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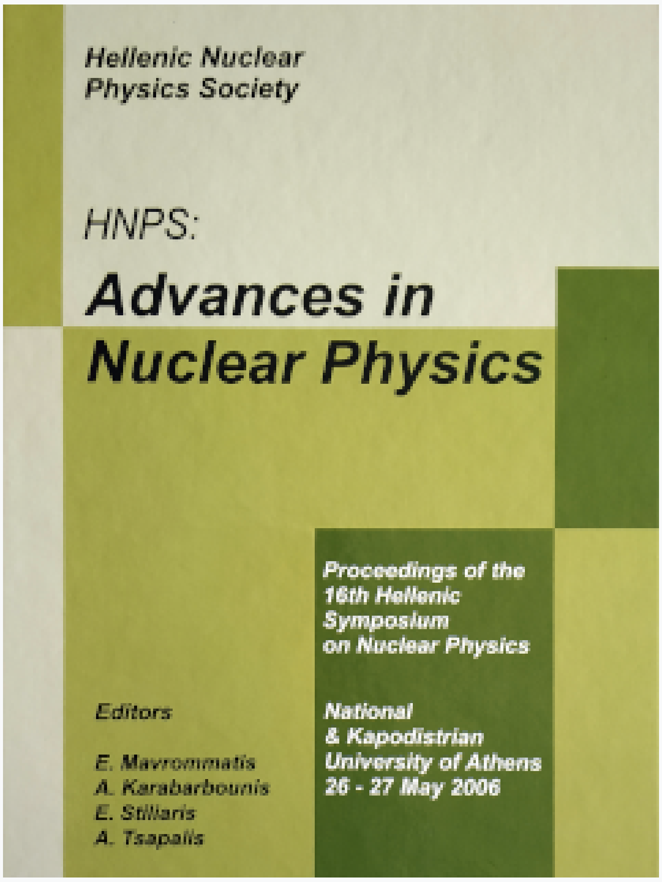

Current Trends in the Endorsement and Quality Assurance of Contemporary Radiotherapy Applications

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Current Trends in the Endorsement and Quality Assurance of Contemporary Radiotherapy Applications

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1. Introduction

Radiation therapy delivery is currently in the process of changing dramatically. This change is being driven in large part by continuing advances in computer hardware and software that has led to the development of sophisticated three-dimensional radiation treatment planning (3D-RTP) and computer-controlled radiation therapy (CCRT) delivery systems. Such planning and delivery systems have made practical the implementation of new techniques such as three-dimensional radiation therapy (3D-CRT), intensity modulated radiation therapy (IMRT) and stereotactic radiosurgery. The goal of these techniques is to conform the spatial distribution of the prescribed dose to the 3D target volume and at the same time to minimize the dose to the surrounding normal structures thus escalating the dose to the tumor and reduce normal tissue complication probabilities. The added complexity of these techniques necessitates dosimetric input data of high accuracy and extensive quality-assurance procedures to ensure that the treatment-planning calculation of the 3D dose distribution coincides with the dose distribution actually delivered.

As contemporary radiation delivery techniques have rendered analytical calculations and conventional experimental dosimetry methods insufficient due to their inherent 3D approach, the small field dimensions and/or steep dose gradients involved, our collaboration has turned to the implementation and development of 3D polymer gel-MRI dosimetry. This method involves the irradiation of water equivalent, integrating gel detectors which combined with MRI can provide 3D dose distributions with excellent spatial resolution.

