Application of polymer-gel dosimetry in stereotactic radiosurgery

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1. Introduction

Stereotactic irradiation with the Leksell gamma knife (Elekta Instrument AB, Stockholm, Sweden) is one of the primary methods used for the stereotactic radiosurgery treatment of intracranial lesions [1,2]. To assure the quality of the whole treatment procedure a proper dosimetric system is required. The polymer-gel dosimeter evaluated by nuclear magnetic resonance (NMR) is a promising tool to satisfy this requirement.

The purpose of this study was to investigate the use of polymer-gel dosimeter as a dosimetric tool for the quality control of stereotactic radiosurgery procedures performed by the Leksell gamma knife.

2. Materials and methods

The polymer-gel dosimeter was prepared according to procedures described elsewhere [3,4]. The prepared polymer-gel was poured into ten cylindrically shaped glass vessels (inner diameter 15 mm, length 75 mm, wall thickness 2 mm) used for the dosimeter calibration. Spherically shaped glass vessels (inner diameter 46 mm, wall thickness 3 mm) or glass made phantom that mimicked exactly the shape of the rat body were used for the irradiation on the Leksell gamma knife. All samples (including calibration) used for each experiment described in this study originated always from the same batch.

Calibration of the polymer-gel dosimeter was done on 60Co unit THERATRON 1000 (MDS Nordion, Canada).

Altogether four applications of polymer-gel dosimeter were carried out: (1) head phantom with the polymer-gel dosimeter was used for verification of 4, 8, 14, 18 mm single isocenters irradiation, (2) head phantom with the polymer-gel dosimeter was used for verification of four different tumors treatment plans, (3) head phantom with the polymer-gel dosimeter was used for verification of six different eye lesion’s treatment plans and (4) specially designed rat phantom filled by polymer-gel dosimeter was used for verification of experimental animal treatment plans. Further details regarding phantoms construction can be found elsewhere [5,6]. To simulate the procedure as closely as possible, the head phantom was fixed in the stereotactic frame (figure 1) and underwent stereotactic NMR localization. Treatment plans were calculated for the head phantom using the Leksell GammaPlan...
treatment planning software. All steps during treatment planning were done as usually for an ordinary patient’s treatment (figure 1). Finally, the head phantom was irradiated in the Leksell gamma knife based on the calculated treatment plans. Phantom was irradiated in the Automatic Positioning System (APS) or by using trunnions (figure 1). Similarly special rat phantom filled by polymer-gel underwent stereotactic imaging, treatment planning and irradiation (figure 2).

![Figure 1](image1.png)

Figure 1. Water filled head phantom with polymer-gel. (a) Water filled head phantom with polymer-gel was fixed in the Leksell stereotactic frame. For the NMR stereotactic investigation a special indicator box was attached to the frame. (b) Treatment planning was done by using the Leksell GammaPlan treatment planning software. (c) The phantom was irradiated in the Automatic Positioning System (APS) or in (d) trunnions.

The evaluation of the polymerized dosimeter was performed on a Siemens Expert 1T scanner in the transmitter/receiver head coil. A multi-echo sequence with 16 echoes was used for the evaluation of irradiated polymer-gel dosimeters. The parameters of the sequence were as follows: TR 2000 ms, TE 22.5–360.0 ms, slice thickness 2 mm, FOV 255 mm, matrix size 256x256, pixel size 1.0x1.0 mm², one acquisition. To calculate the T2-relaxation time of the investigated polymer-gel dosimeter Siemens Numaris software version VB 33D was used. All NMR measured T2-relaxation data were corrected to one reference temperature of 25.0 °C using an algorithm described elsewhere [4].

![Figure 2](image2.png)

Figure 2. Special rat phantom filled by polymer-gel. (a) Polymer-gel filled rat phantom was fixed in the Leksell stereotactic frame. For the NMR stereotactic investigation a special indicator box was attached to the frame. (b) Treatment planning was done by using the Leksell GammaPlan treatment planning software. (c) The phantom was irradiated in trunnions.
Two parameters that described geometric discrepancies between calculated and measured dose distributions were defined. Since the dose was prescribed to 50% isodose in the case of the head phantom irradiation and to 70% isodose in the case of the rat phantom irradiation these isodoses were used as reference levels for the geometric inaccuracies evaluation. The first parameter was defined as a misalignment in the position between the center of the profile calculated by the treatment planning system and measured one. The values of these differences were denoted as $\Delta X$, $\Delta Y$, $\Delta Z$. The second parameter expressed the difference between the width of the 50% (for the head phantom) and the 70% (for the rat phantom) isodose curves calculated and measured ones. Values of these differences were denoted as $\Delta W_x$, $\Delta W_y$, $\Delta W_z$.

