ABSTRACT
Unlike the conventional radiotherapy, the dosimetry in Gamma Knife is complicated due to geometry of the γ-beams. A normoxic polymer gel phantom is prepared in a spherical glass balloon of 16 cm diameter. The phantom that is irradiated is scanned in the MR unit, as the degree of polymerization affects the relaxation time constants of the gel. Linearity is observed between the delivered dose and the reciprocal of the gel T2 relaxation time constant. For dose calibration, 100 ml gel containing vials are irradiated at predefined doses. Dose distributions are the results of a single shot of irradiation, obtained by collimating all 201 Cobalt sources to a known target in the phantom. Stereotactic frames and fiducial markers are attached to the phantom for MR scanning. The dose distribution predicted by the Gamma Knife planning system is compared with that of the gel Dosimetry. The results with the gel phantom are in good agreement with the GammaPlan predicted values; the isodose diameters measured by the gel dosimetry and the GammaPlan differed by 5% at most. The normoxic gel phantom can be used clinically in 3-D dose assessment of the quality control measurements of the Gamma Knife.

KEY WORDS
Dose measurement, normoxic gel, gel dosimetry, gamma knife.

1. Introduction
In Stereotactic Radiosurgery, dose delivered in a single session of treatment can be as high as ten times the regular doses in radiotherapy. Therefore, the treatment dose should be precisely and accurately delivered to the target while minimizing the irradiation of the surrounding healthy tissues [1]. Unlike the conventional radiotherapy beams, narrow gamma beams are used in the Gamma Knife, and the lateral electron equilibrium is not established, complicating the dosimetry [2,3].

Recently, the formulation for a new type of polymer gel, manufactured and processed under normal atmospheric conditions, was published under the name MAGIC gel, composed of 8% (by weight) gelatin Type A from porcine skin Sigma Bloom 300; 9% of methacrylic acid; 83% of distilled water; 10 mmol/l of (99%) hydroquinone; 2 mmol/l of (99%) ascorbic acid, and 0.02 mmol/l of CuSO4·5 H2O [5,6].

2. Materials and Methods
With the polymer gel dosimetry, the amount of polymerization at any point is a function of the dose delivered [1]. The degree of polymerization of the gel affects the mobility of the neighboring water protons and can be detected with the MR scans as a decrease in T1 or T2 relaxation time constants [7]. From the knowledge of T1 or T2 parameters at any point in the gel, the dose distribution can then be calculated and constructed by deriving a (1/T2) map from a set of T2 weighted MR images. The radiation response of MAGIC has been found to be linear up to 30 Gray [7].

2.1 Preparation of the Gel
Normoxic gel preparation in the laboratory takes about 3 hours. The mixture is prepared in a fume hood. The solutions are heated in a thermostatically controlled electrical heating plate equipped with a magnetic stirring tool. To obtain 5 liters of gel, 4150 ml of triple distilled water and 400 g of gelatin are placed in a beaker and the gel powder is left in water for 15 minutes, until it was totally dissolved, at room temperature. Later, the beaker is heated in an electrical oven to 45°C, and then taken out and placed on an electrical heating plate with magnetic stirring until 50°C to obtain a clear solution. When the gelatin is completely melted and has become almost homogeneous, the beaker is allowed to cool down to 35°C.

Meanwhile, three solutions are prepared: 5.5 g of hydroquinone diluted in 500 ml of de-ionized water, 0.25 g of copper sulphate diluted in 100 g of water and 1.76 g of ascorbic acid diluted in 100 g of water. Then, 100 g of the ascorbic acid and 5 g of copper sulphate solutions are poured into the hydroquinone solution and mixed together. The hydroquinone-copper sulphate and ascorbic acid mixture together with 450 g of methacrylic acid are added to the cooled gelatin solution.

The anti-oxidant is always included at the end of the preparation procedure to minimize the amount of additional oxygen penetrating through the gel. The
solution is stirred until the mixture is homogeneously dissolved.

Figure 1. The calibration vials and the irradiated phantom

The gel was poured into two 2-liter capacity spherical glass balloons and into six 100-ml volume PVC vials. The spherical balloon had a diameter of 16 cm like the standard Gamma Knife phantom. Stereotactic frames and fiducial markers are attached to the phantom for MR scanning and localization in the image processing.

