

Feasibility study using MRI and two optical CT scanners for readout of polymer gel and PresageTM

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Abstract. The aim of this study was to compare the conventional combination of three-dimensional dosimeter (nPAG gel) and readout method (MRI) with other combinations of three-dimensional dosimeters (nPAG gel/PresageTM) and readout methods (optical CT scanners). In the first experiment, the dose readout of a gel irradiated with a four field-box technique was performed with both an Octopus IQ scanner and MRI. It was seen that the MRI readout agreed slightly better to the TPS. In another experiment, a gel and a PresageTM sample were irradiated with a VMAT field and read out using MRI and a fast laser scanner, respectively. A comparison between the TPS and the volumes revealed that the MRI/gel readout had closer resemblance to the TPS than the optical CT/PresageTM readout. There are clearly potential in the evaluated optical CT scanners, but more time has to be invested in the particular scanning scenario than was possible in this study.

1. Introduction

Traditionally, three-dimensional (3D) dosimetry [1] has been based on polymer gel that is read out by magnetic resonance imaging (MRI) [2], but the introduction of a promising radiochromic plastic dosimeter have created interest in optical computed tomography (optical CT) scanners as readout modality. The advantage of optical CT scanners is the ability to scan both plastics and polymer gel dosimeters and the fact that it is dedicated to 3D dosimetry [3]. It could also be located close to the clinical environment in a radiotherapy department, thus making MRI readout obsolete. In this initial feasibility study, two optical CT scanners are tested in two different experiments and compared to the well-established combination of polymer gel and MRI.

2. Material and methods

2.1. Readout modalities

The two optical CT scanners used were the fast laser scanner from the University of Surrey [4] and an Octopus IQ scanner (MGS. Research, Inc., Madison, CT, USA) located at Aarhus University. The MRI machine used to scan the gels were a conventional 1.5 T unit (Symphony, Siemens, Germany) located in Skåne University hospital in Malmö.



2.2. Preparation, irradiation and readout

In the first experiment, a normoxic polyacrylamide gel (nPAG gel) [5] was manufactured as described elsewhere [6] and poured into an acrylic cylindrical container (\varnothing 15 cm, length 17 cm). The gel was X-ray CT scanned and a four-field box technique with 3x3 cm 6 MV photon beams (0° , 90° , 180° and 270°) was planned using the CT data. The prescribed dose to the four-field box was 3 Gy, delivered with a dose rate of 600 MU min⁻¹ with a Varian Trilogy Tx (Varian Medical Systems Palo Alto, CA, USA). After irradiation, the gel was left to polymerize for 16 hours before the optical CT scan with the Octopus IQ scanner was initialized. Identical readout scans were performed pre- and post-irradiation with the gel placed upright on exactly the same position, using default Octopus IQ driver settings to control the motors and detector. A number of 300 projections with 145 slices, each divided on 180° , were acquired with a total scan time of approximately 48 minutes. The pre-irradiation scan was used to account for potential defects in the optical density of the gel. The refractive index liquid used was optimized for nPAG gel dosimeters and based on a mix of glycerol, water and a dye. Reconstruction was performed with a resolution of 1x1x1 mm³ with units of optical density, which was converted to relative absorbed dose by normalization to a region in the centre of the four-field box using MATLAB (MathWorks, Natick, MA, USA). A 3x3x3 box-filter was applied to smooth the raw data.

The MRI readout of the gel was conducted 24 hours after irradiation. The image acquisition was carried out using a 32-echo multi-spin echo sequence with 25 ms echo time and 9780 ms repetition time. The voxel size was 1x1x3 mm³ with two averages and four concatenations. The imaging time was 3 hours. In-house developed software was used to create R2 maps from the MRI data and the additional image processing was done using MATLAB. The R2 maps were converted to relative absorbed dose by background subtraction using the R2 value from an unirradiated region in the gel and normalization to a central volume in the four-field box. The dose distribution was linearly interpolated to 1x1x1 mm³ (as was the dose images from the treatment planning system (TPS) with an original resolution of 2x2x2 mm³). The raw data was smoothed with a 3x3x3 box-filter.

In the second experiment, a PresageTM sample (Heuris Pharma LLC, NJ, USA) [7] was procured and wrapped in two layers of 0.5 cm thick SuperFlab bolus material. This was done to achieve the same thickness as the gel container it should be compared with. The gel in question was manufactured and poured into two identical 0.5 l cylindrical glass containers (\varnothing 8 cm, length 12 cm). One of the bottles was left unirradiated and later used to obtain a background R2 value for the irradiated gel. The samples were X-ray CT-scanned and a clinical prostate Varian VMAT plan was used to receive clinically relevant dose modulation. However, the prostate target was reduced in size to fit into the small PresageTM sample. The target dose was prescribed to 3 Gy given with one full clockwise arc rotation and a collimator rotation of 30° using 450 MU and a varying dose rate between 200 and 600 MU/min. The plan was delivered to both dosimeters using a Varian Clinac iX linear accelerator. Due to low sensitivity to absorbed dose in the PresageTM sample, three identical dose deliveries were carried out consecutively.

