Journal of Physics: Conference Series **573** (2015) 012050 doi:10.1088/1742-6596/573/1/012050

Feasibility on using composite gel-alanine dosimetry on the validation of a multiple brain metastasis radiosurgery VMAT technique

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Abstract. This work presents an end-to-end test using a composite Gel-Alanine phantom, in order to validate 3-dimensionally the dose distribution delivered by a single isocenter VMAT technique on the simultaneous treatment of multiple brain metastases. The results obtained with the gel and alanine dosimeters are consistent with the expected by the treatment planning system, showing the potential of this multidosimetric approach and validating dosimetrically the multiple brain metastases treatment using VMAT.

1. Introduction

The addition of Stereotactic Radiosurgery (SRS) to the initial treatment of brain metastasis improves local control [1]. Although these results are well established for up to three lesions, there are promising data for a scenario of more than three and up to ten lesions [2]. Traditionally, multiple brain metastases are treated with SRS each one with its respective isocenter, taking about 20 minutes per lesion. With the advent of Volumetric Modulated Arc Therapy (VMAT) it is now possible to treat multiple metastasis using a single isocenter, in much less time, with more efficiency and comfort to the patient.

Nevertheless, the safe use of the VMAT technique on producing such complex volumetric dose distributions (DD) requires an extensive dosimetric validation [3]. To address this challenge, this work aims to study the feasibility of using a composite Gel-Alanine phantom on an end-to-end test, in order to validate 3-dimensionally [4] the DD delivered by a single isocenter VMAT technique on the treatment of multiple brain metastasis. The phantom is a cylinder filled with dosimetric gel (which plays a role of cortex material) and with alanine pellets (the brain metastasis) distributed along its volume.

2. Materials and Methods

2.1. Phantom preparation

The MAGIC-f gel dosimeter was used, its preparation was performed in a fume hood under normal levels of oxygen following the work of Fernandes *et al* 2008 [5] and applied in the same way as described in papers [6, 7].

Three plastic cylindrical phantoms with approximately 14.5cm of diameter and volume of 1.4l were used. On the first (Gel-Alanine), a PVC holder was used to position 12 alanine dosimeters distributed along the phantom volume. Alanine dosimeters were covered with paraffin film (Parafilm) to avoid contact with gel. The other two phantoms had gel only (Gel 1 and 2). The Gel-Alanine and Gel 1 received the VMAT treatment, and Gel 2 was used as reference in the MRI scanner. Calibration vials of gel were also prepared from the same batch and irradiated with doses of 1 to 12 Gy for the construction of calibration curves.

2.2. Treatment plan process and treatment

The Gel-Alanine phantom was immobilized with a frameless stereotactic thermoplastic head mask (BrainLab AG, Germany) to be attached to a stereotactic fiducial coordinate system. This whole setup was scanned on a Somaton Definition AS CT (Siemens Healthcare AG, Germany) with 1 mm slice thickness and distance, resulting on a final voxel size of 0.70 x 0.70 x 1.00 mm^3.

The CT data was imported on the iPlan treatment planning system (TPS), version 4.1 (BrainLab). The fiducial coordinate system was identified and accounted for. Among the 12 alanine pellets distributed inside the phantom, 5 lesion cores were delineated (term that will be adopted further on the text. Around each lesion core, a PTV was grown and a different dose prescription assigned: "PTV1" (1.5 cm diameter, 1.75 cm^3 volume, around a single pellet and dose of 6 Gy), "PTV2" (irregular C-shape with 2.8 cm and 1.0 cm major and minor axis, 2.9 cm^3 volume, around a single pellet and dose of 5 Gy), "PTV3" (1.0 cm diameter, 0.50 cm^3 volume, around a single pellet and dose of 9 Gy), "PTV4" (3 cm diameter, 14.1 cm^3 volume around three pellets and dose of 7 Gy) and "PTV5" (1.5 cm diameter, 1.75 cm^3 volume, around two pellets and dose of 8 Gy).

The isocenter on iPlan was defined as the geometric center of PTV 4, and the case was exported to Eclipse TPS, version 10 (Varian, USA) and ExacTrac 6D image guidance radiotherapy system (IGRT), version 5 (BrainLab). On Eclipse, a VMAT plan was created for a Novalis Tx linear accelerator equipped with a Millennium High Definition MLC, using 3 arcs: 1 full 360º coplanar arc and 2 partial (155º) arcs at couch angles 45º and 315º, the collimator angle was kept at 15º.

