Original

Effect of Gold Nanoparticle on Percentage Depth Dose Enhancement on Megavoltage Energy in MAGICA Polymer Gel Dosimeter

Mahdavi M.[1*], Khadem-Abolfazli M.[1,2], Mahdavi S.R.M.[3], Ataei Gh.[2]

[1]Ph.D, Physics Department, Mazandaran University, Babolsar, Iran,
[2]M.Sc, Para Medical Department, Babol University of Medical Sciences, Babol, Iran
[3]Ph.D, Medical Physics Department, Tehran University of Medical Sciences, Tehran, Iran

ABSTRACT

Background: Radiation-sensitive polymer gels are among the most promising three-dimensional dose verification tools and tissue-like phantom developed to date.

Objective: The aim of this study is an investigating of percentage depth dose enhancement within the gel medium with used of conformal distribution gold nanoparticle as contrast agents by high atomic number material.

Methods: In this work the normoxic polymer gel dosimeter MAGICA tissue-equivalence was first theoretically verified using MCNPX Monte Carlo code and experimentally by percentage depth dose curves within the gel medium. Then gold nanoparticles (GNPs) of 50nm diameter with different concentrations of 0.1mM, 0.2mM, and 0.4mM were embedded in MAGICA gel and irradiated by 18MV photon beam.

Results: Experimental results have shown dose increase of 10%, 2% and 4% in 0.1mM, 0.2mM and 0.4mM concentrations, respectively. Simulation results had good agreement in the optimum concentration of 0.1mM. The largest error between experimental and simulation results was equal to 9.28% stood for 0.4mM concentration.

Conclusion: The results showed that the optimum concentration of gold nanoparticles to achieve maximum absorbed dose in both experimental and simulation was 0.1 mM and so it can be used for clinical studies.

Keywords

Percentage depth dose, Polymer gel dosimeter, Gold nanoparticles

Introduction

Gel dosimetry has been worked as a clinical dosimeter since the 1950s. During the last two decades, however, the number of investigators in this field has increased rapidly, and the knowledge of gel dosimetry has been expanded considerably. Gel dosimetry is still in its research phase and it seems that its contribution to clinical use proceeds slowly [1]. In this study a new type of gel dosimeter with acronym of MAGICA was used. This type of gel dosimeter was manufactured by adding agarose to the ingredient of MAGIC gel dosimeter [2]. MAGICA gel dosimeter was manufactured in Novin Radiation Medicine Institute (I.R. Iran) in 2004 [3]. In this study, for the first time, MAGICA polymer gel was used with GNPs and depth dose enhancement was evaluated by gel dosimetry in close relation to the Monte Carlo simulation of irradia-

*Corresponding author:
M. Mahdavi, , Physics Department, Mazandaran University, P. O. Box 47415-416, Babolsar, Iran, E-mail: m.mahdavi@ umz.ac.ir

tion condition within megavoltage X-ray field.

Materials and Methods

Experimental

GNPs preparation

In contemporary research, various synthesis techniques are being developed for GNPs fabrication. In this study, GNps of 50 nm size obtained from PNF Co. (Payamavaran Nano Fardanegar Co, Tehran, Iran) as gold nanoparticles in aqueous solution with 7mg/ml (7000ppm) concentration. In PNF Company, nanoparticles are produced by applying extra high electric voltage and current and the primary bulk wire with 0.1mm diameter is then converted into the nanoparticles via pulse explosive process. Figure 1 shows GNPs prepared.

Figure 1: GNPs prepared from PNF Co (www.pnf-co.com) (50 nm, 7000ppm)

