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The impact of various amounts of fabricating components on the response of PASSAG polymer gel dosimeter: An optimization study

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Abstract

Polymer gel dosimeters are used to measure three-dimensional dose distribution with high spatial resolution. Recently, a novel polymer gel dosimeter, known as PASSAG, has been introduced in which has several advantages over other polymer gel dosimeters; however, its response-dose sensitivity is relatively low. It has been shown that the sensitivity of polymer gel dosimeters can be changed by various amounts of components used in their fabrication. This study aims to assess the dosimetric characteristics of PASSAG gel dosimeter for different amounts of components in its formulation. For this purpose, different formulations of PASSAG gel dosimeter were first fabricated, and then they were irradiated using 6MV X-rays in a 0–10Gy dose range. After the irradiation process, the responses (R_2) of gel dosimeters were read out by a 1.5T MRI scanner during one-month post irradiation time. According to the results, the maximum R_2-dose sensitivity belonged to PASSAG gel dosimeter with 5% gelatin, 4% AMPS sodium salt (as monomer), and 4% Bis (as crosslinker) that showed a 31% increased sensitivity compared to conventional PASSAG gel dosimeter (5% gelatin, 3% monomer, and 3% crosslinker). Moreover, an excellent linear R_2-dose response was observed for optimized PASSAG gel dosimeter. The dose resolution values of optimized PASSAG gel dosimeter also varied between 0.14 and 0.42Gy in a 0–10Gy dose range. Other findings revealed that the R_2 values of the optimized gel dosimeter had a relative stability during 15–18°C and 20–24°C scanning temperatures. Furthermore, a temporal stability in the R_2 values of the optimized gel dosimeter was observed during 15–30 days post irradiation time. The R_2-dose sensitivity of optimized gel dosimeter also varied during 30 days post-irradiation time (from 31.00% to 47.97%).

Introduction

Polymer gel dosimeters are made of radiation-sensitive chemical materials (Abtahi et al., 2014b). Following irradiation with ionizing radiation, the monomers used in structure of these dosimeters are polymerized as a function of absorbed radiation dose (Baldock et al., 2010; Khezerloo et al., 2017b). Of note, the radiation-induced structural changes can affect several properties of gel dosimeters, such as changes in the proton nuclear magnetic resonance relaxation times, elasticity, opacity, and mass density (Senden et al., 2006); subsequently, these characteristics can be read out by magnetic resonance imaging (MRI) (Maryanski et al., 1993), ultrasonography (Mather et al., 2002), optical scanning (Maryañski et al., 1996), and X-ray computed tomography (Hilts et al., 2000).

Compared with other dosimeters (such as films, ionization chambers, and thermoluminescent dosimeters), polymer gel dosimeters are favorable in most dosimetric properties, including relative accuracy, spatial resolution, inherent three-dimensionality, and beam energy independency (for a beam energy range) (Farhood et al., 2019). As mentioned, the unique three-dimensional (3D) dosimetry possibility with high spatial resolution made these dosimeters as an ideal tool for verifying the dose delivery to target in radiotherapy (Resende et al., 2019). Especially, since modern radiotherapeutic techniques provide complex conformal dose distributions with a high dose gradient between the normal and tumoral tissues, 3D verification of dose distribution before radiotherapy is necessary and can decrease any possible error (Abtahi et al., 2016; Khezerloo et al., 2017a, 2018).

