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Radiation dose enhancement of gold nanoparticle on different polymer gel dosimeters

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Abstract. In this work, we evaluated the dose enhancement produced by gold nanoparticle on ten different polymer gel dosimeters with a concentration of 7mgAu /g over a wide photon energy range of 15KeV to 20MeV and the results were compared with Soft tissue ICRU-44 produced. Our result showed that maximum DEF was observed at 40KeV, while it was almost negligible at higher energy range. Dose enhancement produced by AuNP on the gel dosimeter medium was varied compared to the reference ICRU-44 tissue, it was ± <1% for PAGAT, NIPAM, nPAG and ± <5% for PABIG, VIPAR, HEAG, BANG1, nMAG & ± <10% for MAGIC, ABAGIC gel dosimeters. Hence, we conclude that choosing the proper gel dosimeter is essential in dose enhancement study.

1. Introduction

Polymer gel consists of monomers [1-4]. Upon the irradiation, free radicals which initiate polymerization, the degree of polymerization are created, which is directly proportional to the radiation absorbed dose [5-7]. It was first proposed by Maryanski in 1993 [8]. Polymer gel systems are useful for complicated radiotherapy treatment plan verification and machine quality assurance [9] in IMRT, SRS, SRT, Proton therapy, Neutron boron capture therapy. The following imaging modalities can be used to extract the dose information within the exposed polymer gels such as OCT, MRI, X-ray CT etc. Gel dosimeters have a number of advantages, including true three-dimensional, soft tissue/water equivalence, directional independence, energy independence and it can be modified depending on the application [10-13]. Nanoparticle size ranges from 1 to 100 nm but definition includes particles up to 1µm which have also been reported. Due to their unique properties, nanoparticles can be used in biomedical application such as drug delivery, biosensors, imaging, and therapeutic agents [14-17]. Owing to its high atomic number, metal nanoparticle absorbs the low energy X-rays, which enhances the absorbed dose when it is loaded within the cancer tissue. Nanoparticles are well accumulated in the tumour via two mechanisms such as enhanced permeability and retention effect. Alternatively, nanoparticle binds with folate targeting material. Roeske *et al* theoretically analyzed the dose enhancement factor over the atomic number (Z) ranging from 25 to 90 at 5mg/ml concentration using 13 different energies from the radioactive source and external beam linac spectrum. They found that DEF linearly increased to Z>70, and his result suggests that high Z material joined the low energy photon, which can produce significant therapeutic advantages (dose enhancement) [17]. Marques *et al* analyzed the dose enhancement of gold nanoparticle on MAGIC-f polymer gel dosimeter by using 250KV X-rays. He found that DEF was 106%, 90% and 77% over the concentration of 0.10mM,

0.05mM and 0.02mM [18]. Also, many researchers have studied the dose enhancement effect of the gold nanoparticle using polymer gel dosimeter [19-22]. In the current study, we theoretically analyzed the dose enhancement factor over ten different polymer gel dosimeters. We also discuss the standard reference ICRU-44 soft tissue results.

2. Materials and Methods

Polymer gel elemental composition was taken from the published article [10]. Theoretical dose enhancement factor was calculated using the following formula proposed by Corde *et al* [23]. The mass absorption coefficient was generated by using NIST WinXCOM [24]. A major part of the dose enhancement study was performed at 7mg/g concentration of gold. Hence, we used the same concentration for easy comparison [25].

$$DEF = \frac{\left(\frac{\mu en}{\rho}\right)^{soft\ tissue+AuNp}}{\left(\frac{\mu en}{\rho}\right)^{soft\ tissue}}$$

Where: $(\mu_{en}/\rho) = \sum_i W_i (\mu_{en}/\rho)_i$
(μ_{en}/ρ) is the mass energy absorption coefficient.
W_i & $(\mu_{en}/\rho)_i$ are the atomic weight fraction, mass energy absorption coefficient of the i^{th} element