Gel fabrication

A MAGICA polymer gel dosimeter was prepared. All chemicals (gelatin, ascorbic acid, CuSO4.5H2O, hydroquinone and methacrylic acid) were provided by Sigma Aldridge with experimental grade. HPLC water was obtained from Novin Medical Radiation Institute in Tehran. The preparation of the gel was carried out in a similar procedure as described by Fong et al. (2001) with slight difference due to the presence of agarose in MAGICA formulation [2]. For preparation, first, water was divided into 5 flasks of varying sizes, ready for dissolving each substance. Gelatin was added to about 60% of the total HPLC de-ionized water. Two electrical heating plates provided with magnetic stirring and thermostat control were used to heat the solutions. Gelatin was allowed to swell for about an hour and then the solution was stirred and heated to about 50°C until a clear solution was obtained, ensuring all gelatin powder has been dissolved. When the temperature of gelatin solution reached near 40°C, agarose was added to about 30% of warm water which had been heated up to 50°C. Agarose solution was stirred and heated to about 90°C at which agarose was thoroughly dissolved. At this time gelatin solution should be near 50°C. Both solutions were allowed to cool. The gelatin solution was larger in volume compared to the agarose solution, thus agarose solution cools faster in spite of its higher temperature. However, the cooling rates can be adjusted with respect to each other by proper adjustment of the heating plates. When both solutions cooled to an equal temperature about 47°C, agarose solution was added to the gelatin solution and stirring continued. Stirring didn't stop before the end of fabrication. At 45°C, Hydroquinone was added to the mixture in 5% of water weight. The remaining 5% of water were divided into two portions and in each portion Ascorbic Acid (AA) and Copper (II) sulphate were dissolved after being weighed. These two chemicals, which together play the role of oxygen scavenger, were added to the mixture.

When temperature declined to about 37°C Methacrylic Acid (MAA) was added at the same temperature. The amount of MAA for all gel fabrications was 9% of the total weight of gel except in one experiment in which more MAA was used. The gel was then decanted into test tubes or poured into the phantoms and left in a typical refrigerator at about 4°C to set.

When the preparation of final polymer solution was completed, MAGICA gel separated in four portions. One part is 400 ml for MAGICA gel and three parts in same capacities separated into 200 ml for incorporation different concentration gold nanoparticle in MAGICA

gel by routine mechanical mix without heating.

Three different GNp concentrations were considered: 0.1mM, 0.2mM, and 0.4mM. After preparation of MAGICA and Gold Nano _ MAGICA (GN_MAGICA) they were poured into calibration tubes and test vials for putting in a refrigerator at about 4°C.

Irradiation procedures

Gel samples were irradiated with 18 MV photon beams from Varian 2100 C/D (Varian Medical Systems, Palo Alto, CA) linear accelerator. The control MAGICA gel vial and GN_MAGICA vials were arranged randomly in the water-filled phantom size 25×25×10 cm3 (Fig.2).

The irradiation set up for GN_MAGICA listed in table 1. Also, for calibration MAGICA gel, calibration tubes fixed in the water-filled phantom that is show in figure3.

Figure 2: Gel vial arrangement prepared for irradiation.

Table 1: Irradiation set up information including field size, source to surface distance, number of monitor unit and deliver dose.

Field size	25×25 cm^2
SSD	100 cm
Dose rate	424 MU
Dose	500 cGy

Figure 3: MAGICA calibration tubes arrangement in the water phantom.

These tubes were irradiated with doses in the range of 0-600cGy (0, 100, 250, 500, 600 cGy) for 18 MV photon beam with SSD equal to100 cm and field size of 25×25 cm2. Dosimetry by ionization chamber (Farmer, PTW co) was done to ensure that proper and uniform dose was received by the polymer gel medium within the radiation field.

MRI reading and preparing an R_2 map

Several methods exist for dose response read out in gel dosimetry such as optical CT, Raman spectroscopy, nuclear MR, MRI and etc. In this study the proton magnetic properties variation was exhibited by magnetic resonance imaging (MRI).

Gels were imaged using a 0.5 T MRI (Philips) 24 hours after irradiation to ensure that the polymerization mechanism has completely MRI was done. An MRI protocol that minimized the noise in 0.5T MR image was found (table 2).

The gel phantom was put in head coil as show in figure 4. To ensure that the obtained R_2 values were not influenced by possible temperature gradients in the gel, phantoms were left in MRI room 4 hours before scanning. Since the gel temperature during imaging increased up to 30C, a little motion artifact is expected in MR image. R_2 (=1/T2) maps were computed using modified radiotherapy gel dosimetry image processing software coded in MATLAB (version 7.3.0.2.6 Math works).

Table 2: Optimum imaging protocol used for a Philips 0.5 T MRI system readings. **TE:** Echo time, **TR:** Repetition time, **ES:** Space between echoes, **Echo No:** Number of echoes, **NEX:** Number of averages, **FOV:** Field of view, **No. Slice:** Number of slices, **MS:** Matrix size.

