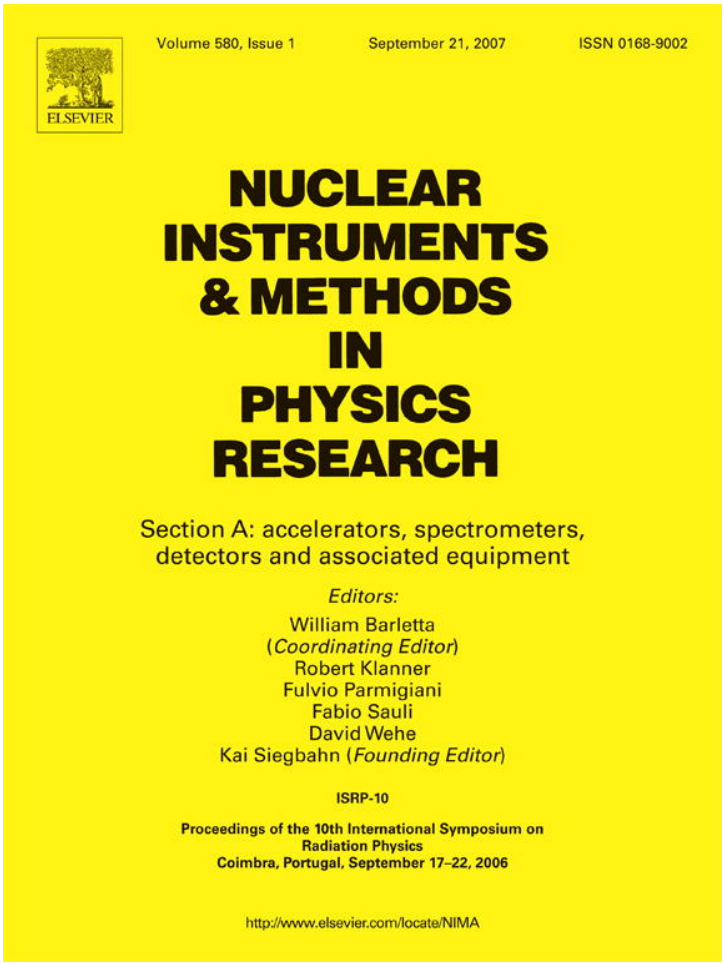

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Gel dosimetry measurements and Monte Carlo modeling for external radiotherapy photon beams Comparison with a treatment planning system dose distribution

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Abstract

Gel dosimetry has proved to be useful to determine absorbed dose distributions in radiotherapy, as well as to validate treatment plans. Gel dosimetry allows dose imaging and is particularly helpful for non-uniform dose distribution measurements, as may occur when multiple-field irradiation techniques are employed. In this work, we report gel-dosimetry measurements and Monte Carlo (PENELOPE®) calculations for the dose distribution inside a tissue-equivalent phantom exposed to a typical multiple-field irradiation. Irradiations were performed with a 10 MV photon beam from a Varian® Clinac 18 accelerator. The employed dosimeters consisted of layers of Fricke Xylenol Orange radiochromic gel. The method for absorbed dose imaging was based on analysis of visible light transmittance, usually detected by means of a CCD camera. With the aim of finding a simple method for light transmittance image acquisition, a commercial flatbed-like scanner was employed. The experimental and simulated dose distributions have been compared with those calculated with a commercially available treatment planning system, showing a reasonable agreement.

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Keywords: External radiotherapy; 3D dosimetry; Fricke gel dosimeter; Monte Carlo simulation