3. Results and discussion

Radiation dose enhancement is defined as the ratio of the absorbed dose in the tissue in the presence and absence of any contrast agent (gold, iodine, bismuth etc). According to the published data, the photoelectric effect is the major contribution for dose enhancement. DEF was considerably varied with the function of incident photon energy, nanoparticles concentration and size; hence, finding the optimal energy was an important task to get significant clinical benefits. First, we checked the reliability of our methods. For this, we considered DEF produced in the ICRU-44 tissue medium, which was 1.45307, 1.9762 at 80KeV and 50 KeV respectively. These values were in good agreement with the previously published monte-carlo method for 100nm size gold nanoparticle at same 7mg/ml concentration is within ±<4% [23].

These variations might be due to the following two reasons. On the one hand, we studied the different target medium soft tissues /water and on the other, the exclusion of secondary photons. In our method, maximum DEF was 2.0688 at 40KeV which was consistent with the previous Brun *et al* experimental method [24]. This dose enhancement could be due to the L-shell (11.9-14.4KeV) photoelectric effect. Incident photon energy was just above the respective shell binding energy. This produced significant DE effect and the energy was equal to the corresponding electron shell which is clinically not advantageous. Because it just knocks out the electron, this photoelectron does not have sufficient kinetic energy for biological damage. For dose enhancement study, K-shell binding energy is also important but it is not necessary to remain equal to incident photon energy. The probability of photoelectric effect decreased when incident photon energy increased. Due to this, there was no considerable enhancement at higher energies.

The Chemical composition of the target medium is also one of the factors which affect the dose enhancement factor produced by the gold nanoparticle. Low energy photons readily interact with high atomic number material via photoelectric effect (Z3/E3). In this analysis, we considered ten different polymer gel dosimeters. Each gel dosimeter consisted of its own chemical composition [10]. DEF was considerably varied according to polymer gel dosimeter medium. Between the ABAGIC and MAGIC gel dosimeters, we found maximum DEF which consisted of material with the medium atomic numbers such as sulphur (Z=16) and copper (Z=29) which may contribute to the dose enhancement while with

other gel dosimeters, we did not observe many variation. PAGAT, NIPAM and nPAG gel dosimeters may have the similar chemical composition of ICRU-44 soft tissue so DEF was within <1% level.