TR	1500 ms
TE	20-160 ms
Echo number	8
FOV	230 mm
MS(matrix size)	256 mm^2×256
NEX	3
Slice thickness	3 mm (calibration tubes)
	5 mm(GN_MAGICA vials)
Slice number	5
Shimming	done

Figure 4: Gel vials put in the center of head coil

Monte Carlo simulation

Radiation transport in matter using Monte Carlo method was used as described in MC-NPX version 2.4.0 code to determine photoelectric, Compton, pair-creation and Rayleigh cross sections and calculate dose deposition in MAGICA polymer gel. Gold presence in gel was similar to the experiment set up. Percentage depth dose curves (PDD) were obtained experimentally and by simulation using the cross sections determined in MCNPX code to 18 MV clinical beams. The Varian 2100 C/D accelerator head was simulated by using the open literature information for 18 MV photons. The phantom size was 25×25×11 cm3 and SSD was 100 cm for all simulations. F2 tally was used for depth dose calculation. Simulations were done by using three 2.4 GHz Pentium 4 processor and time of the single simulation was about 20 days for obtaining the less than 1.6% relative error in gel vial area. Photon and electron energy cut-offs were set to 1 keV and 10 keV in the entire geometry, respectively. The number of histories for each simulation was estimated to be 9.5×108 in number. Figure 5 shows the geometry of simulated phantom.
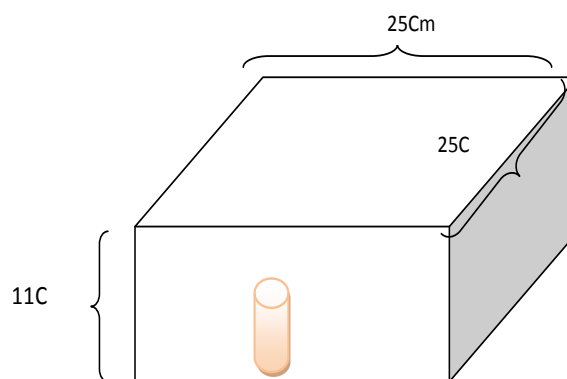

Figure 5: geometry of simulated phantom

Results and Discussion

MAGICA response to the 18 MV x-ray beam was characterized by R_2 signal relation to Dose. Figure 6 show calibration curve.

As it can be seen the calibration curve is almost linear within the range of 0-600 cGy which has been experienced in this study with gel sensitivity is about 0.0109 s-1cGy.

Also, for verification of dosimeter behavior of MAGICA polymer gel, Farmer chamber dosimeter has been used. The percentage depth dose curve of two dosimeters was compared
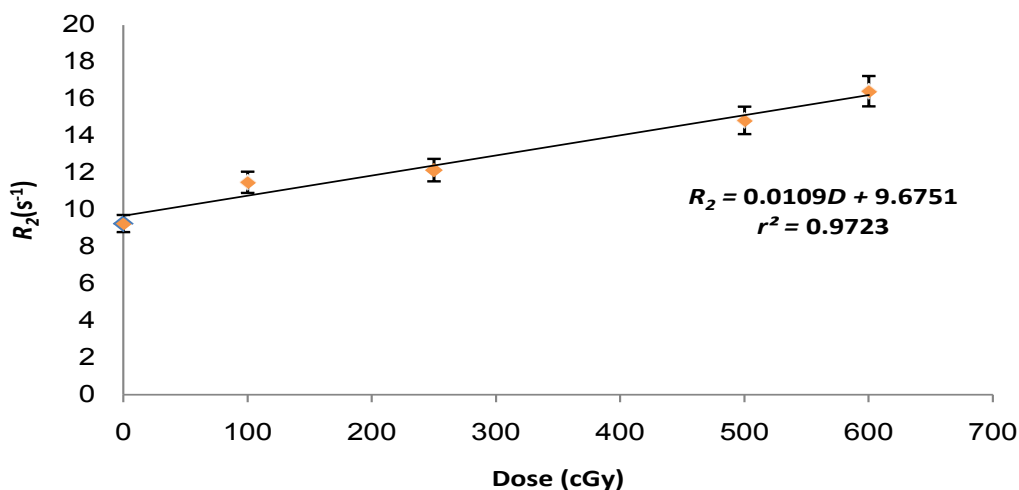
$$R_2 = 0.0109D + 9.6751$$
$$r^2 = 0.9723$$

