Normoxic Polymer Gel of Hydroxy-Ethyl-Acrylate (HEA) as Radiation Therapy Dosimeter

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ABSTRACT: An absorbed X-radiation dose in the range of radiotherapy for cancer patients (0-12 Gy) was measured and characterized in a polymer/Gel dosimeter (Polym/Gel) which composed of normoxic hydroxyl-ethyl-acrylate/Gel (HEA/Gel). The characterization of the irradiated HEA/Gel by Nuclear Magnetic Resonance (NMR) showed that the relaxation rate $R_2$ (t) for proton was increased following the radiation dose indicating the polymerization of HEA/Gel monomer to poly(hydroxyl-ethyl-acrylate/Gel) PHEA/Gel. The PHEA/Gel was characterized by Raman spectroscopy which confirmed the polymerization of HEA/Gel with reference to the a new chemical bond formation at Raman shift of 1415 cm$^{-1}$ which in turn was being increased following the radiation dose. The color change of PHEA/Gel due to radiation polymerization was been studied by optical density-meter out of MRI image which showed that the optical density increased along the axis of the radiation field in depth profile for a limited distance then decreased by increasing the radiation.

KEYWORDS: Polymer Dosimeter in Radiotherapy, HEA.

INTRODUCTION
For the high secured accuracy of radiation therapy dose that should not exceed ± 5% of the prescribed tumor dose \cite{1}, the Polymer-gel dosimeters have been introduced and consided as an effective tool for analyzing and mapping the radiotherapy treatments for cancer patients depending on physical and chemical changes that occur in the polymer after irradiation. In the field of radiation dosimeter Frickel Gel (ferrous sulphate solution incorporated to a gel matrix in order to fix it to a solid structure) \cite{2} dosimeter has played a major role which its principle depend on the conversion of ferrous (Fe$^{2+}$) ions within the gel matrix to ferric ions (Fe$^{3+}$) by irradiation \cite{3} and Gel dosimeter which was shown to be a useful technique for mapping the dose distributions of radiotherapy and Brachytherapy among cancer patients. The radiation change within the dosimeters can be visualized, traced and correlated to the specific given radiation dose. The common instruments and systems used for studying the effects of radiation in Gel dosimeters are: magnetic resonance imaging MRI (depending on proton relaxation), Raman spectroscopy (depending on the radiopolymerization \cite{4}, and UV-visible spectroscopy (depending on the color change) \cite{5}, Computerized Tomography (CT) \cite{6} and ultrasound \cite{7}. However, Frickel Gel dosimeter showed a diffusion of the ferrous and ferric ions following irradiation that leads to a loss of spatial integrity of the
dosimeter \cite{8} while polymer/Gel dosimeter could maintain the spatial integrity depending on the polymerization by radiation \cite{9, 10}. The most preferred systems used to characterize the polymer/Gel dosimeter up to date are MRI as it depends on the relaxation rate of proton content within the polymer/Gel and Raman spectroscopy which in principle depends on Raman shift (Chemical bond vibration). The current undertaking aimed studying the radiation damage of Polymer Gel of Hydroxy-ethyl-acrylate at normal atmosphere using ascorbic acid as well as to contemplate the application in radiotherapy simulation in three dimensions (3D).

**MATERIALS and METHODS**

The polymer/Gel of PHEA/Gel was prepared under ambient conditions, by dissolving 3 w/v gelatin in de-ionized water containing 2 w/v ascorbic acid under controlled temperature using water bath at 45 °C, the solution subjected to continuous stirring for 1 hour, then the cross-linker BIS (N,N'-methylene-bis-acrylamide) as 2 w/v and 13 w/v of monomer HEA (2-hydroxyethylacrylate) as listed in table 1, were added and followed by continuous stirring for 2 hours. The final solution was poured in cylindrical vials (internal diameters as 5 cm radius and 20 cm length) and irradiated with different radiation doses of (2, 4, 6, 8, 10 to 12 Gy) using x-radiation from radiotherapy unit (Linac-8 MV).

