Verification of dose volume histograms in stereotactic radiosurgery and radiotherapy using polymer gel and MRI

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1. Introduction

Currently there is no available dosimetric system except gel dosimeter that would capture whole three dimensional dose distribution delivered by treatment unit into the planned target volume (PTV) or organ at risk (OAR). Such potential and soft tissue equivalence of polymer gels make it possible to measure dose volume histograms (DVHs) of arbitrary volumes in phantoms filled with polymer gel imitating real patients [1,2]. Generally in clinical radiotherapy DVHs represent one of the criteria for treatment plan evaluation within treatment planning procedure and treatment effectiveness.

In this work we focused on DVHs measurement in stereotactic radiosurgery (SR) performed with the Leksell gamma knife (ELEKTA Instrument AB, Stockholm, Sweden) and stereotactic radiotherapy (SRT) performed with linear accelerator 6 MV Varian Clinac 2100 C/D (Varian Medical Systems, Palo Alto, USA) in conjunction with BrainLAB stereotactic system (BrainLAB, Germany; hereafter linac) using modified BANG gel and magnetic resonance imaging (MRI). The aim of the experiments was to investigate a method for acquiring entire dose volume information from irradiated gel dosimeter and calculate DVHs.

2. Materials and methods

2.1. Polymer gel preparation.

Polymer gel preparation followed our well established method [3,4]. Material substance was bubbled with nitrogen almost throughout the procedure; about 15 minutes before filling the dosimeter glass containers (Fig 1) tetrakis was added to further inhibit oxygen influence. The gel was poured into the measurement flask and calibration vials inside hermetically closed perspex box continually flushed with nitrogen. The gel composition was the following: 5% gelatine (swine skin, 300 Bloom, SIGMA Aldrich), 3% acrylamide (Riedel-de Haen, Seelze, Germany), 3% N,N'-methylene-bisacrylamide
(APPLICHEM, Darmstadt, Germany), 5 mM tetrakis(hydroxymethyl)-phosphonium (80% water solution, SIGMA, Aldrich), distilled water.

2.2. Dosimeter calibration:
Nine calibration vials filled with polymer gel were homogenously irradiated (±0.5%) with two lateral fields 30 × 30 cm² immersed in cubic PMMA phantom filled with water to doses up to ~10 Gy with ~1 Gy step. One vial was left unirradiated for background reading. In the experiment (the Leksell gamma knife) cobalt unit THERATRON 1000 (MDS Nordion, Canada) was used whereas in the second experiment the calibration batch was irradiated on 6 MV linac. In both experiments the calibration was performed approximately at the same time as the irradiation of measurement samples.

2.3. Measurement phantom, treatment planning and irradiation.
Figure 1 depicts the special head phantom in which dosimeter flasks were irradiated. The rest of the volume in the phantom was filled by water. Prior to treatment planning the phantom underwent MRI or CT stereotactic localization. Since the special holder enables reproducible positioning of a single dosimeter flask inside the phantom (± tenths of mm), CT localization for linac experiment was carried out with dosimeter container filled with water to prevent unnecessary irradiation of the gel material.

Dosimeter flask was contoured to define the volume from which DVH was calculated in the treatment planning system (TPS) – GammaPlan or BrainScan. This approach enables to easily define the same volume in the measured dose distribution since the glass walls of the measurement flask are

![Figure 1](image1.png)

**Figure 1.** 1 - head phantom, 2 - special holder for dosimeter flask, 3 – dosimeter flasks.

![Figure 2](image2.png)

**Figure 2.** Upper panel – arrangement of special scanning phantom, lower panel – selected axial T2 map.
well perceptible in T2 maps (Fig 2). For the Leksell gamma knife irradiation simple treatment plans were created (four plans with single shot placed approximately in the center of the flask using 4, 8, 14, 18 mm collimator and four multiple shots plans). For the linac irradiation, three plans using different irradiation techniques with micro MLC collimators were created. The maximum planning dose was about 8 Gy for all eleven plans.

2.4. MR imaging.
MR scanning of irradiated samples was performed one day post irradiation using a Siemens EXPERT 1T scanner in the transmitter/receiver head coil. A multiple spin-echo sequence with 16 equidistant echoes was used. The parameters of the sequence were as follows: TR 2000 ms, TE 22.5 – 360 ms, slice thickness 2 mm, FOV 500 mm, pixel size 1.95 mm, one acquisition. T2 relaxation time was calculated using Siemens NUMARIS software version VB 33D; first echo was excluded. To obtain the response throughout the whole dosimeter volume about 60 2 mm slices were required which yields a total scanning time of about 8 hours (8 min 33 s per one slice). It is likely that the temperature varied slightly in the MRI room during scanning over such a long time. Furthermore heating of the gel by absorption of RF pulses was not monitored. Another aspect is temporal instability of magnetic fields and spatial variations in RF fields in the MR scanner, leading to signal variations at different positions over the gel volume. For all these reasons we have introduced a special scanning method together with a Perspex scanning phantom (Fig 2) which allows scanning the measurement flasks together with calibration vials immersed in a water-filled container and thus provides calibration vials response for each slice.

3. Data processing and DVHs calculation
R2 value for each calibration point was averaged from 12 voxels in homogenously irradiated region inside the particular calibration vial. Since the calibration dependence was not linear, an exponential fitting model was used: 

$$R2 = a \cdot (1 - c \cdot \exp(-b \cdot D))$$

Fig 3).

Before recalculation of R2 maps into dose maps according to the corresponding calibration curves, a noise reduction image filter was applied (hybrid median filter, 5 x 5, which respects intensity gradients). Routine for data pre-processing and DVHs calculation was run under MatLab (The MathWorks, USA).

**Figure 3.** Calibration curves for selected slices.
4. Results
For all irradiated flasks integral and differential DVHs were calculated. Dose values were normalized to the maximum planned dose. Relatively good agreement between TPS calculations and gel measurements was observed (Fig 4). The highest deviations were observed at low and high dose regions (i.e. below 1.5 Gy and around maximum dose).

5. Conclusions
Experiment has shown that the polymer gel dosimeter used and the evaluation methodology described are capable of measuring DVHs for volumes that received higher doses, such as PTV. Measuring DVHs for OARs is questionable. Even a voxel size ~2 mm did not render acceptable noise level in R2 maps. Furthermore our scanning method confirmed that attention to signal variations along longitudinal axis of imaged dosimeter during acquisition must be paid (Fig 3), which is a crucial aspect when DVHs are calculated.

![Figure 4](image_url)

**Figure 4.** Differential and integral histograms of one dosimeter flask irradiated on linac – the most noticeable disagreement is at low and high dose regions due to high amount of noise in T2 maps.

6. References
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