RapidArc™ treatment verification using polymer gel dosimetry

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Abstract. The aim of this study was to verify a novel volumetric arc therapy technique, RapidArc™. Polymer gel dosimetry system was used to measure the advanced inhomogeneous 3D dose distribution produced using the technique RapidArc™. A preclinical installation of the novel beam delivery approach was set up on a linear accelerator at Rigshospitalet in Copenhagen. A prostate treatment plan was delivered to a 1.3 l nPAG gel phantom using one single arc rotation from 200 to 160 degrees, and a target dose of 3.3 Gy. Magnetic resonance imaging of the gel was carried out using the 1.5 T scanner and MATLAB was used for image processing and 3D rendering. The difference in relative absorbed dose between the treatment planning system (TPS) and gel measurement was calculated voxel by voxel within the 80% and the 95% isodose volume, respectively. Measurements agreed well with the TPS within the treated volume. Within both isodose volumes 90% of the voxels showed a deviation less or equal to 5%. This study shows that the 3D gel dosimetry system is a useful tool for dose verification of advanced treatment delivery techniques.

1. Introduction
RapidArc™ is a novel radiation therapy technique where the treatment is delivered during one single rotation (up to 360 degrees) of the linear accelerator gantry. This type of volumetric arc therapy (VMAT) is made possible by simultaneously varying the MLC positions, the rotation speed of the gantry, and the dose rate during the treatment [1]. RapidArc™ delivery aims to shorten the treatment time and to produce a better or equal target-volume coverage and sparing of the normal tissue compared with multiple-field IMRT. The first treatment of a cancer patient with this technique was carried out very recently and few scientific articles regarding the use of RapidArc™ has been published [2]. The advanced inhomogeneous 3D dose distribution produced by RapidArc™ is difficult to verify with conventional means, using single dose point measurements or 2D detectors arrays. The 3D gel dosimetry has the advantage to be able to obtain the absorbed dose in the entire irradiated volume, since the gel integrates the absorbed dose and that the response is independent of incident radiation direction [3]. In addition, the high-resolution gel system functions both as a phantom and a
detector since the gel composition is near soft tissue equivalent [4]. A preclinical installation of the RapidArc™ beam delivery approach was set up on a linear accelerator (Clinac iX, Varian) at Rigshospitalet in Copenhagen. The purpose of this installation was to perform measurements to verify the correctness of the doses delivered. The polymer gel system was one of several detector systems used in this investigation [5].

2. Material and methods

2.1. Gel preparation

In this study the normoxic polymer gel system nPAG was used. It is based on 3% w/w acrylamide (electrophoresis grade, ≥99%, powder, Sigma Aldrich) and 3% w/w N,N’-methylenebisacrylamide (electrophoresis grade, ≥98%, powder, Sigma Aldrich). Gelatine (swine skin, 300 bloom, Sigma Aldrich) was used as the matrix substance and tetrakis(hydroxymethyl)-phosphonium chloride (techn. ~80% in water, Sigma Aldrich) as an oxygen scavenger. The remaining constituent was ultra pure deionized water (resistivity > 18.2 MΩ cm). The gelatine and water were mixed in room temperature and then heated to 45°C until the gelatine was completely dissolved, which took about 1 hour. The monomers were added before cooling the mixture to 35°C. Ten minutes before the gel was poured into bottles and vials the oxygen scavenger was added. The gels were prepared under normal levels of oxygen and the solutions were stirred continuously through the entire mixing procedure. The phantoms were left to set in the dark at room temperature for about 24 hours before irradiation.

2.2. Treatment planning and RapidArc™ dose delivery

As a base for the treatment planning, CT-images of the gel phantom were acquired using a spiral CT scanner (Sensation Open, Siemens Medical Systems). The slice thickness was 3 mm. The treatment planning system (beta version RapidArc™ optimiser, Varian Medical Systems) was used to generate the RapidArc™ 18 MV treatment plan, with an arc rotation from 200 to 160 degrees, and a target dose of 3.3 Gy. The output varied between 200 and 600 MU/min during the 320 degree rotation. A 1.3 l gel phantom was irradiated using a Clinac iX linear accelerator (Varian Medical Systems) (figure 1).

![Figure 1](image)

Figure 1. (left) The gel phantom aligned with the set-up lasers at the linear accelerator, and (right) a intensity image of a horizontal slice through the gel phantom with the measured relative absorbed dose (as calculated from the MRI R2 image).