1. Introduction

Modern radiation therapy is becoming increasingly complex, both in terms of the delivery techniques used and in the often irregular shape of the targets. Conformal and intensity-modulated radiation therapy (IMRT) techniques are widespread in clinical use, treating a variety of tumor types in many different anatomical sites. Planning objectives are devoted to accurate dose conformation sparing nearby healthy tissues. Verification of this complex dose distribution demands efficient dosimetry techniques, resolving a real and accurate 3D dose distribution. Gel dosimeters offer the possibility of achieving such continuous distributions. Gel dosimeters consist of a ferrous sulfate solution fixed in an aqueous gel matrix. Under radiation, Fe^{2+} ions in gel are oxidized to Fe^{3+} ions and amount of Fe^{3+} produced is proportional to the absorbed dose. In addition, the gelatin infused ferrous solution constitutes a water equivalent dosimeter [1,2]. The aim of this study was to determine whether gel dosimeters optically analyzed by means of a commercial scanner can be reliable, to produce consistent results for external radiotherapy relative dose distribution determinations. Experimental distributions have been obtained by means of gel dosimeters for a 4-field box technique. The obtained

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results have been compared with Monte Carlo simulations (PENELOPE®) [3] and a treatment planning system (PLATO®-Nucletron Inc.).

2. Materials and methods

The gel dosimeters elaboration process was carried out in chemical laboratory facilities. A Fricke (ferrous sulfate) solution infused with Xylenol Orange was incorporated to a gel matrix (porcine skin gelatin) as described in Refs. [1,4–7]. The solution was introduced in properly designed polystyrene layers. Some samples have been utilized for the irradiation, whereas others have been used for calibration.

Fricke gel dosimeter layers have been irradiated with a 10 MV photon beam from the Clinac 18 Varian® linear accelerator (Linac). Unfortunately, the greatest possible field size was $3 \times 3\,cm^2$ due to the dimensions of the employed dosimeters ($4 \times 4\,cm^2$ of sensitive area with negligible boundary effects).

Gel dosimeters have been first irradiated with a unique $3 \times 3\,cm^2$ field at SSD = 100 cm to compare experimental percentage depth dose (PDD) and beam profiles at different depths. After that, a set of six gel layer dosimeters, placed at the center of a water phantom, was irradiated with a 4-field box isocentric technique, placing the isocenter at the center of the detection volume of the piled up dosimeter set.

The analysis method is based on optical light-transmittance detection [1,4], performing before and after phantom exposure dosimeter images by means of a commercial flatbed-like scanner. Suitably developed software, written in MatLab®, traduces the dosimeter images into optical density differences (ΔOD), which normalized can be compared with relative dose distributions or, eventually, employing appropriate calibration factors, with absolute dose distributions [1,4]. In order to ensure linearity between ΔOD and dose distributions, it is necessary to analyze the scanner response studying characteristics like illumination homogeneity and reproducibility. A suitable set of homogeneous samples could be employed in order to check the scanner uniformity. The Monte Carlo (MC) calculations used to compare experimental results were performed using the PENELOPE® package. The simulation main program was based on the sample PENCYL provided in the 2003 PENELOPE® distribution. Modifications were introduced in order to allow a divergent rectangular beam. An energy distribution for the incident photon beam was also introduced, according to the experimental parameters of the linear accelerator involved. MC calculations were performed to simulate the particular multiple fields experimental set up. The simulations were carried out in a cluster facility with 3.0 MHz Pentium processors, each with 10^7 primary particles, which typically implied 2×10^5 s of CPU time. Experimental results were also compared with PLATO (NUCLETRON®) External Beam Treatment Planning System RTS version 2.3. Photon beam dose calculation algorithms used in RTS version 2.3 are described by Bortfeld et al. [8].

3. Results

Preliminary tests have been performed in order to study some flatbed-like scanner properties. Uniformity in the region of interest (ROI) has been tested scanning several times different uniform-color (homogeneous) samples. The obtained color uniformity (gray scale) is shown in Fig. 1.

A suitable mask has been manufactured in order to ensure good reproducibility for the dosimeter positioning during the scan. Therefore, the mask position on the scanner has been selected according to the best scanner uniformity.

Experimental results for PDD and a beam profile at 5 cm depth compared with data from a beam scanning system are shown in Fig. 2.

Due to different concentrations of components and changes in the elaboration process, a calibration curve is required each time gel dosimeters are employed. The obtained calibration curve for the gel dosimeters shows a good linearity of dose vs. optical density differences from 2 to 10 Gy (Fig. 3a).