The vials are scanned in MR to obtain the dose-(1/T2) calibration curve. The balloon and vials are protected from sunlight UV by wrapping them in aluminum foils.

The gels at room temperature, are kept in the dark, for approximately 10 hours until they become completely solidified; and then stored in the refrigerator. The accuracy of the gel dosimeter depends very much on the state of the gel; the gel has to be solid and static (the radiochemical products should not diffuse) in the container [7]. The gel normally melts around 30°C; therefore, the gel phantoms should be refrigerated until irradiation.

2.2 Calibration of the Dosimeter

For calibration, gel vials are irradiated using Cobalt 60 teletherapy (Theratron 780 C, Theratronics, Canada) source, at predefined dose levels with 180° opposite beam positions, in order to create a uniform dose distribution throughout the gel samples. Each vial is so placed that the center lied in the central axis of a 30 cm x 30 cm x 30 cm water tank, 10 cm below the surface. The central point of the vial had a source to skin distance (SSD) of 80 cm and was irradiated with a field size of 10 cm x 10 cm. The vials are exposed to doses of 5, 10, 15, 20 and 25 Grays respectively. One of the vials is not irradiated.

A stable polymerization of the gel was reached a week after the irradiation. The gel phantom and vials are then scanned in a clinical 1.5 Tesla (Siemens Symphony) MR unit, using the head coil with the spin-echo sequence (TR=2000ms; TE=17, 67, 84, 100 and 150 ms; matrix size: 256x256, slice thickness: 2mm). MR scans of the gel vials are used to establish a dose curve as a function of the calculated relaxation rates, R2 (=1/T2) (Figure 2). This curve is the reference curve for dose readings in the phantom.

One shot of 20 Gray is given to the phantom with the 18 mm helmet and from the MR images of the phantom pixels T2 values are calculated. To compute the R2 relaxation rate of the pixels the signal intensity for each echo time is fitted into a mono-exponentially decaying function, using a non linear minimization algorithm based on the Levenberg-Marquardt method. The dose maps near the dose maximum point are calculated and mapped along the three axes of the phantom and compared with those predicted by the GammaPlan.

Figure 2 The Calibration Curve: R2 (sec-1) vs. Dose (Gy)

Figure 3. The isodose curves obtained by gel dosimetry in the coronal plane, for the slice at Y=90 mm in the stereotactic frame coordinates. The dose scale is in units of Gray. The shot centre is the origin of the coordinate system used in the calculations of the gel dosimetry.
The distances between the points of intersection of the isodose lines with the coordinate system are used to determine the vertical and horizontal diameters of the 30%, 50% and 70% isodose curves (Figures 3, 4, 5 and 6). The GammaPlan dose distributions are compared with the gel dosimetry dose mappings. By using fiducial markers and the Leksell frame coordinates; identical slices are determined as in the GammaPlan images.

The dose delivered to any point in an arbitrarily shaped gel phantom can be measured with the gel dosimetry. Gel dosimetry has the strength of mapping the dose distribution in three dimensional spaces, in any slice for any arbitrary orientation. The gel can clarify any crossed dose distribution region.

Particularly, gel dosimetry can be deployed as an assessment tool for complex dose distributions; and it can demonstrate the dose distribution for volumes nearby air cavities. This would especially be useful in cases where the amount of dose is of utmost importance for the critical organ protection and tumor control, and where the air cavity structures can effect the dose distribution.

4. Conclusion

Slice dose distributions are compared at locations where the maximum dose has the largest area. In Leksell frame coordinates, this slice is located at \( Z = 90 \) mm in the axial plane; at \( Y = 90 \) mm in the coronal plane and \( X = 92 \) mm in the sagittal plane.

The isodose diameters measured by the gel dosimetry and the GammaPlan differed by 5% at most. This verifies that the gel dosimetry is a reliable technique in calculating the relative dose distributions with Gamma Knife treatment and can also be useful in the 3-D dose measurement of the Cyber Knife.

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References


