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Dose response evaluation of a low density anoxic polymer gel dosimeter using MRI

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ABSTRACT

Background: The human body contains of different tissues and cavities with different physical and radiological properties. Most important among these are tissues and cavities that are radiologically different from water, including lungs, sinuses and bones. Gel dosimetry provides a unique feature to display dose distributions occurring in clinical radiation therapy in three dimensions. ***Materials and Methods***: The low density polymer gel dosimeter is composed of 12% gelatin, 5% methacrylic acid, 0.15% sodium dodecyl sulfate, 10 mM THPC, and approximately 83% ultrapure deionized water. Post- preparation irradiation time for all samples was 5 hr. The time between irradiation and scanning for all gels experiments was 18 hr. The gel dosimeters were imaged using a 1.5 T clinical MRI scanner in a transmitter/receiver head coil. ***Results:*** There was a linear correlation between the doses and R_2 responses from 0 to 12 Gy. However, above the 14 Gy probably due to saturation and or consumption of the monomers the dose response was reduced. The low-density gels had a mass density between 0.35 and 0.45 $g.cm^{-3}$ and the CT values of about -650 to -750 Hounsfield units. These values are close to those of the normal human lung tissue, which ranges from -770 to -875 Hounsfield units. ***Conclusion:*** Increasing the gel temperature during rotation in the household mixer and probably reactions between the gelatin-free radicals and monomers led to a higher R_2-background response.

Keywords: *Low density polymer gel dosimetry, radiation therapy, MRI.*

INTRODUCTION

Polymer gel dosimeters are fabricated from radiation sensitive chemicals which, upon irradiation, polymerize as a function of the absorbed radiation dose. These dosimeters have specific advantages when compared to one-dimensional dosimeters, such as ion chambers, and two dimensional dosimeters, such as film [1-9].

Several chemical gel dosimeters have been developed and can be subdivided into two major classes. A first class is the Fricke gel dosimeter composed of a ferrous sulfate solution and a gelling agent [10-15].

On account of the lower electron density in the lung tissue, the dose distribution in the lung cannot be verified with the existing polymer gel dosimeters. To maximize the therapeutic benefit of radiation therapy, it is essential that the absorbed dose delivered to all irradiated tissues in the presence of such inhomogenities be predicted accurately [16].

In a study, to verification of three dimensional intensity modulated radiotherapy (IMRT) an inhomogeneous phantom of the human thorax including lungs and spine was used [17]. In another research the dose distribution measurements in a lung tissue equivalent phantom were performed [18].

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However, it is well- known that diffusion of ferrous and ferric ions [19-22], resulting in blurring and loss of spatial accuracy in the measured dose maps.

Alternatively, a second class of gel dosimeters was developed consisting of a gelatin hydrogel in which co-monomers are dissolved [23-26]. In these dosimeters upon irradiation, a radiation- induced polymerization reaction occurs and the degree of polymerization is dose dependent [27]. The dose maps from polymer gel dosimeters can be reconstructed from R_2 images through calibration with a dose - R_2 curve [28].

In recent years, the low density gel dosimeters have been developed consisting of a gelatin hydrogel in which methacrylic acid is dissolved [29-31]. However, the low density gel dosimeters have some disadvantages when compared to soft tissue equivalent dosimeters as follows: Unstable homogeneity, weak temporal stability, poor reproducibility, lower dynamic range and higher R2 background.

Thus, the aim of this study was to make a low density polymer gel dosimeter that capable of measuring the three dimensional dose distributions in human lung tissue with high confidence. In addition further attempts will be investigated on factors influencing the uniformity of the gel.

