Original Article

Does nitrogen gas bubbled through a low density polymer gel dosimeter solution affect the polymerization process?

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Abstract

Background: 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. Thus, the aims of this study are to make a low density polymer gel dosimeter and investigate the effect of nitrogen gas bubbles on the R_2 responses and its homogeneity.

Materials and Methods: Two different types of low density polymer gel dosimeters were prepared according to a composition proposed by De Deene, with some modifications. In the first type, no nitrogen gas was perfused through the gel solution and water. In the second type, to expel the dissolved oxygen, nitrogen gas was perfused through the water and gel solution. The post-irradiation times in the gels were 24 and 5 hours, respectively, with and without perfusion of nitrogen gas through the water and gel solution.

Results: In the first type of gel, there was a linear correlation between the doses and R_2 responses from 0 to 12 Gy. The fabricated gel had a higher dynamic range than the other low density polymer gel dosimeter; but its background R_2 response was higher. In the second type, no difference in R_2 response was seen in the dose ranges from 0 to 18 Gy. Both gels had a mass density between 0.35 and 0.45 $g.cm^{-3}$ and CT values of about -650 to -750 Hounsfield units.

Conclusion: It appeared that reactions between gelatin-free radicals and monomers, due to an increase in the gel temperature during rotation in the household mixer, led to a higher R_2-background response. In the second type of gel, it seemed that the collapse of the nitrogen bubbles was the main factor that affected the R_2-responses.

Key Words: Low density polymer gel dosimetry, magnetic resonance imaging, nitrogen gas, radiation therapy

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INTRODUCTION

Polymer gel dosimeters are fabricated from radiation-sensitive chemicals, which upon irradiation, polymerize as a function of the absorbed radiation dose. These dosimeters, which uniquely record the radiation dose distribution in three-dimension (3D), have specific advantages when compared to one-dimensional dosimeters, such as ion chambers,

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and two-dimensional dosimeters such as films.[1-9] The human body consists of a variety of tissues and cavities with different physical and radiological properties. The most important among these are tissues and cavities that are radiologically different from water, including lungs, oral cavities, teeth, nasal passages, sinuses, and bones. Therefore, the dose distribution in lungs 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.[10]

An inhomogeneous anthropomorphic phantom of the human thorax was developed, including the lungs and spine, for verification of three-dimensional (3D) intensity-modulated radiotherapy (IMRT).[11] The phantom and spinal cord were filled with undiluted Fricke gel, whereas, the lungs were filled with a special low-density Fricke gel. Dose distribution measurements were performed by magnetic resonance imaging (MRI) of a phantom containing lung tissue equivalent compartments made of ferrous sulfate gel.[12] However, it is well known that diffusion of ferrous and ferric ions, which occur in Fricke gels,[13-17] result in blurring and loss of spatial accuracy in the measured dose maps. However, it may be expected that the ion diffusion coefficient in low density Fricke gel dosimeters is significantly reduced.

In recent years, a second class of low-density gel dosimeters has been developed consisting of a gelatin hydrogel in which methacrylic acid is dissolved.[17] Several variations of these polymer gel dosimeters have been proposed.[18,19] Although, in recent years, only limited research has been done on the construction of low-density gels, in all of them there are unresolved problems. These include: Unstable homogeneity, weak temporal stability, lack of reproducibility, lower dynamic range, and non-optimized imaging parameters. Also in low-density gels the R_2 background is higher rather than that in water and soft tissue equivalent gels. Thus, the aim of this study is to make a low density polymer gel dosimeter and investigate the effect of nitrogen gas bubbles on the R_2 responses and its homogeneity.

MATERIALS AND METHODS

Low density polymer gel dosimeter preparation

In this study a low density polymer gel dosimeter was fabricated according to a composition proposed by De Deene, with some modifications.[17] Two types of low density polymer gel dosimeters were prepared. Both gel dosimeters were composed of 12% (w/w) gelatin (300 Bloom, type A), 5% (w/w) methacrylic acid, 0.15% (w/w) sodium dodecyl sulfate (SDS), tetrakis hydroxymethyl phosphonium chloride (THPC) 10 mM, and ultrapure deionized water (approximately 83% (w/w). In the first type of gels, no nitrogen gas was perfused through the gel solution and water.

