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Dose-rate dependence of PAGAT polymer gel dosimeter evaluated using X-ray CT scanner

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Abstract In recent years, X-ray CT imaging of polymer gel dosimeter has been applied to direct measurement of 3D dose distributions. This work presents the dependence of PAGAT polymer gel dosimeter response to different beam dose rate using X-ray CT scanner as an evaluation tool. The normoxic PAGAT polymer gel was prepared on bench top and irradiated to different doses at different dose-rate ranging from 0.5 to 5 Gy/min. After irradiation the dosimeter samples were imaged with X-ray CT scanner using appropriate scanning protocol. The results showed that PAGAT gel dosimeter formulations investigated in this study has the smallest dose rate dependence and the change in dose sensitivity amounts to 2 % over the dose rate interval studied.

1. Introduction

In polymer gel dosimeter, the free radical induced polymerization consists of free radical generation, chain initiation, propagation and termination. The initiation of polymerization proceed through the reaction of monomer with radiation induced water radicals and the rate of generation of free radicals dependent upon the irradiation dose rate [1,2]. Higher rates of radical generation lead to higher concentration of radicals. Propagation proceeds through the formation of long polymer chain, rate of which is proportional to the radical concentration. The chain termination involves the combination of two free radicals. This behavior of dependence of propagation and termination rate on the radical concentration makes incident beam dose rate dependent polymer gel dosimeter. The dependence of the polymer gel sensitivity depends on the polymer gel constituents and concentration of gelatin [1,3-6].

Studies were carried out by Maryanski *et al* [7,8] and Novotny *et al* [9] on BANG-2 (BIS acrylamide nitrogen gelatin) gel and concluded that there is no energy and dose rate dependence of dose response for electrons in the range 2-15 MeV and the dose rate in the range 20-400 cGy/min. Ibbott *et al* [10] and Massillon *et al* [11] also reported that, the dose response of the BANG gel is independent of both dose rate and modality of the beam used. De Deene *et al* [1] studied the dose rate dependence of normoxic polymer gel dosimeters and reported that the normoxic PAG (poly acrylamide gelatin) polymer gel dosimeter has the smallest dose rate dependence while the normoxic MAG (methacrylic acid gelatin) dosimeter has the greatest dose rate dependence. Bayreder *et al* [12] stated in their study that tetrakis hydroxymethyl phosphonium chloride (THPC) based normoxic methacrylic acid polymer gel shows the insignificant dose rate dependence at the lowest dose level (D=2 Gy) and considerable dose rate effect arises for all other doses with a maximum impact at the upper limit of the linear dose range. The objective of this work is to evaluate the dependence of the PAGAT (poly acrylamide gelatin and tetrakis hydroxy methyl phosphoniun chloride) polymer gel dosimeter response to different dose rate. The response of the polymer gel dosimeter is determined by calculating the slope of the linear portion of dose-response curve.

2. Materials and Method

Three batches of PAGAT normoxic polymer gel dosimeter were prepared following the experimental procedure described elsewhere [13,14]. In summary all the dosimeters were prepared under normal atmospheric conditions from acrylamide (Sigma Aldrich), N, N^1- methylene-bis-acrylamide (BIS) (Sigma Aldrich) and gelatin (300 bloom, Sigma Aldrich). The proportions of chemical compositions (by weight) were 3.5 % BIS, 3.5 % acrylamide, 5 % gelatin and 88 % triple distilled water. During the manufacture process, gelatin was added to water at room temperature and allowed to soak for 15 minutes before heating to 50° C. While continuously stirring, acrylamide and BIS were subsequently added and stirred until complete dissolution was achieved. After the gelatin-monomer mixture was cooled down to 37° C, 10 mM of THPC was added as anti oxidant and transferred to small plastic cylindrical vials of diameter 2.5 cm and length 4 cm. All the vials were sealed with nylon lined top caps to minimize further oxygen contamination. The vials were then kept in refrigerator and left to set for 3 hours prior to irradiation.

