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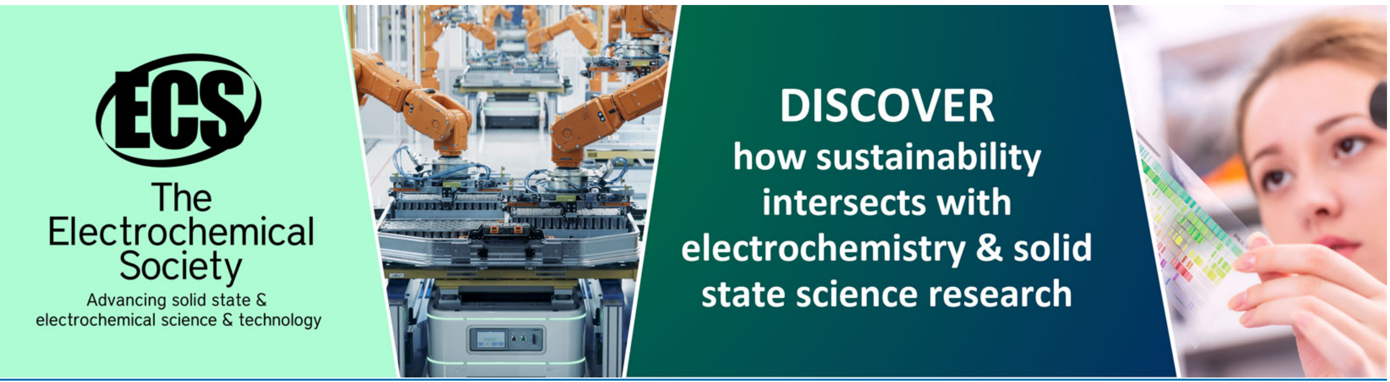

Contrast enhancement of magnetic resonance imaging (MRI) of polymer gel dosimeter by adding Platinum nano- particles

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Abstract. In this research different concentrations of Platinum nanoparticles (Pt-NPs) embedded in PAGAT polymer gel and irradiated with Cobalt -60 (^{60}Co). The OD of samples indicate significant dose enhancement caused by Pt-NPs. Different concentrations of Pt-NPs were investigated: 0.5×10^{-2},1×10^{-2}, 2×10^{-2} and 3×10^{-2} mg/l and these were presented the enhancement in OD by the factor of 11.56, 27.10, 15.84 and 10.07 respectively. As the mean energy of ^{60}Co is 1.25 MeV and atomic number (Z) of Pt is 78, the predominant effect will be Compton effect and Photoelectric cannot occurred. This work studied the feasibility of using PAGAT polymer gel combined with Pt-NPs as a suitable tool to perform dosimetric investigation of nanoparticles application in radiotherapy as dosimeter and dose enhancer.

1. Introduction

One of the primary aims of radiation therapy is to reduce the dose to healthy tissue and increase the dose to tumor cells. Developing technology help us to reach this goal by using metal nanoparticles application in field of radiology and radiation therapy. Experiments in living cells and *in vivo* indicate the effectiveness of the metal nanoparticles when apply low energy x-ray radiations (below conventional 1 MeV linear accelerator (linac) radiation. More studies on DNA have been carried out in order to better understand the fundamental processes of sensitization and to further improve of current method. It is proposed a new method based on the combination of Platinum nanoparticles (Pt-NPs) with irradiation by fast ions (hadron therapy)[1]. It was observed that nanoparticles could enhance strongly lethal damage in DNA. It was shown that the sensitization in presence of nanoparticles is increased because of auto-amplified electronic cascades inside the nanoparticles, which reinforces the energy deposition in the vicinity of the metal. Therefore, the combination of fast ion radiation (hadron therapy) with platinum nanoparticles could improve cancer therapy protocols effectively.