A set of six piled up Fricke gel dosimeter layers has been irradiated by multiple-field (4-field box) technique with a $3 \times 3\,cm^2$ 10 MV photon beam. A total dose of 20 Gy has been delivered to the isocenter. A view of an irradiated gel layer dosimeter is shown in Fig. 3b.

In view of the linear correspondence between ΔOD and absorbed dose (Fig. 3a), it is possible to compare relative dose distributions with normalized ΔOD [1,4]. Typical normalized ΔOD distribution surfaces are shown in Fig. 4.

The employed incident spectrum has been suitably optimized in order to establish the optimal photon incident spectrum. Discrete and continuous parameterized spectra have been considered and optimized by χ^2 criteria in order to establish the optimal spectrum [2].

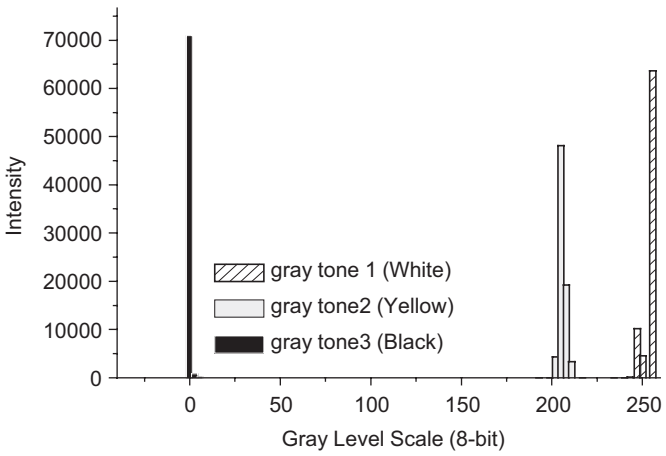

Fig. 1. Scanner uniformity in the ROI.

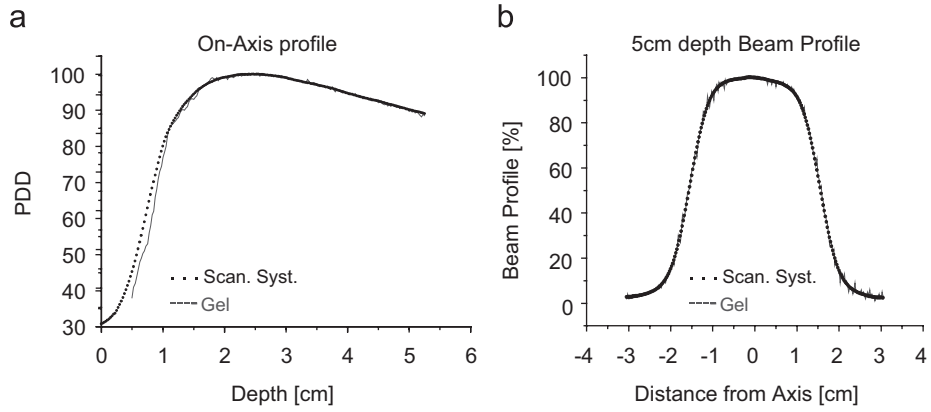

Fig. 2. Profiles for a $3 \times 3\,cm^2$ SSD = 100 cm (a) PDD and (b) 5 cm depth beam profile.