In this work an example of quality assurance using the above method is given. Polymer gel-MRI measured, 3D dose distributions are compared to corresponding treatment planning calculations and conventional (film) measurements in clinical brain stereotactic radiosurgery applications using Leksell Gamma Knife® system. This system utilizes 201 intersecting ^{60}Co beams and four helmets with different size collimators to form four standard clinical beam sizes of 18, 14, 8 and 4 mm nominal diameter with a total geometrical accuracy in dose delivery of the order of 0.5 mm. For patient treatment, a stereotactic frame is attached to the patient's head under local anesthesia which establishes a three-dimensional (3D) coordinate system for the determination of the precise target location through imaging (usually MRI). Single or multiple isocenters (shots) using the four available helmets can be utilized to treat targets of any shape. Polymer gel-MRI dosimetric method can simulate the entire patient treatment and has the unique advantage of providing 3D dose distribution measurements with high resolution [1]–[3] in a water equivalent material [4] thus allowing for the experimental verification of the 3D steep dose gradients met in gamma knife applications [5]–[8]. This work presents the 3D verification of single shot gamma knife applications as well as the verification of a highly conformal multiple shot patient plan. Moreover, the method was used to verify the treatment of multiple brain metastases, an application which involves the use of multiple shots to treat the different metastases (targets). Experimental results were compared against corresponding treatment planning (GammaPlan) calculations in the form of relative dose distributions in all three directions for all the verified applications, as well as with film measurements.

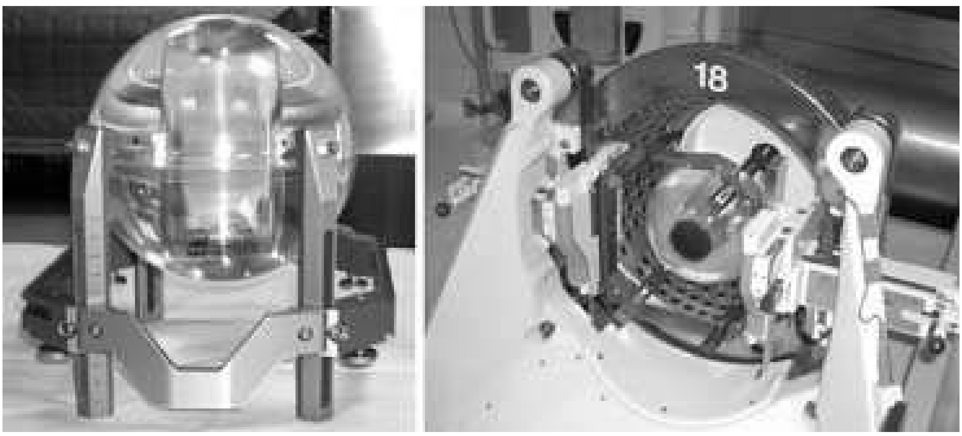

Figure 1. (a) The Leksell stereotactic frame attached to the spherical head phantom containing a gel vial. (b) The irradiation experimental set up with the stereotactic frame attached to the spherical Plexiglas head phantom containing a gel vial mounted on the Leksell gamma knife unit.

2. Materials and Methods

2.1. Gel Preparation

Two different gel formulations, called PABIG and VIPAR, that were developed by our group and described in previous works [3,9], were employed.

Seven gel filled Pyrex® cylindrical vials of 95 mm total height and 47.5 mm inner diameter were prepared. Six for the needs of irradiations and two were served as control (i.e. zero dose) readings for the two different gel formulations. The gel filled vials were stored in the lab overnight at a room temperature of about 20^o C, transferred to the gamma knife department on the following day, and irradiated at approximately 23^o C.

2.2. Irradiations

For the purpose of irradiations, the gel vial was accommodated in a custom-built, spherical (16.3 cm diameter) Plexiglas phantom. The Leksell stereotactic frame was attached to the phantom via fastening the four fixation screws on pre-determined phantom positions. An MR imaging session of the gel-phantom-stereotactic frame assembly was performed on a 1.5 T whole body Philips ACS NT MR imager (Philips Medical Systems, Best, The Netherlands) with an RF quadrature receiver head coil, using MR sequences identical to the ones used for patient imaging (a spoiled T1-weighted 3D-Fast Field Echo sequence of TR: 25 ms/TE: 1.8 ms/Flip Angle: 35^0, and a T2-weighted Turbo Spin Echo sequence of TR: 2700 ms/ TE: 160 ms/Flip Angle: 90^0). The acquired images were imported to the GammaPlan TPS software and six treatment plans resembling gamma knife treatments were generated: four plans resembling single shot treatments with the four different collimator helmets, one highly conformal clinical plan which involved four 8 mm and one 14 mm collimator helmet shots and one plan resembling the treatment of four brain metastases with the use of four 8 mm collimator shots.

