Dose overshoot reduction by tetrakis hydroxymethyl phosphonium chloride in polyacrylamide gel dosimeter

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Abstract. This work deals with an influence of the antioxidant tetrakis (hydroxymethyl) phosphonium chloride (THPC) on the edge enhancing effect of a polyacrylamid gel and THPC (PAGAT) dosimeter. Four batches of PAGAT gel were produced with different THPC concentrations: 0, 1, 2 and 4 mM. It was proved that antioxidant THPC reduce the edge enhancing effects on the cost of reduced sensitivity of the gel dosimeter.

1. Introduction

In the complex radiotherapy treatments, mainly radiosurgery, IMRT and brachytherapy, quite steep dose gradients often appear. For these applications a gel dosimeter is usually considered to be the only system capable of recording the full three dimensional dose distributions. In reality, however, the edge enhancing effects (dose overshoots) were observed near steep dose gradients [1], especially when the polyacrylamid gel (PAG) dosimeter is irradiated to relatively high doses. The PAG gels are spatially stable for doses up to 12 Gy [2].

Vergote et al. [3] studied the dose overshoot dependence on the gelatine concentration and proposed a mathematical model to predict the time-dependent post-irradiation evolution of the measured dose distribution in PAG dosimeters. In this study, the antioxidant tetrakis (hydroxymethyl) phosphonium chloride (THPC) was tested to reduce the edge enhancing effects.

2. Materials and Methods

2.1. Gel manufacture

Four batches of PAGAT gel were produced with various THPC (80% aqueous solution, Sigma-Aldrich, Switzerland) concentrations: 0, 1, 2 and 4 mM. The PAGAT components used: 3% (by weight) acrylamid (Sigma-Aldrich, Germany), 3% N,N'-methylenebisacrylamid (AppliChem, Darmstadt, Germany), and 5% gelatine from porcine skin (300 Boom, Sigma-Aldrich, USA). All gels were made in a nitrogen environment to avoid oxygen contamination.

To prepare the PAGAT dosimeter, gelatine was added to the distilled water and left to soak over the night. In the morning, N,N'-methylenebisacrylamid and acrylamid were added to the solution and allowed to dissolve during bubbling with nitrogen gas. The gel was heated to 50°C using water bath with temperature control. When all components completely dissolved, the temperature was lowered to 35°C and the gel divided into four glass bulbs. The THPC was added according to the table 1 and each
batch was again bubbled with nitrogen gas for about 30 min. Then the gel was placed in a refrigerator (4°C) to solidify over the night.

Table 1. THPC amount in PAGAT (3% AA, 3% bis, 5% gelatine)

| PAGAT batch | THPC (mM) |
|-------------|-----------|
| A           | 0         |
| B           | 1         |
| C           | 2         |
| D           | 4         |

2.2. Irradiation

Before irradiation, all the gel dosimeters were taken out of the refrigerator and allowed to equilibrate to a room temperature. Each glass bulb was placed in a purpose-built round holder and irradiated by the Leksell Gamma Knife Perfexion (Elekta, Sweden) in the Na Homolce Hospital, Prague, Czech Republic. The prescribed dose to maximum (30 Gy, dose rate: 3,504 Gy/min) was delivered by a single 16 mm shot. The irradiation took place about 52 h after the polymer gel fabrication.

2.3. Scanning

The dosimeters were scanned 6 times (1-123 h post-irradiation) at 1,5 T MR scanner Magnetom Avanto Syngo B15 (Siemens, Germany) in the Na Homolce Hospital, Prague, Czech Republic. The glass bulbs were placed in a water bath together with three calibration control vials filled with copper sulphate solutions of different concentrations (Figure 1), and scanned using a head coil (Head Matrix). Body coil acted as a transmitter. A multiple spin-echo sequence was used with 32 equidistant echoes and 1 acquisition (TE = 30,3-969,6 ms, TR = 4s, voxel size: (0,48x0,48x3)mm). The slice thickness used was 3 mm, the FOV was (260x183)mm and the matrix (384x270)px. Two slices were obtained within one TR. The measured signal-to-noise ratio (SNR) in the parametric images ranged between 80 (second echo) and 40 (32nd echo). SNR measurements were performed with the same container which was used for scanning of the gel bulbs but filled with water.

2.4. Data Processing

The R2 relaxation rate of each pixel was derived by fitting the time course of the pixel value in the consecutive base images to a mono-exponential decay using a linear fit of log values. The first base image was left out. The temperature variations were corrected by using the average values of calibration control vials filled with copper sulphate solutions of different concentrations. For data processing Matlab (The MathWorks, Inc., USA) and Microsoft Office Excel (Microsoft Corporation, USA) were used.

3. Results and Discussion

An R2 image of irradiated PAGAT gel with 4 mM THPC is shown in figure 1. The R2 profiles in figure 2 illustrate an overshoot near the edge on both sides of the 16mm shot. Each profile differs in THPC amount added to the PAGAT gel. Increasing the THPC concentration clearly restricts the edge enhancing effects. Figure 3 displays the time-dependent post-irradiation evolution of the measured dose distribution in PAG dosimeters. The edge enhancing effect in PAGAT gel with THPC concentration 4mM (b) is significantly lower than in the PAG gel without antioxidant THPC (a).
**Figure 1.** R2 map of PAGAT gel with 4 mM THPC. The dose to maximum 30 Gy was delivered by a single 16 mm shot on the Leksell Gamma Knife Perfexion.

**Figure 2.** R2 profiles 22h post-irradiation of PAGAT gel with various THPC concentration. The profiles were obtained by average of 5 pixels along the black line in Figure 1.

**Figure 3.** R2 post-irradiation profiles of PAGAT gel with THPC concentration (a) 0mM (b) 4mM.

The dose overshoot shape in this case is determined mostly by two events: First, the THPC as a scavenger of free radicals reacts both with oxygen (biradical) and with radicals at the end of polymer chain and radicals on the gelatine; thus, the polymerization process is affected. And second, irradiated volume (ca (28x19)mm ellipsoid) is too small considering the monomers diffusion velocity; therefore, the resulting edge enhancing effect is substantially influenced by monomers diffusion in 3D area. Both physical-chemical effects will be incorporated in the oncoming model.

Due to preparing the PAGAT gel in anoxic conditions, sensitivity reduction of the gel dosimeter is not so noticeable in this experiment.
4. Conclusion
THPC dose overshoot reduction effect in PAGAT dosimeter was investigated. The comparison of PAGAT gel with various THPC concentrations (0, 1, 2 and 4 mM) proved that antioxidant THPC is useful for reducing the edge enhancing effects. Further research in dose overshoot problem is ongoing, especially for situation of 3D dose gradients such as those occurring in radiosurgery.

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