The plan was submitted to the institutional (Hospital Sírio-Libanês) patient specific quality control program, that consists of three separate measurements: (i) composite ionization chamber absolute dose measurement (CC13, 0.125 cm^3 volume, IBA Dosimetry GmbH, Germany), and (ii) composite planar EBT3 Gafchromic (ISP, USA) film dosimetry on a cubic solid water RW3 slabs phantom (IBA Dosimetry) and (iii) per field Portal Dosimetry (PD) technique, version 10.0 (Varian).

Before treatment delivery, the institutional machine pre-treatment quality control program was applied. After that, the phantom was positioned according to the institutional IGRT protocol, that consists of: (i) positioning through ExacTrac 6D correction (translations and rotations), (ii) verification using OBI kV Cone Beam CT technique (kV-CBCT). The doses due to these procedures were considered low enough to be disregarded (< 15 cGy at the phantom surface).

2.3. Magnetic Resonance Imaging and Gel Dosimetry Evaluation

Magnetic resonance images (MRI) of the three phantoms were acquired 1 day after irradiation using a 3T scanner (Phillips, Achieva). These images were centered in the head coil (where the phantoms were positioned) using a GRASE 3D multi spin-echo sequence with 8 echo times multiples of 35 ms, repetition time of 1000 ms and voxel size of 2 x 2 x 2 mm^3. The MRI field inhomogeneity was subtracted from the images of the irradiated phantom. The R2 DD maps were calculated in a software develop in MatLab®.

2.4. Alanine Dosimetry Evaluation

Alanine dosimeter cylinders (2.5 mm radius, 3 height) with 65.5 mg of mass were used. In some cases two and three pellets were stacked to simulate larger metastases. A group of dosimeters was irradiated in the same accelerator with the appropriate build up to produce a calibration curve. They were analysed in a Jeol JES-FA200 X-band Electron Spin Resonance spectrometer at ambient temperature.

3. Results and Discussion

3.1. Plan quality assurance results

(i) Ion chamber: The mean dose on the chamber volume calculated by Eclipse was 644.6 cGy and the measurement was 658.8 cGy (2.2% difference).

(ii) EBT3 composite dosimetry: performed on the coronal plane, at the same level as measured by the chamber (isocenter). The mean dose at a ROI defined on the calculated and on the measured dose matrices were 645.7 cGy and 653.2 cGy, respectively (1.6% difference). The 2%/2mm gamma analysis between them resulted in 99.8% of approved points (doses < 10 % ignored) (figure 1).

(iii) PD: performed per field, on original gantry angles, un-normalized, within jaw aperture. The gamma (2%/2mm) passing rates for each of the 3 arcs where: 97.9%, 98.7% and 98.4% (figure 1).

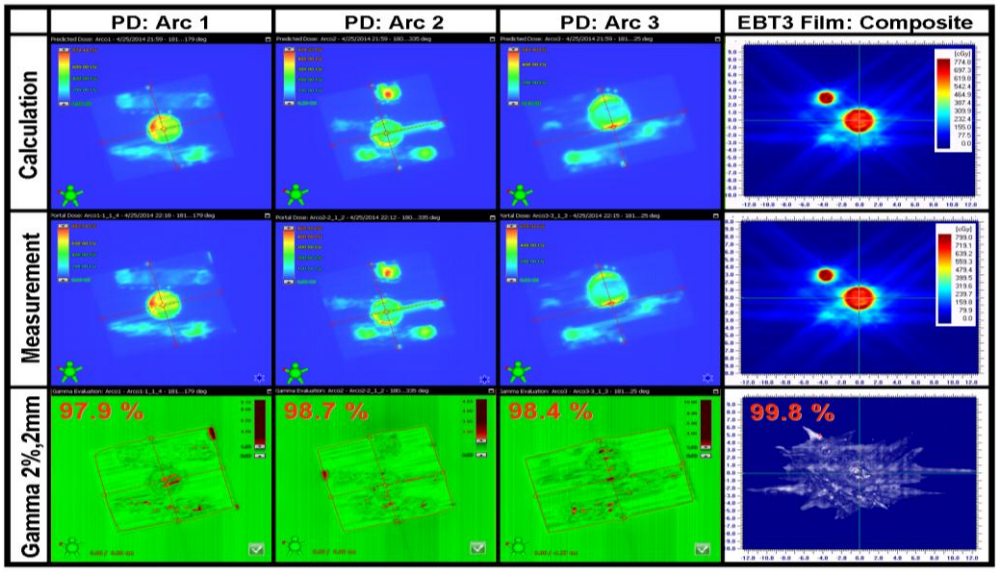

Figure 1. Quality assurance results: calculations (first row), measurements (second row) and gamma evaluations (2 %/2 mm) (third row) for each VMAT arc evaluated by PD (first to third columns) and composite film dosimetry on coronal plane (fourth column).

