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Cerium nanoparticle effect on sensitivity of Fricke gel dosimeter: Initial investigation

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Abstract. Fricke gel dosimeters (FXGs) have been the preferred dosimeters because of its ease in preparation and water and tissue equivalency. Visible changes happen three dimensionally in the dosimeter as the ferrous (Fe^{2+}) ions change into ferric (Fe^{3+}) ions upon irradiation and the measure of this change can be correlated to the dose absorbed. Nanoparticles are promising entities that can improve the sensitivity of the gel dosimeter. Cerium Oxide nanoparticle was investigated for possible enhancement of absorbed dose in the FXG. Various concentrations of the nanoparticle based gel dosimeters were prepared and irradiated for a clinical dose range of 0-3 Gy in a telegamma unit. The optimal concentration of 0.1 mM nanoparticle incorporated in the FXG enhances the radiation sensitivity of the unmodified FXG taken as reference without modifying the background absorbance prior to irradiation. The gel recipe consisted of 5% (wt) gelatin, 50 mM Sulphuric acid, 0.05 mM Xylenol Orange, 0.5 mM Ferrous Ammonium Sulphate and 0.1 mM Cerium (IV) Oxide nanoparticle (< 25 nm particle size) and triple distilled water. The FXGs with nanoparticle showed linear dose response in the dose range tested.

1. Introduction

Gel dosimetry is gaining popularity in the field of medical physics that applies it as a dose measuring tool for quality assurance in radiotherapy treatment plans [1]. Since advances in technology have escalated the complexity in treatment delivery, the radiation delivered by the treatment unit requires verification before it can be administered to patients [2-9]. Gel dosimeters provide three dimensional (3D) information of the radiation dose absorbed, when irradiated [10-12]. However the sensitivity of the gel dosimeters to radiation dose is also important in this scenario.

Fricke chemical dosimeters have been widely used as reliable radiation dosimeters in the past decades [13, 14]. The idea of incorporating the same into a gelatin matrix to obtain the dose information in 3D was proposed by Gore in 1984 [15]. FXGs are the most preferred among the various gel dosimeters found in the literature, due to its water and tissue equivalence [16-18], ease in preparation and the availability of spatial dose information very soon after irradiation [19]. The absorbed dose in the FXG can be determined by the post irradiation measurement of the ferric (Fe^{3+}) ions [20]

Radiation sensitization effects on tumor tissues have created huge interest aiming at the therapeutic enhancement of radiation [21]. This can be achieved by the incorporation of nanoparticles (NPs) that plays a pivotal role in enhancing the absorbed dose through increased photon absorption [22]. Gold based NPs have been mostly studied and reported because of their favorable characteristics such as high biocompatibility and inertness to tissue interaction that are ideal for radiosensitization [23-26].

The effect of gold NPs in enhancing the dose response in MAGICA polymer gel has been reported by Khadem [27]. Marques reported that the absorptions interactions enhanced the local dose due to photoelectric absorption [28]. Though gold NPs have shown dose enhancement in the gel dosimeter, the high cost of the material is a disadvantage and this limits its practice. Various authors have reported the addition of additives to get better radiation sensitivity in the FXG. Recently, Maeyema reported on the clay nanoparticle for FXGs with Argon gas bubbling [29].

Nanotechnology has invaded every field from electronics to medicine in recent days. Metal oxide nanoparticles such as TiO, ZnO and CeO have been widely incorporated as catalysts [30]. Since nanoparticles are a promising entity in enhancing the response of gel dosimeters to radiation, we have explored the feasibility of incorporating Cerium nanoparticle into the FXG as a cost effective alternative for gold NPs. The dose response characteristic of the nanoparticle based Fricke gel dosimeter is reported in this study.

2. **Materials and Methods**

Cerium being a widely used catalyst, it was chosen for our experiments. Cerium (IV) oxide nanoparticle (<25 nm particle size, CAS No. 1306-38-3) was procured from Sigma Aldrich.

