Absolute dose verifications in small photon fields using BANG™ gel

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1. Introduction
Polymer gel dosimeters change their magnetic resonance (MR) and optical properties with the absorbed dose when irradiated [1,2] and are suitable for narrow photon beam dosimetry in radiosurgery [3]. Such dosimeters enable relative and absolute 3D dose verifications in order to check the entire treatment chain from imaging to dose application [2,4–6] during commissioning and quality assurance.

For absolute 3D dose verifications in radiosurgery using Gamma Knife B, commercially available BANG™ Gels (BANG 25 Gy and BANG 3 Gy) together with dedicated phantoms were chosen in order to determine the potential of absolute gel dosimetry in radiosurgery.

2. Material and methods
The abbreviation BANG stands for Bis (N, N’-methylene-bisacrylamide, the monomer, 3 %), acrylamide (the monomer, 3 %), nitrogen (the atmosphere under which the gel is produced, 1 %) and gelatine (the matrix, 5 %). These chemical components have to be dissolved in distilled water (the solvent, 88 %) under nitrogen atmosphere in a sealed system to prevent any oxygen contamination which inhibits the radiation induced polymerization. The gel was produced by MGS Research Inc. and filled into dedicated Barex® containers (diameter = 43 mm, height = 30 mm) to prevent any oxygen diffusion into the gel.

For calibration measurements the 18 mm collimator helmet of a Gamma Knife B (mean photon energy = 1.25 MeV) was used. The Barex® containers filled with BANG 25 Gy or BANG 3 Gy gel were mounted in the central part of a tissue equivalent spherical phantom (diameter = 16 cm) and were irradiated with a dose rate of 3.5 Gy/min.

The corresponding dose dependent R2 values were calculated for each voxel using up to 4 single spin echo pulse sequences (slice thickness = 1.1 mm, FoV = 29 cm, matrix size = 256 x 256, voxel size = 1.13 x 1.13 x 1.1 mm³, TR = 500–4000 ms, TE = 20–155 ms, 1–8 interleave acquisitions, scan time per echo time = 17–68 min) using a clinical 1.5 T MR scanner and a head coil. The MR imaging parameters used were varied in order to maximize the signal to noise ratio and therefore minimize the statistical uncertainty in the measured R2 values, with the aim of achieving approximately 1 mm isotropic resolution in 3D.
For each calibration measurement the mean $R^2$ value was calculated and the standard deviation within the homogeneous area of the dose distribution was calculated using a dedicated gel analyses software developed in house [7].

The influence of dose rate, ambient light exposure, fractionated irradiation, scan temperature and ageing was studied for both gel types.

Based on these data, 3D absolute dose verifications using a Gamma Knife B together with an anthropomorphic head phantom were performed. The head phantom was handled in the same manner as a patient and typical clinical dose distributions were applied. Here an example of a plan using three isocentres with one 8 mm collimator and two 4 mm collimators and a maximum dose of 25 Gy was chosen to illustrate the dose verification.

3. Results

The linear dose–$R^2$ relationship for the BANG 25 Gy gel is shown in figure 1 for three different gel batches. For a given batch the slope and intercept of the calibration curve varies strongly with gel temperature during scanning [8] (figure 2). The dose response curve gets steeper with decreasing temperature. It is also steeper when analyzed with an increasing time delay after irradiation (figure 3). In figure 4 the calculated (solid line) and measured (broken line) dose distribution of the three isocenter plan together with the corresponding $R^2$ image is shown. The calculated (solid line) and measured (broken line) absolute dose profiles along the cross hair positions as shown in figure 4 (x- and y-axis) are shown in figures 5 and 6 respectively together with the error band which denotes $\pm \sigma_D$ (dotted lines).

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** Relaxation rate $R^2$ as a function of dose from 0–25 Gy for three different BANG 25 Gy gel batches. **Figure 2.** Relaxation rate $R^2$ as a function of dose for one BANG 25 Gy gel batch and different read out temperatures.
Figure 3. Relaxation rate R2 as a function of dose from 0–25 Gy for one BANG 25 Gy gel batch for different read out delays.

Figure 4. Calculated (solid line) and measured (broken line) absolute isodose lines.

Figure 5. Calculated (solid line) and measured (broken line) absolute dose profile along the x-axis (left-right cross hair in figure 4) including the error band (dotted line).

Figure 6. Calculated (solid line) and measured (broken line) absolute dose profile along the y-axis (down-top cross hair in figure 4) including the error band (dotted line).
4. Discussion

Both gel types (BANG 25 Gy and Bang 3 Gy) show a linear dose-R2 relationship. High resolution absolute 3D dose verifications in radiosurgery using BANG™ gel are feasible. However, the sensitivity of the gel is highly batch dependent. Also temperature and ageing effects must be taken into account when using the gel for absolute dose verifications with a typical dose error of about 5 % (1 SD). Based on MR analyses of the gel, image distortions, mainly susceptibility effects, which cause some geometrical shift of the measured dose distribution with respect to the stereotactic coordinate system, have to be considered [9]. In our case a systematic shift of 1.5 mm was observed and corrected for.

For the analyses of measured and calculated 3D dose distributions differential dose volume histograms and correlation values, dependent on the displacement vector of the measured and calculated 3D dose distribution, were calculated. However, the comparison of absolute dose profiles including the calculated error band has been found to be valuable.

The most sensitive parameter in terms of dose uncertainty is the uncertainty in the measured R2 values which could be decreased by an increased number of measurements.

References

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