Evaluation of Dose Delivery Accuracy of Gamma Knife Using MRI Polymer Gel Dosimeter in an Inhomogeneous Phantom

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Abstract : Polymer gel dosimetry is still the only dosimetry method for directly measuring three-dimensional dose distributions. MRI Polymer gel dosimeters are tissue equivalent and can act as a phantom material. Because of high dose response sensitivity, the MRI was chosen as readout device.
In this study dose profiles calculated with treatment-planning software (LGP) and measurements with the MR polymer gel dosimeter for single-shot irradiations were compared.
A custom-built 16 cm diameter spherical plexiglas head phantom was used in this study. Inside the phantom, there is a cubic cutout for insertion of gel phantoms and another cutout for inserting the inhomogeneities. The phantoms were scanned with a 1.5T MRI (Siemens syngo MR 2004A 4VA25A) scanner. The multiple spin-echo sequence with 32 echoes was used for the MRI scans. Calibration relations between the spin-spin relaxation rate and the absorbed dose were obtained by using small cylindrical vials, which were filled with the PAGAT polymer gel from the same batch as for the spherical phantom.
1D and 2D data obtained using gel dosimeter for homogeneous and inhomogeneous phantoms were compared with dose obtained using LGP calculation.
The distance between relative isodose curves obtained for homogeneous phantom and heterogeneous phantoms exceed the accepted total positioning error (>±2mm).
The findings of this study indicate that dose measurement using PAGAT gel dosimeter can be used for verifying dose delivering accuracy in GK unit in presence of inhomogeneities.

Key words: Gamma Knife (GK), PAGAT Gel Dosimeter, Inhomogeneity, Planning System (LGP)
1. Introduction

Stereotactic Gamma-Knife (GK) radiosurgery plays an important role in managing small intracranial brain lesions (of volume typically less than 25 cm³) (1, 2). Currently, polymer gel dosimetry is still the only dosimetry method for directly measuring three-dimensional dose distributions. Polymer gel dosimeters are tissue equivalent and can act as a phantom material (3, 4).

In this study the PAGAT (PAG And THPC anti-oxidant) gel dosimeter was used to investigate the effects of air and PTFE inhomogeneities on dose delivery accuracy of Gamma Knife systems. Some studies examined the shot placement accuracy of Gamma Knife units by measuring dose distribution or measuring the distance between the location of the maximum dose and the mechanical center (5-7).

Comparison of 1D line profiles and 2D dose distributions between measurements and LGP calculations was undertaken by some investigators (7-11). However, investigation of dose distribution in a single shut GK treatment in presence of air and PTFE inhomogeneities is the purpose of this study.

2. Materials and methods

In this study PAGAT polymer gel dosimeter was fabricated according to composition proposed by Venning et al (2005) (12) who noted Using MRI, the formulation to give the maximum change in the transverse relaxation rate $R_2$ was determined to be 4.5% $N,N'$-methylene-bis-acrylamide (bis), 4.5% acrylamide (AA), 5% gelatine, 5 mM THPC, 0.01 mM hydroquinone (HQ) and 86% H2O.

For fabricating the gel dosimeter, the De Deene et al (2006) (13) proposed method have been used.

Phantom in this study was a 16cm spherical plexiglas in which there is a cubic cutout for inserting the gel vials (4×4×4 cm³) and another cutout (4×4×3 cm³) for inserting the air and/or a bone equivalent material (Poly-tetra-fluoro-ethylene (PTFE), with density of 2.2 gm/cm³). Designing the phantom and it’s cutouts for inserting the inhomogeneities were performed using EGSnrc code (unpublished results).

Figure 2 shows the phantom placed in a Gamma Knife unit (model C) for irradiation.

The calibration tubes were irradiated using the Theratron Co-60 machine using a special container in which the calibration vials could be located horizontally. The calibration vials were irradiated from 0 to 50 Gy with steps of 2.5 and 5 (i.e. 0, 2.5, 5, 10, 15, 20, 25, 30, 35, 40,45 and 50). Post-manufacture irradiation time was 24 hours.

Figure 1. Phantom placed in a Gamma Knife unit (model C) for irradiation.
The evaluation of the polymerized dosimeter was performed on a Siemens (syngo MR 2004A 4VA25A) 1.5 T scanner in the transmitter/receiver head coil. A multi-echo sequence with 32 echoes was used for the evaluation of irradiated polymer-gel dosimeters. The parameters of the sequence were as follows: TR 3000 ms, TE 22–640 ms, slice thickness 1 mm, FOV 128 mm, matrix size 256×256, pixel size 0.5×0.5 mm², one acquisitions. The R2 and dose maps were computed using modified radiotherapy gel dosimetry image processing software coded in MatLab.

3. Results and Discussion

Calibration data for the PAGAT gel batch used in this work were derived by the analysis of axial T2 maps of the calibration gel tubes 24 hours post-irradiation and a cubic and quadratic fit was performed on R2 values of PAGAT(A) and (2), in the dose region of 0–30 Gy, and 5-40, respectively. Post-irradiation imaging time was also 24 hours.

