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Radiation Sensitivity of MAGIC-F Polymer Gel by Gold Nanoparticles

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Abstract

Gold nanoparticles have been applied much more extensively in radiotherapy. This study used MAGIC-f polymer gel with gold nanoparticles in order to assess the dose-response of the speed of the sound. The MAGIC-f polymer gel with and without nanoparticles were placed under the megavoltage irradiation of Cobalt-60 with the doses of 0-60Gy with the step of 6Gy. Afterwards, the speed of the sound was assessed using an ultrasonic transmission device and the R2 parameter was assessed using Magnetic Resonance Imaging (MRI) at 25°C and 24h after irradiation. The highest sensitivity of ultrasound and MRI parameters was obtained in the range of 6-42Gy, and gel saturation occurred above 48Gy. Additionally, in the linear range of 6-42Gy, the speed of the sound and R2 parameters in MAGIC-f polymer gel was more with gold nanoparticles than without them. The presence of gold nanoparticles increases the absorbed dose. The presence of gold nanoparticles increases the absorbed dose and the speed of the sound can be use for dose - response curve extraction.

Keywords: Nanoparticles, Radiotherapy, Gel dosimetry, Ultrasound

Introduction

In the past two decades, nanoparticles have been used much more extensively in radiotherapy and diagnostic radiology (McMahon et al. 2008, Hainfeld et al. 2008). The presence of gold nanoparticles in materials increases photon interactions in it, consequently increasing the energy absorbed by it (Cho et al. 2009). The presence of metal nanoparticles in a material increases its effective atomic number and the mass attenuation coefficient (Cho 2005). Ultrasonic methods for dose determination through the extraction of physical-ultrasonic parameters have recently received very limited attention. Atkins et al. (2010) used MAGIC polymer gel in order to investigate the parameters of the speed of sound, attenuation coefficient, density and acoustic impedance in the dose range of 0-50Gy. In this study MAGIC-f polymer gel was chosen because of the highest sensitivity, stability and melting point. Afterwards, the parameter of R2 (MRI) and the speed of the sound of MAGIC-f polymer gel in the dose range of 0-54Gy with 6Gy steps were investigated. By extracting and examining the dose-response diagram of the speed of the sound and their comparison with MRI parameter, the efficiency of this method and polymer gel sensitivity in the range of irradiation doses 24 h after irradiation was obtained at 25°C.

Materials and methods

For the manufacture of MAGIC-f polymer gel, Animal gelatin material (Gelatin sheets 4072, Merck Co., Darmstadt, Germany), Formaldehyde (a chemical compound doctor luxurious, Tehran, Iran), Ascorbic acid, meta acrylic acid Monomethyl Ether stabilized with hydroquinone (Merck Co., Darmstadt, Germany), Copper sulfate and twice distilled water were prepared. After 24 h, samples were removed from refrigerated after reaching to room temperature (22.5± 0.2°C) and irradiated with 1.25 MeV of Cobalt-60 in the range of 0 to 54Gy in 6Gy steps (with 20×20cm2 field of view at a distance of 80cm from the surface of the gel). The absorbed dose was calculated at 1 cm depth from the surface of the gel with accuracy 2%. To prepare a polymer gel MAGIC-f in the presence of gold nanoparticles, gold nanoparticle solution was added to MAGIC-f gel (4 gr/lit). Turkevich method was used for the synthesis of gold nanoparticles as reduction method. For the preparation of 100 ml suspension of gold nanoparticles, the solution of Tetrachlorouric acid (HAuCl4: 3H2O) (0.01%) in four times distilled water are used. The 1 ml of trisodium citrate solution (1%) simultaneously are quickly steered to reach the verge of boiling. Then slowly reducing solution is added drop by drop and the solution is allowed to cool down in the open air. The reducing agent (citrate) acts as a protective coating which contributes to the stability of the nanoparticles in the ionic weak. To determine the range of nanoscale gold particles using dynamic light scattering (DLS) instrument (Zetasizer) and transmition electron microscopy were used. To avoid reconnection small particles of nanometer dimensions and to ensure more of its gold nanoparticles remain in their size, nanoparticles are made of gold solution for 10 minutes at room temperature (25˚C), sonication was carried out.After calibration ultrasound system, the speed of the sound (SOS) in m.s-1 using ultrasonic device (Sonost2000, Osteosys Co., Ltd., Seoul, Korea) 500kHz frequency based on the transit method was measured 24h after irradiation. The readings were performed 3 times for each sample to reduce error readings below 10 percent (n=5). The speed of the sound of MAGIC-f gel polymer before irradiation and after 0-54Gy irradiation with 6Gy steps were measured and dose-response plot was drawn. The dose-response curve based on the ability of T2 parameter Magnetic Resonance Imaging (MRI) was extracted and compared with the speed of the sound response. T2 imaging protocol was performed with 400 ms TR, 1×1×3 voxel size, 350 field of view, 22, 44, 55, ... ms TE1, 16 number of echo, 1-51 signal to noise ratio, 2 smoothing filter, 2 enhanced factor and 25% distance factor.