3.2. Gel and Alanine results

The association of the two detectors in the same measurement enables to evaluate DD 3D (with gel) and point doses (with alanine) inside target volumes and to compare this two methods in order to cross validate them.

For both irradiated gel phantoms, the calculated and measured DD for the 5 PTVs had good passing rates on gamma (figure 2). In the Gel-Alanine, the Parafilm packing trapped some air inside the gel, despite the maximum care on trying to minimize it. Thus, some inhibition of gel response occurred and can be seen especially in PTV5, where some points fails in the gamma map.

The alanine point dose measurements for the lesion cores 1, 2, 3, and 5 are in good agreement with the mean dose expected by Eclipse (TPS) with differences of less than 5% (table 1). For lesion core 4 a leak of the gel into the dosimeter was found that impeded a precise measurement of the dose at this point. Gel mean doses in all lesion cores are also in agreement with the expected value by Eclipse.

The results show good consistency among all the dosimetric methods currently used to verify DD in VMAT and the new methods using Magic-f gel and ESR/alanine

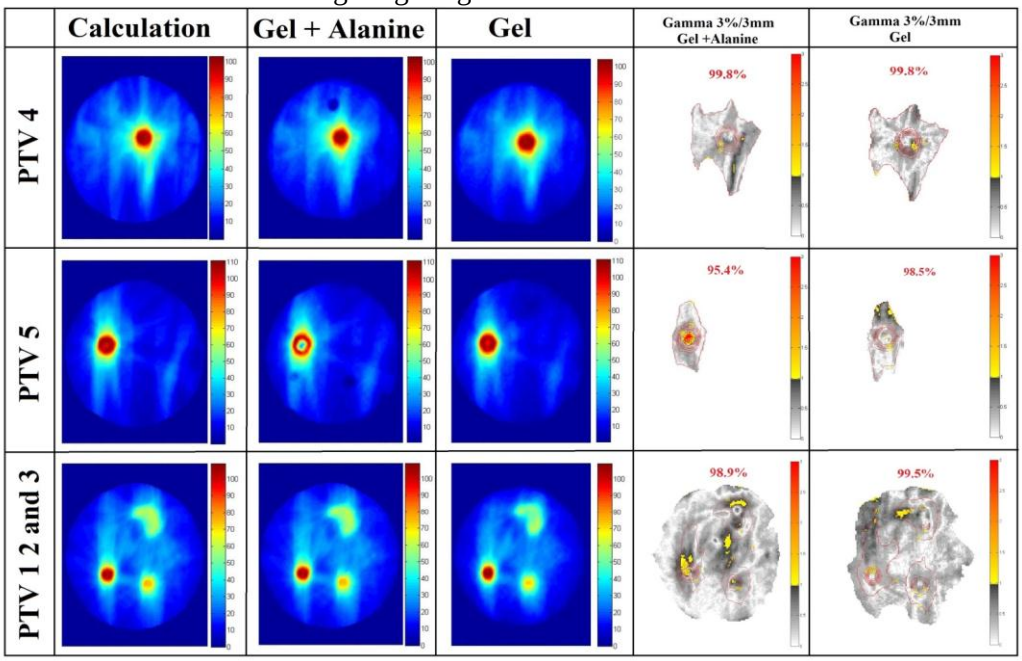

Figure 2. Calculated DD by Eclipse (first column), measured DD by gel+alanine (second column), measured DD by gel (third column) and gamma analysis, 3%/3mm (fourth and fifth columns) for: PTV 4 (first row), PTV 5 (second row) and PTVs 1, 2and 3 (third row). Gamma analysis used threshold of 30%, 25% and 10% for PTVs 4, 5 and (1, 2, 3).

Table 1. Eclipse expected mean dose, alanine doses and gel mean doses as well the percentage difference between the measured and expected values for all lesion cores.

	Lesion 1	Lesion 2	Lesion 3	Lesion 4	Lesion 5
Eclipse Mean dose (Gy)	6.81	5.43	10.78	7.86	9.00
Alanine doses (Gy)	6.55	5.38	10.29	-----	8.64
Difference (%): Alanine-TPS	3.82	0.09	4.54	-----	4.00
Gel Magic-f doses (Gy)	6.93	5.59	10.77	7.73	8.92
Difference (%)	1.7	2.29	0.09	1.65	0.8

3. Conclusions

The Gel-Alanine composite phantom enabled the dosimetric validation of multiple brain metastases treatment using VMAT. Both Alanine and Gel have its own pros and cons, but, when combined, they complement each other and can be considered as an almost ideal tool for this application, featuring: high resolution 3D dose information, reliable absolute dose measurement, dose rate independence, water equivalence, redundant cross validation, flat energy and dose linearity responses.

4. References

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