MATERIALS AND METHODS

Low density polymer gel dosimeter preparation

In this study a low density polymer gel dosimeter was fabricated according to composition proposed by De Deene [30, 31], with some modifications. The low density polymer gel dosimeter is composed of 12% gelatin, 5% methacrylic acid, 0.15% sodium dodecyl sulfate, 10 mM THPC, and approximately 83% ultrapure deionized water. The gelatin was dissolved in 90% of the total water at room temperature. After allowing the gelatin powder to swell for about 15 minutes, in order to obtain sol, the gelatin solution was heated to 45°C. An SDS solution then was made with the remaining water (10%). While the gelatin solution was cooled down to 30°C, nitrogen gas (purity 99.9%) was perfused through the glove box. The oxygen concentration in the glove box was monitored by an oxygen meter (Oxi 330/set, WTW). When the oxygen meter showed an oxygen concentration of less than 0.02 mg/l, SDS solution was added to the solution, under heavy stirring for two minutes. The methacrylic acid was combined in the solution and magnetically stirred for two minutes. The SDS solution improves the gel stability and homogeneity. The gel was beaten up by using a household mixer. After approximately two minutes, a white viscous creamy substance, with very small bubbles was obtained. To remove the inhibitory effect of the dissolved oxygen, THPC was added while still beating the gel. After rotation the gel solution in a household mixer, its color became white and its volume increased. After another ninety seconds, the gel was poured into the vials. To increase the gel homogeneity, all samples kept in rotation during thirty minutes at a rate of three rotations per minutes. The samples were then stored in the refrigerator (4°C) for five hours before irradiation.

Irradiation

An external treatment unit (Phoenix Co-60 machine) located in radiation therapy section of Seyed Alshohada Hospital, Isfahan was chosen as the photon source. Ten cylindrical plastic vials of equal shapes and sizes (diameter: 2.4 cm and height: 12 cm) were filled with gel and exposed to certain doses from 0 Gy to 18 Gy at steps of 2 Gy. The vials were placed at the depth of a maximum dose, in a water-filled recipient. The field size was 35 × 25 cm^2 and the source-to-phantom distance (SSD) was 80 cm. To investigate the 3D dose distribution, cubic recipient containing 1000 ml of gel was irradiated to 10 Gy through the bottom using a single square beam (10 × 10 cm^2). To maintain the gel strength, during irradiation, the water temperature in the container was maintained at lower than 15°C. Post- manufacture irradiation time for all samples was 5 hr.

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Magnetic resonance imaging evaluation

The time between irradiation and scanning for all gels experiments was about 18 hr. The gel dosimeters were imaged using a 1.5 T clinical MRI scanner (Siemens MAGNETOM Avanto, Germany) in a transmitter/receiver head coil. A multiple spin-echo sequence with 32 echoes was used for the evaluation of an irradiated low density polymer gel dosimeter. The parameters of the sequences were as follow: T_R = 3000 ms, T_E = 16.5 ms, slices thickness =1 cm, interval (slice gap) = 0.1 mm, field of view (FOV) = 230 mm, matrix size = 256 × 256, pixel size = 0.89 × 0.89 mm^2, number of excitations (NEX) =1 and total scan time = six minutes. To evaluate the temporal stability of a low density gel dosimeter, the calibration vials were scanned for 18, 42, and 66 hours, after irradiation. The R_2 responses and dose maps were computed using a modified radiotherapy gel dosimetry image processing software developed in the matrix Laboratory (MatLab).

Density determination

Transmission tomography of the gel samples was carried out using a CT scanner (Shimadzu Medical Systems, Japan) was installed in imaging section of Alzahra hospital, Isfahan. To scanning the gel samples a pulmonary protocol with a slice thickness of 5 mm was used. The electron density of the gels was obtained from the CT images. The mass densities were also calculated using the weight of the gel and the volume of the sample.

RESULTS

There was an approximate linear correlation between the R_2-responses and doses, from 0 Gy to 12 Gy (figure 1). However, above 14 Gy the dose response was reduced. The fabricated gel had a higher dynamic range than the other low-density polymer gel dosimeters; but its background R_2-response was higher. The temporal stability of the gel was investigated for the R_2-response up to three days (18, 42, and 66 hours, respectively) after irradiation. The stability data were derived from consecutive MR measurements of 10 calibration vials.

