MAGAT gel dosimetry for its application in small field treatment techniques

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Abstract. Purpose of this work is to present the role of in-house manufactured MAGAT gel for treatment verification in small field dosimetric techniques such as Gammaknife (GK) and intensity-modulated radiation therapy (IMRT). Magnetic resonance imaging (MRI) is one of the most extensively used imaging technique for polymer gel dosimetry hence we used this method for gel evaluation. Different MR scanners and MRI sequences were used in this study for obtaining calibration plot between R2 and absorbed dose. An experimental plan was created for Gammaknife and IMRT. The prepared gel was filled in spherical glass phantom and in-house designed human head shape phantom for verification purpose. We used 8 TE values for all the imaging sequences for two reasons. Firstly it is sufficient enough to give good signal to noise ratio. Second considering the enormous scanning time involved in multiple spin echo sequence. MATLAB based in-house programs were used for R2 estimation and dose comparison. The isodose comparison with MAGAT gel showed reasonable agreement for both Gammaknife and IMRT techniques.

1. Introduction
The development of a new polymer gel named MAGIC paved the way for manufacturing gels on the bench top in laboratory. These types of polymer gels became known as normoxic gel dosimeters as presence of oxygen in the gel was removed by introducing antioxidants in the chemical composition. A typical polymer gel dosimetry involves three steps including gel fabrication, gel filling in anthropomorphic phantom containers and vials for calibration, gel irradiation and finally imaging of polymerized gel. However there is no “gold standard” for 3D dosimetry. Through this work we present our methodology to verify small field techniques using in-house manufactured MAGAT gel.

2. Materials and Methods
Two different MAGAT gel preparations were undertaken. The first preparation was used for GK dosimetry and the second preparation was used for IMRT dosimetry. Three MRI scanners (Siemens Avanto (1.5 T), Siemens Sonata (1.5 T) and a newly installed Philips Achieva (3 T)) were used for this study. The gel samples scanned with Philips Achieva MRI were converted to T2 maps using the inbuilt scanner algorithm. Whereas gel samples scanned in MRI Avanto and MRI sonata were converted to dicom images and R2 calculations were made using Maximum Likelihood Estimation
The (MLE) algorithm coded in MATLAB programme. The codes have an option of subtracting background and skipping the first echo from R2 calculation. For plan verification in GK and IMRT, spherical glass container and in-house made acrylic phantom were used respectively.

**Figure 1.** The spherical glass phantom filled with MAGAT gel fixed in the Leksell frame for experimental irradiation in Gammaknife.

![Figure 1](image)

**Figure 2 (a).** Locally designed human head shaped acrylic phantom used for experimental irradiation of IMRT plan. **(b)** An experimental target created in the phantom which is doughnut shape target (Coronal View). **(c)** Two cylindrical inserts of human shaped phantom showing gel irradiation region created by seven field and nine field IMRT.

2.1. Gel Preparation
The gel preparation was done as per the composition given in Table 1. In composition B hydroquinone was added to avoid any polymerization initiation before irradiation.

|                         | Composition A | Composition B |
|-------------------------|---------------|---------------|
| Gelatin                 | 8 %           | 6 %           |
| Methacrylic acid        | 9 %           | 9 %           |
| THPC                    | 10 mM         | 10 mM         |
| H2O                     | 83 %          | 85 %          |
| Hydroquinone            | 10 mM         | 0.05 mM       |
| Gel Volume              | 3000 mL       | 1500 mL       |
| Dose Range              | 0-17 Gy       | 0-5 Gy        |

2.2. Calibration Method
Calibration of the gel for GK verification was carried out with a Cobalt unit (Theratron 780) using source to axis distance (SAD) technique. The cylindrical glass vials had a wall thickness of 1 mm, an outer diameter of 13 mm, and a length of 95 mm. The vials were placed in the water-filled tank and irradiated at a depth of 10 cm from the water surface to the middle of the test tube with a single field of 10 x 10 cm². To obtain calibration curves, eleven test tubes were irradiated with doses in the range of 0-17 Gy on the same day of treatment planning execution to the spherical glass phantom.
Calibration of gel for IMRT study was carried out with 11 Acrylic tubes of 15 cm length, 2 cm outer diameter, 1.5 cm inner diameter. Five vials each were used for calibration to doses from 50 cGy to 500 cGy, one as control vial. The tubes were placed in water tank and irradiated with parallel opposed 6 MV photons from CL2300CD (Varian) and SynergyS (Elekta) with field size of 16 x 16 cm².