After discarding the first echo of the 32-echo train, a single T2 (spin–spin relaxation time) map was automatically derived for each reconstructed slice. These maps were exported from the scanner in DICOM-3 format and then imported into MatLab (14) to construct a 2D T2 matrix which was subsequently converted to an R2 (= 1/T2) relaxation rate matrix. The R2 matrix was subsequently converted into a relative dose matrix normalized to the maximum prescribed dose of 40 Gy.

Figure 2 compares the relative dose profiles along the X axis of the experimental reference coordinate system for the PAGAT gel irradiated with the 18 mm collimator helmet between homogeneous and GP prediction. Dose difference between these profiles is in average 2.7%±1.9%, and in maximum is 6%.

![Figure 2](image)

Figure 2. Relative dose profiles along the X axis of the experimental reference coordinate system for the irradiation with the 18 mm collimator helmet, obtained using homogeneous phantom (— - -), and GP prediction (—). Dose difference is also depicted (–––).

Figure 3 compares the relative dose profiles along the X axis of the experimental reference coordinate system for the PAGAT gel irradiated with the 18 mm collimator helmet between homogeneous and heterogeneous phantoms.
Dose difference between homogeneous phantom and air inserted phantom is in average 5.2%±3.3% and in maximum 13.2%, and dose difference between homogeneous phantom and PTFE inserted phantom is in average 6.1%±3.9%.

Figure 4 shows the comparative relative dose distributions for the irradiation with the 18 mm collimator helmet between homogeneous and PTFE inserted phantom and also between homogeneous and air inserted phantom.

As depicted in figure 4, distance between 100%, 90%, and also 50% isodose lines in maximum exceed the 2mm. In addition, in PTFE inserted phantom relative isodose at most reach 95% and in air inserted phantom it exceed 105%.

The total positioning error, based on the surface contouring accuracy, MRI fiducial correspondence and overall positioning accuracy of the Gamma Knife is ±2 mm, similar to the
error expected for patient treatment (15), so, the distance between relative isodose curves exceed the total positioning error.

4. Conclusion
The discrepancies observed between the results obtained for heterogeneous and homogeneous phantoms suggest that GP predictions must be corrected in order to take care of the air- and bone-tissue inhomogeneities.
In this respect it is worthwhile to mention that an air inhomogeneity that could be assumed as maxillary or frontal sinuses gives rise to modifications of the dose profiles and dose distribution.

References

[1] Leksell L. The stereotaxic method and radiosurgery of the brain. *Acta Chir Scand* 1951;102:316–319
[2] Mack A, Scheib SG, Major J, et al. Precision dosimetry for narrow photon beams used in radiosurgery-determination of Gamma Knife output factors. *Med Phys* 2002;29:2080–2089
[3] Fong P, Keil D, Does M, Gore J. Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere. *Phys Med Biol* 2001;46:3105–3113
[4] Venning A, Nitschke K, Keall P, Baldock C. Radiological properties of normoxic polymer gel dosimeters. *Med Phys* 2005;32:1047–1053
[5] Ertl A, Saringer W, Heimberger K, Kindl P. Assurance for the Leksell gamma unit: Considering magnetic resonance image-distortion and delineation failure in the targeting of the internal auditory canal. *Med Phys* 1999;26:166–170
[6] Guo WY, Chu WC, Wu MC. An evaluation of the accuracy of magnetic-resonance-guided Gamma Knife surgery. *Stereotact Funct Neurosurg* 1996;66:85–92
[7] Watanabe Y, Akimitsu T, Hirokawa Y, Mooij RB, Perera GM. Evaluation of dose delivery accuracy of Gamma Knife by polymer gel dosimetry. *J Appl Clin Med Phys* 2005;6:133–142
[8] Novotny J, Dvorak P, Sprevacek V. Quality control of the stereotactic radiosurgery procedure with the polymer-gel dosimetry. *Radiother Oncol* 2002;63:223–230
[9] Ertl A, Berg A, Zehetmayer M, Frigo P. High-resolution dose profile studies based on MR imaging with polymer BANG(TM) gels in stereotactic radiation techniques *Magn Reson Imag* 2000;18:343–349
[10] Novotny JJ, Novotny J, Sprevacek V. Application of polymer gel dosimetry in gamma knife radiosurgery. *J Neurosurg* 2002;7:556–562.
[11] Scheib SG, Gianolini S. Three-dimensional dose verification using BANG gel: A clinical example. ... *J Neurosurg* 2002;97:582–587
[12] Venning AJ, Hill B, Brindha S, Healy BJ, Baldock C. Investigation of the PAGAT polymer gel dosimeter using magnetic resonance imaging. *Phys Med Biol* 2005;50:3875–3888
[13] De Deene Y, Vergote K, Claeyss C, De Wagter C. The fundamental radiation properties of normoxic polymer gel dosimeters: a comparison between a methacrylic acid based gel and acrylamide based gels. *Phys Med Biol* 2006;51:653-673
[14] MathWorks. Image Processing Toolbox 5. *MATLAB* v 7 2007
[15] Moskvin V, Timmerman R, DesRosiers C, et al. Monte Carlo simulation of the Leksell gamma Knife (R): II. Effects of heterogeneous versus homogeneous media for stereotactic radiosurgery. *Phys Med Biol* 2004;49:4879-4895