The readouts of the PresageTM sample were carried out with the fast laser scanner at the University of Surrey with a total scan time of 25 minutes. Due to the setup arrangements of the scanner, the projections had to be corrected for distortion using the WARP_TRI algorithm in IDL 6.3 (ITT Visual Information Solutions, Boulder, Colorado, USA). Reconstruction of the absorbance projections was done using IDL 6.3. To reduce the optical and reconstruction artifacts, a 5x5x9 box-filter was applied to the reconstructed data. In MATLAB, linear interpolation to increase the pixel side from 0.3 mm to 1 mm was carried out and the resulted matrix were smoothed with a 3x3x3 box-filter. The TPS data was linearly interpolated from 2.5x2.5x2 mm³ to 1x1x1 mm³.

The scanning of the gel with MRI was carried out 24 hours post irradiation. A 32-echo multi-spin echo sequence was used with the following parameters: echo time 25 ms, repetition time 6000 ms, voxel size 1x1x3 mm³, two averages and four concatenations. The scan time was 1 hour and 43 minutes. A smaller part of the unirradiated gel was scanned with the same parameters. Further image processing was performed as described above.

3. Results and discussion

Overall, good agreement was found between the readout of the polymer gel, irradiated with a simple 3x3 cm four-field box, carried out with MRI and the Octopus IQ scanner (figure 1). To investigate the dose difference between the two data sets and the data from the TPS, the volumes were positioned in approximately the same position, thus excluding any possible set-up variations. The relative absorbed dose differences were calculated voxel-by-voxel within a volume of interest, i.e. a volume enclosed by the 90% isodose surface. A relative dose difference histogram for Octopus and MRI versus the TPS (X versus Y means that $X_{\text{voxel}}(i) - Y_{\text{voxel}}(i)$ in the $\text{VOI}_{90\%}$ of Y) are presented (figure 1, right column). The mean dose deviation for Octopus versus TPS and MRI versus TPS were $(-1 \pm 3) \%$ and $(0 \pm 3) \%$, i.e. a little bit better for the MRI readout. For the gel batch tested in this study the dose response was confirmed to be linear in the relevant dose range, which meant that the background subtracted R2 data and optical density could be directly translated to relative absorbed dose.

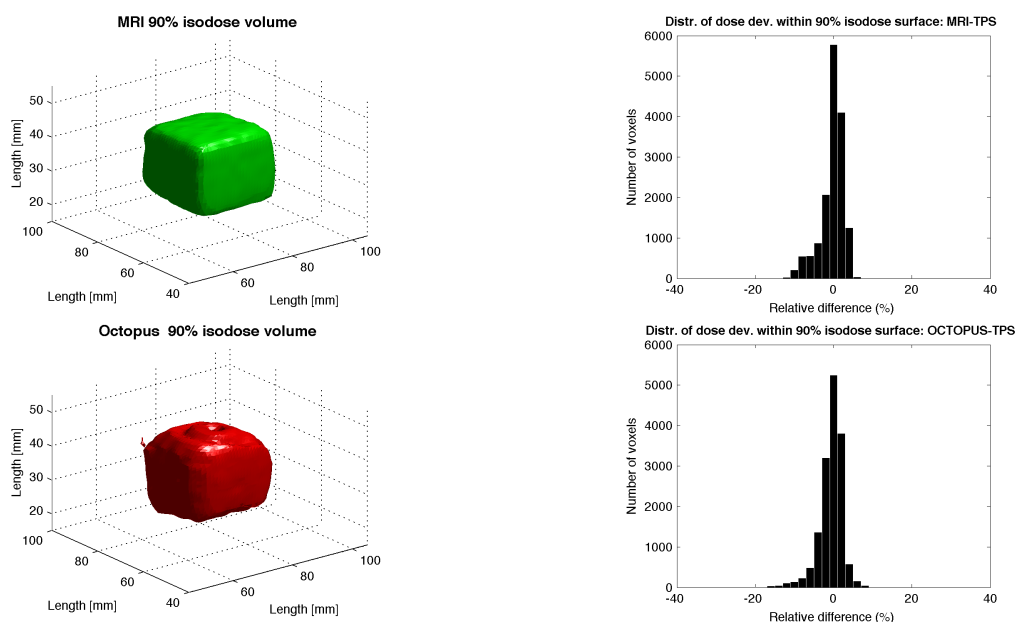


Figure 1: Isodose volumes of the four-field box irradiated on a polymer gel dosimeter from MRI (top left) and Octopus IQ (bottom left) readouts. The corresponding distributions of voxel-by-voxel dose deviations in a volume enclosed by the 90% isodose surface between the Octopus IQ readout and the TPS (top right) and between the MRI readout and the TPS (bottom right).