After the introduction of acrylamide-based polymer gel dosimeter by Maryanski et al., in 1993 (Maryanski et al., 1993), the researchers have presented different types of polymer gel dosimeters over the past years. Moreover, some studies have optimized and/or improved the polymer gel dosimeters (Abtahi et al., 2014a; Anaraki et al., 2018; Hsieh et al., 2011; Senden et al., 2006; Venning et al., 2004, 2005). In a previous study (Farhood et al., 2018a), we improved PAGAT polymer gel dosimeter introduced by Venning et al. (2005); in this regard, acrylamide monomer used in the formulation of PAGAT gel dosimeter was replaced with 2-Acrylamido-2-Methy-1-PropaneSulfonic acid (AMPS) sodium salt monomer (Farhood et al., 2018a). Among the characteristics of the improved polymer gel dosimeter (PASSAG) include: high safety (LD_{50} for its monomer >16,000 mg/kg), cost-effective, eco-friendless, and negative genetic toxicity and carcinogenicity (Farhood et al., 2018a). Additionally, the findings obtained from dosimetric assessments of PASSAG gel dosimeter showed an excellent linear R_2-dose response, photon energy and dose rate independency, and water/soft tissue equivalence (Farhood et al., 2018a, 2018b).

The previous studies on PASSAG gel dosimeter have shown that although this dosimeter has the excellent dosimetric results, its response-dose sensitivity is relatively low (Farhood et al., 2018a, 2018b). It is noteworthy that the "*response-dose sensitivity*" is a useful quantity to compare various formulations of gel dosimeters, and it also affects other dosimetric parameters, such as dose resolution, minimum detectable dose calibration, and error estimation (Abtahi et al., 2014a; Baldoc et al., 2001; Deene, 2004; Farhood et al., 2019). Various methods have been proposed to increase the response-dose sensitivity of the polymer gel dosimeters. For instance, some studies have used different additives for improving the response-dose sensitivity of polymer gel dosimeters (Aliasgharzadeh et al., 2020; Anaraki et al., 2018; Chacón et al., 2018; Fernandes et al., 2008; Hayashi et al., 2012; Yoshioka et al., 2010a). Other studies have been reported that optimization in the chemical concentrations of monomers or/and crosslinkers applied in formulation of polymer gel dosimeters can enhance their response-dose sensitivity (Chain et al., 2011; Jirasek et al., 2010; Kozicki et al., 2017a).

In the current work, the effects of various amounts of fabricating components on the response-dose sensitivity and dose resolution of PASSAG polymer gel dosimeter were investigated by MRI. Furthermore, it was tried to assess the MR readout dependence on scanning room temperature and temporal stability of PASSAG gel dosimeters.

Section snippets

Preparation of PASSAG polymer gel dosimeters

In the present project, the conventional formulation of PASSAG gel dosimeter was optimized. In this regard, new formulations of PASSAG gel dosimeter with different amounts of fabricating components were prepared and compared

with that reported by Farhood et al. (2018a). The chemical components used for fabricating the different formulations of PASSAG gel dosimeter were deionized water (Obtained from water deionizer, Absaz Co., Iran), gelatin (from porcine skin, type A, 300 Bloom, Sigma Aldrich, …

R_2-dose curve and R_2-dose sensitivity

As mentioned earlier, 11 different formulations were used to prepare PASSAG gel dosimeters. However, a number of these formulations (#1, #4, #5, #6, #7, #8, and #9) showed the following findings: 1) Bis in the solution was not completely dissolved (formulations #8 and #9), 2) nonlinear R_2-dose responses (formulations #4, #7, #8, and #9), or 3) the obtained gel dosimeters were autopolymerized before the irradiation (and we did not irradiate them) (formulations #1, #5, and #6); therefore, we did…

Conclusion

In the present study, we optimized the R_2-dose sensitivity of conventional PASSAG polymer gel dosimeter. The results demonstrated that the R_2-dose sensitivity of optimized PASSAG gel dosimeter (5% gelatin, 4% AMPS sodium salt, and 4% Bis) was increased by 31% than its conventional formulation (5% gelatin, 3% AMPS sodium salt, and 3% Bis) one day after the irradiation. Other dosimetric findings of optimized PASSAG gel dosimeter include: **a)** there was an excellent linear R_2-dose response in a…

CRediT authorship contribution statement

Akbar Aliasgharzadeh: Conceptualization, Methodology, Investigation, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Vahid Anaraki:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – review & editing, Visualization. **Daryoush Khoramian:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – review & editing, Visualization. **Mahdi Ghorbani:** Conceptualization, Investigation,…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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