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Fricke dosimetry for synchrotron stereotactic radiotherapy

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Abstract

In synchrotron stereotactic radiotherapy (SSR) the tumor is loaded with a high Z element, and exposed to monochromatic x-rays from a synchrotron source, in stereotactic conditions. The SSR treatment efficiency is related to the heavy element concentration achievable in the tumor, to the radiation energy, and the irradiation geometry [1,2]. The experimental dose verification of SSR in three dimensions with a good spatial resolution is highly desirable for radiotherapy [3]. In this study, Fricke dosimeter and Monte Carlo calculations were employed for assessing 2D dose distribution.

Keywords

radiotherapy, dosimetry, synchrotron, stereotactic, fricke

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Fricke dosimetry for synchrotron stereotactic radiotherapy

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1. Introduction

In synchrotron stereotactic radiotherapy (SSR) the tumor is loaded with a high Z element, and exposed to monochromatic x-rays from a synchrotron source, in stereotactic conditions. The SSR treatment efficiency is related to the heavy element concentration achievable in the tumor, to the radiation energy, and the irradiation geometry [1,2].

The experimental dose verification of SSR in three dimensions with a good spatial resolution is highly desirable for radiotherapy [3]. In this study, Fricke dosimeter and Monte Carlo calculations were employed for assessing 2D dose distribution.

2. Materials and methods

2.1. Fricke samples and irradiation

We used standard a Fricke gel solution incorporated in an agarose gel matrix. It was poured into several acrylic containers: calibration tubes and a cylindrical phantom (12 cm in diameter and 15 cm height). The sealed recipients were stored in a fridge before irradiation. The irradiations were performed at room temperature with a monochromatic beam tuned at 78.8 keV. The x-ray dose was evaluated independently with a HPGe detector (Eurisys Mesures, Lingolsheim). The dose rate in water at the sample level was 0.353 Gy/sec. Two irradiation schemes were utilized:

(1) one tube was irradiated through its longitudinal axis to get depth dose information;
(2) the cylindrical recipient was irradiated in stereotactic conditions. The target region (pseudo tumor) was positioned on the rotation axis and the irradiation was performed in tomography mode with a beam of 10 mm in width and 0.9 mm in height. Fourteen contiguous irradiations were necessary for covering 12.6 mm in height (figure 1). In addition, four tubes filled with the same Fricke gel were irradiated at 0, 1, 2 and 5 Gy for calibration.

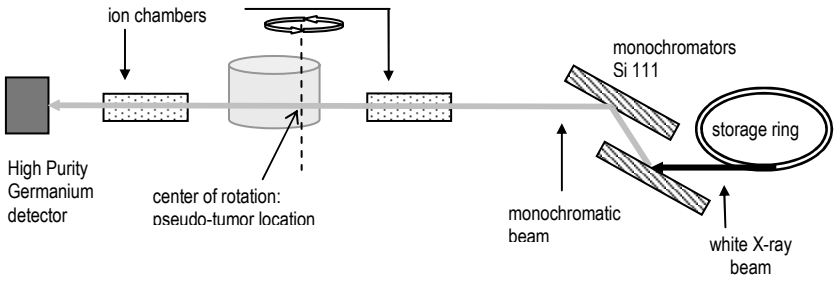


Figure 1. Stereotactic irradiation configuration at the ESRF medical beamline. The cylindrical phantom is placed on a rotating stage and can be translated orthogonally to irradiate several slices.

After irradiation, the recipients were imaged by magnetic resonance (MR) via the sampling of the relaxation curve (R1) using series of inversion recovery sequences.

2.2. Monte Carlo simulation

Monte Carlo calculations are well suited for predicting dose distributions. The Monte Carlo data for this work were generated using the MCNP electron/photon/neutron transport code developed at the Los Alamos National Laboratory [4]. This code has been used for various dosimetry problems. We developed an interface for MCNP. This preprocessor transforms the data from the CT image into a heterogeneous material lattice. Energy deposition was recorded in each voxel of the irradiated Fricke phantom slice (129×129 voxels). The simulation was stopped when the statistical uncertainty was below 5% in the region of interest.

3. Results

3.1. Dose response

The linear relationship between the x-ray dose and the Fricke gel relaxation time was first established (figure 2). Points were fitted with a first order polynomial equation (least squares method):

$$R_1\ [ms^{-1}] = 7.10^{-5}\ D\ [Gy] + 0.001\ (R^2 = 0.9983) \quad (1)$$

3.2. Depth dose

The first centimeter of the Fricke gel was not readable. Measured and simulated data are in good agreement within the experimental error range of 10% (figure 3).

