Application of Polymer Gel dosimetry in Dose Verification of IMRT

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A B S T R A C T

Purpose: Dosimetry is an integral part of radiotherapy and dose verification is one of the important stages in modern radiotherapy. Nowadays gel dosimeters are the only dosimeters that can record dose distribution in three dimensions only with a single measurement. The purpose of this study was to evaluate the capability of polymer gel dosimetry in dose verification of compensator-based IMRT.

Methods: A cerrobend slab with 4 cm thickness was manufactured and percentage depth dose curves for 18 MV photon beam and 10×10 cm^2 field size were obtained by ionization chamber and polymer gel dosimeter. Then, an anthropomorphic pelvic phantom with gel inserts was constructed and irradiated with compensator-based IMRT technique.

Results: A comparison of the result of dose measurements with ion chamber and gel dosimeter showed that in spite of changing mean beam quality, compensators have no effect on response of gel dosimeter. Besides, according to distance to agreement (DTA) analysis there was good agreement between calculated and gel measured dose distributions.

Conclusion: The methodology presented in this work proved the feasibility of polymer gel dosimeter as an ideal tool for pretreatment IMRT QA and also the constructed phantom can be used efficiently in other radiotherapy techniques. Future works will be focused on the development of lung equivalent polymer gel dosimeter.

Keywords:

Compensator,
Gel Dosimetry,
MRI,
IMRT.

1. Introduction

Intensity modulated radiation therapy (IMRT) techniques optimize beam intensity incident on the patient surface by using an inverse planning algorithm [1-3]. MLC-based IMRT techniques are the most common used techniques because of its treatment delivery automation. Another technique to deliver IMRT is compensator-based IMRT that has some advantage over MLC-based IMRT such as simplicity, shorter treatment time but the main disadvantage of this technique is the lack of automation[4].

Verification of planned dose distribution is a very important step in radiotherapy to ensure the highest quality of radiotherapy treatments. Among dosimetric tools for treatment verification, three dimensional dosimeters are of interest. Three-dimensional dosimetry can be fulfilled by gel dosimetry and it has been used in many works [5-10]. Polymer gel dosimeters consist of chemicals which when placed under irradiation, polymerize as a function of the absorbed radiation dose. Furthermore, due to a large proportion of water, polymer gels are nearly water-equivalent and hence radiologically soft-tissue equivalent [11]. In spite of having a unique feature of capturing dose in

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three dimensions, clinical applications of the polymer gel dosimetry is lacking because of the cost of both the polymer gel and the scanning tool[5].

In this paper, we presented the outcomes of 3D dose distribution measurements using MAGIC polymer gel in combination with a 1.5 Tesla (1.5T) magnetic resonance imaging (MRI) for radiation therapy of a prostate cancer study using the compensator-based IMRT technique and percentage depth dose under 4 cm slab. The purpose of this paper is to test the capability of polymer gel dosimetry in compensator-based IMRT.

2. Materiels and Methods

2.1. Phantom Design and Gel Preparation

An anthropomorphic phantom with human pelvis shape was designed for gel dosimetry purpose, as shown in Figure 1. The phantom consists of slabs which are integrated to form a human pelvis shaped with two holes in the middle where gel inserts can be positioned for measurement. The tissue-equivalent part of phantom was made of Poly methyl-methacrylate (PMMA) and the bone-equivalent part was made of polytetrafluoroethylene (PTFE). Two cubic inserts with dimensions of 3.5×3.5×4 cm^3 and 6×6×7 cm^3 for prostate and bladder respectively determined for gel dosimetry.

Figure 1. Constructed anthropomorphic pelvic phantom

For the gel preparation, gelatin was soaked in water for 0.5 hr. The contents were stirred by heart-stirrer at 50°C till a clear solution was obtained, at this time hydroquinone was added. The temperature was brought down to 38°C and appropriate amounts of ascorbic acid, $CuSO_4$•$5H_2O$ and Methacrylic acid was added and the contents were stirred further [12]. The prepared gel was poured into gel insert which were used for compensator-based IMRT plan verification and into glass vials for calibration.

2.2. Treatment Plan and Irradiation

Compensators perturbs beam by hardening the primary photon spectrum and generating scattered photons and electrons [3, 13]. For investigating this effect on the response of gel dosimeter, percentage depth dose (PDD) curves were measured in the presence of 4 cm cerrobend slab using polymer gel and ion chamber.

The CT images of the phantom with gel inserts inside it were imported into TiGRT (LinaTech) treatment planning system. The target and organs at risk were delineated. A five-field compensator-based IMRT plan was created and using exported data related to compensators shape, compensators were constructed (Figure 2). The phantom with gel inserts filled with MAGIC gel was positioned on the treatment table and was irradiated according to planned radiation fields. A daily fraction dose of 2 Gy was delivered to the planning target volume. After irradiation, the phantom was left in the MRI scanning room for approximately 5 hours before scanning to attain thermal equilibrium.

