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# Study of the use of gel dosimetry in combination with 3D printing phantom for personalized pretreatment QA in radiotherapy

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**Abstract.** In modern radiotherapy, pretreatment patient-specific quality assurance (PSQA) generally consists in delivering the treatment plan to a phantom equipped with a detector and in comparing the measured dose and the dose calculated by the treatment planning system (TPS) in order to detect any gap between both dose distributions. Dosimetric gels have interesting properties for QA. In this work, the use of gel dosimetry together with a patient-based 3D printed phantom for personalized PSQA is investigated. CT images of a patient with a right mesencephalic brain tumor were used to generate a 3D printed phantom. Then it was filled with water and a radiochromic gel jar and irradiated according to the patient intracranial stereotactic plan using a Novalis TrueBeam STX accelerator. Measured dose distributions agree well with the calculated ones. Regarding 3D gamma-index (1 mm – 2%) estimated within the central 85% of the jar volume, 96.3% of points pass the test. In addition, 86.5% of the points pass the local 2D 3 mm-3% gamma-index. Results are promising but further work is needed to improve the protocol and investigate the possibility to extend it to end-to-end tests.

## 1. Introduction

Modern radiotherapy techniques such as intensity modulated radiation therapy, volumetric modulated arc therapy or stereotactic radiotherapy are more and more complex. Thanks to the use of either multiple beams or arcs with simultaneously gantry rotation, MLC shape adjustment and dose rate modulation, highly conformal doses to the tumor volume is delivered while preserving close organs at risk. It is a requirement that medical physicists conduct pretreatment QA measurements to detect any gap between calculated and delivered doses. This generally consists in delivering the plan to a phantom and comparing both measured and calculated dose distributions. With advanced RT techniques, due to the complex shape of dose distributions, QA is challenging and accurate and spatially precise dosimeters are needed in combination with new PSQA procedures. Dosimetric gels have interesting properties for QA [1]: in addition to the ones mentioned above they are water equivalent and 3-D dose distributions can be obtained in a single irradiation. Regarding phantoms, commercially available phantoms are not always anatomically correct. However with the arrival and still maturing technology of three-dimensional printing, it is now possible to construct personalized phantoms from the CT images of the patients [2].

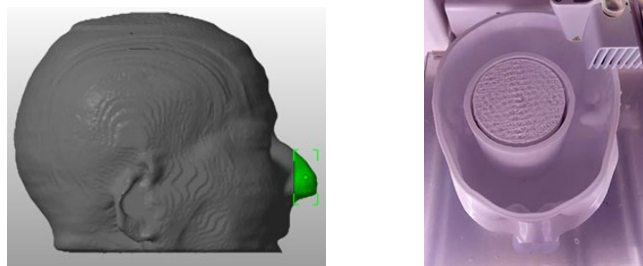


This study describes the feasibility of using 3D-printed patient specific phantoms in combination with a radiochromic gel in order to perform pretreatment patient-specific quality controls in stereotactic radiotherapy.

## 2. Material and methods

### 2.1. Phantom construction and gel manufacture

A patient with a right mesencephalic brain tumor was selected. The first step consisted in creating a numerical phantom from the CT images of the patient. Then this numerical model was converted into a mesh using STL format. Finally the phantom was 3D printed at scale 1:1 using an Ultimaker 3 extended printer which is based on fused deposition modeling. The phantom consisted in a 1.2mm thick wall made of PET including a place to insert a radiochromic gel jar (Figure 1). The nose was printed separately to be used as a plug [3].

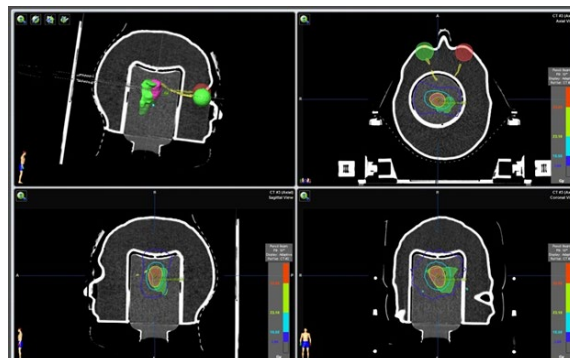


**Figure 1.** 3D model created from the CT images (left) and 3D printing of the model with a gel insert (right)

An in-house protocol was used for the preparation and the calibration of the radiochromic TruView™ gels [4]. Two jars of 400 ml from the same batch were used: one for the calibration and another dedicated to the measurement in the phantom. Before irradiation, 512 projections of the gel jars were acquired at 632 nm using the commercial Vista™ Optical-CT scanner.

### 2.2. Treatment planning

CT images of the phantom equipped with the stereotactic mask and including the gel jar were acquired and imported in the iPlan TPS (BrainLab) to recalculate the intracranial stereotactic treatment plan (Figure 2). The original plan consisted in 3 fractions of 11 Gy, it has been adapted in order to deliver 3 Gy to the target volume which is the optimal dose for the TruView™ gel. The ballistic was composed of 6 dynamic arc beams, the total number of delivered MU was 451.



**Figure 2.** Axial, sagittal and coronal views of the iPlan computed dose distribution created using the 3D-printed phantom

### 2.3. Irradiation

For the calibration, the jar was placed vertically in a water tank without the lid and irradiated with a 12 MeV electron beam and a 6.5 cm×6.5 cm field. The maximum dose delivered was 4 Gy.