Results

The gold nanoparticles distribution was measured using Dynamic Light Scattering (DLS) (Malvern Instruments Ltd, Malvern, UK). The results of the dynamic light scattering (DLS) of synthesized gold nanoparticles showed an average size of 11.4±0.2 nm (Fig. 1). In this graph, the vertical axis is the percentage of light intensity reflected by the particles at each size.

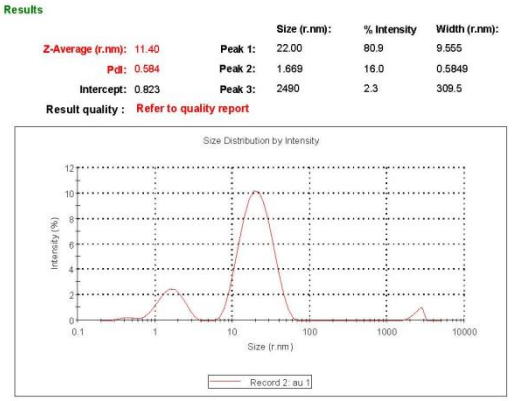


Fig. 1. Dynamic light scattering (DLS) of synthesized gold nanoparticles. The horizontal axis is the particle size in nm, and the vertical axis is the percentage of light intensity reflected by the particles at each size.

Nano-sized gold particles using a transmission electron microscope (TEM) were measured (EM 208S model, Philips Co., Japan). (Fig. 2).

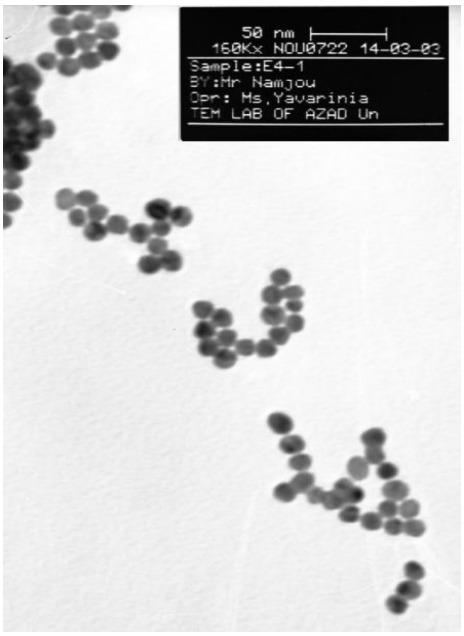
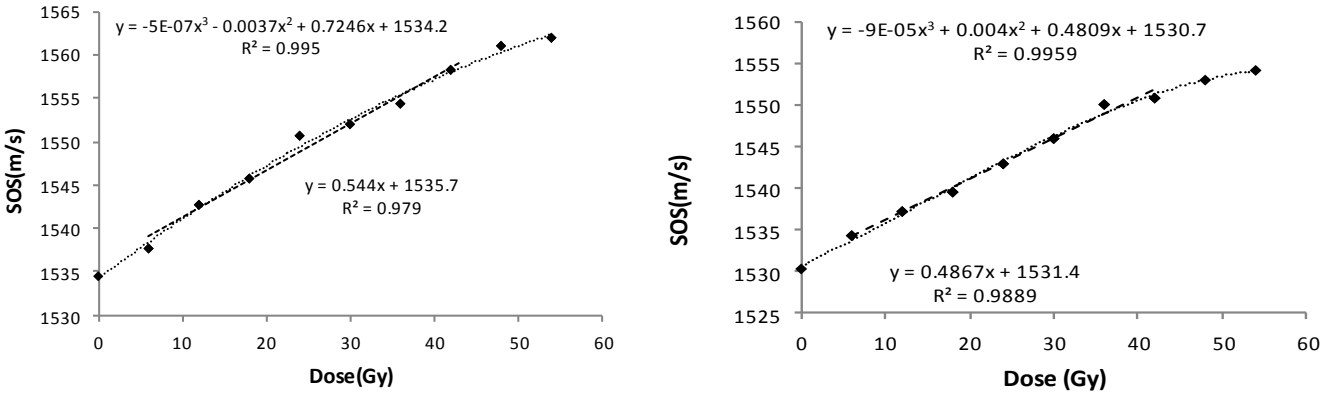


