A procedure to mathematically amend possible thickness disuniformities in gel-layer dosimetry

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Abstract. The continuous development of conformal radiotherapies requires a corresponding improvement of dosimetric techniques. Fricke gel-layer dosimetry, coupled with a suitably developed software, has proven to be a reliable technique for 3D absorbed dose distribution verification. The method is based on the evaluation of the light transmitted by gel-layers due to the fact that the optical density difference between irradiated and non irradiated dosimeters is proportional to the absorbed dose. Measurement are performed by means of a planar illumination source and a computer-controlled CCD camera. Recently, adoption of gel layers with increased superficial dimensions has evidenced a possible thickness disuniformity of layers, thus introducing a new source of measurement inaccuracy. In this work, a method to mathematically amend this possible source of error is proposed. Dose profiles along the central axis of phantoms irradiated with X-ray therapy and Boron Neutron Capture Therapy fields, obtained with and without the application of the proposed correction procedure, were compared with ionization chamber measurements and Monte Carlo simulations, respectively. The obtained results show a good reliability of the proposed procedure.

1. Introduction

Gel dosimetry has proven to be a valid dose distribution verification system for various radiotherapy applications [1]. Different kinds of dosimeters have been proposed by the scientific community, and different kinds of imaging techniques have been developed [2]. In the last years, our group has significantly improved the Fricke gel-layer dosimetry technique by defining their best chemical composition [3], by optimizing the image acquisition assessment [4] and by developing a dedicated software for image analysis [5]. These improvements allowed to adopt Fricke gel-layers for both X-ray radiotherapy [6] and BNCT [7] dose distribution measurements. A particular attention was dedicated to detect possible systematic or random sources of errors which might determine inaccuracies in the evaluation of the delivered dose distributions. Algorithms for artifacts amendment due to eventual small defects in the gel structures or inhomogeneous illumination of the sample were proposed [8]. Recently, adoption of gel layers with increased superficial dimensions has shown that the layers thickness might not be uniform, thus introducing a further source of inaccuracy. In this work, a method to mathematically correct this source of error is proposed.
2. Materials and methods

2.1. Fricke gel-layer dosimeters and experimental assessment

The adopted tissue-equivalent gel dosimeters were radiochromic Fricke gels in form of layers having a thickness of 3mm and a 11x11cm^2 surface. Their standard composition was: Porcine skin in the amount of 3% of the final weight, ferrous sulphate solution [1mM Fe(NH_4)_2(SO_4)_2·6H_2O], sulphuric acid [25mM H_2SO_4] and Xylenol-Orange [0.165mM C_31H_27N_2Na_5O_13S]. The experimental assessment consisted of a planar illumination source, a CCD camera for the acquisition of optical transmission images of the gel layers and a computer for the CCD control and for the storage and elaboration of the acquired images. Further details regarding the instrumentation may be found elsewhere [3].

The method for attaining images of dose distribution is based mainly on the following steps: i) grey-level images of the transmitted light at about 585nm are detected for each dosimeter before (GL_{585,b}) and after (GL_{585,a}) irradiation; ii) the difference in optical density \( \Delta(OD) \), which is linearly correlated to the dose \( D \) until saturation, is evaluated for each pixel with coordinates \((m,n)\) applying the function

\[
\Delta(OD)(m,n) = \log \left[ \frac{GL_{585,b}(m,n)}{GL_{585,a}(m,n)} \right] \quad (1)
\]

iii) knowing the linearity factor between \( D \) and \( \Delta(OD) \), superficial matrices of dose distribution are finally obtained.

A dedicated software was developed with the programming environment MATLAB® (The MathWorks Inc, Natick MA, USA) to automatically perform steps i) to iii) and to interactively determine dose profiles, surfaces as well as isodose curves [4].