In the other types of gel, to expel the dissolved oxygen; nitrogen gas was perfused through the deionized water and gel solution [Figure 1c]. 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 45ºC. An SDS solution was made with the remaining water (10%). In both gels, while the gelatin solution was cooled down to 30 ^{0}C, nitrogen gas (purity 99.9%) was perfused through the glove box. Nitrogen gas was also perfused through the second type of gel. The oxygen concentrations in the glove box and in the second type of gel were 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 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 another 90 seconds, the gel was poured into the vials. After adding the SDS solution to the gel solution and its rotation in a household mixer, its color became white and its volume increased [Figure 1a and b]. The gel vials were then stored in the refrigerator (4 ^{0}C) for five hours before irradiation.

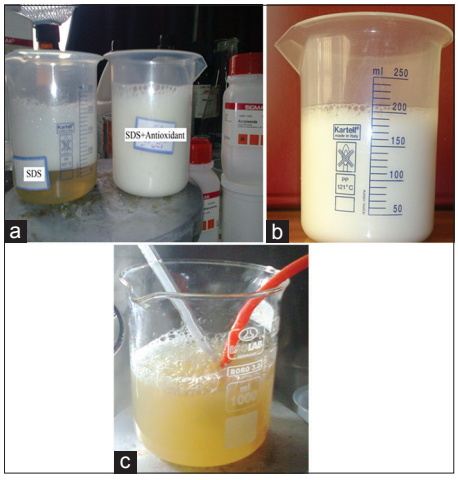

Figure 1: Low density polymer gel dosimeter obtained by adding the SDS solution (left) and adding the antioxidant (right) (a) the same recipient (b), and (c) by perfusion of nitrogen gas through the gel solution

Irradiation

An external treatment unit (Phoenix Co-60 machine) located in Radiation Therapy Section of the Seyed Alshohada Hospital, Isfahan, Iran, was chosen as the photon source [Figure 2]. Ten cylindrical plastic vials of equal shapes and sizes (diameter: 2.4 cm and height: 12 cm) were filled from each types of gels 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 maintain the gel strength, during irradiation, the water temperature in the container was maintained at lower than 15ºC. Post-irradiation time in the gels, with and without perfusion of nitrogen gas through the water and gel solution was 24 and five hours, respectively.

Magnetic resonance imaging evaluation

The time between irradiation and scanning for all gel experiments was about 18 hours. 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 pulse 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 polymer gel dosimeter, the calibration vials were scanned for 18, 42, and 66 hours, after irradiation. The R_2 responses 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). A pulmonary protocol with a slice thickness of 5 mm was used to scan both types of gels. 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

Dose response evaluation

Coronal T_2-weighted MR images obtained from four calibration vials are shown in Figures 3 and 4. In Figure 3 two calibration vials that contain homogeneous gels without nitrogen perfusion are shown. Two calibration vials containing inhomogeneous gels with nitrogen perfusion are seen in Figure 4. All the calibration vials were irradiated with 10 Gy. It is shown in Figure 3 that both calibration vials are homogeneous. Therefore, it is easy to measure the coronal T_2-weighted images. On the other hand as shown in Figure 4 due to gel inhomogeneity measuring the proper T_2-weighted images is impossible.

In the first type of gel, without perfusion of nitrogen gas bubbles through the water and gel solution, there was an approximate linear correlation between the R_2-responses and doses, from 0 Gy to 12 Gy [Figure 5]. The fabricated gel had a higher dynamic range than the other low-density polymer gel dosimeters; [18,19] 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 the consecutive MR measurements of 10 calibration vials. The results showed that no significant differences

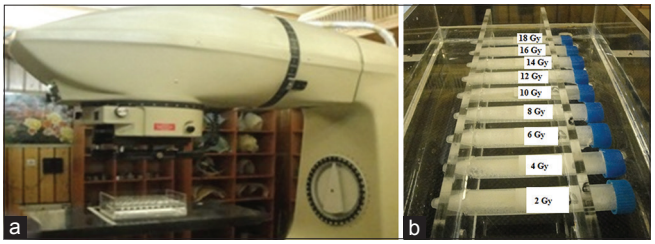

Figure 2: Calibration vials exposed to certain doses, from 0 Gy to 18 Gy in steps of 2 Gy (a) and (b) A special container for irradiation of the calibration vials

