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DOSE MEASUREMENTS FOR GAMMA KNIFE WITH RADIOPHOTOLUMINESCENT GLASS DOSEMETER AND RADIOCHROMIC FILM

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Stereotactic radiosurgery (SRS) is designed for patients with small lesion areas that are not suitable for actual surgery. SRS delivers high dose to the lesion with high gradient on the irradiation margin area. In this study, radiophotoluminescent glass dosemeter (RPLGD) and radiochromic film were used to measure the output factor of a gamma knife. Also, a Monte Carlo code (OMEGA/BEAM) was applied to simulate the output factor. For 14 and 8 mm sizes of helmet collimators, the variations of output factors determined with RPLGD, radiochromic film, the Monte Carlo code and Elekta were all within 0.5 %. When helmet collimator size was 4 mm, the output factors detected from RPLGD, radiochromic film and Monte Carlo simulation were all within 3.2 % when compared with Elekta. Taken together, RPLGD, radiochromic film and Monte Carlo simulation will be used as precise tools to measure the output factor of a gamma knife.

INTRODUCTION

Stereotactic radiosurgery (SRS) not only solves the problem of traditional operation on small lesion areas that is difficult to execute, but also improves the quality of life for patients who have to choose traditional surgery. Cylindrical collimator of SRS can generate a smaller penumbra and deliver dose exactly to the lesion area. Ion chambers, thermoluminescent dosemeters, polymer gels and films are usually used to measure the radiation dose of SRS(1). Monte Carlo simulation is also a tool to verify the clinical dose of SRS(2, 3).

The aim of this study is to use the OMEGA/BEAM Monte Carlo code to simulate the output factors of a gamma knife and to compare simulation results with radiophotoluminescent glass dosemeter (RPLGD) and radiochromic film. This study compared the physical characteristics, including dose linearity, energy dependence and angular dependence between RPLGD and radiochromic film. Also, the study used radiochromic film and polystyrene phantom to evaluate the accuracy of dose delivered by the gamma knife.

MATERIALS AND METHODS

Dosemeters and dose readout systems

The RPLGD (GD-302M, Asahi, Japan) and FDG-1000 readout system (Asahi, Japan) were used in this work. The effective atomic number and density of GD-302M were 12.04 and 2.61 gm cm^{-3}, respectively. The shape of GD-302M was cylindrical, with 1.5 mm in diameter and 12 mm in length. The readout area has an active length of 0.6 mm and a total active volume of <1 mm^3(4). Radiochromic film (MD-55, Nuclear Associates, USA) and Kodak LS50 film digitizer (Kodak, USA) were also used in this study. MD-55 provides excellent spatial resolution and has the effective atomic number, which is equivalent to that of tissue(5). GD-302M and MD-55 were used to measure the output factors from four helmet collimators (4, 8, 14 and 18 mm) of Leksell Gamma Knife-B type (Elekta, Sweden).

Characteristics of dosemeters

In this study, the following characteristics of the GD-302M and the MD-55 that were examined: dose

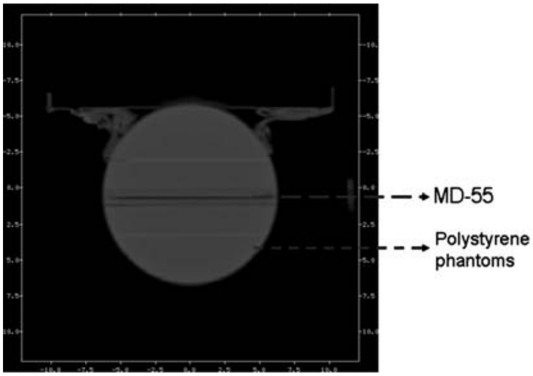

Figure 1. MD-55 film was placed in the polystyrene phantoms for dose measurement.

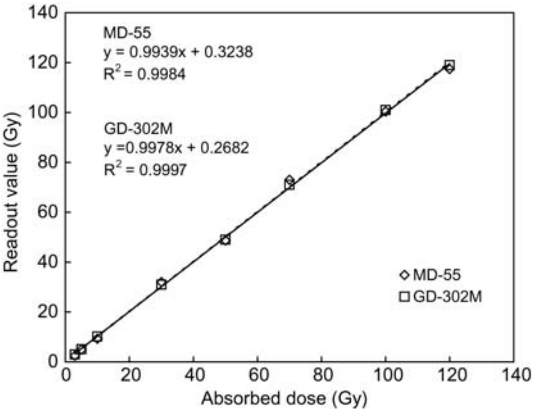

Figure 2. Dose linearity for MD-55 and GD-302M. Each data point was measured five times and its coefficient of variation was <3.

linearity, energy dependence and angular dependence. For dose linearity study, dosemeters were used to verify the linearity of the readout values for exposure with ^{60}Co source in the range of absorbed dose from 3 to 120 Gy. Pantak HF 420 X-ray machine (Pantak, USA) was used as X-ray radiation source to study the energy dependence. This study set eight points within the energy range from 22 to 1250 keV, including 22, 25, 38, 67, 102, 151, 662 (^{137}Cs) and 1250 keV (^{60}Co). The relative response of each dosemeter was normalised to the ^{137}Cs readout value. The ^{60}Co was used to deliver 15 Gy for dosemeters, with 11 different entrance angles, including $0°, \pm 10°, \pm 30°, \pm 60°, \pm 70°$ and $\pm 80°$. For angular dependence study, the relative response of each dosemeter was normalised to the 0° readout value.