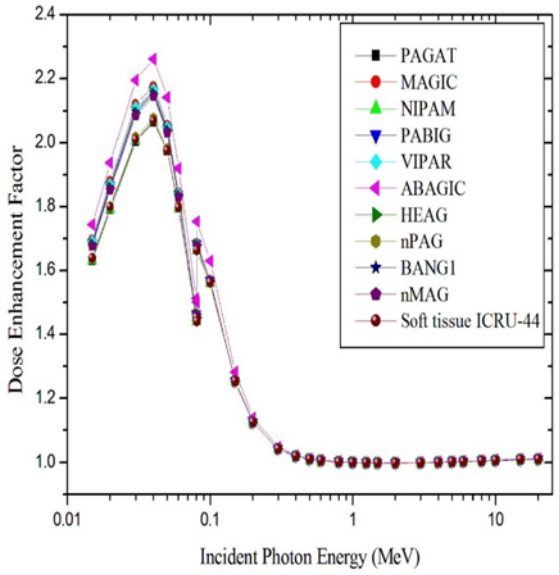

Figure 1. Dose enhancement of gold nanoparticle with 7mgAu/g

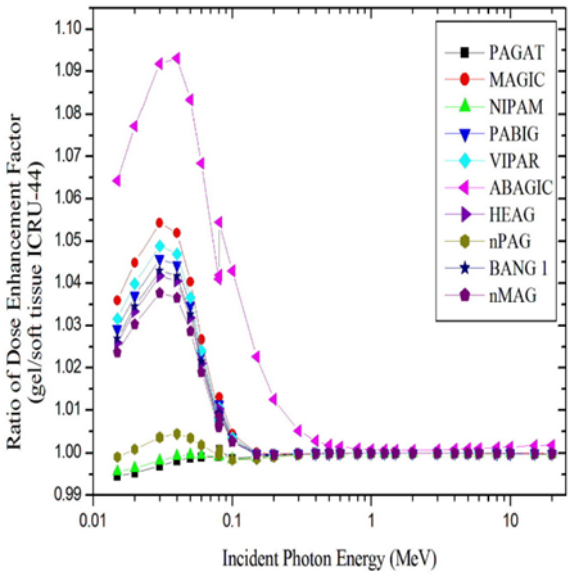

Figure 2. Ratio of dose enhancement factor of polymer gel and ICRU-44 soft tissue

4. Conclusions

Administration of high atomic number metal nanoparticle into the tumour leads to enhanced radiotherapy outcome. This type of treatment is known as Nanoparticle enhanced x-ray therapy (NEXT). Polymer gel dosimeter is one of the media for practically evaluating the DEF. Before the clinical use of metal nanoparticle in cancer treatment, many of the parameters such as biocompatibility, tumour targeting, incident photon energy, concentration and size of NP etc have to be considered. In addition, one more parameter, namely, the chemical composition of the targeting tissue is also important for better therapy dose calculation. PAGAT, NIPAM and nPAG polymer gel is the proper medium for dose enhancement study and similar DEF was absorbed as ICRU-44 soft tissue.

5. References

[1[Baldock C *et al* 1998 *Phys. Med. Biol*. **43** 695-702
[2] Baldock C *et al* 2010 *Phys. Med. Biol*. **55** R1-63
[3] Hill B *et al* 2005 *Med. Phys*. **32** 1589-97
[4] Mather M L *et al* 2003 *Ultrasonics* **41** 551-9
[5] Lepage M *et al* 2002 *Phys. Med. Biol*. **47** 1881-90
[6] Davies J B *et al* 2008 *Radiat. Phys. Chem*. **77** 690-96
[7] Murry P *et al* 2000 *Austral. Phys. Eng. Sci. Med*. **23** 44-51
[8] Maryanski M J *et al* 1993 *Magn. Reson. Imag.* **11** 253-8
[9] Vial P *et al* 2008 *Med. Phys*. **35** 4362-74
[10] Singh V P *et al* 2014 *Radiat. Phys. Chem*. **05** 033
[11] Maryanski M J *et al* 1996 *Med. Phys*. **23** 699-705
[12] Keall P *et al* 1999 *Austral. Phys. Eng. Sci. Med*. **22** 85-91
[13] Venning A J *et al* 2005 *Med. Phys*. **32** 1047-53
[14] Rippel R A *et al* 2011 *J. Nanosci. Nanotechnol*. **11** 3740-8
[15] Kim C K *et al* 2009 *Nanoscale* **1** 61-7
[16] Mahmoudi M *et al* 2011 *Nanoscale* **3** 3007-26
[17] Roeske *et al* 2007 *Tech. Can. Res. Ther*. **6** 395-401
[18] Marques T *et al* 2010 *J. Phys.: Conf. Ser* **250** 012084

[19] Khadem-Abolfazli M *et al* 2013 *Int. J. Radiat. Res.* **11** 55-61
[20] Rahman W N *et al* 2010 *AIP. Conf. Proc.* **1266** 107-10
[21] Rahman W N *et al* 2012 *Australas. Phys. Eng. Sci. Med.* **35** 301-9
[22] Kakade and Sharma *et al* 2015 *J. Can. Res. Ther.* **11** 94-7
[23] Mesbahi *et al* 2013 *Bio Impacts.* **3** 29-35
[24] Brun E *et al* 2009 *Colloids and Surfaces B: Biointerfaces* **72** 128-134
[25] Hubbell J H *et al* 1996 *NIST Standard Reference Database* 26