The PAGAT gel filled vials were placed one at a time in a tissue equivalent wax phantom (20 x 22 x 22 cm^3). For the investigation of dose rate dependence of PAGAT gel dosimeter, irradiations were performed at different dose rate ranged from 0.5 to 5 Gy/min with Siemens Primus linear accelerator. First batch of gel dosimeter containing 180 vials were irradiated to the dose range of 1-30 Gy with 15 MV X-ray photon beam for each dose rate mentioned above. The second batch containing 34 vials irradiated by 6 MV X-ray beam with doses in the range of 1-30 Gy for two different dose rate of 0.5 and 2 Gy/min. The third gel batch containing 34 vials were irradiated to the dose ranging from 1-30 Gy at two different dose rate (0.74 and 1.23 Gy/min) with ^{60}Co photon beam from Alcyon-II cobalt unit. All the irradiations were performed with parallel opposed radiation beam with collimator size of 10 x 10 cm^2 so that homogeneous dose distribution was obtained across the dosimeter vials, and one gel dosimeter vial was kept unirradiated. Earlier the irradiation, absorbed dose and dose rate at the center of the dosimeter vial were measured with 0.13 cc compact chamber (Wellhofer-Scanditronix) and DOSE-1 electrometer (Wellhofer-Scanditronix) by mimicking the same set up.

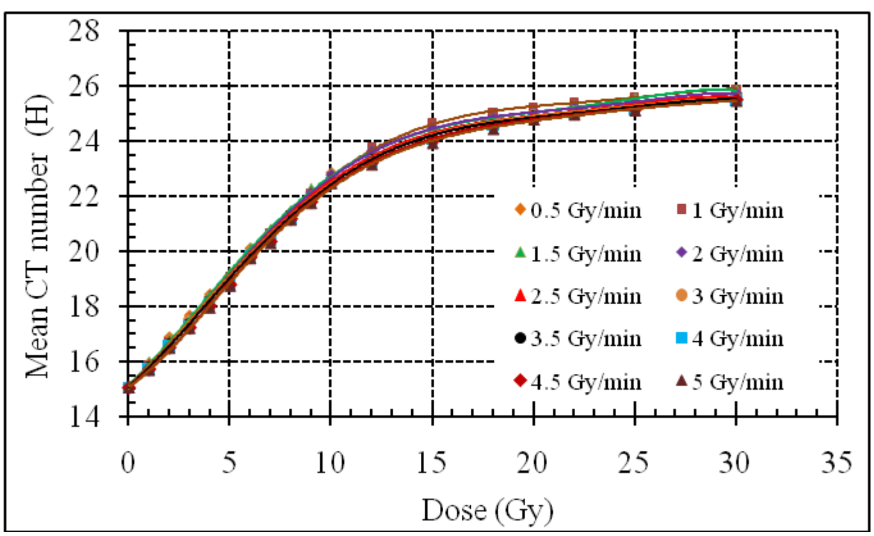

Figure 1. Dose response curves of PAGAT polymer gel dosimeters irradiated with 15 MV X-ray beam at different dose rate.

X-ray CT imaging was performed on all the dosimeters vials after 24 hours of irradiation using a Siemens Somatom Emotion CT scanner. All the dosimeter vials were kept at scanner room for about 2 hours to ensure the temperature equilibrium. The dosimeters vials were imaged with 130 kV tube voltage, 200 mA tube current, 1.5 s exposure time and slice thickness of 5 mm [15,16]. The scan was repeated 25 times and averaged together. ROI of area 10 mm^2 was drawn at the center of each vial and mean CT number ($\overline{N}_{CT}$) was extracted.