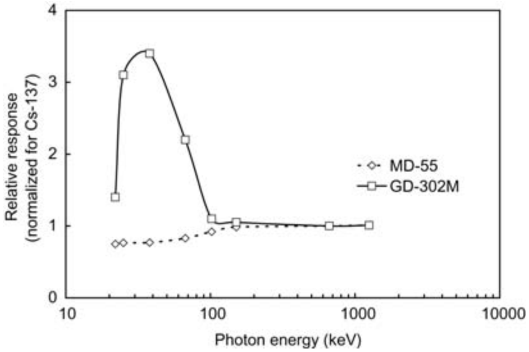

Figure 3. Energy dependence for MD-55 and GD-302M. Each data point was measured five times and its coefficient of variation was <3.

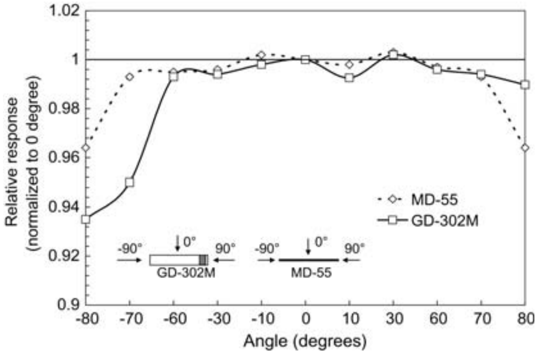

Figure 4. Angular dependence for GD-302M and MD-55. Each data point was measured five times and its coefficient of variation was <3.

Two-dimensional dose measurements

MD-55 film was used to evaluate the accuracy of dose delivered by the gamma knife to a polystyrene phantom. MD-55 film was placed in the polystyrene phantoms for dose measurement (Figure 1).

Monte carlo simulation

Output factors and two-dimensional dose distributions were simulated using OMEGA/BEAM program (the National Research Council of Canada). The entrance and exit diameters of beam channel were set according to the four sizes (4, 8, 14 and 18 mm) of the collimator(2). As an input for the OMEGA/BEAM program, the photon cut-off energy was set 0.01 MeV, electron cut-off energy −0.7 MeV and detector volume −1 mm × 1 mm × 1 mm.

Table 1. Comparison for output factors from MD-55, GD-302M, simulation and Elekta.

Helmet	MD-55	GD-302M	Simulation	Elekta
18	1.000 ± 0.006	1.000 ± 0.004	1.000 ± 0.015	1.000
14	0.982 ± 0.015	0.985 ± 0.010	0.985 ± 0.015	0.984
8	0.954 ± 0.016	0.959 ± 0.013	0.954 ± 0.014	0.956
4	0.843 ± 0.027	0.856 ± 0.019	0.860 ± 0.013	0.870

