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MAGIC-Type Polymer Gel for Three-Dimensional Dosimetry in Radiotherapy

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Abstract— During the radiotherapy, it is only possible to determine whether or not the prescribed dose is delivered to the tumor and whether the critical organs exceed the tolerance doses by dosimetric control of the dose calculation algorithms of the treatment planning systems. Nowadays, dosimeter systems such as point (ion chambers, TLDs, diodes) or planar dose measurement (such as radiochromic film or 2D diode array) are used in clinics. With these dosimetric systems, point or planar dose measurement is possible.Radiotherapy, a three-dimensional treatment approach using more than one beam that is not in the same plane, requires dosimetric systems that can show three-dimensional (3D) dose distributions. For this reason, studies on three dimensional dose measurements by using different gel compounds, and magnetic resonance imaging (MRI) are being carried out. In this study we used a new formulation of polymer gel dosimeter, MAGIC (Methacrylic and Ascorbic acid in Gelatin Initiated by Copper). It has been developed that responds well in normal atmosphere to produce dosimeter gels, an aqueous solution of gelatin, open to the atmosphere, is mixed with methacrylic acid, copper(II) ions, ascorbic acid and hydroquinone. The gel was irradiated using a linear accelarator and MR images of gel dosimeters are taken with 1.5T MR device.

Index Terms— 3D dosimetry, MAGIC, Polymer Gel, MRI, Radiotherapy

1 Introduction

High-energy X-rays, electron beams and radioactive isotopes are used in radiotherapy. It is the most important target to determine whether the prescribed dose is given to the patient during treatment. It is also important to determine the doses of radiation-sensitive critical organs entering the treatment site. Since the dose of treatment is often limited by the dose of these critical organs. Commonly dose distribution is calculated by treatment planning softwares theoretically depending on Computed Tomography (CT) or Magnetic Resonance (MR) image of patient and contours of target and critical organs determined by physicians. There are some dosimeteric tools to evaluate three dimensional dose distribution but there is no dose verification protocol specific to individual patient treatment plan. Gel dosimeter are expected to fill this gap. But there are some technical insufficiencies for these materials needs to be augmented.

Polymer gel dosimeters are the most commonly used three-dimensional gel dosimeters.

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Water and gelatin also contain monomers and crosslinkers that polymerize in response to free radicals produced by water radiolysis [1].

Many different dosimeters have been produced depending on the crosslinker and monomer type they contain. Magnetic Resonance Imaging (MRI) is used for imaging of normoxic polymer gels. The assumption of different proton pools is used to understand the effect of polymerization, the dose response of irradiated gels irradiated, on magnetic resonance R1 (= 1 / T1) and R2 (= 1 / T2) relaxation rates [9]. A polymer gel dosimeter has three main proton pools. Protons formed by free and free-like protons consisting of free water molecules and monomers, protons formed by water molecules bound to growing polyacrylamide and macromolecules, protons formed by gelatin and gelatin bound water molecules.

2 MATERIALS AND METHODS

MAGIC (Methacrylic and Ascorbic acid in Gelatin Initiated by Copper) gels include gelatin, methacrylic acid, ascorbic acid, $CuSO_4 \cdot 5H_2O$, distilled water and hydroquinone Table 1, [2]. Hydroquinone is a free radical scavenger, methacrylic acid is monomer, protection against oxygen suppression is provided by the formation of an acid ascorbic–copper complex [3].

Gel mixture containing components 83% ultra-pure water (HPLC grade), 8% gelatin (300 bloom Sigma-Aldrich), 9% methacrylic acid (Merck-800578), ascorbic acid (2mmol / l), copper sulfate $CuSO_4.5H_2O$ (0.02mmol / l) as indicated in Table 1 is produced with the methods previously used by Fong et al.

TABLE 1
MATERIALS AND QUANTITIES REQUIRED TO OBTAIN 1000 GRAMS OF MAGIC GEL (MAA RATIO OF 9%).