The results showed that no significant differences were observed in the dose response, with respect to post-irradiation time (figure 2). The results showed that different concentrations of THPC (2, 5, 8, 10 mM) have had different effects on gel strength. The best result was obtained by using of THPS at concentrations of 10 mM.

The PDD curves in both TPS and gel measurement are seen in figure 3. As shown a fairly agreement was founded between the gel measured and treatment planning system (TPS) calculated dose distribution. As mentioned above, to study the three dose

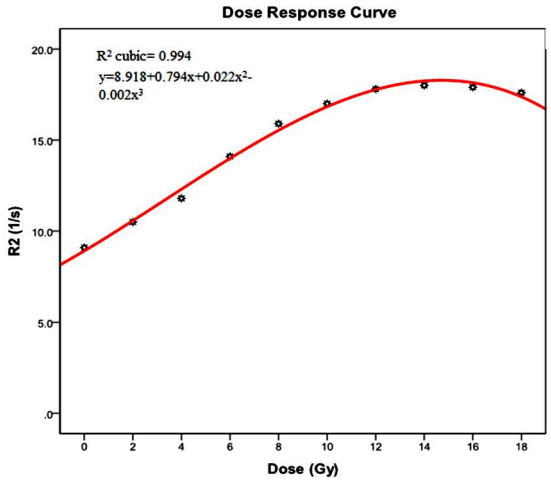

Figure 1. R_2-dose curve for a low-density polymer gel dosimeter, 18 hours after irradiation, based on three separate experiments.

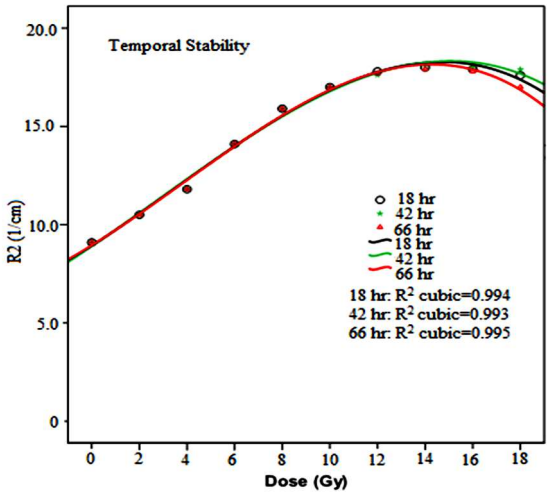

Figure 2. R_2-dose curve at different post-irradiation times in low density polymer gel dosimeter.

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distribution, a cubic recipient containing 1000 ml of gel was immersed in a larger water container. The container then was scanned by using a CT scanner with a slice thickness of 5 mm. To obtain isodose curves, these images then were imported to the TPS computer. As can be shown, typically two separate isodose curves that were obtained from two consecutive CT images in TPS are shown in figure 4. In addition, both relative isodose curves that were obtained in gel and coronal T2-weighted MR dose image of the gel for 10×10 cm^2 field are seen in figure 5.

After adding the SDS solution to the gel solution and its rotation in a household mixer, its color became white and its volume increased. As mentioned above, the low-density gels had a mass density of between 0.35 to 0.45 gcm^{-3} and the CT values varied from approximately - 650 to -750 Hounsfield units.

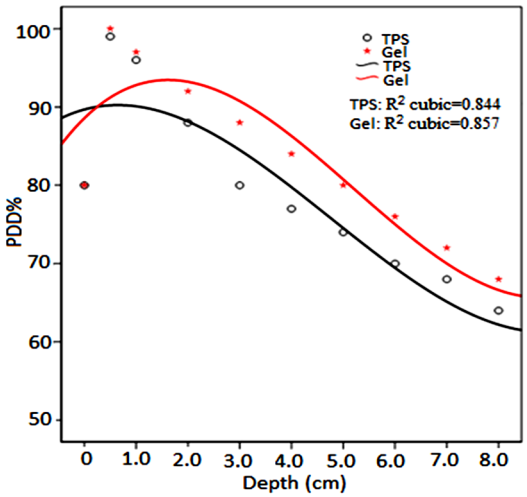

Figure 3. The depth dose curves for a low density polymer gel dosimeter that were obtained from TPS and gel measurements.