3.3. Dose distribution

The dose maps obtained from the Fricke dosimeter and with MCNP are shown on figure 4. The dose enhancement following synchrotron stereotactic irradiation is clearly visible. A sharp gradient of dose is obtained: the normal tissue surrounding the target volume is spared efficiently.

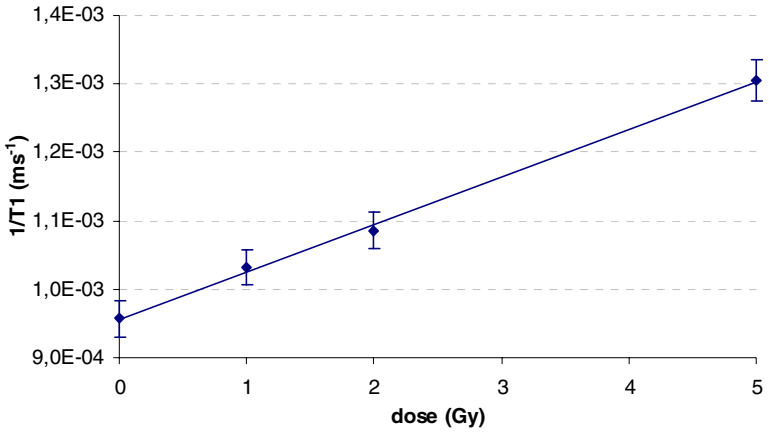


Figure 2. Dose response curve of the Fricke gel irradiated by a monoenergetic beam of 78.8 keV. The error bars represent the standard deviation of the 1/T1 values observed on the NMR image within the calibration tubes.

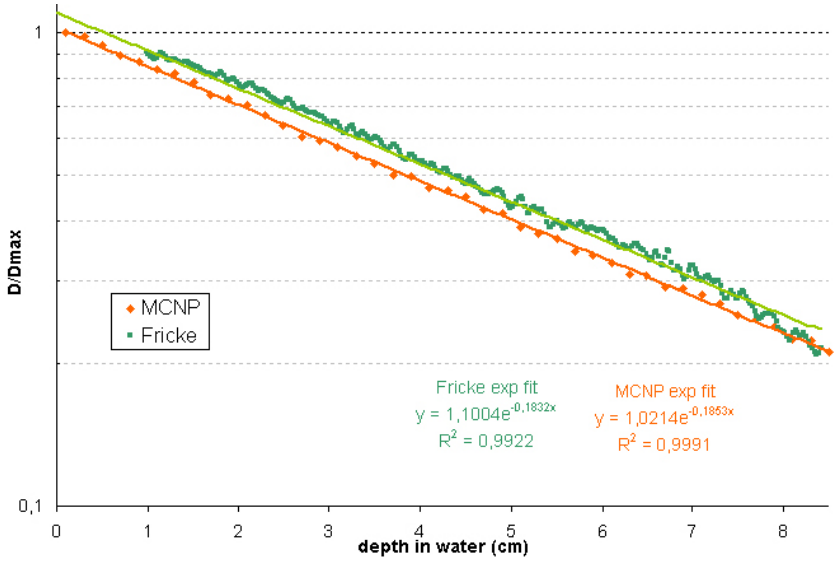
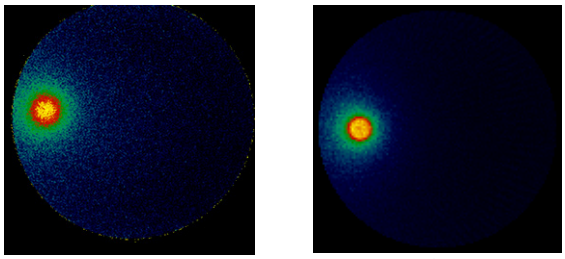


Figure 3. Logarithm plot of the depth dose curve for Fricke gel irradiated at 78.8 keV and simulated data obtained by MCNP.



(a) (b)

Figure 4. Dose maps obtained from the MR imaging of the Fricke gel (a) and the Monte Carlo calculation (b).

4. Discussion

In this study, we have utilized Fricke dosimetry and Monte Carlo simulations in a simplified configuration of synchrotron stereotactic radiotherapy (SSR), where only the ballistic dose enhancement is taken into consideration. The results are in good agreement. The Monte Carlo code provides satisfying results compared to Fricke dosimetry.

Fricke gel allows a spatially accurate quantification of dose in a tissue equivalent medium. However, the dose distribution resulting from a SSR treatment involves the dose increment due to presence of the high Z element in the tumor. This latter effect is difficult to evaluate experimentally in 3D geometries since dosimetric gels are chemically reactive. Further investigations might lead to find suitable candidate for increasing locally the effective atomic number of these gels. Moreover, x-ray CT imaging of the gel would be highly desirable in our configuration [5].

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