2.3. Gel R2 response linearity validation

The dose response was evaluated by means of R2 measurements as a function of absorbed dose and investigated for absorbed doses between 0 and 8 Gy. To ensure homogenous absorbed dose to the gel vials, they were placed at 3 cm depth in a 30x30x30 cm³ cubic water phantom and irradiated using a 20 x 20 cm² 18 MV photon beam. The linear accelerator was set to deliver 600 MU/min. The R2-data of the irradiated 1.3 l gel phantom was converted to relative absorbed dose using background subtraction and normalization in a region of homogenous dose.
2.4. Magnetic resonance imaging and image processing
Approximately 24 h after irradiation, magnetic resonance imaging of the gel was carried out using the
1.5 T MRI unit (Siemens Symphony, Siemens Medical Systems), and the same protocol and set up as
described elsewhere [6]. The images were acquired using a 32-echo multi spin echo sequence with an
inter-echo spacing of 25 ms. The repetition time was 4000 ms and the voxel size was 1 x 1 x 3 mm³.
In-house developed software was used for T2-calculation [7], and MATLAB 7.4.0 was used for image
processing and 3D rendering. The raw data was smoothed with a 3x3x3 box-filter.

3. Results and discussion
The experimental gel dosimetry measurements carried out in this study were used for the verification
of the absorbed dose delivery using a novel volumetric arc therapy technique (RapidArc™). The 3D
R2-data of the irradiated gel phantom was converted to 3D relative absorbed dose using background
subtraction and normalization in a region of homogenous dose close to the isocentre. The relative
evaluation was justified since a approximately linear dose response covering the used dose range was
observed (figure 2).

![Graph showing R2 versus absorbed dose. The R2 value as a function of the absorbed dose. The r^2 value of the linear fit equals 0.996.](image)

The treatment plan data and the measured relative absorbed dose volume were aligned by matching
the inner surface of the glass bottles in the isocentre planes. The relative dose distributions in
both volumes were normalized to a volume of 1 x 10 x 10 voxels in the centre of the isocentre slice.
The dose differences were calculated for the volume within the 95% isodose surface corresponding to the treated volume [8]. The volume within
the 80% isodose surface was analysed in the same way. The relative dose difference between the TPS
and the gel measurement were compared in the isocentre slices. The 80% and 95% isodose curves
shows a very good agreement and the difference image shows deviations within ±3% in absorbed dose
(figure 3). The white isodoses illustrates the 80% (3 pt line) and 95% (2 pt line) measured relative
absorbed dose levels respectively. The black isodoses illustrates the same levels for the absorbed doses
as calculated by the TPS. To illustrate the good agreement the 80% isodose surfaces were calculated
and projected in 3D view (figure 4). The difference in relative absorbed dose between the TPS and gel
measurement was calculated voxel by voxel for the 112 071 voxels within the 80% isodose volume
and 76 877 voxels within the 95% isodose volume. The mean difference and the standard uncertainty
was (0.9±3.1) % and (1.4±2.8) % for the 80% and 95% isodose volumes, respectively (figure 6).
Within both isodose volumes 90% of the voxels showed a deviation less or equal to 5%. Outside the
analysed volumes some large deviations were detected, especially close to the glass walls. A factor
potentially contributing to the deviations could be the uncertainty in the absorbed dose calculations by
the TPS outside the field and close to the surface. Since the dose rate variation increases with the
distance from isocentre due to the gantry rotation, an additional explanation to the discrepancies could
be the dose rate dependency of the polymer gel system [9]. Measurements with other detector systems
are desirable since these deviations in the low dose volume could depend on either or both the TPS
and the gel measurements.
5. Conclusion
A 3D gel dosimetry system was used for a dosimetric verification of a RapidArc™ treatment. Measurements agreed well with the treatment planning system within the treated volume. Within analysed isodose volumes of 80% and 95% respectively, 90% of the voxels showed a deviation less or equal to 5%. Discrepancies between the calculated and measured relative absorbed dose in the low dose volume could be attributed to both calculations and measurements, and a comparison with additional detector systems would be of great interest. This study shows that gel dosimetry is a very useful tool for dose verification of advanced treatment delivery techniques such as RapidArc™.
Figure 5. (left) An overlay of the 80% isosurfaces from the TPS (red) and the gel measurement (green). Difference images are presented for (upper right) one slice above isocentre and (lower right) one slice below.

Figure 6. The distribution of the deviations between the TPS and the gel measurement. (left) The 112,071 voxels corresponds to the 80%-absorbed dose volume. (right) The 76,877 voxels corresponds to the 95%-absorbed dose volume.

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