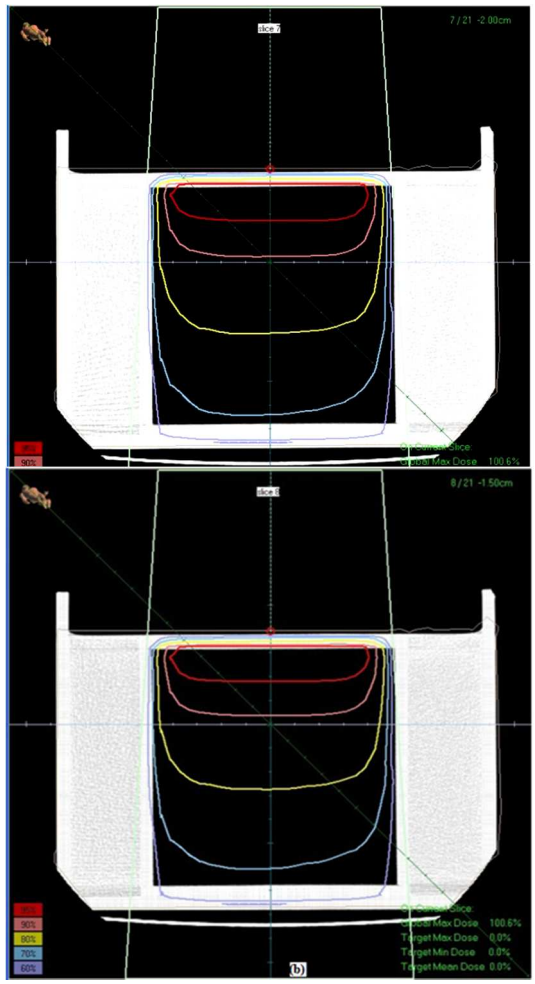

Figure 4. Two separate isodose curves (a, b) were obtained from two consecutive CT images from a cubic recipient (1000 ml) in TPS.

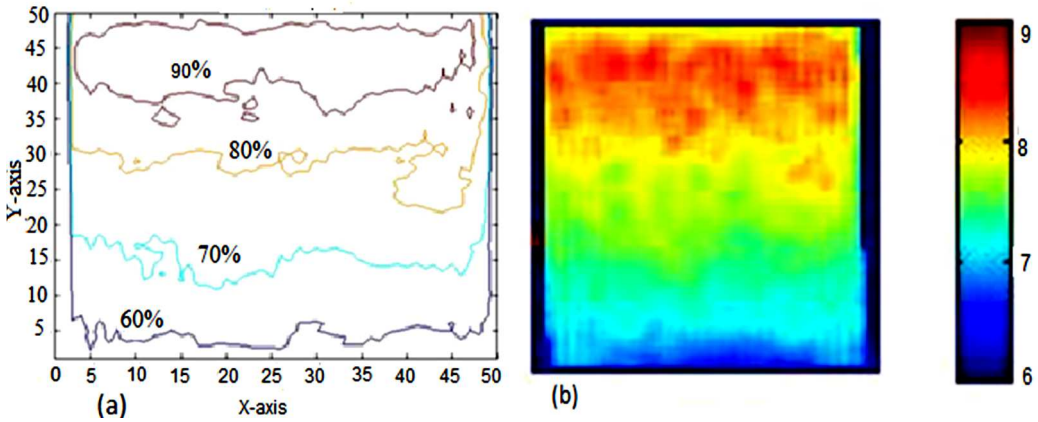

Figure 5. Relative isodose curves were obtained in a low density polymer gel dosimeter (a) and (b) Coronal T2-weighted MR dose image of the gel dosimeter for 10×10 cm^2 field.

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DISCUSSION

An anoxic polymer gel dosimeter with a reduced density was obtained by adding SDS solution to the normal-density gel in the glove box.