3. Results

Example of polymerization in four different experiments that occurred after polymer-gel irradiation is given in figure 3.

![Figure 3](image-url)

**Figure 3.** Example of polymerization for different experiments performed in this study. (a) Dose distribution for one single 18 mm isocenter, (b) dose distribution for acoustic tumor created by thirteen 4 mm isocenters, (c) dose distribution for glaucoma created by four 8 mm isocenters and (d) dose distribution in rat phantom created by four 4 mm isocenters.

Example of dose profiles measured and calculated by treatment planning system is given in figure 4. Summary of results for all evaluated profiles is given for all four experiments in table 1.

![Figure 4](image-url)

**Figure 4.** Example of dose profiles (solid lines – treatment planning system calculations, squares - polymer-gel dosimeter measurements) for different experiments performed in this study. (a) Dose profile for one single 18 mm isocenter, (b) dose profile for acoustic tumor, (c) dose profile for glaucoma and (d) dose profile in rat phantom.
### Table 1. Summary of results for all evaluated profiles expressed as deviations between center of the profile and width of reference isodose for measured and calculated (by treatment planning system) dose profiles.

| Experiment 1        | ΔX [mm] | ΔY [mm] | ΔZ [mm] | ΔWX [mm] | ΔWY [mm] | ΔWZ [mm] |
|---------------------|---------|---------|---------|---------|---------|---------|
| 4 mm isocenter      | 0.3     | 0.3     | 0.1     | 0.2     | 0.3     | 0.6     |
| 8 mm isocenter      | 0.5     | 0.1     | 0.4     | 0.2     | 0.1     | 0.3     |
| 14 mm isocenter     | 0.1     | 0.4     | 0.5     | 0.5     | 0.7     | 0.2     |
| 18 mm isocenter     | 0.3     | 0.0     | 0.4     | 1.0     | 1.2     | 0.2     |

| Experiment 2        |         |         |         |         |         |         |
| Acoustic schwannoma | 0.1     | 0.1     | 0.2     | 1.6     | 0.9     | 1.4     |
| Pituitary adenoma   | 0.4     | 0.4     | 0.3     | 1.5     | 3.0     | 0.6     |
| Meningioma          | 0.3     | 0.1     | 0.9     | 2.1     | 1.1     | 0.4     |
| Metastasis          | 0.4     | 0.2     | 0.8     | 1.5     | 1.9     | 1.3     |

| Experiment 3        |         |         |         |         |         |         |
| Uveal melanoma plan 1 | 0.3   | 0.4   | 0.3   | 0.5   | 0.9   | 0.5   |
| Uveal melanoma plan 2 | 0.5   | 0.4   | 0.5   | 0.7   | 0.2   | 0.6   |
| Uveal melanoma plan 3 | 0.4   | 0.2   | 0.2   | 0.3   | 0.3   | 0.4   |
| Glaucoma plan 1      | 0.3     | 0.5     | 0.7     | 0.5     | 0.7     | 0.7     |
| Glaucoma plan 2      | 0.5     | 0.1     | 0.5     | 0.6     | 0.4     | 0.4     |
| Retinoblastoma       | 0.2     | 0.3     | 0.2     | 0.5     | 0.5     | 0.6     |

| Experiment 4        |         |         |         |         |         |         |
| Experimental animal | 0.5     | 0.6     | 0.3     | 0.7     | 0.3     | 0.6     |

#### 4. Discussion

Polymer-gel dosimeter was used altogether in four different experiments in this study. These experiments allowed to check the entire stereotactic procedure with the Leksell gamma knife including target stereotactic localization on NMR, treatment planning and irradiation. Consequently, both mechanical and dosimetric (relative dosimetry) parameters could be evaluated at the same time and the total inaccuracy of the procedure could be assessed.

Results of all experiments demonstrated a reasonable agreement between the dose profiles calculated by the treatment planning system and those experimentally measured by the polymer-gel dosimeter. These results confirmed the accuracy of the entire treatment chain containing NMR target localization, treatment planning calculations of the relative dose distribution and the precision of irradiation.

The results demonstrated that the polymer-gel dosimeter system allows effective measurement of very steep dose gradients for rather complicated three-dimensional dose distributions.

#### 5. Conclusions

Effective use of polymer-gel dosimeter for quality control of stereotactic irradiation by the Leksell gamma knife was demonstrated in this study. Rather complicated threedimensional dose distributions with very steep dose gradients were measured for the simulation of clinical as well as experimental conditions with good agreement with values calculated by the treatment planning system.
Acknowledgements

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