High resolution dosimetric imaging of polymer gels prepared under normoxic conditions: Stereotactic radiation with a 16 mm collimator

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1. Introduction

Recent advances in stereotactic radiation techniques, IMRT and brachytherapy enable radiation treatment of increasing small planning target volumes. Steep dose gradients are therefore necessary to apply radiation only in the tumor volume. Polymer gel dosimetry is the method of choice for measuring 3D-dose distributions including dose gradients with high resolution in an acceptable amount of time.

Polymer gel dosimetry is based on radiation induced polymerization altering T₂-relaxation time. Although polymer gels have great dosimetric potential, they are difficult to be manufactured. As oxygen is a polymerization inhibitor the gel must be prepared in a highly hypoxic environment and sealed in oxygen impermeable vials. This drawback has recently been overcome by Fong et al [1]. The authors used ascorbic acid as oxygen scavenger in order to suppress the oxygen effect on polymerization, which is the reason for calling this type of gels normoxic. De Deene et al [2] and Gustavsson et al [3] have performed further investigations on normoxic polymer gels.

We present first results on self-manufactured normoxic gels and their applicability for measuring high dose gradients with high resolution in stereotactic radiation therapy.

2. Materials and methods

The gel was prepared under normal levels of oxygen using gelatin (swine skin, 300 Bloom, Sigma Aldrich), methacrylic acid (99%, Sigma Aldrich), tetrakis-hydroxy-methyl-phosphonium-chloride solution (THPC, 99%, Sigma Aldrich) and deionized water (HPLC-grade, Sigma Aldrich) (table 1).

The gelatin was given to 700 ml water at room temperature. After it has swelled from soaking it was heated to 50°C in a water bath. A clear solution was achieved after about half an hour. The methacrylic acid solution and the THPC solution were added in separate containers of 100 and 70 ml of water. The gelatin solution was cooled down to about 35°C. Methacrylic and THPC solutions were added to the gelatin solution. A homogenous mixture was achieved by continuous stirring. The gelatin solution was finally poured into 30 ml vials (outer diameter = 28 mm) made of Barex⁶° (BP Amoco, UK). We used this type of container material because of its excellent oxygen barrier properties. We still observed reduction of polymerization near container walls in other type of container materials.
The vials were then put into a refrigerator to let the gelatin become solid. About 40 hours after gel preparation calibration measurements and stereotactic radiation were performed.

**Table 1.** Composition of 1000 ml gel.

| Chemical     | Concentration     |
|--------------|-------------------|
| Water        | 87% (w/w), 870 ml |
| Gelatin      | 8% (w/w), 80 g    |
| Methacrylic acid | 5% (w/w), 50 g  |
| THPC         | 2 mM, 0.3316 g    |

For small sized target volumes a 16 mm collimator (BrainLAB, Heimstetten, Germany) was used in a stereotactic radiation scheme as applied in standard clinical routine. The vials were positioned in a 40 x 40 x 39 cm³ water phantom (Med-Tec MT-150, US) in isocentric conditions so that the planning target volume was located within the gel. A 6 MV (QI = 0.68) high energy photon beam was provided by an Elekta Sl精密加速器（Elekta Oncology systems, UK). Treatment planning is performed on a dedicated stereotactic treatment planning system (BrainSCAN Version 5.21, BrainLAB, Germany).

The absorbed dose for stereotactic irradiations is verified within a cross calibration procedure in a 5x5 cm² field using a small volume chamber (0.015 cm³ PTW type 31006, Germany) and a calibrated Farmer type chamber (0.6 cm³, PTW type 30006, Germany). The latter chamber is calibrated in a 60Co beam in absorbed dose to water. Dose determination is performed following the IAEA TRS-398 protocol.

Kodak EDR-2 films are used to measure relative dose distributions. After being processed (Kodak M 35 X-Omat), the films are scanned with a Vidar VXR-12 plus scanner (Vidar Systems Corp., Herndon VA, USA). Film analysis is performed using the RIT 113 software package (Version 3.11, Radiological Imaging Technology, US) for film dosimetry. Gray scale values are converted to OD values using a calibration film and following a calibration procedure recommended by the vendor.