Chemical Component	Amount (gram)
Gelatin (300 Bloom)	80
Methacrylic acid	90
Ascorbic acid	0.352
CuSO4:5H2O	0.02
Hydroquinone	2
Pure water	828

The prepared gels were kept in the refrigerator at + 4°C for 48 hours and then brought to the linear accelerator room where they were irradiated and expected to reach thermal equilibrium. The pre-irradiation linear accelerator was calibrated to be 1cGy = 1MU. When the gel samples were in the gantry 0°, the 10 cm x10 cm area size SSD was placed in the center of the area to be 100 cm and irradiated one by one (Figure 1). Prepared gel samples Varian Clinac® IX brand (Palo Alto, USA) Linear Accelerator device at 6 MV photon energy, d = 5 mm depth, 400 cGy / min dose rate, 50 cGy - 100 cGy - 200 cGy - 400 cGy - 600 cGy - 800 cGy - 1000 cGy and 2000 cGy doses were delivered. Gel samples were kept in the refrigerator at + 4°C until MR images were taken.

Figure 1. Irradiation set-up at Linac.

3 RESULTS AND DISCUSSION

The assumption of different proton pools is used to understand the effect of radiation-induced polymerization on magnetic resonance relaxation rates (R1 and R2). There are three different proton pools in an irradiated polymer gel. The first is unreacted monomers and free water molecules, the second is polymerized molecules and water molecules attached to them, and the third is the proton pools of gelatin and the water molecules attached to it. Each environment has its own relaxation rates. This difference causes the spin-spin relaxation time (T2 = 1 / R2) and spin-lattice relaxation time (T1 = 1 / R1) between each group to be different, so that dose-response evaluation can be performed by magnetic resonance imaging.

The irradiated gel samples, which were kept in the refrigerator for polymerization, were taken to the MRI room and left for approximately 10 hours to reach thermal equilibrium. The images of irradiated gel samples were obtained by using GE coil SIGNA Explorer model MRI device using RF head coil (1.5T). The imaging protocol is TR = 4040 ms (time of repetition), TE = 113 ms and 123 ms (echo time). It is seen that there is a difference between the irradiated sample and the irradiated samples (Figure 2).

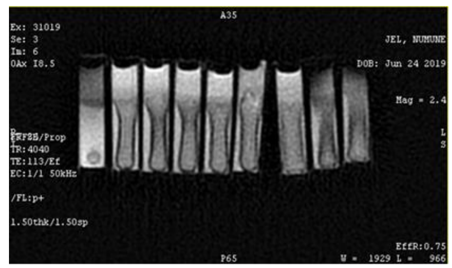

Figure 2. Sagittal plane MR images of the gel samples. Unirradiated leftmost side, irradiated samples with increasing amount 50 cGy - 100 cGy - 200 cGy - 400 cGy - 600 cGy - 800 cGy - 1000 cGy and 2000 cGy from left to right.

MR intensities measured by placing identical ROIs on the same sections of x-ray exposed gels. These values are plotted against radiation dose delivered to gels (Figure 3).

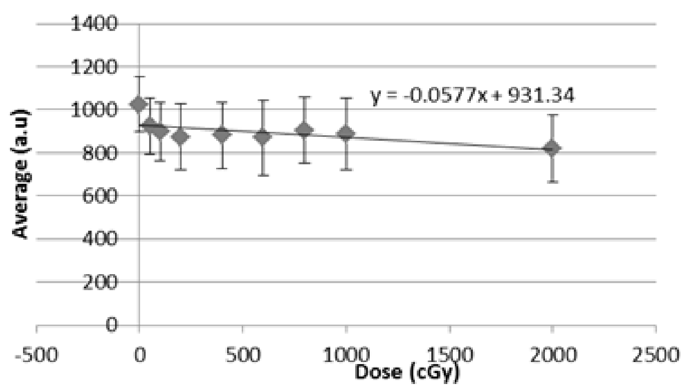

Figure 3. Linear dose-response curve.

Slope of the fitted curve is found as approximately 0.06 showing a weak relation between our variables. Since these are our preliminary results we will try to increase the slope of fitting line. Then we will concentrate on bone tissue equivalency of our polymer gels while conserving the dosimetric properties of our materials.

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