Fig. 2. Image of gold nanoparticle spherical model using a transmission electron microscope, ×160000

After making MAGIC-f polymer gel with and without gold nanoparticles and irradiation with Co-60 gamma device, the speed of the sound at 25°C and 24h after irradiation was measured for the doses of 0-54Gy with the steps of 6Gy. Furthermore, 24h after the irradiation, MRI images of MAGIC-f with T2 protocol were taken and then the amounts of T2 were converted into R2 using calculated R2 in MATLAB software. Afterwards, the sensitivity of speed of sound parameter and MRI parameter (R2) were studied and compared in the range of 0-54Gy at 25°C 24h after irradiation, with gold

nanoparticles and without gold nanoparticles. The Pearson correlation and non linear regression analyses between the speed of sound (SOS) and absorbed dose (Gy) were shown in Fig. 3 (a, b).



(a) (b)

Fig. 3. The speed of the sound sensitivity in the range of 6-42Gy, reading was performed 24h after irradiation, the correlation coefficient and linear regression function in the 6-42Gy dose for polymer gel (a) with gold nanoparticles and (b) without gold nanoparticles are 54 and 49 cm.s-1.Gy-1, respectively.

In these diagrams, the coefficient of the variance (CV) is less than 4%. The curve is fitted on the points with the order of three. The correlation coefficients were more than 0.98 and 0.99, respectively. The sensitivity of the speed of the sound parameter in the range of 42 to 54Gy were 15 and 19cm.s-1.Gy-1, respectively. For this parameter, the saturation of the gel started from the irradiation dose of 48Gy.

The Pearson correlation and linear regression analyses between the speed of sound and the R2 parameter with and without gold nanoparticles was shown in Fig. 4. The results show that there is a significant correlation between the speed of sound and the R2 parameter with and without gold nanoparticles (R=0.96 and R=0.98 with p-value<0.05, respectively).

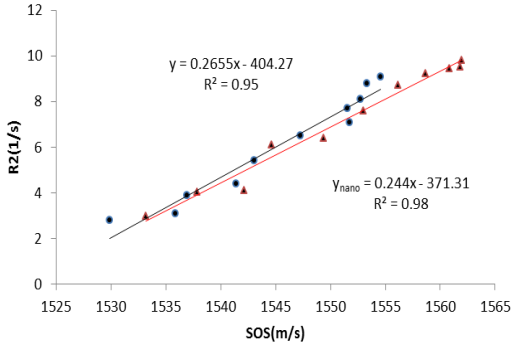


Fig. 4. Dependence of the speed of sound and the R2 parameter with (red line) and without (blue line) gold nanoparticles, the doses of 0-54Gy with 6Gy steps

Conclusion

MAGIC-f polymer gel is superior to other polymer gels in terms of sensitivity, stability and melting point, which is why it was used in this study. Investigation of the dose-response diagram of ultrasound parameter of the speed of the sound and the parameter of R2 (MRI) of MAGIC-f polymer gel in the dose range of 0-54Gy with the step of 6Gy with and without gold nanoparticles indicate the ability of this method in reading absorbed dose. It was also shown in this study that the use of gold nanoparticles increases photon collisions with gold atoms which increases the absorbed dose in substance. The R2 (MRI) parameter and the ultrasound parameter of the speed of the sound were used to show dose increase due to the effect of gold nanoparticles. With further study in the area of dose reading with acoustic methods and increasing the sensitivity of this method, the conventional method of MRI will be hopefully replaced by less costly, easier and more available method for dose estimation.

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