2.3. Gel irradiation
For Gammaknife irradiation three shots with 8, 14 and 18 mm collimator were used for creating an experimental plan in Leksell GammaPlan (LGP 5.32 version). See figure 1. For IMRT treatment verification an experimental cylindrical target and doughnut shaped target were created in Eclipse TPS and Pinnacle TPS respectively. A seven field IMRT (Eclipse 6.5) and Nine field IMRT plan (Pinnacle Version ADAC, Superscript (3) 8.0M Philips Medical System) was created respectively.

Table 2. MRI scanning parameters used for gel scanning.

| Scan date  | Scanner name           | MRI sequence | Gel | TR     | No of echoes | TE    | Slice thickness | NAX | FOV |
|------------|------------------------|--------------|-----|--------|--------------|-------|----------------|-----|-----|
| 18/1/2010  | Philips Achieva(3T)     | CPMG (TSE)   | 7 Field IMRT  | 7      | 5321 ms     | 8     | 15 ms          | 3 mm | 1   | 256 |   |
| 18/1/2010  | Philips Achieva(3T)     | GRASE (EPI)  | 7 Field IMRT  | 7      | 7210 ms     | 8     | 15 ms          | 3 mm | 1   | 256 |   |
| 23/1/2010  | Magnetom Avanto (1.5T)  | CPMG         | 7 Field IMRT  | 7      | 7210 ms     | 8     | 22 ms          | 3 mm | 1   | 256 |   |
| 30/1/2010  | Magnetom Sonata(1.5T)   | CPMG         | 9 Field IMRT  | 7      | 7210 ms     | 8     | 22 ms          | 3 mm | 1   | 256 |   |
| 6/2/2010   | Magnetom Avanto (1.5T)  | CPMG         | 7 Field IMRT  | 12     | 5600 ms     | 8     | 22 ms          | 3 mm | 1   | 256 |   |
| 6/2/2010   | Magnetom Avanto (1.5T)  | CPMG         | 9 Field IMRT  | 7      | 5600 ms     | 8     | 22 ms          | 3 mm | 1   | 256 |   |
| 7/7/2009   | Magnetom Sonata(1.5T)   | CPMG         | Gamma knife   | 11     | 7000 ms     | 8     | 14 ms          | 2 mm | 1   | 256 |   |

![Figure 3](image)

**Figure 3** (a) illustrates the R2 map of the spherical container with the 11 vials placed in either side. (b) shows the cylindrical gel insert with seven acrylic vials. Three small white spots indicate the fiducial points created using Vitamin E capsules.

3. Results and Discussion
Overall in this study we did six scans with calibration vials used for IMRT verification. We restricted our spin echo sequence to 8 as we assumed it was sufficient enough to give good SNR. Also
considering the availability of scanner the imaging sequence was chosen in this fashion for all the scanning. Time period between scans in each machine was around five to seven days. The gel vials used for Gammaknife verification was scanned only once as shown in Table 2. In Philips Achieva machine the gel was first scanned within two hours after removal from refrigerator and was not allowed to stabilize to MRI room temperature deliberately. \( R^2 \) was 0.951 and 0.967 for TSE and GRASE sequence.

We used MLE for other scans as it is more reliable for noisy data than other algorithms. For the scanning done in the fifth day after the first scan and seventh day after the second scan the \( R^2 \) was 0.993 and 0.994 respectively. See figure 4b & 4c. During this study gel vials were left in the MRI room for 4 to 5 hours before scanning. Final scan was done on the sixth day from the third scan. The gel vials were left in the scanning room for more than 10 hrs to attain room temperature. The calibration plot showed a \( R^2 \) of 0.998 which was better than its predecessor. In the calibration plot for GK, good linearity was observed between 2 to 14 Gy with \( R^2 \) value of 0.996. A second degree polynomial fit for the whole measurement for 0 to 17 Gy gave \( R^2 \) of 0.996. However the correct functional form to fit calibration curves is mono or bi exponential fit [4]. In this work we have shown only one IMRT plan with nine field for treatment verification comparison. A comprehensive 3D comparison was done for Gammaknife and IMRT treatments with MAGAT gel. Figure 5 a & b show isodose comparison for Gammaknife and IMRT at one z position.
Figure 4 (a-d) shows calibration curves plotted between R2 and Dose for IMRT verification. Figure 4 e & 4 f show calibration plot for Gammaknife verification.

Figure 5 (a) Isodose comparison between calculated Gammaknife TPS dose (thin line) and measured MAGAT Gel dose (composition A) (thick line). (b) Isodose Comparison between calculated IMRT dose (Pinnacle) (thin line) and MAGAT Gel dose (composition B) (thick line).

4. Conclusion
MAGAT gel is useful for treatment verification, provided certain dosimetric limitation of gel is known before using it for dosimetry. We were able to show that measurements done with different MRI scanners gave different R2 values and hence the gel measurement is scanner dependent. Dosimetric verification with MAGAT gel for small field techniques such as Gammaknife, IMRT showed reasonable agreement.

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