IMRT prostate dosimetry using a normoxic polymer gel and MRI

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1. Introduction

Conventional dosimeters such as ionization chambers, thermoluminescent dosimeters and diodes are point dose measuring devices and therefore difficult to use for spatial evaluation of dose distributions. The film dosimeter is limited to 2D measurements, and the response is dependent of radiation direction [1]. However, using gel dosimetry, dose information can be obtained in 3D with high spatial resolution. Intensity modulated radiation therapy (IMRT) usually involves steep dose gradients in all directions. For verification of this type of treatments gel dosimetry has shown to be suitable [2–4].

The aim of this study was to investigate the feasibility of using a new type of normoxic polymer gel dosimeter and a water filled homogenous pelvis phantom with a gel insert for verification of IMRT prostate dose distributions.

2. Materials and methods

2.1. Phantom and gel manufacturing

The polymer gel was prepared in a fume cupboard, under normal levels of oxygen. Gelatine (8% w/w, swine skin, 300 bloom, Sigma Aldrich) was melted under stirring in ultra pure deionized water (~90% w/w). After the gelatine was completely dissolved and the mixture temperature had decreased to 35°C, the methacrylic acid (2% w/w, purity grade approx., 99%, Sigma Aldrich) was added. Finally, Tetrakis(hydroxymethyl)-phosphonium (2 mM, techn. ~80% in water, Sigma Aldrich) was added after a few minutes of stirring. The gel was poured into small screw-top glass vials (calibration, Ø 1.5 cm, length 6 cm), test tubes (depth dose, Ø 1.6 cm, length 13 cm) and the plexiglass insert phantom (figure 1). All gels were left to set in a fridge. The insert was placed in the water filled pelvis phantom (figure 2) before left to set.

2.2. Treatment planning

The pelvis phantom and the gel insert were filled with water and imaged using a CT-scanner (General Electric). The obtained slice thickness was 3 mm. The scans were sent to the treatment planning
system (OTP v1.2, Nucletron). A prostate planning target volume (PTV), rectum and femoral heads from an existing clinical case were copied onto the scans. A five field step and shoot IMRT prostate technique using 18 MV photons was constructed as described by Damen et al [5]. The plan was optimized for the PTV to receive an absorbed dose between 95% and 107%. For the organ at risk (OAR, the rectum) no more than 40% of the volume was allowed to receive more than 96% of the normalization dose. The final IMRT treatment consisted of a total of 25 segments.

2.3. Irradiation, magnetic resonance imaging and evaluation

The water filled pelvis phantom with the gel insert was irradiated according to the optimized treatment plan. The absorbed dose to the PTV was 2 Gy. The gel filled screw-top glass vials and the test tubes, used for dose response and depth dose evaluation, respectively, were irradiated in water.

Magnetic resonance imaging was undertaken using a 1.5 T Siemens Symphony scanner (Siemens Medical Systems, Erlangen, Germany), and a 32-echo multi spin echo sequence. The inter-echo spacing was 10.6 ms, the repetition time 4000 ms and the voxel size was 1x1x3 mm³. The gels were scanned centrally positioned in the head coil (receiver), using the body coil as transmitter. An image plane non-uniformity study was performed using a phantom of similar size as the insert, containing a homogeneous, unirradiated gel.

In-house developed software was used for image processing [6]. The absorbed dose matrix obtained using OTP was interpolated to fit the absorbed dose grid measured with gel dosimetry. Background subtraction was carried out using the R2 value (2.1 s⁻¹) for the unirradiated vials and test tubes. The R2 images were manually matched with the computed dose matrices using the posterior beam as reference. Normalization of the measured and the calculated dose distributions was performed in the isocenter plane in the centre of the PTV, using a circular region of 10 pixels.

2.4. Ionization chamber measurements

In order to perceive a correlation between relative and absolute absorbed dose, an ionization chamber measurement was performed in the same phantom as used for gel measurement (figure 2). The ionization chamber (RK8305, Scanditronix) was positioned in a central part of the PTV, corresponding to a calculated absorbed dose of 2.08 Gy. The ionization chamber was calibrated against a Baldwin-Farmer type chamber (NE2571, Nuclear Enterprises) in a water phantom.
3. Results and discussion

The image plane non-uniformity was found to be lower than 1%. Hence, no spatial background correction was needed. An approximately linear absorbed dose response was confirmed when evaluating the vials irradiated to different absorbed doses (figure 3). The dose response of the gel was further investigated using depth dose curves. The agreement with corresponding diode data was very good (figure 4).

![Figure 3. R2 as a function of absorbed dose. The intercept and the slope were 2.07 s⁻¹ and 1.19 s⁻¹.Gy⁻¹, respectively, and the R2 value for the linear fit was 0.998. The error bars are smaller than the dots.](image)

![Figure 4. Central depth dose curve for an 18 MV, 5x5 cm², photon beam measured using gel (dotted) and diode (solid).](image)

A qualitative comparison between the measured and the calculated dose distribution was undertaken by visual comparison of isodose lines (figure 5). The best agreement was found for the 75 % and 90 % isodose lines. A modified gamma method and dose-volume-histograms (DVHs) were used for quantitative comparison [7]. Only scattered points in the PTV and OAR failed the chosen gamma criteria (3%, 3 mm) in the central slices. However, somewhat larger regions failed the criteria in the cranial slices. For both the PTV and the OAR DVHs, the agreement between calculated and measured data was very good (figure 6). The calculated mean relative dose to the PTV was 101.9 ± 2.2%, while the corresponding gel measured value was 101.4 ± 3.2%. The absorbed dose measured using the ionization chamber was 2.10 Gy, corresponding to an over estimation of 1.3%. The small disagreement shown for both the isodose lines and the DVHs may be attributed to difficulties in the determination of a correct background value [3] or minor shortcomings of the treatment planning system.

4. Conclusion

The investigated gel/phantom system was shown to be feasible for complete IMRT dose distribution verification. Isodose lines and DVHs and absolute dose agreed well for the measured and computed dose matrices. The phantom may be improved by the use of fiducial markers to enable computerized matching of the measured and calculated dose distributions. Also high-density inserts may be used to simulate the femoral heads.
Figure 5. Isodose lines of the isocenter plane, gel (dotted) and calculated (solid). A low pass filter (median, 3x3) was applied to the measured absorbed dose matrices.

Figure 6. Dose volume histograms for the OAR (grey) and the PTV (black) of the measured (dotted) and the calculated (solid) relative absorbed dose distributions.

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