Figure 6: MAGICA polymer gel dosimeter R_2 response on absorbed dose in range of 0-600cGy.
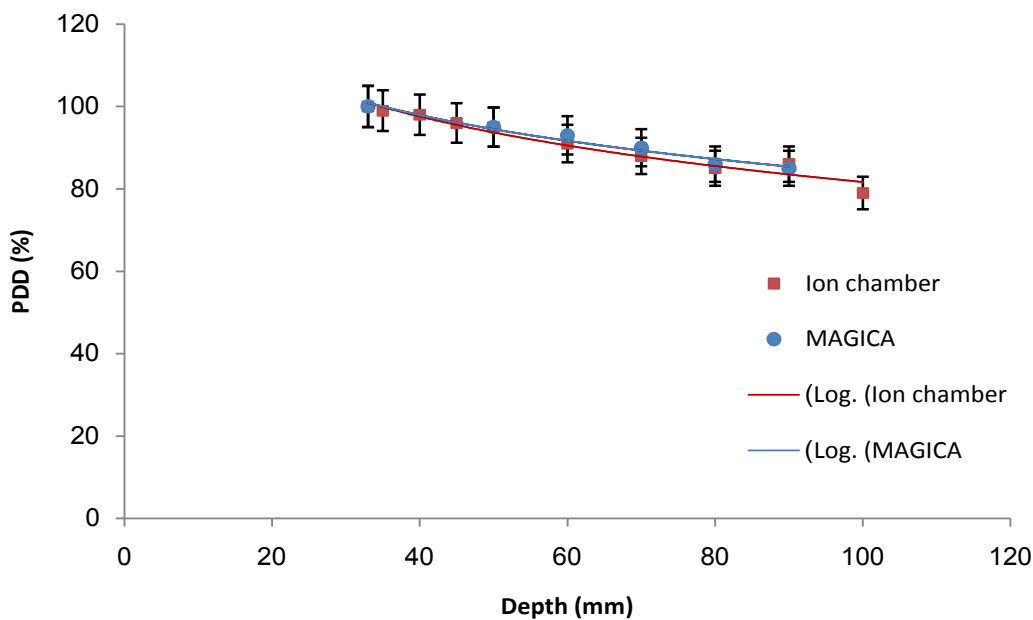

Figure 7: Percentage Depth Dose (PDD (%)) of curve MAGICA gel and ion chamber measured in water phantom

with each other that are shown in figure7.

According to the figure 7, it is concluded that they have appropriate accordance so that it's P-value is 0.001<0.05.

We obtained percentage depth dose for different concentrations of GNPs in GN_MAGICA and the results were shown in figure 8.

Figure 8 illustrate when GNPs concentration increases from 0.1mM to more concentration depth dose decreases, but when the concentration increases from 0.2 to 0.4mM the PDD behaves inversely and PDDs of both concentration are situated below the MAGICA gel alone in spite of PDD of 0.1mM concentration that
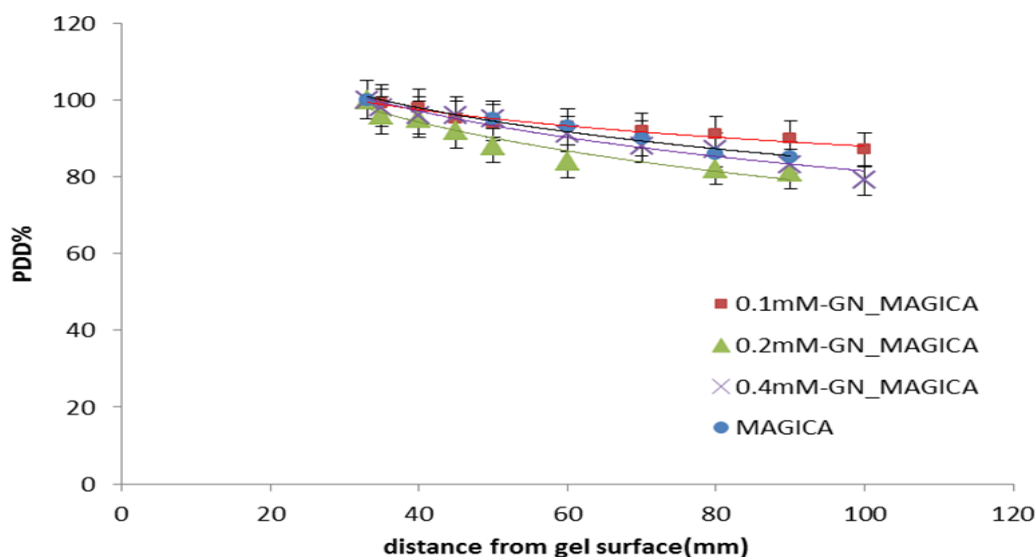
Figure 8: Comparison of three GNPs concentration with MAGICA depth dose curve
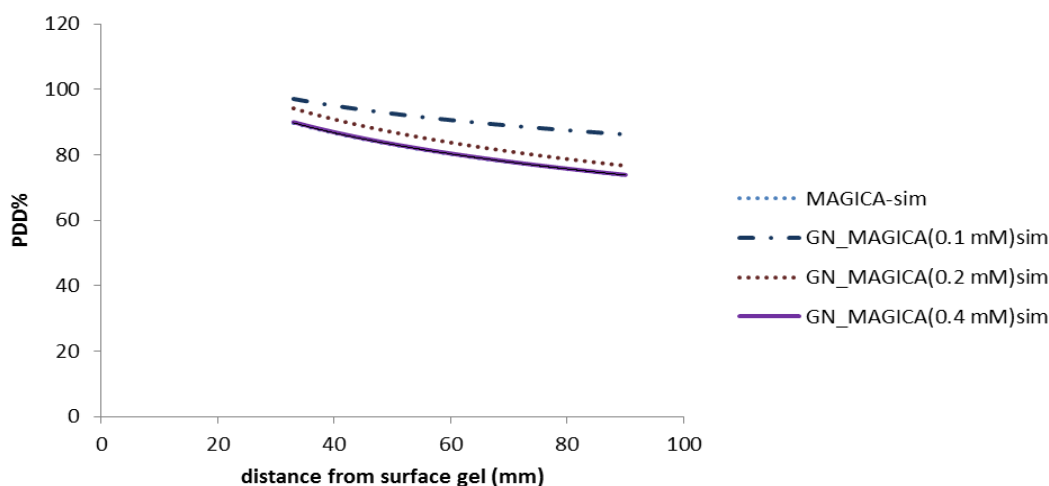