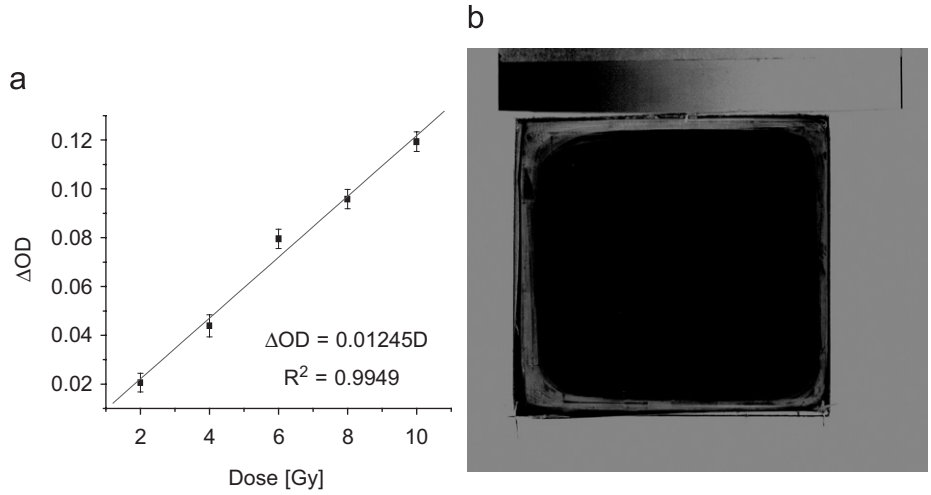

Fig. 3. (a) Calibration curve with linear fit. (b) View of a Fricke gel dosimeter irradiated with a 4-field box technique.

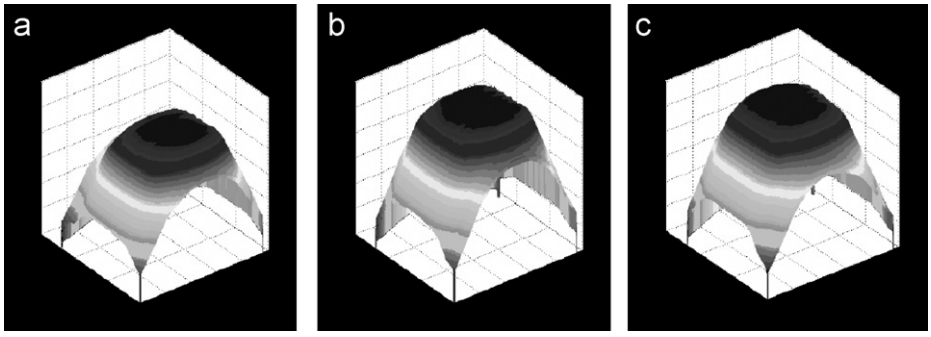

Fig. 4. Normalized ΔOD distributions obtained by piled up gel dosimeter layers: (a) external, (b) middle, and (c) central.

The spectrum has been optimized employing reference data from the $10 \times 10\,cm^2$ field size and the obtained results for the PDD and beam profile are shown in Fig. 5.

In order to perform a comparison among gel dosimeters and MC results with TPS 3D distributions, several dose profiles corresponding to different planes have been assessed. Fig. 6 shows on- and off-axis dose profiles corresponding to different planes.

Fig. 7 shows the ROI's surface percentage covered by different isodoses for the central plane.

4. Discussion

Considering this work as a preliminary study on the reliability of the technique, the obtained dose distribution by means of Fricke gel measurements and MC simulations

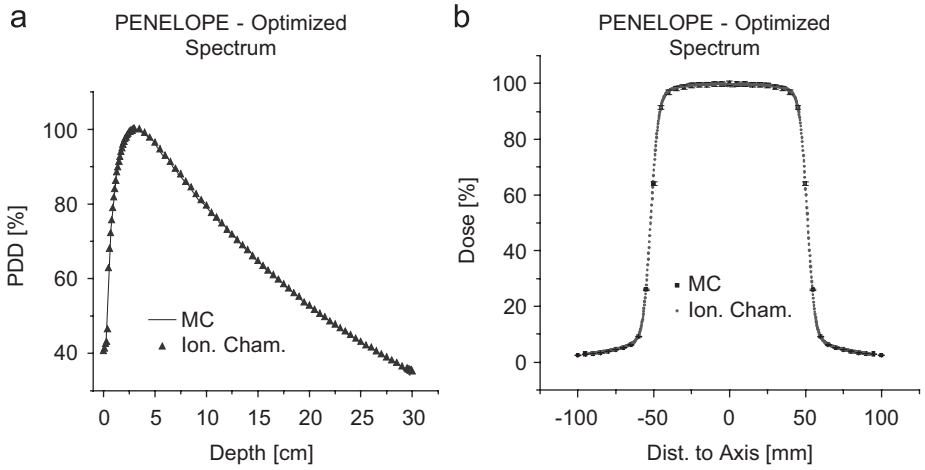

Fig. 5. MC and reference data for the 10 MV photon beam from a Varian 18 Clinac: (a) PDD and (b) 50 mm depth beam profile.