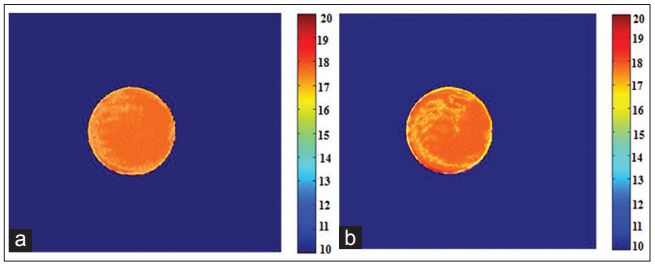

Figure 3: T_2-weighted images obtained from two calibration vials containing homogeneous gels

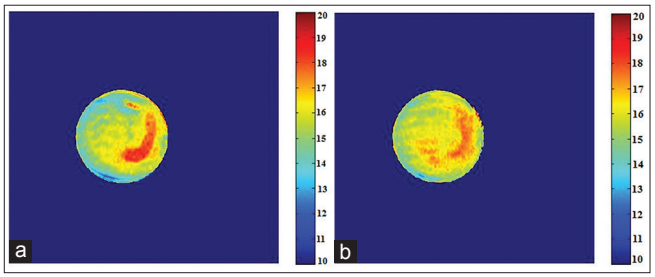

Figure 4: T_2-weighted images obtained from two calibration vials containing inhomogeneous gels

were observed in the dose response, with respect to post-irradiation time [Figure 6]. In the second type of gel, with perfusion of nitrogen gas bubbles through the water and gel solution, no difference in R_2 responses was seen in the dose ranging from 0 to 18 Gy [Figure 7]. This type of gel irradiated 24 hours after fabrication. It is clear that no specified R_2-dose curve was seen and the R_2 background response was also higher than in the first type.

Density determination

The electron density of the gels was obtained from the CT images. Both gels were scanned by a pulmonary protocol with a slice thickness of 5 mm. The gels had a mass density between 0.35 and 0.45 g.cm^{-3} and the CT values varied from approximately -650 to -750 Hounsfield units. In addition, it should be noted that in both studied gels there was no difference in gel strength or appearance.

DISCUSSION

Two types of anoxic polymer gel dosimeters, with a reduced density were 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.[17-19] In one of them,[18] the low-density gel has been achieved by mixing the gel with expanded polystyrene spheres. In this study, the dynamic range of the dose response to T_2 is limited from 2 to 8 Gy. In other words, the dynamic range is relatively short and the background dose response is relatively higher than those of water-equivalent gel dosimeters.

In another article[17] the gel components were combined in a glove box and the dose response curves for both the R_2 and MT responses were measured. In addition, they showed that the dose responses for both R_2 and MT of a gel foam dosimeter were density-dependent. In addition, in a recent study, two types of low density polymer gels were made. In one type of gel, nitrogen gas was perfused through the solution and in other type of gel; nitrogen was perfused through dry Styrofoam beads.[19] As mentioned, in our study two types of gels were made. During gel fabrication, to expel dissolved oxygen from the glove box, nitrogen gas was slowly perfused through the glove box. Dissolved oxygen concentrations were monitored by an oxygen meter. As mentioned above, the low-density gels had a mass density of between 0.35 to 0.45 g.cm^{-3} and the CT values varied from approximately - 650 to -750 Hounsfield units. It was clear that the mass density and CT number of the fabricated gel were very close to those of the lung tissue. The R_2-dose curve without perfusion of

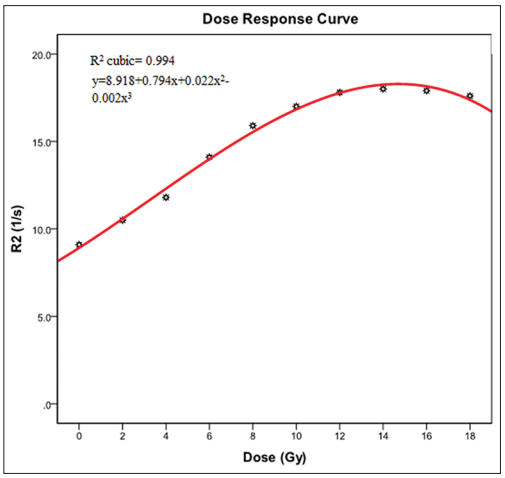

Figure 5: R_2-dose curve for a low-density polymer gel dosimeter without perfusion of nitrogen gas bubbles, 18 hours after irradiation, based on three separate experiments