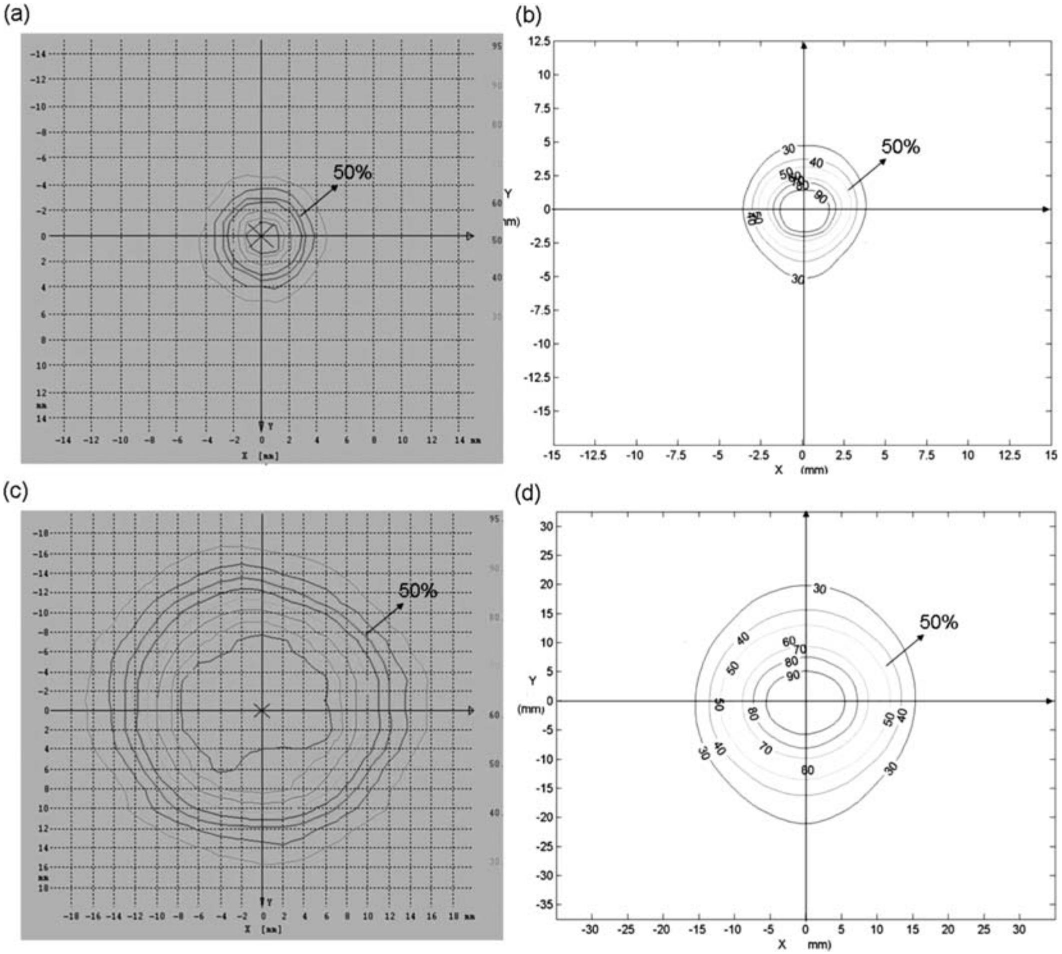

Figure 5. The two-dimensional dose distributions of MD-55 measured values (**a**: 4 mm, **c**: 18 mm) and Monte Carlo calculated values (**b**: 4 mm, **d**: 18 mm).

RESULTS AND DISCUSSION

Radiation detection characteristics of dosemeters

R^2 is the proportions of variability in a data set. As the R^2 approaches 1, the relationship between readout value and irradiation dose is direct proportion function. The value of R^2 for GD-302M and MD-55 were 0.9997 and 0.9984, respectively (Figure 2). When the relative response was normalised to 662 keV, energy dependence of MD-55 decreased by 18 % at 22 keV (Figure 3). Because the effective atomic number was 12.04 for GD-302M, the energy dependence reached to 320 % from 22 to 662 keV.

The obtained data imply that MD-55 radiation sensitivity was not significantly affected by entrance angles in the range of 0° to ±80° (Figure 4). On the other hand, when the entrance angle was −80°, the GD-302M response was 7 % lower than that at 0° (Figure 4). This data can be explained by the fact that the radiophotoluminescence signal readout centre of GD-302M is 0.7 mm beneath its surface and such situation result in radiation attenuation(4).

Relative output factors

The relative output factors of GD-302M, MD-55, Monte Carlo simulation and Elekta(6) are shown in Table 1. When helmet collimators size were 14, 8 and 4 mm, the output factors measured from GD-302M were 0.985, 0.959 and 0.856, respectively. For 14, 8 and 4 mm sizes of helmet collimators, the output factors measured from MD-55 were 0.982, 0.954 and 0.843, respectively. For 14, 8 and 4 mm of helmet collimators, the output factors simulated with OMEGA/BEAM were 0.985, 0.954 and 0.860, respectively. When helmet collimator size was 4 mm, the output factors determined by GD-302M, MD-55 and Monte Carlo simulation agreed within 3.2 % with the readings from Elekta. This data suggested that the variations of output factors obtained from GD-302M, MD-55 and Monte Carlo were all within the normal range.

Two-dimensional dose distributions

The two-dimensional dose distributions of MD-55 and Monte Carlo simulation are shown in Figure 5. There is no significant difference between MD-55 measured values and Monte Carlo calculated values. According to the phantom experiment results, we found that MD-55 proved to be a good measurement tool for dose verification of the gamma knife treatment.

CONCLUSION

Gamma knife is a high single dose for lesion; therefore the accuracy of dose delivery is crucial for treatment efficiency. This study showed that both MD-55 and GD-302M had good dose linearity from 3 to 120 Gy. When the entrance angles are within −80° to 80° and −60° to 80°, both MD-55 and GD-302M are suitable for dose measurement. In addition, the study also demonstrated that GD-302M, MD-55 and OMEGA/BEAM simulation were useful to verify the output factors of the gamma knife.

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