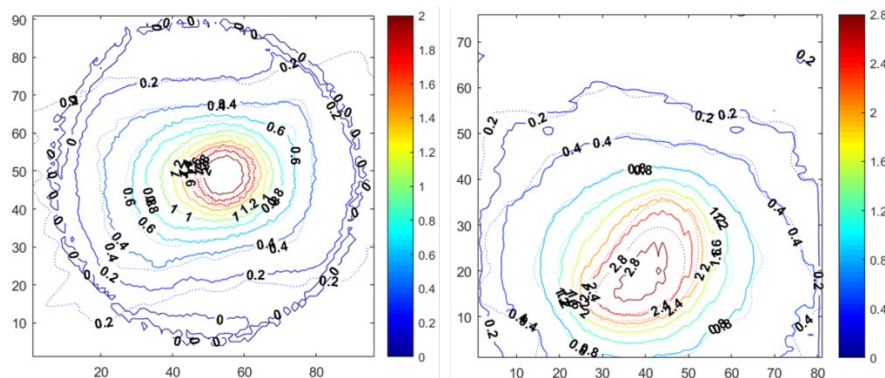
The phantom with the gel jar was placed on the treatment table with the stereotactic mask. Then, kV images using the ExacTrac system were acquired in order to allow a precise repositioning of the phantom. Finally, one treatment fraction of 3 Gy was delivered on the phantom using a Novalis TrueBeam STX accelerator (Varian Medical System).

### 2.4. Gel reading and data analysis

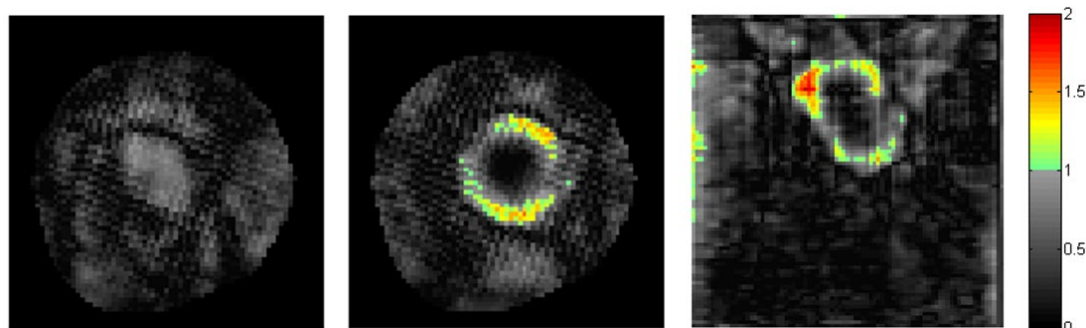
Gels were optically read 75 minutes after irradiation. Using the VistaRecon™ software (Modus Medical Devices Inc.), reconstructions were made with a voxel resolution of 0.5 mm × 0.5 mm × 0.5 mm. Then the data were processed using Matlab (vR2013b, The MathWorks, Inc.). For the calibration jar, the central-axis changes in optical attenuation with depth of gel dosimeters were fit against the central-axis depth dose extracted from the TPS library. For the jar in the phantom, the quantitative comparisons included dose distributions and 2D and 3D gamma index.

## 3. Results and discussion

As observed in Figure 3, the measured dose distribution is in agreement with the calculated one (Figure 3). The shape and the dose levels are similar. Regarding 3D gamma-index (1 mm – 2%) estimated within the central 85% of the jar volume, 96.3% of points pass the test (Figure 4). For a slice located at the center of the gel dosimeter, the local 2D 3 mm-3% gamma-index evaluated within the central 85% of the cylinder diameter reaches 86.5% of points passing the criteria.

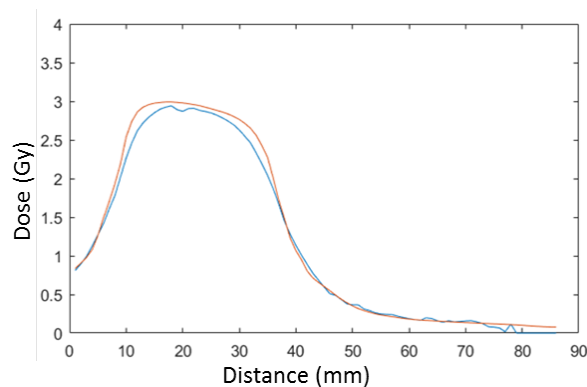


**Figure 3.** 2D dose distributions obtained with the gel (dotted lines) and with the TPS (solid line) in an axial plane (left) and a coronal plane (right) across PTV



**Figure 4.** 3D global gamma analysis (1 mm – 2%) in two axial planes (left and middle) and in a coronal plane (right) at PTV level

However, it can be observed that some discrepancies are observed in the strong dose gradient around the target volume (Figure 4 and Figure 5). The gel underestimates the dose in that region. This could be due to the diffusion of ferric ions through the gel which causes the degradation of the spatial and dosimetric information with time. The protocol has been developed to limit this diffusion but these measurements haven't been performed in control laboratory conditions as usual in particular in terms of temperature. The TruView™ gels are temperature-sensitive and their response may have been slightly impacted. Moreover, this underestimation could also come from reading artefacts with the optical scanner. As a matter of fact, the tank needs to be filled and degassed the day before. However due to time constraints, it has only been done the day of measurements.



**Figure 5.** Dose profiles of the calculated and measured axial dose distribution at PTV centre along the head-foot direction

#### 4. Conclusion

Gel dosimetry in combination with patient-based 3D-printed phantoms is a promising technique for personalized PSQA in stereotactic radiotherapy. However, further studies are needed to improve the protocol. Future work will also investigate the possibility to extend the method to end-to-end tests.

#### 5. References

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