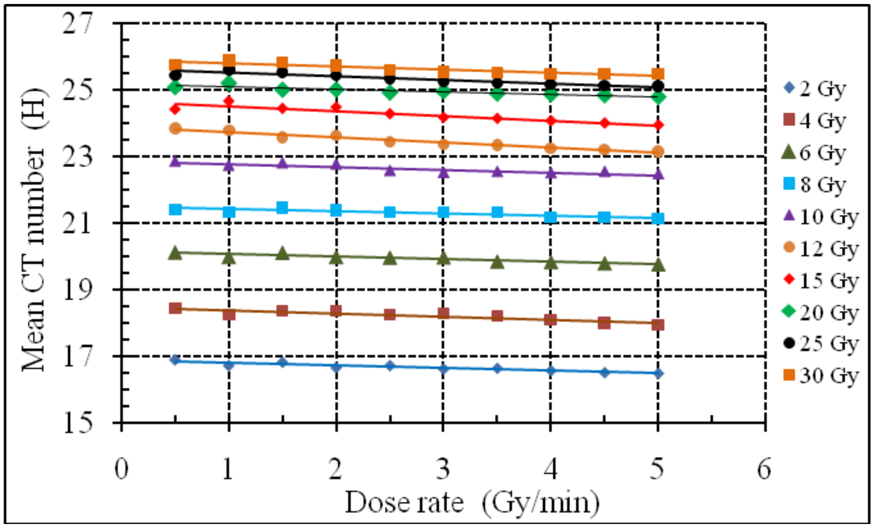

Figure 2. Mean CT number response plots of PAGAT polymer gel dosimeters as a function of dose rate irradiated with 15 MV X-ray beam to different doses.

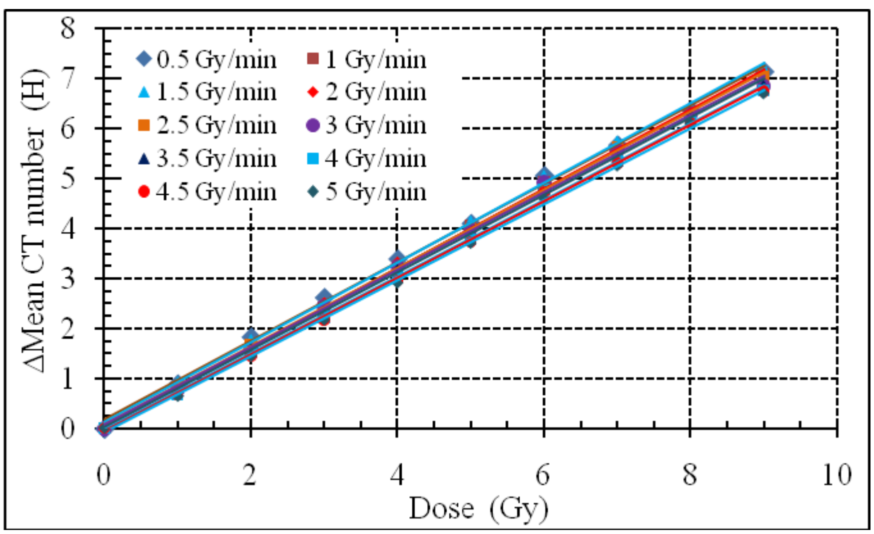

Figure 3. Linear part of dose response curves of PAGAT polymer gel dosimeters irradiated with 15 MV X-ray beam at different dose rate.

3. Results and Discussion

The response of PAGAT polymer gel dosimeter as a function of dose in the range of 0-30 Gy for different dose rate using 15 MV X-ray beam are displayed in figure 1 and figure 2. In the range 0-9 Gy dose response curve could be fitted by linear function (figure 3). Dose rate dependence of PAGAT gel dosimeters was examined by comparing the dose response determined at 2 Gy/min. The dose response curves obtained at 0.5 Gy/min and 5 Gy/min were almost identical to that obtained at 2 Gy/min. This study shows that PAGAT gel dosimeter has the smallest dose rate dependence. The change in dose sensitivity amounts to 2 % over the dose rate interval studied and the results were comparable to the previous study [17]. Figure 4 presents the dose response curves of PAGAT gel irradiated with 6 MV X-ray beam and ^{60}Co beam at different dose rates. These dose response curves are similar to that obtained with 15 MV X-rays at 2 Gy/min dose rate. Dosimeter sensitivity as a slope of linear portion (0-9 Gy) of dose response curve was also investigated as a function of dose rate for different photon beams and shown in figure 5. The dosimeter sensitivity at 0.5 Gy/min was 0.786 HGy^{-1} and at 5 Gy/min was 0.764 HGy^{-1}. The standard deviation between the dosimeter sensitivity was 0.012.