Figure 9: Compartion between MAGICA and GN_MAGICA percentage depth dose in simulation

is situated well above the MAGICA gel alone.

Also the percentage depth dose curve gained from Monte Carlo simulation by using of MC-NPCX code has been illustrated in figure 9.

In this curve, the increase of absorbed dose in buildup region can also been seen which in concentrations 0.1mM, 0.2mM and 0.4mM, equals to 9%, 6% and 2% respectively.

The percentage depth dose of MAGICA and GN_MAGICA with different concentrations, compared between experimental and simula-

tion results were illustrated in figure 10.

Based on the figure10, the mean of error percent between simulation and experimental data by using of following relation is computed:

$$error\% = \frac{calculation\ data - experimental\ data}{experimental\ data}$$

So that the error level for MAGICA polymer gel equals 1.01% and GN_MAGICA with concentrations of 0.1mM, 0.2mM and 0.4mM is 2.8%, 5.7% and 9.8% respectively.
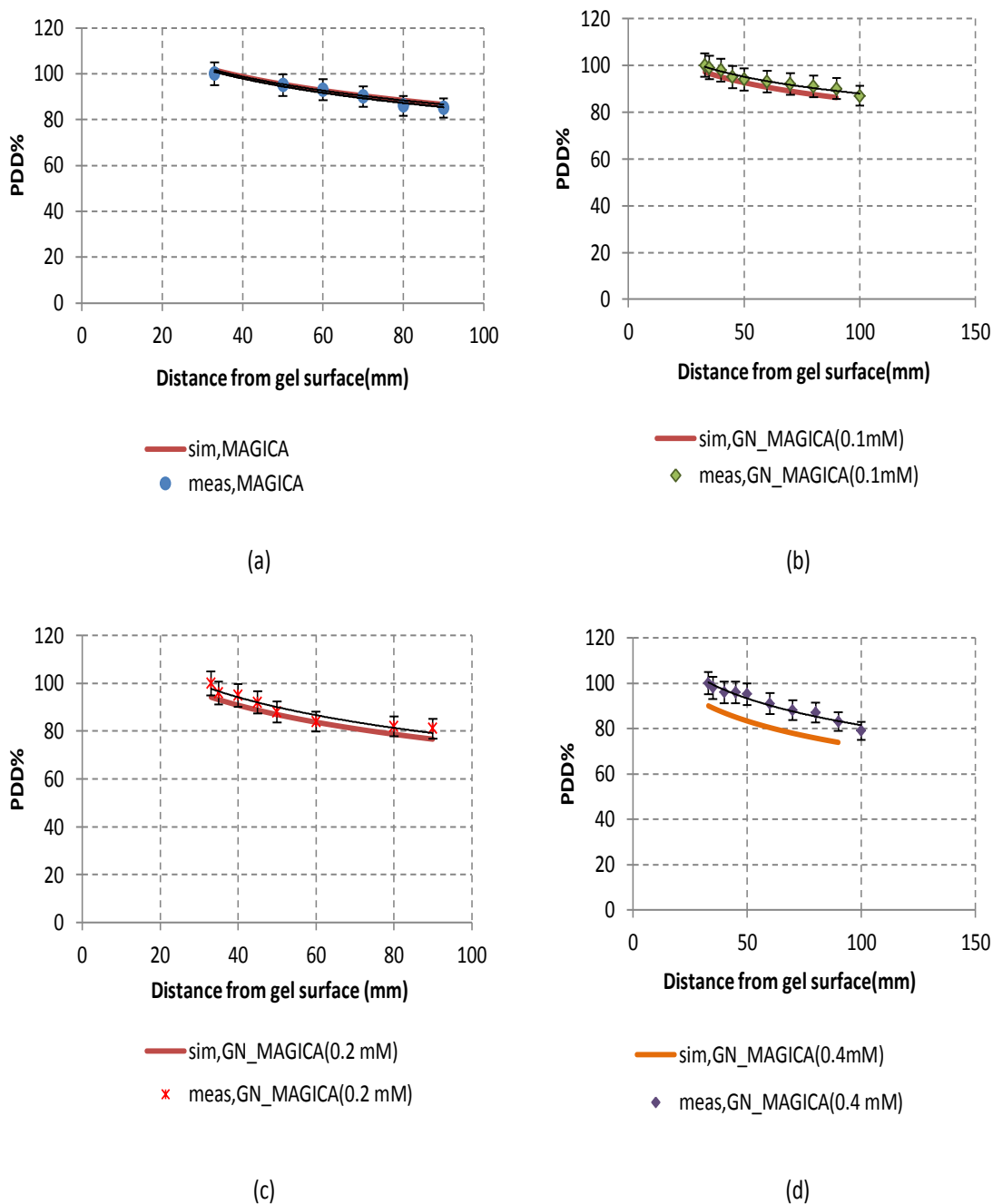
(a)

(b)

(c)

(d)

Figure 10: . Comparison percentage depth dose curve between simulation and experimental in different GNPs concentration.
(a) PDD simulation and experimental MAGICA (p-value<0.05)
(b) PDD simulation and experimental GN_MAGICA (0.1mM) (p-value<0.05).
(c) PDD simulation and experimental GN_MAGICA (0.2mM) (p-value<0.05).
(d) PDD simulation and experimental GN_MAGICA (0.4mM) (p-value<0.05)

Conclusion

Two major advantages of polymer gel dosimeters were their ability to determine integrated 3D dose distribution, as well as their ability to form in different shapes [4]. In fact, polymer gel dosimeters were monomers which distributed in a gelling matrix. Ionizing radiations convert these monomers to polymers via distinguished mechanism [5]. The