To the best of the author's knowledge, till date, three articles, on low-density polymer gel dosimeters have been published. In one of them [29], the low-density gel has been achieved by mixing the gel with expanded polystyrene. In the latter research it was found that the measured R2 is more susceptible to the microstructure of the gel due to susceptibility differences between the nitrogen bubbles and the interstitial gel phase [30]. In addition, in a recent study [31] two types of a low density polymer gel dosimeter has made. In one type of gel, to remove the dissolved oxygen, nitrogen gas was perfused through the solution and in other type; nitrogen gas was perfused through dry Styrofoam beads. However, the results were very similar to previous researches [30, 31],

As mentioned above, in our study to remove dissolved oxygen, nitrogen gas (purity 99.9%) was perfused through the glove box. During gel preparation oxygen concentration in glove box was monitored by an oxygen meter. The concentration of dissolved oxygen was lower than 0.02 mg/l. As showed in figure 1, there is an approximate linear correlation between doses and R_2 responses from 0 to 12 Gy. However, above 14 Gy probably due to saturation and or consumption of the monomers the dose response was reduced.

Although the background R_2 response in this study was higher than that in other studies [29, 30], its dynamic range was higher. It appears that the increase in gel temperature during rotation in the household mixer and probably reactions between gelatin-free radicals and monomers led to pre-irradiation polymerization. Therefore, it causes a higher R_2-background response. Thus, it seems reasonable to shorten the time between the preparation and irradiation of the gel.

As mentioned above, the low-density gels had a mass density of between 0.35 to 0.45 $g.cm^{-3}$. These values are lower than those of 0.58 to 0.63 $g.cm^{3}$ that has been reported by Haraldsson *et al.* [29], but higher than values which were reported by De Deene *et al.* [30, 31]. As explained, the fabricated gel had the CT values ranges from-650 to -750 Hounsfield units. It is clear that these values are lower than those reported by Haraldsson *et al.* which range from -400 to -500 Hounsfield units [29]. On the other hand, the CT number of the fabricated gel was very close to those of the normal human lung tissue, which ranges from -770 to -875 Hounsfield units [29].

It is obvious that THPC antioxidant is added to remove the inhibitory effect of oxygen, but we found that different concentrations of THPC (2, 5, 8 and 10 mM) have had different effect on gel strength. We showed that gels sets more rapidly in the presence of THPS at concentrations of 10 mM. Also no significant differences were observed (figure 2) in the R_2-dose response in the low density polymer gel dosimeter with respect to post irradiation time. It is indicated that polymerization-induced radiation does not change up to three days after irradiation, hence, one can conclude that the gel has good stability and homogeneity.

The depth dose curves in the low density polymer gel dosimeter obtained from TPS and gel measurements are shown in figure 3. It is clear that a fairly agreement was found between the gel measurements and TPS calculated dose distribution. It is indicated that the gel density and homogeneity is very close to the normal human lung tissue. Small differences in the mass density and Hounsfield number of the fabricated gel with those of the normal lung tissue, confirm the results of this research.

Two separate isodose curves that were obtained from two consecutive CT images from a cubic recipient (1000 ml) in TPS are shown in figure 4. There are four smooth isodose curves and it is indicated that the fabricated gel has well homogeneous. The relative isodose curves and coronal T_2-weighted MR dose image obtained from a cubic recipient also are shown in figures 5a and 5b. It is clear that there is a fairly agreement between the relative isodose curves and coronal T_2-weighted MR dose image. There are many factors that may change the results or reproducibility of the experiments.

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Most important among these is gel temperature. We concluded that to maintain the gel strength, during irradiation, the water temperature in the container should be maintained at lower than 15°C.

CONCLUSION

An anoxic polymer gel dosimeter with a reduced density was obtained by adding SDS solution to the normal-density gel in the glove box. Small differences in the mass density and Hounsfield number of the fabricated gel with those of the normal lung tissue, is a good outcome. However, in order to get more reliable results, preserve the gel uniformity during the preparation, irradiation and scanning is very important.

Conflicts of interest: *none to declare.*

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