2.1. Gel dosimeter preparation

Five batches of the FXG recipe with 5% (wt) gelatin (300 bloom gelatin from porcine skin, (Sigma Aldrich) and each containing different concentrations of the nanoparticle solutions were prepared. Initially, gelatin was added to triple-distilled water and stirred using a magnetic stirrer while maintaining a temperature of 40 ^{o}C for 1 hour. The solution was then cooled to 25 ^{o}C and required quantities of Sulfuric acid (Qualigens), Xylenol Orange (Sigma), Ammonium Ferrous sulfate (SD-fine) were added. Finally the nanoparticle solution was added to each of the four batches of FXG. The final solution of the gel dosimeter consisted of 50 mM H_2SO_4, 0.05 mM Xylenol Orange and 0.5 mM Ferrous Ammonium Sulphate and the nanoparticle solution (0.05, 0.1, 0.2, 0.8 mM). The FXG without the nanoparticle solution added to it was taken as the reference. The gel solution was then transferred to cuvettes of 4 ml capacity and 1 cm path length. The samples as gel solutions in cuvettes were segregated into different boxes with labels for each concentration of the nanoparticle and kept in the refrigerator overnight and maintained at 4 ^{o}C for gelation.

2.2. Irradiation and measurement of gel dosimeters

The irradiation was performed on a telecobalt unit (Theratron 780C) with special arrangement in a water bath for the gel cuvette positioning. The gels were irradiated for doses ranging from 0-3 Gy with parallel-opposed lateral fields with a field size of 35 x 35 cm^2. The optical absorbance and transmittance of all the FXG cuvettes were measured with a UV-1800 double beam spectrophotometer (Shimadzu, Japan) at a wavelength of 585 nm.

3. **Results and Discussion**

3.1. Dose response

Five gel samples were irradiated for each dose in each concentration of the nanoparticle based FXG as well as the reference gel. Dose response curves were generated from absorbance in cuvettes and arithmetic mean value of the samples as shown in figure 1. The nanoparticle added FXGs exhibited linearity in dose response with R^2 values 0.9941, 0.9951, 0.996 for 0.05 mM, 0.1 mM and 0.2 mM concentration of the nanoparticle solution respectively compared to 0.9968 as the R2 value of the unmodified gel. Since p-value for the analysis of variance of the residuals was 0.3148 with 95% confidence interval, the quadratic term becomes non-significant. Hence we conclude that our data is consistent with the linear first-order model.

The gels prepared with 0.8 mM nanoparticle solution also showed improved dose response but we were not able to firmly conclude the amount of nanoparticle concentration as Cerium particle precipitates were found in it. Hence further increase in the concentration of nanoparticle in the FXG was not studied.

3.2. Background absorbance

Though all the nanoparticle FXG dosimeters showed improved dose response, the pre-irradiation measurements with the spectrophotometer showed higher background absorbance in the FXGs prepared with 0.2 and 0.8 mM concentrations of the nanoparticle solution suggesting darker gels if prepared in bulk quantities. Contrary to the former, the FXGs with 0.1 mM and 0.05 mM Cerium nanoparticle based FXGs showed negligible change in the background absorbance measurements.

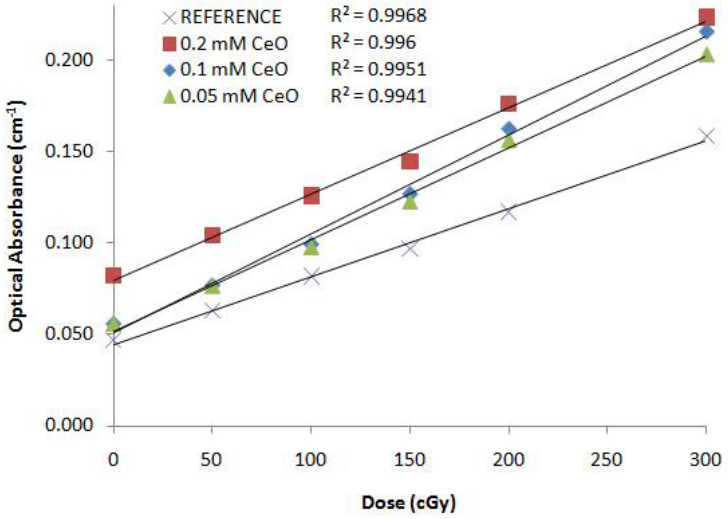

Figure 1. Comparison of dose response of 0.05 mM, 0.1 mM and 0.2 mM CeO_2 nanoparticle FXG with unmodified FXG reference)

4. Conclusion

The feasibility of incorporating Cerium oxide nanoparticle has been studied successfully. The optimal concentration of 0.1 mM nanoparticle incorporated FXGs show improved dose response making this gel dosimeter a promising tool for radiotherapy quality assurance. Further studies will be carried out to define the other radiological properties of this gel dosimeter and the possibility of using the findings in lower bloom gelatin commercially available in India.

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6. References

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