polymerization degree is dependent on the absorbed dose in gel dosimeter. After polymerization, magnetic properties of polymer surrounding protons are changed [4]. These changes could be exhibited by magnetic resonance imaging. The spin-spin relaxation rate R2=1/T2 is related to the absorbed dose which was delivered to a gel phantom [6-8]. One of the polymer gels advantages is able to directly measure the effects of contrasts agents or metallic radiation dose enhancers such as iodine and gold nanoparticles (GNPs) inside the dosimeter. In gel dosimeters, contrast agents may have uniform dispersion within the dosimeter and therefore the effects of this material can be directly quantified. Physical measurement of the dose enhancement produced by high Z materials with other types of radiation dosimeters, such as film and ionization chambers, are quite complicated According to experimental and simulation results, by adding of gold nanoparticles to the MAGICA polymer gel absorbed dose is increased. Of course in 0.2mM and 0.4mM concentrations, absorbed dose enhancement wasn't significant and less than in 0.1mM concentration. So it can be concluded that in concentrations more than 0.1mM for gold nanoparticle with 50 nm size, shielding effect has been created. However by attention to the used 18 MV energy, predominancy of the phenomenon of pair production in these results will be seen. Totally, in experimental results, the absorbed dose enhancement in 0.2mM gold nanoparticle concentration was lower than 0.4mM. But in simulation method, it was observed that by increase of gold nanoparticles concentration, the absorbed dose enhancement has decreased.

Acknowledgment

Conflict of Interests

None declared.

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