Subsequently, Porcel [2] tested different rang of x-ray energy combine with Pt-NPs to investigate the effect on the DNA. Obviously photoelectric was the predominant effect in this study and produced photoelectrons ionized the Platinum atoms. These findings showed that any high Z nanoparticles might behave like radiation enhancer, no matter ionizing radiation is electromagnetic or charged particles. Enhancement the dose by high Z materials depend on source of irradiation energy[3]. In dosimetric point of view, in kilovoltage range, photoelectric will be the predominant effect, as photoelectric depend upon Z^3/E^3 (Z=atomic number and E= energy) [4]. But it is need to investigate the Megavoltage ranges of energy like gamma ray (γ-ray) by ^{60}Co when the Compton effect is predominant. In this work different concentration of Pt-NPs were embedded in PAGAT polymer gel and irradiated by γ-ray to investigate the dose enhancement in MeV range of energy, which the predominant effect is Compton effect.

2. Materials and methods

2.1. Platinum nanoparticles synthesize

The beam from Nd:YAG laser was focused by a lens (F = 25 mm) on the surface of a platinum plate (99.99%, thickness 1.0 mm) fixed inside a small container with 6 ml of distilled water. The laser pulse duration was about 10 ns, the pulse-repetition rate 10 Hz, and the maximum energy of the pulse is 0.34 J/pulse. The duration of the ablation experiment was 1 hour. It has been demonstrated that this physical method is free of any reducing agents and is applicable to the preparation of nanoparticles of any metal elements through ready formation of the metal atoms by laser ablation [5].

Immediately after the ablation experiment, the UV-Vis (Shimadzu UV-1650PC) absorption spectra of Platinum colloids were measured. The peak in 216 nm showed that the Pt-NPs was formed in water. A transmission electron microscope (TEM) (Hitachi H-800) was employed to take electron microphotographs of the resultant nanoparticles[6]. The average size for formed Pt-NPs was 10 nm. Atomic absorption (AA) was used for detecting the concentration of metals in solution, which was 1 mg/l.

2.2. Nanoparticle incorporation in gel

PAGAT (Acrylamide, gelatin, Hydroquinone, THPC)[7] was prepared at 38 °C. Pt-NPs solution was added in the last step of preparation to the PAGAT. Two groups of gels were prepared, first without nanoparticles and second with nanoparticles. The sample not containing Pt-NPs served as control. Gel homogenization was achieved by routine mechanical mixed. Four different Pt-NPs concentrations were considered: 0.5×10^{-2}, 1×10^{-2}, 2×10^{-2} and 3×10^{-2} mg/l.

2.3. Irradiation procedure and MRI reading

Gel samples were irradiated by ^{60}CO at University Kebangsaan Malaysia (UKM) using gamma cell (220 Excel model 220 E S/N 117R) at the dose rate of 2.2550 kGy/h. The samples were placed inside the water to guarantee backscattering conditions and created the tissue equivalent situation during irradiation. Control gel samples and samples containing Pt-NP were irradiated with a dose 6 to 25Gy with interval 2 Gy.

Optical density measurement was carried out by densitometer (Vectoreen, model 07-440, USA), which correlates with received dose and contrast in printed MRI images. Samples were scanned by Magnetic Resonance Imaging (MRI) (Magneton SP Siemens, Germany) 12 hours after irradiation. A multiple spin-echo sequence was used with the following parameters: *T2* weighted imaging was carried out using 64 spin-echoes with a TE of 74 ms, TR of 5000 ms, slice thickness of 4 mm, matrix size of 256 × 256, FOV 250 mm [7, 8].

3. Results and discussion

PAGAT polymer gel response to γ-ray was characterized by comparing the OD in samples without nanoparticles and with Pt-NPs. The PAGAT response was found to be linear over the entire dose range explored from 6 Gy up to 25 Gy. Here also we can conclude that maximum enhancement was seen in PAGAT doped with 1×10^{-2} mg/l Pt-NPs which is seen in Figure 1, (b).