Figure 2. A photograph of the gel vial irradiated with the Leksell gamma knife unit using a GammaPlan generated plan resembling treatment of four metastases with four different shots.

The phantom along with the attached stereotactic frame (Fig. 1a) was mounted on the Leksell gamma knife® model 4200C (Fig. 1b) where six irradiations corresponding to the different plans were performed using a different gel vial for each irradiation (VIPAR gel vials were used for the single shot verifications and PABIG gel vials were used for the multiple shot verifications). In Figure 2 a photograph of the gel vial resembling the treatment of four metastases is presented.

2.3. Gel Dosimetry

Two days post-irradiation, the gel vials were imaged on the same MR scanner used to provide the images imported to the TPS for planning purposes. A volume selective 32-echo Carr-Purcell-Meiboom-Gill pulse sequence was employed (TE1, TE2,..., TE32 = 40 ms, 80 ms,..., 1280 ms, TR of 2.3 s, reconstructed voxel size of $1 \times 1 \times 1$ mm^3), with phase encoding being applied in two orthogonal directions and Fourier interpolation taking place in the slice reconstruction direction. After discarding the first echo of the 32-echo train, a single T2 map (an image on which pixel signal intensity represents the NMR spin-spin relaxation time T2 of the corresponding gel voxel) was automatically derived for each reconstructed slice [10]. These maps were exported from the scanner in DICOM-3 format and then imported into MATLAB V.6.5 (The Mathworks, Natick Mass., USA) to construct a 3D T2 matrix which was subsequently converted to an R2 (=1/T2) relaxation rate matrix which allows for the accurate partition of the scanned volume in any orthogonal plane.

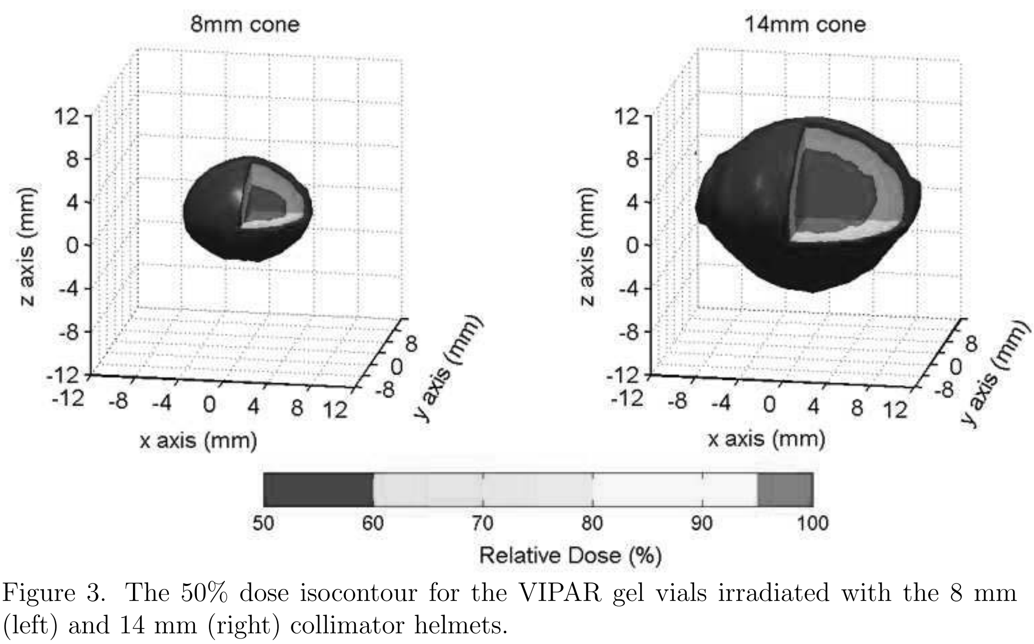

Figure 3. The 50% dose isocontour for the VIPAR gel vials irradiated with the 8 mm (left) and 14 mm (right) collimator helmets.