All MR investigations were performed on a 3 T whole body scanner (MEDSPEC 30/80, Bruker Medical, Erlingen, Germany) equipped with an actively shielded gradient. Small slice thickness and high in-plane resolution (voxel size: 240x240x1000 μm³) is possible using a 1H-birdcage resonator with an inner diameter of 35 mm [4].

For MR investigation a RARE sequence with equidistant echoes (TE = 20, 40 ... 400 ms) was used (TR = 5 s, FOV = 30 mm, 128x128 matrix, slice thickness 1 mm). The calibration measurements were obtained using 4 averages. For polymer dosimetry on the stereotactic irradiation scheme 16 averages were used for SNR reasons. MR-measurements were performed one day after irradiation.

### 3. Results and discussion

#### 3.1. Calibration

The calibration results are shown in figure 1. The errors in $R_2$ are indicated and amount to about 5%. We investigated dose sensitivity up to 15 Gy. In the low and high dose regime deviations from linearity can be observed.

The non-linear region in the low dose regime (see arrow in figure 1) might appear due to small amounts of oxygen left in the gel as Haraldson *et al.* have assumed [5]. In the cap region of the Barex vial we observe slight polymerization inhibition. It has also been proposed by Haraldson that impurities cause non-linear effects in the low dose regime. We believe to have avoided this effect by choosing highly pure chemicals for gel preparation.
3.2. Planning data and film dosimetry

The result of dose planning ($D_{\text{max}} = 7$ Gy) is shown in figure 2a as axial 2D-dose map positioned in the isocenter. An averaged dose profile (figure 3) is obtained from this image using 10 neighboring profiles as indicated by the rectangular in figure 2a. Film dosimetry is consistent with the planned dose distribution.

3.3. Polymer gels

The absolute dose distribution obtained by MR polymer gel dosimetry calibration data is shown in figure 3a. The maximum dose is in good agreement with the planning data ($D_{\text{max}} = 7.29 \pm 0.32$ Gy, summing up over 1000 pixels in the dose plateau). A dose profile corresponding to that of the planning data is obtained from summing up over 10 neighboring profiles (figure 3b). However there are deviations in the dose distribution between planning data and film on the one hand and polymer gel on the other: whereas the planned dose distribution and the film dosimetry results in a Gaussian-type dose profile, MR polymer gel dosimetry indicates a broader plateau. We cannot explain this difference yet.

**Figure 1.** Relaxation rate $R_2 = 1/T_2$ (s$^{-1}$) as a function of the applied dose $D$ (Gy) applied via an Elekta SlI precise accelerator. The data points have been fitted by a 5th order polynomial. Errors are obtained by a histogram analysis as standard deviation for $T_2$ within a ROI of about 3000 pixels.

**Figure 2.** (a) Slice in the isocenter of the stereotactic radiation as obtained by the planning data system; (b) Dose profile summing up over 10 pixels along the rectangular ROI in figure 2a.
Figure 3. (a) Dose distribution in the isocenter of the stereotactic radiation as obtained from polymer gel dosimetry; (b) dose profile along the ROI in figure 3a. The absolute dose in the plateau region agrees with the maximum dose in the planning data system. With difference to the Gaussian-shape dose profile of figure 2b a broader dose plateau results by gel dosimetry.

4. Conclusion

Polymer gels can be prepared under normal atmospheric conditions. Our first results show a linear dose regime between 0.5 and 7 Gy. However we still observe slight polymerization inhibition in the cap region due to permeating oxygen and an offset at low dose levels. A dedicated MR equipment allows small voxel sizes of 240x240x1000 µm$^3$ in dosimetric imaging. Whereas the absolute maximum dose in the plateau region is confirmed by the planning data system there are significant differences in the plateau width. Further studies are necessary to elucidate the reasons for the observed differences in the regime of high dose gradients.

References

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