gamma Knife technique and may constitute one more option of dosimeter in radiation therapy applications. The phantom prepared with 270 Bloom porcine gelatin presents appropriate consistence and integrity (i.e., does not occurs formation of fungus) at room temperature ($\sim 25^{\circ}\text{C}$) during the time between irradiation and evaluation. The 270 Bloom porcine gelatin is of easy preparation at laboratory, inexpensive and commercially available. The dose delivered to any point in the phantom can be measured, the dose distribution can be mapped in three-dimensional spaces, in any slice for any orientation.

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