The MRI readout of the gel irradiated with the VMAT field agreed well to the TPS (figure 2, upper row). The 90% isodose volume read out with MRI and the one calculated by the TPS were almost identical and the relative absorbed dose differences between the two volumes calculated voxel-by-voxel within the 90% isodose surface, resulted in a mean and standard deviation of $(0 \pm 2) \%$ (figure 2, top right). Due to limitations in the distortion correction, only approximately half the irradiated volume of the scanned PresageTM sample with the fast laser scanner at the University of Surrey could be corrected and are thus presented here. The two volumes (TPS and fast laser readout) presented at 90% isodose volume, share the same features (figure 2, bottom row). The distribution of dose deviations for the fast laser scanner versus the TPS resulted in a mean deviation of $(-2 \pm 10) \%$ within the 90% isodose surface (figure 2, bottom right). The skewed appearance of the distribution suggests that the volume measured was smaller than the one from the TPS. The optomechanical complexity of

the scanner requires very accurate alignment to work properly and if that was not achieved, it is possible that the beam in some spots missed the detector and gave lower signal in some positions in the projections. This could be one explanation to the divergence between the investigated volumes. Limitations on the time available to perform the experiment meant that it was not possible to optimise the refractive index of the matching fluid used, which led to the well-known edge artefact in the form of dark stripes at the edge of the projections and the useful field-of-view in the resulting reconstructions was reduced. Similarly, whilst it is recommended to do a scan of the sample both prior to irradiation and afterwards [8], this was unfortunately not possible in this study.

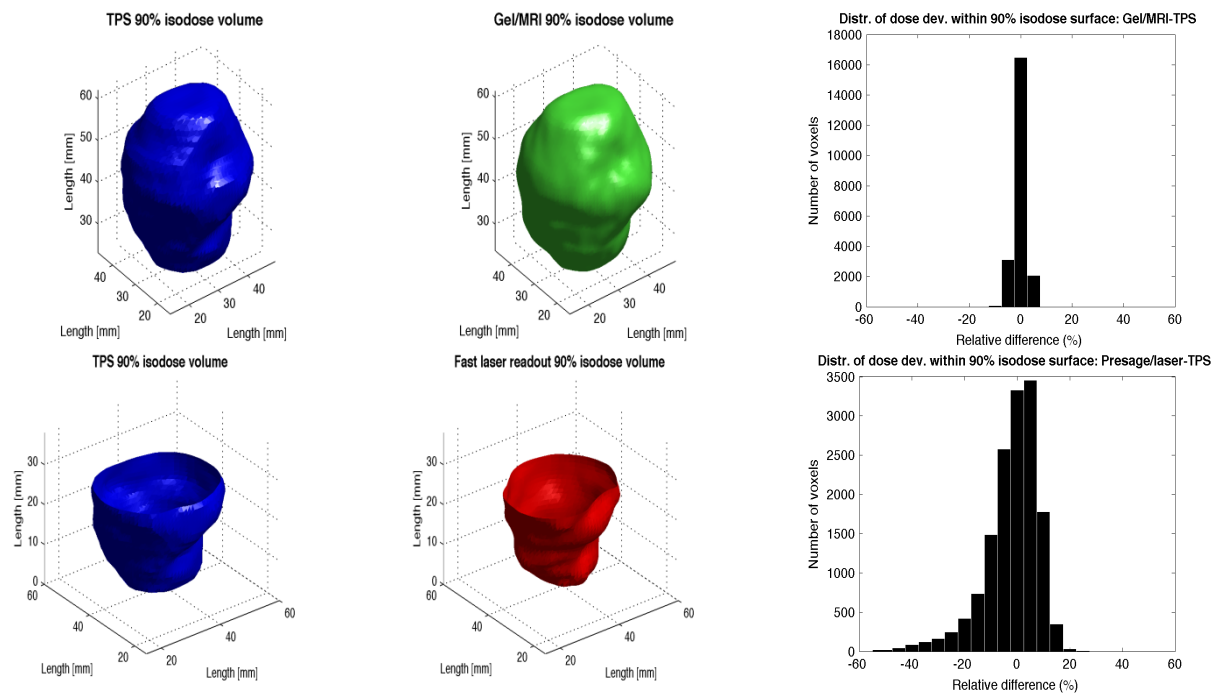


Figure 2: Isodose volumes projected into 3D views for the TPS and gel/MRI and corresponding distributions of dose deviations inside the 90% isodose volumes (upper row) and the TPS and a PresageTM sample read out by the fast laser scanner from the University of Surrey (bottom row).

4. Conclusion

The results of this study showed that the conventional gel and MRI dosimeter/readout combination correlated better to the TPS than optical CT readouts. This illustrates that it is non-trivial to implement an optical CT programme and more time is needed to “work up” the optical techniques for this particular scenario, coupled with ongoing improvements to the scanners and readout methods.

5. Acknowledgements

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6. References

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