**Table 1: The total formulation of the Polymer/Gel dosimeter**

<table>
<thead>
<tr>
<th>Cross linker, BIS (%)</th>
<th>Binder, Gelatin (%)</th>
<th>Monomer, HEA (%)</th>
<th>Antioxidant, Ascorbic Acid (%)</th>
<th>Diluents, Water (%)</th>
<th>Sample No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td></td>
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</table>

**RESULTS and DISCUSSION**

Figure 1 shows the color change due to x-ray irradiation of the HEA/Gel dosimeter along the axis of the radiation field in vial. The film which was taken from MRI revealed that the hue of the black color at 1 cm depth corresponded to depth at 1 cm, was increased following the depth increment and the high degree of black color occurred at ~ 1.5 cm depth which corresponds to depth of 1.5 cm, then the hue of the black color decreased with further depths (3, 4, 5, up to 10 cm) increment along the axis of irradiation field in polymer/Gel of PHEA/Gel, similar results were observed by Alwan et al., \cite{11}. 

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Figure 1. the color changes after irradiation of the PHEA/Gel dosimeter along the axis of the radiation field in vials receiving doses from 2, 4, 6, ..., 12 Gy.

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>2 Gy</th>
<th>4 Gy</th>
<th>6 Gy</th>
<th>8 Gy</th>
<th>10 Gy</th>
<th>12 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1.5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2 shows the optical density along the axis of radiation field in depth profile of the polymer/Gel of PHEA/Gel in vials. The measured optical density was increased along the axis of the radiation field in depth profile up to about 1.5 cm then decreased along further depth in exponential curve pattern. The high optical density occurred at ~ 1.5 cm which corresponded to build up region (dose maximum (d_max) of the radiotherapy unit (Linac-teletherapy-6 MV). Also by increasing the radiation dose from 2 Gy up to 12 Gy, the optical density increased from 0.48 up to 0.9 (a u). Such optical density change in polymer/Gel due to irradiation was highlighted recently by Mariani et al. \cite{12}.
Figure 2. the optical density along the axis of radiation field in depth profile of the polymer/Gel in vial

Figure 3 shows the Raman intensity versus Raman shift (cm\(^{-1}\)) for different radiation doses for the monomer HEA at 1.5 cm. The spectrum confirmed the polymerization of HEA, which was indicated by the formation of new chemical bond at Raman shift of 1415 (cm\(^{-1}\)) that refers to cheek bond, the intensity of Raman shift at 1415 cm\(^{-1}\) increased following the radiation dose indicating more polymerization of the composites and the increment followed exponential model as shown in Fig.4. [13].

01 = 2 Gy
02 = 4 Gy
03 = 6 Gy
04 = 8 Gy

Figure 3. Raman intensity versus Raman shift cm\(^{-1}\) at different radiation doses for the monomer HEA at 1.5 cm
Figure 4. Intensity of relaxation rate $R_2(t)$ for the protons within the PHEA/Gel versus radiation dose obtained by NMR system.

revealed that the intensity of relaxation rate increases with increasing the radiation dose from 0 up to 12 Gy which was due to monomer HEA polymerization. The relaxation rate $R_2(t)$ was increased with the dose increment in an exponential form. Same results were observed by Baldock et al.,[13] and Jirasek et al. [14].

CONCLUSIONS

The tumor dose in radiotherapy can be measured depending on the physical, chemical and optical changes induced in the polymers by irradiation, specifically in HEA/Gel polymer. The absorbed dose in such polymer showed an exponential relation in view of relaxation time obtained by NMR and polymerization (radio-chemical process) which is obtained by Raman spectroscopy as well as depending on the optical density variation in the polymerized HEA/Gel, which is obtained by density-meter or optical spectroscopy.

REFERENCES