3. Results and Discussion

In Figure 3, 3D dose distribution measurements are presented for the VIPAR gel vials irradiated with the 8 mm and 14 mm collimator helmets (single shot irradiations). These distributions reveal the general characteristics of the radiation fields defined by the 201 intersecting beams with the 8 mm and 14 mm collimator helmets, in terms of the extent of the 50% isosurface in the three planes that defines the corresponding FWHM values of the field and the ellipsoidal form of the distribution due to the source configuration in model 4200C. In the same figure, a cut out of the 50% dose isosurface defined by the central axial, coronal and sagittal planes is also presented allows for the inspection of the relative dose distribution and the dose gradient in each field. The 3D approach inherent in the polymer gel dosimetry method allows for the derivation of dosimetry results along any direction in the scanned volume. In Figure 4 central VIPAR polymer gel dose profile measurements for the 8 mm single shot irradiation are presented, along with corresponding film measurements and corresponding data predicted by the GammaPlan treatments planning system (TPS). A close matching of the VIPAR relative dose profiles with the other two data sets can be observed that validates the accuracy of the investigated single shot gamma knife application.

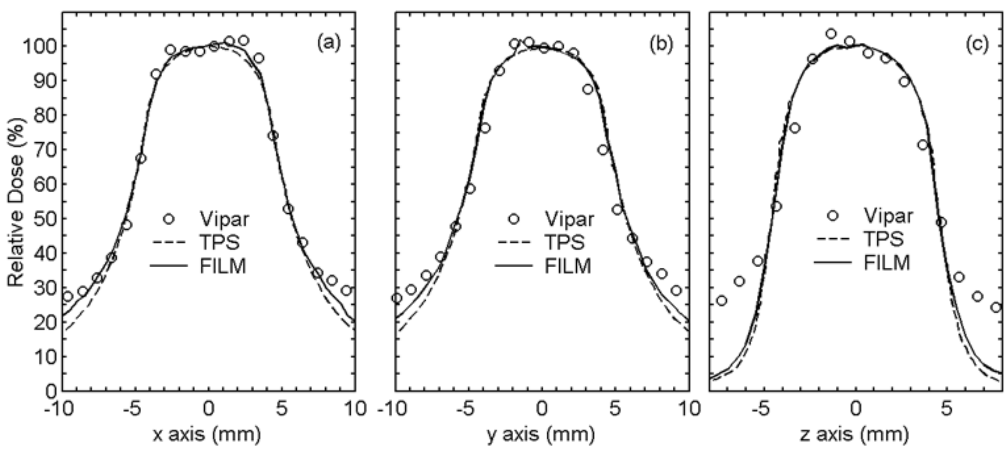

Figure 4. Dose profiles for the VIPAR gel irradiated with the 8 mm collimator helmet. Corresponding treatment planning system calculations as well as radiochromic film measurements are also presented for comparison.

Figure 5 presents the comparison of measured (using PABIG polymer gel dosimetric method) and GammaPlan calculated relative dose isocontours on a central axial, sagittal and coronal plane, superimposed on the corresponding T2 images, for the highly conformal, multiple shots, clinical plan. Overall, no systematic offset can be observed between measured and calculated planar relative dose isocontours of Figure 5 which are in good agreement within the experimental uncertainty of one imaging pixel.