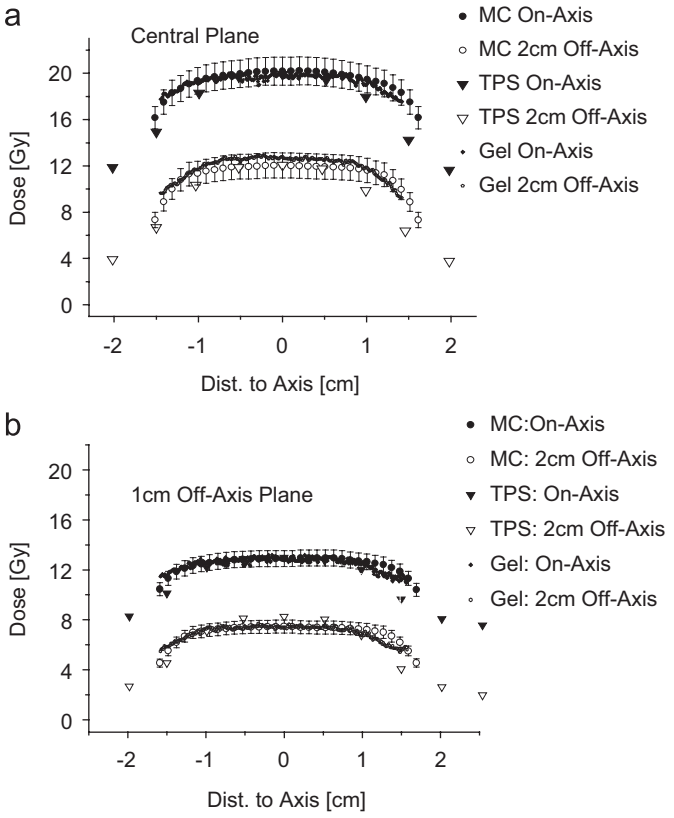

Fig. 6. Central (a) and 10 mm displaced (b) planes dose profiles.

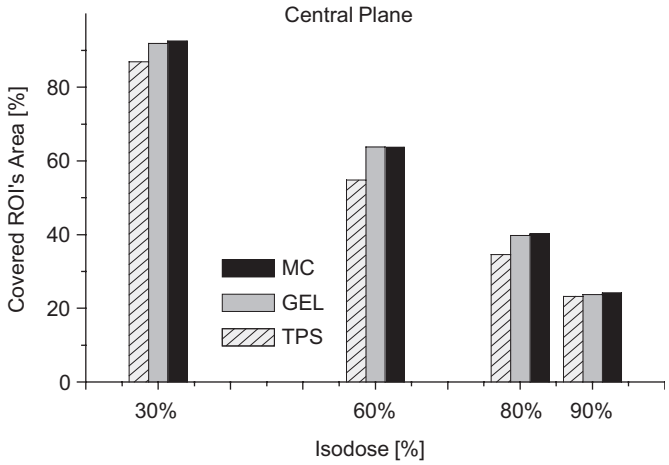

Fig. 7. Central plane dose–surface histogram.

show a reasonable agreement with the TPS dose distributions, especially for on-axis profiles. However, some important differences have been found when comparing the off-axis dose profiles, which exceptionally reach 13% in correspondence to high-dose gradient regions. Fig. 7 also suggests that the grater relative differences are found for high-dose gradient regions.

The choice of a commercial scanner for images acquisition using the Fricke gel-layer technique appears as a simple and useful tool for dose distributions determination. However, it is mandatory first to study some relevant properties of the scanner.

Manufacturing greater gel dosimeter layers with the required properties seems to be not immediate. However, greater Fricke gel dosimeters are actually under study [9] in order to establish the feasibility of employing wider field sizes, as those commonly used in radiotherapy.

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