Calibration of gel for IMRT study was carried out with 5 glass vials of 10 cm length, 2cm outer diameter, 1.5 cm inner diameter. Four vials were used for calibration in this way: 0.5, 1, 2 and 3 Gy. One vial was used as control vial. The vials were placed in water tank and irradiated with 18 MV photons with field size of 20 × 20 cm^2.

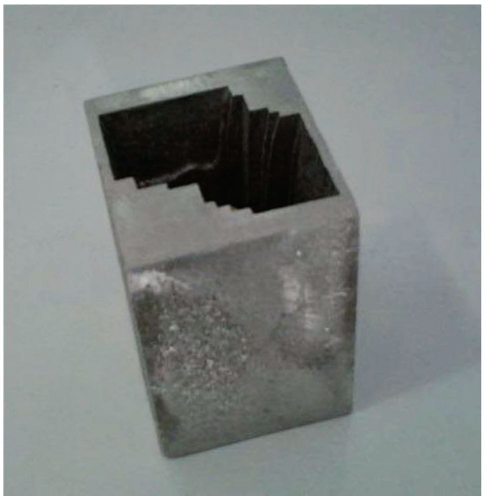

Figure 2. One of the constructed compensators

2.3. Gel Evaluation

Because of high dose response sensitivity of MAGIC-MRI combination, the MRI was employed as a readout system. The gel inserts and calibration vials were imaged by a 1.5 T Siemens MRI scanner (Symphony, Germany) in the head coil. A multi-echo sequence with 32 echoes was used for the evaluation of irradiated polymer-gel dosimeters. The parameters of the sequence were as follows: TR= 5000 ms, TE =22–704 ms, slice thickness 5 mm, field of view (FOV) 256 mm×256 mm, matrix size 256×256, pixel size 1×1 mm^2, and one acquisition.

The R2 (spin lattice relaxation rate) maps were computed using an in-house MATLAB code (Mathworks, Inc.). It should be noted that the first echo of the 32-echo train was discarded because of 180 RF pulse errors. Calibration data for the MAGIC gel batch used in this work were derived by the analysis of R2 maps of the calibration gel vials 3 days post-irradiation and a linear fit was performed on R2 values of MAGIC in the dose region of 0-3 Gy. The R2 matrix was subsequently converted into a relative dose matrix, normalized to the maximum prescribed dose of 2 Gy.

Dose grids obtained from measurements and calculations were linearly interpolated into a common spatial grid of 1×1×1 mm. For data analyzing, distance to agreement (DTA) was used in 3 dimensions. The DTA is the distance between a measured point and the nearest point in the calculated dose matrix (acceptable tolerance usually is 3 mm) [14].

The root mean square error (RMSE), a quadratic scoring rule which measures the average magnitude of the error, was used as the figure of merit to evaluate differences between ion chamber and gel results (PDDs) in the presence of 4 cm cerrobend slab.

3. Results

Figure 3 shows the dose calibration data. The regression analysis shows that the slope is a=0.7879. The coefficient of the determinant R2 was 0.998 which showed an excellent linear fit for the dose range of interest.

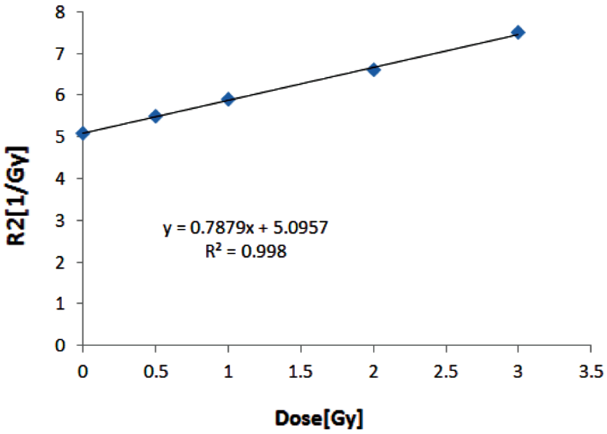

Figure 3. R2 as a function of absorbed dose.

Figure 4 represents obtained PDDs for ion chamber and gel in the presence of 4 cm cerrobend slab. The RMSE value was less than 3% between ion chamber and gel.