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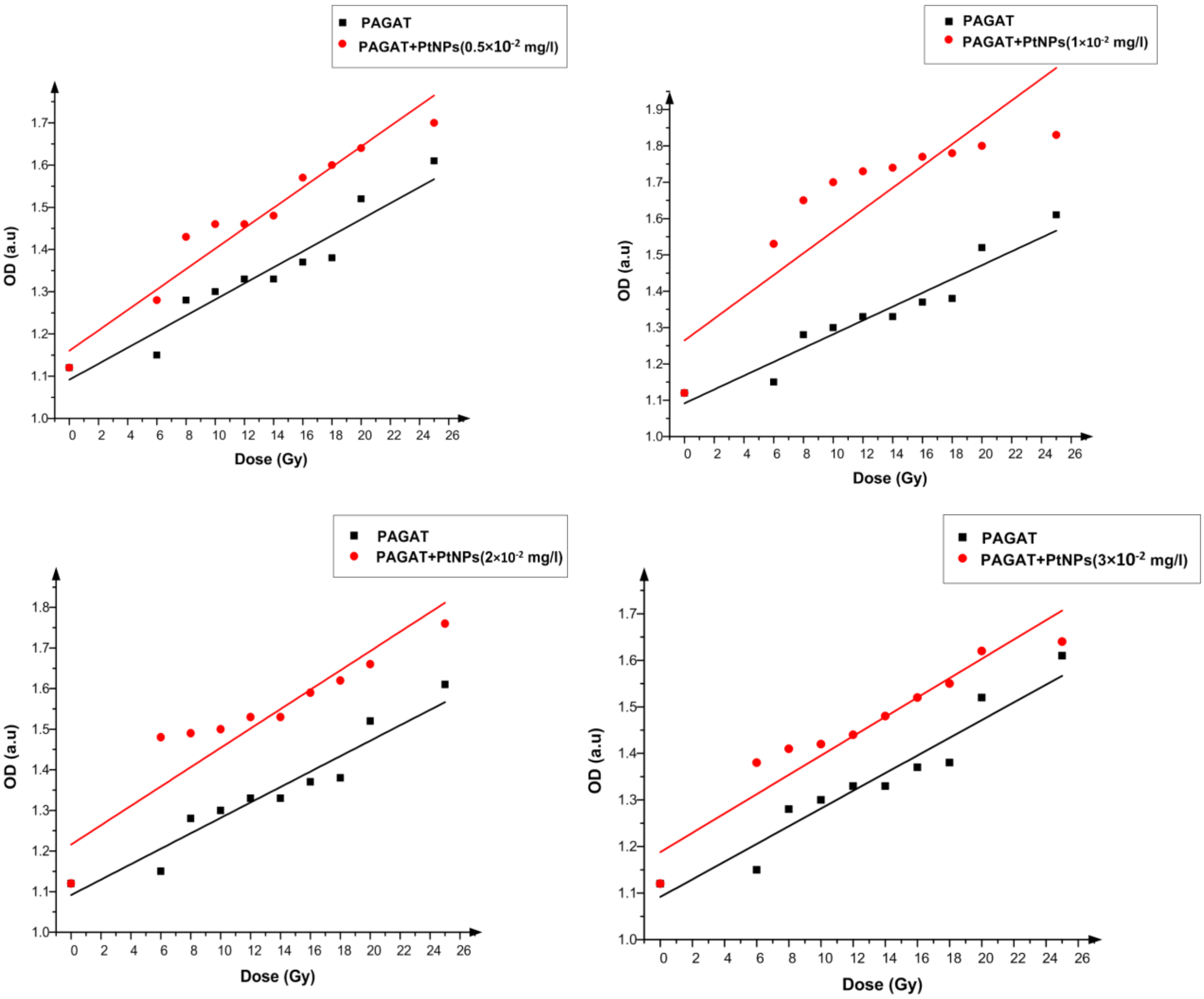

Figure 1. Optical density versus dose without nanoparticles and with different concentration of Pt-NPs (a) 0.5×10^{-2} mg/l, (b) 1×10^{-2} mg/l, (c) 2×10^{-2} mg/l, (d) 3×10^{-2} mg/l.