2.2. Thickness disuniformity correction of gel-layers

In this paper, a method to enhance the accuracy of the previously described procedure is proposed. The method is based on the acquisition of a further light-transmittance image of the non irradiated gel-layer with an optical band-pass filter centered around 430nm (GL_{430,b}). In fact, assuming that before irradiation ferrous ions inside the dosimeters are homogeneously concentrated, possible differences in gray level values of the image are due only to a thickness inhomogeneity of the layer. The additional information can be adopted to develop normalization matrices \( N_b \) (before irradiation) and \( N_a \) (after irradiation) which can be applied for amending the images acquired at 585nm. Function (1) becomes:

\[
\Delta(OD_{cor})(m,n) = \log \left[ \frac{GL_{585,b}(m,n) \cdot N_b(m,n)}{GL_{585,a}(m,n) \cdot N_a(m,n)} \right] \quad (2)
\]

The obtained algorithm (2) was integrated in the previously developed software for the achievement of planar and volumetric dose distributions. Figure 1 illustrates the image processing chain of a single gel layer applying algorithms (1) and (2). Superficial representations of matrices \( GL_{585,b}(m,n) \), \( GL_{585,a}(m,n) \), \( N_b(m,n) \), \( N_a(m,n) \), \( GL_{585,b}(m,n) \cdot N_b(m,n) \), \( GL_{585,a}(m,n) \cdot N_a(m,n) \), \( \Delta(OD)(m,n) \) and \( \Delta(OD_{cor})(m,n) \) are shown.

2.3. Depth dose measurements

Experiments were performed in order to check the reliability of the proposed method. Depth dose profiles in a cubic polystyrene phantom (30 cm side) were detected at the center of a 10x10cm^2 X-beam field (Varian Clinac 2100c, 18 MV). Dose profiles obtained applying equations (1) and (2) were then compared with measurements achieved by means of a cylindrical ionization chamber (Scanditronix RK, 0.12cc).

Moreover, a series of dose measurements were carried out placing the gel dosimeters both in a standard water phantom and in a cylindrical 16cm wide and 14cm high tissue-equivalent phantom, and irradiating them in a BNCT thermal column reactor. Some of the adopted dosimeters were doped with...
40ppm of $^{10}$B and therefore permitted to obtain boron dose. Results were compared with Monte Carlo calculations of thermal neutron flux performed with MCNP5 [9].

Figure 1: Partial and final results of the image processing chain on a single gel layer applying algorithms (1) (left column) and applying the correction algorithm (2) (right column). The normalization matrices $N_b$ (before irradiation) and $N_a$ (after irradiation) are the smaller ones, represented in the central column.
3. Results
The dose profiles measured by means of two different Fricke gel-layers exposed to an X-ray radiotherapy field, processed with and without thickness disuniformities amendment, are reported in figure 2. Ionization chambers measurements are shown for comparative aims.

![Image of percentage depth dose (PDD) profiles](image)

Figure 2: Percentage depth dose (PDD) on-axis profiles obtained with 2 Fricke-gel layers exposed to a 18 MV X-ray radiotherapic beam (Varian Clinac 2100c) (a) without thickness disuniformities amendment and (b) with thickness disuniformities amendment. Profiles were compared to PDDs obtained by means of an ionization chamber.

The dose profiles measured in two different experimental set-ups with two different Fricke gel-layers exposed to an epithermal neutron beam for BNCT, processed with and without thickness disuniformities amendment, are reported in figure 3. Monte Carlo simulations are shown for comparative aims.

![Image of percentage depth dose (PDD) profiles](image)

Figure 3: Percentage Depth Dose (PDD) profiles for thermal neutrons measured in (a) a water phantom and in (b) a gelatin phantom exposed to an epithermal neutron beam for BNCT. In green and red are reported data without thickness disuniformities amendment and with thickness disuniformities amendment, respectively. Black dots represent data obtained by means of Monte Carlo simulations.

4. Conclusion
The reported results show that the proposed procedure for the mathematical amendment of possible thickness disuniformities of gel-layer dosimeters is reliable. When larger dosimeters are involved, the thickness disuniformity effect cannot be neglected. In those cases, the procedure is necessary for the correct achievement of the delivered dose distributions. After appropriate optimization, the procedure is ideally applicable not only to Fricke gel-layers, but to any kind of gel dosimeter in form of layer.
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