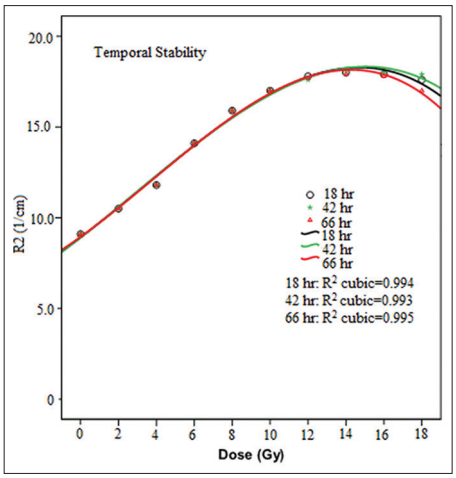

Figure 6: R_2-dose curve at different post-irradiation times, without perfusion of nitrogen gas bubbles through the low density polymer gel dosimeter

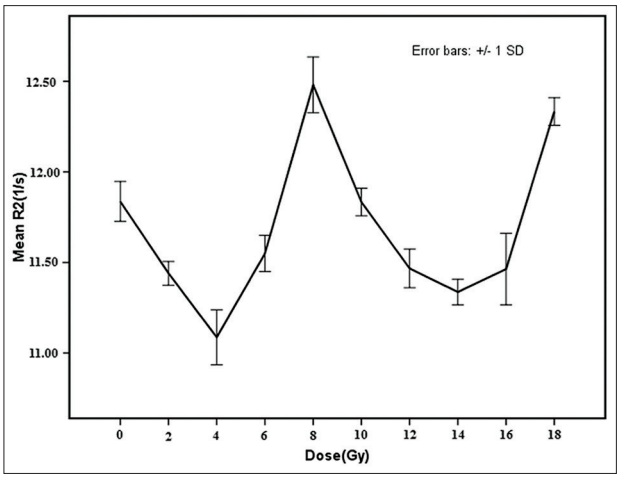

Figure 7: R_2-dose curve for a low density polymer gel dosimeter with perfusion of nitrogen gas bubbles 24 hours after irradiation, based on three separate experiments

the nitrogen gas bubble is shown in Figure 5. As shown, there is an approximate linear correlation between the R_2 responses and dose, from 0 to 12 Gy. However, from 12 to 14 Gy the dose response slightly increased and then decreased. Although the background R_2 response in this study was higher than that in other studies,[17,18] its dynamic range was higher. Also no significant differences were observed [Figure 6] 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.

On the other hand, in the second type of gel; no difference in R_2 responses is seen in dose ranges from 0 to 18 Gy [Figure 7]. It is clear that the R_2-dose curve is unspecified and the total R_2 background response is higher than that of the first type. It seems that by rotating the gel solution in the household mixer, the collapse of the nitrogen bubbles is the main factor that affects R_2 responses. After mixing the gels in the household mixer, the gel temperature is increased by bout 5°C. This may lead to dose inaccuracies of about 5% and also higher R_2 background response.[15,20] As mentioned earlier, in both the gels, the R_2 background responses are higher compared to the earlier researches. However, gelatin is also known for its role as a 'scavenger' of free radicals.[21] It appears that the increase in gel temperature during rotation in the household mixer and probably reactions between gelatin-free radicals and monomers lead 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. However, further investigation is necessary to find the reasons for a higher R_2 background. Finally, it must be noted that the stability of the low density polymer gel dosimeter is not obtained by just adding an SDS solution, antioxidants must also be added [Figure 1a].

CONCLUSION

Two types of an anoxic polymer gel dosimeters, with a reduced density, were obtained by adding an SDS solution to the normal-density gel in a glove box. 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. In addition, it appeared that by rotating the gel in the household mixer, a collapse of the nitrogen bubbles was the main factor that affected the R_2 responses. However, further investigation is necessary to find the main reasons for a higher R_2 background.

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