The OD of non-irradiated samples (with and without Pt-NPs) were evaluated. Chemical interactions between Pt-NPs and gel were discarded considering the OD variation found was 0. Table 1 presents the respective percentage of enhancement from samples non-irradiated (0 Gy) to show no chemical interaction.

The dose enhancement due to Pt-NPs presence in the tissue-equivalent gel was quantified comparing the OD of all different concentrations of Pt-NPs irradiated with the different dose (6 to 25 Gy). According to Figure 1, Concentration (a) presents an increase of 11.16% in OD comparing to gel without Pt-NP; concentrations (b), (c) and (d) present increases of 27.10%, 18.54% and 10.07% respectively (see Table 1).

According to graph which Evans [9] sketch, in the case of γ-ray as the K-edge of Pt is 78.39 KeV and the mean energy of ^{60}Co is 1.25 MeV, then the photoelectric is not occurred, but in presence of Pt-NPs inside, the predominant effect is Compton. As we know the Compton effect occur with free electrons, then the possibility of Compton effect is not related to atomic number of material but to the number of electron per gram. The number of electron per gram is the same for all material except Hydrogen, then what makes a difference between various materials is the number of electron per cubic centimeters (e/cm^3)[4]. The number of e/cm^3 for Pt was calculated (5.17×10^{24}), which was more than other material like gold (4.66×10^{24}) and silver (2.75×10^{24}) and also muscle (3.36×10^{23}).

Table 1. Percentage of enhancements with different concentration of Pt-NPs.

Dose (Gy)	Concentration of Pt-NPs (mg/l)			
	0.5×10^{-2}	1×10^{-2}	2×10^{-2}	3×10^{-2}
0	0	0	0	0
6	11.30	33.04	28.70	20
8	11.72	28.91	16.41	10.16
10	12.31	30.77	15.38	9.23
12	9.77	30.08	15.04	8.27
14	11.28	30.83	15.04	11.28
16	14.60	29.20	16.06	10.95
18	15.94	28.99	17.39	12.32
20	7.89	18.42	9.21	6.58
25	5.59	13.66	9.32	1.86
Average (%)	11.16	27.10	15.84	10.07

It indicated the fact that with fewer amount of Pt nanoparticles (0.5×10^{-2} mg/l) the OD was increasing compare to PAGAT without nanoparticles and this trend continue until 1×10^{-2} mg/l Pt-NPs. This was due to Compton electrons produced, which can increase the probable of radiolysis of water and arise the amount of free radicals, produced. These free radicals can polymerize more monomers and make the gel more opaque.

But the question was that why 1×10^{-2} mg/l Pt-NPs showed better enhancement than 2×10^{-2} and 3×10^{-2} mg/l. Ertl *et al.* [10] explained that iodine as one of dose enhancer was scavenger by radiologically forming $OH^{\bullet}$ radicals and as the reaction rate of I^- with $OH^{\bullet}$ and monomer with $OH^{\bullet}$ were approximately the same, then there was a competition between the monomers and the halide ions to react with $OH^{\bullet}$ resulting in less initiation of polymerization. And the result was to decrease the dose response and the decrease was more pronounced in higher concentration of dose enhancer [11]. In current research, it can also be explained in the same way. If the Pt-NPs, which have positively charge surface, like other nanoparticles, interact with $H^{\bullet}$ and $OH^{\bullet}$, it will reduce the initiation of polymerization, as free radicals are necessary to initiate the polymerization process. Then the optimum concentration of Pt-NPs in the volume of PAGAT that I made was 1×10^{-2} mg/l. Therefore, the application of Pt-NPs as a dose enhancer or dosimeter was proved.

Dose enhancements verified by gel dosimetry presented in this work instigate future investigation. Different size of nanoparticles can be investigated using polymer gel dosimetry aiming to optimize the application of nanoparticles in radiation therapy.

4. Conclusion

The feasibility of using PAGAT polymer gel combine with Pt-NPs as dose enhancer or dosimeter to increase the OD in MRI was investigated in this work. The result showed that in presence of 1×10^{-2} mg/l Pt-NPs, the OD increased by factor of 27.10%.

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