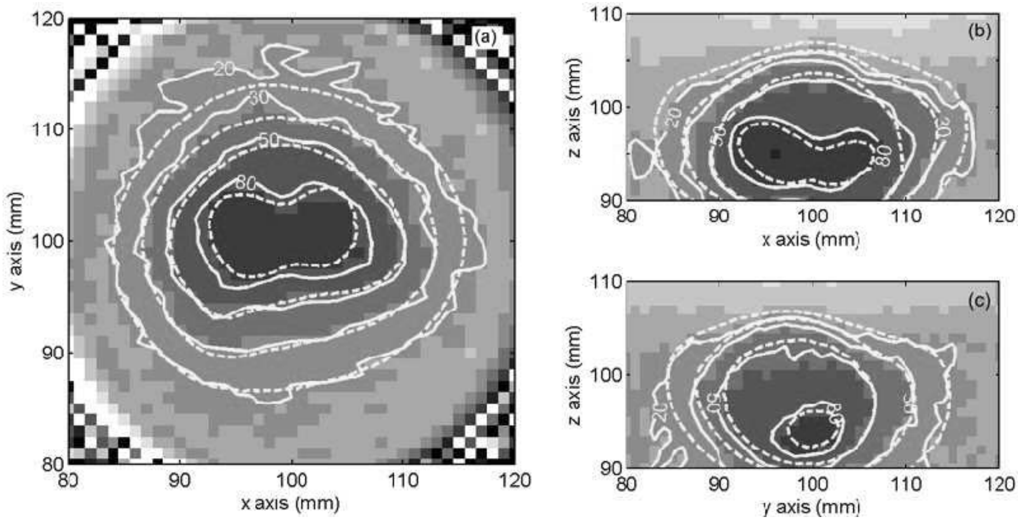

Figure 5. Comparison of PABIG gel measured and GammaPlan calculated dose distributions for the gel irradiated according to a clinical treatment plan presented on (a) an axial (b) a sagittal plane and (c) a coronal plane, superimposed on the corresponding T2 images.

4. Conclusions

The polymer gel -MRI dosimetry method was used in this work for the three-dimensional verification of gamma knife treatments using two different gel formulations. Experimental results were compared to corresponding treatment planning calculations, as well as film measurements and agreement within experimental uncertainties was observed. Overall polymer gel dosimetry poses as an efficient tool for the verification of the complete patient procedure in gamma knife stereotactic radiosurgery applications.

REFERENCES

1. M.J. Maryanski *et al. Magnetic resonance imaging of radiation dose distributions using a polymer-gel dosimeter*, Phys. Med. Biol. 39 (1994) 1437–1455.
2. D.A. Low *et al. Evaluation of polymer gels and MRI as a 3-D dosimeter for intensity-modulated radiation therapy*, Med. Phys. 26 (1999) 1542–1451.

3. P. Sandilos *et al. Dose verification in clinical IMRT prostate incidents*, Int. J. Radiat. Oncol. Biol. Phys. 59 (2004) 1540–1547.
4. E. Pantelis *et al. Polymer gel water equivalence and relative energy response with emphasis on low photon energy dosimetry in brachytherapy*, Phys. Med. Biol. 49 (2004) 3495–3514.
5. J. Novotny *et al. Quality control of the stereotactic radiosurgery procedure with the polymer-gel dosimetry*, Radiotherapy and Oncology 63 (2002) 223–230.
6. S.G. Scheib and S. Gianolini, *Three-dimensional dose verification using BANG gel: a clinical example*, Journal of Neurosurgery 97 (2002) 582–587.
7. P. Karaiskos *et al. Dose verification of single shot gamma knife applications using VIPAR polymer gel and MRI*, Phys. Med. Biol. 50 (2005) 1235–1250.
8. P. Papagiannis *et al. Three-dimensional dose verification of the clinical application of gamma knife stereotactic radiosurgery using polymer gel and MRI*, Phys. Med. Biol. 50 (2005) 1979–1990.
9. E. Pappas *et al. A new polymer gel for magnetic resonance imaging (MRI) radiation dosimetry*, Phys. Med. Biol. 44 (1999) 2677–2684.
10. P. Baras *et al. Polymer gel dosimetry using a three-dimensional MRI acquisition technique*, Med. Phys. 29 (2002) 2506–2516.