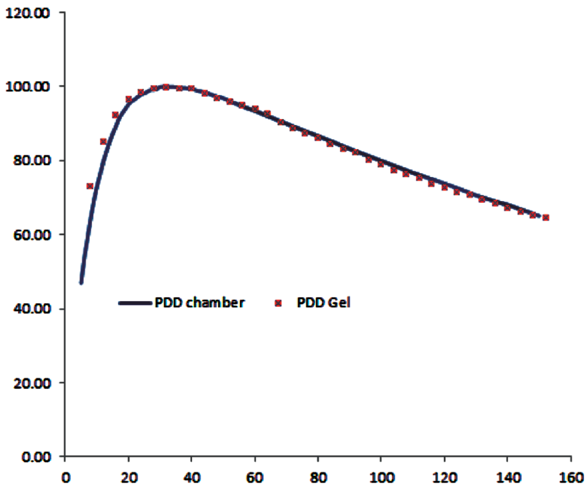

Figure 4. PDD curves obtained by ion chamber (solid blue line) and gel dosimeter (red squares) in the presence of 4 cm cerrobend slab.

Figure 5 shows superimposed dose distributions obtained by gel dosimetry and TPS in PTV region. The three dimensional DTA analysis showed that for 93% of points the DTA value was smaller than 3 mm which indicates very good agreement between calculated and measured results.

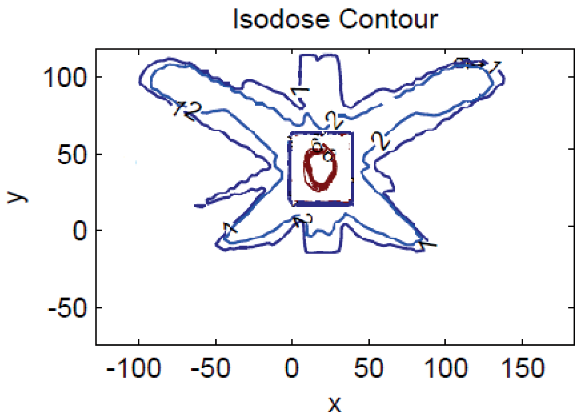

Figure 5. superimposed isodoses of gel measured and TPS calculated. In this figure the x and y axes are coordinate axes. The numbers 1 and 2 correspond to 10% and 30% isodoses, respectively. Also the thick red isodose and narrow red isodose (both indicated by 6) shows 100% isodose for gel and TPS. The blue rectangle shows a margin of gel insert for target.

4. Discussions

Since the advent of gel dosimetry, many researchers used this tool, for example Daniel A.Low et al. [7] investigated the use of polymer gel and MRI as a three dimensional (3D) dosimeter for IMRT dose distributions. Treatment plan was carried out by the Peacock IMRT system and after irradiation 3D maps of the proton relaxation rate R2 were obtained using a 1.5 Tesla MRI system. Gamma index analysis showed good agreement between treatment planning system dose distributions and gel measured dose distributions.

Crescenti et al. [10] changed the compositions amount of MAGIC gel and MR imaging parameters in order to optimizing them for application in IMRT and radiosurgery. According to dose volume histogram (DVH) and gamma index analysis, they concluded that MR based normoxic gel dosimetry is a valuable tool for clinically based dose verification, provided that customized gel compositions and MR imaging parameters are used.

These works were MLC-based IMRT and, hence, the mean energy does not change, whereas in compensator-based IMRT the energy spectrum and the mean energy of the primary photons on the patient's surface significantly change [3].

Vaezzadeh et al [13] showed that 4 cm cerrobend slab for 18 MV photons will increase the mean energy by 6.1% and our results (Figure 4) show that this increase has no significant effect on the dose response of gel dosimeter. This is in agreement with De Deene et al [15] results as they showed there is no significant energy dependence for photon beam energies between 6MV and 25MV for most gel dosimeters.

The depth dose results between ion chamber and gel dosimetry, and three dimensional DTA analysis for calculated and gel measured, all indicate that polymer gel-MRI method can be a valuable tool for compensator-based IMRT dose verification.

One of the stages needed to complete a 3D dosimetry is phantom fabrication. Fabricated phantom in this study can easily be used in other radiotherapy techniques. By using this phantom there is no need to design a large gel phantom with high cost. Another way to 3D dosimetry is film-based dosimetry that needs many films to be placed in solid phantom. Polymer gel dosimetry is easier than film-based dosimetry and more cost effective.

5. Conclusions

The purpose of this study was to test the applicability of polymer gel dosimetry in dose verification of compensator-based IMRT. For investigating of energy dependency of polymer gel under the use of compensator, 4 cm cerrobend slab was employed and results showed that MAGIC polymer gel dosimeter is energy independent. Finally, a treatment plan verification in pelvic phantom was carried out. The spatial analysis using DTA showed very good agreement between calculated and gel measured data.

The methodology presented in this work proved the feasibility of polymer gel dosimeter as an ideal tool for pretreatment IMRT QA and also the constructed phantom can be used efficiently in other radiotherapy techniques. Future work will be focused on the development of lung equivalent polymer gel dosimeter.

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