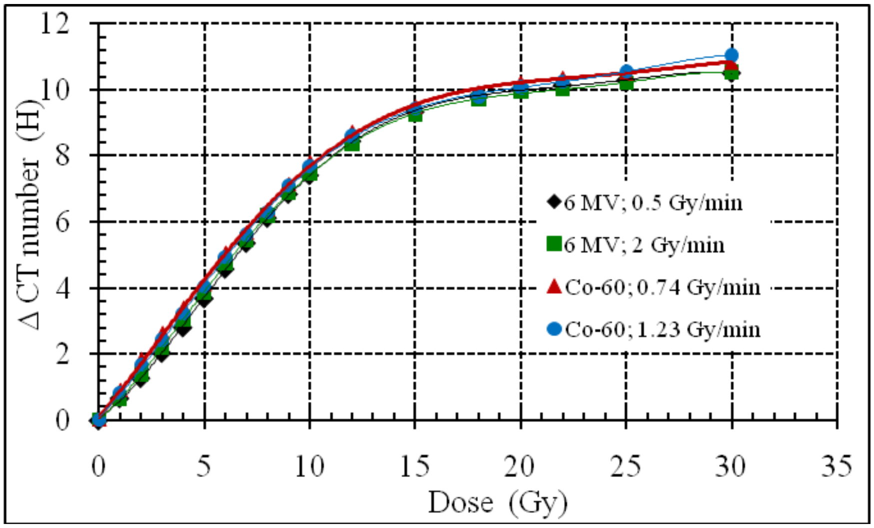

Figure 4. Dose response curves of PAGAT polymer gel dosimeters irradiated with 6 MV X-ray beam and Co-60 beam at different dose rates.

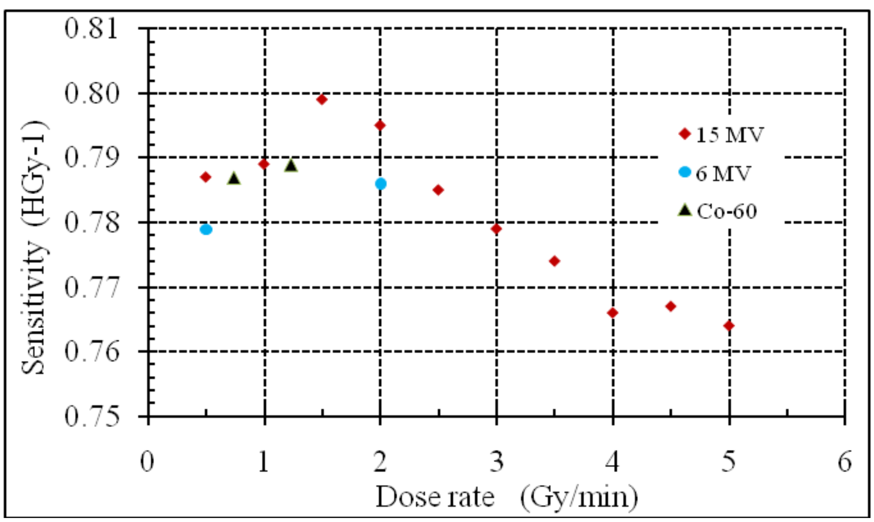

Figure 5. Sensitivity as a slope derived from the linear part of dose response curves of PAGAT polymer gel as a function of different dose rate.

4. Conclusion

The results of this study showed that PAGAT polymer gel dosimeter formulation investigated with X-ray CT scanner exhibited trend in polymer gel sensitivity dependence on dose rate range 0.5-5 Gy/min and was clinically insignificant. But this very small dose rate dependence of PAGAT gel sensitivity might lead to potential error while using PAGAT gel for absolute dosimetry.

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