Properties of radiophotoluminescent glass dosimeters for computed tomography dosimetry

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Authors: A. Hirosawa, K. Matsubara, H. Kondo, K. Koshida; Kanazawa/JP  
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Aims and objectives

Radiophotoluminescent glass dosimeters (RPLDs) are composed of silver activated phosphate, which forms stable luminescent centers when they are exposed to ionizing radiation. Stable luminescent centers emit visible orange light (600 to 700 nm) when they are stimulated by pulsed ultraviolet rays (about 320 nm), which is called radiophoto luminescence phenomenon. The amount of orange light is proportional to exposed radiation. Therefore RPLDs are used for dose measurement in radiotherapy and radiation diagnosis.

RPLDs are manufactured with or without a tin filter in the capsule. This study compared basic properties (energy dependence, variation, and angular dependence), and single-slice dose distribution of these two types of RPLDs for computed tomography (CT) dosimetry.
Methods and materials

1. RPLDs

We used the RPLDs GD-352M with a tin filter and GD-302M without a tin filter (Asahi Techno Glass, Tokyo, Japan) (see Fig. 1 on page 7 and Fig. 2 on page 7). The RPLDs were annealed at 400°C for 30 minutes prior to each exposure. After each exposure, they were preheated at 70°C for 30 minutes and read using a FDG-1000 reader (Asahi Techno Glass, Tokyo, Japan) in accordance with the manufacturer's recommended protocol.

2. Evaluation of basic properties of the RPLDs

Radiographic X-ray generator (UD150LR2; Shimadzu, Tokyo, Japan) was used to evaluate energy dependence, variation, and angular dependence.

We also used a 6-cm³ general purpose ionization chamber (model 20X6-6; Radcal, Erlangen, Germany) and an electrometer (model 2026C; Radcal) as a reference dosimeter.

1) Energy dependence of dose response

After the distance from the source to the ionization chamber and two RPLDs was set to 150 cm (see Fig. 3 on page 8), the RPLDs were irradiated using X-rays which had the radiation qualities which were recommended by International Atomic Energy Agency (IAEA) (#able 1). 20 RPLDs were used for each radiation quality: 10 RPLDs were GD-302M and others were GD-352M.

Energy dependence was evaluated by the ratio of air kerma measured using the RPLDs to that measured using the ionization chamber.

Table 1. Radiation quality which were recommended by IAEA.

<table>
<thead>
<tr>
<th>Radiation quality</th>
<th>kV</th>
<th>Added filtration</th>
<th>HVL [mmAl]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQR 2</td>
<td>40</td>
<td>2.42</td>
<td>1.46</td>
</tr>
</tbody>
</table>
Table 1 (b): RQA X-ray beam quality

<table>
<thead>
<tr>
<th>Radiation quality</th>
<th>kV</th>
<th>Added filtration [^a]</th>
<th>HVL [mm Al]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQA 2</td>
<td>40</td>
<td>RQR 2+4</td>
<td>2.27</td>
</tr>
<tr>
<td>RQA 3</td>
<td>50</td>
<td>RQR 3+10</td>
<td>3.91</td>
</tr>
<tr>
<td>RQA 4</td>
<td>60</td>
<td>RQR 4+16</td>
<td>5.55</td>
</tr>
<tr>
<td>RQA 5[^b]</td>
<td>70</td>
<td>RQR 5+21</td>
<td>6.97</td>
</tr>
<tr>
<td>RQA 6</td>
<td>80</td>
<td>RQR 6+26</td>
<td>8.36</td>
</tr>
<tr>
<td>RQA 7</td>
<td>90</td>
<td>RQR 7+30</td>
<td>9.46</td>
</tr>
<tr>
<td>RQA 8</td>
<td>100</td>
<td>RQR 8+34</td>
<td>10.30</td>
</tr>
<tr>
<td>RQA 9</td>
<td>120</td>
<td>RQR 9+40</td>
<td>11.97</td>
</tr>
<tr>
<td>RQA 10</td>
<td>150</td>
<td>RQR 10+45</td>
<td>13.52</td>
</tr>
</tbody>
</table>

\[^a\] Permanent filtration 1mm Be

\[^b\] reference radiation quality in the series

2) Variation of dose response

The RPLDs were irradiated under the same conditions as the measurement of energy dependence (see Fig. 3 on page 8). The coefficients of variation (CVs) were calculated using the mean and standard deviation of dose values from 10 RPLDs for each radiation quality.

3) Angular dependence of dose response
After the distance from the source to the ionization chamber to two RPLDs was set to 150 cm, they were irradiated using the reference X-ray radiation beam quality (RQR9) and the radiation beam with an added filter (RQA9) (see Fig. 3 on page 8 and Fig. 4 on page 8). The RPLDs were irradiated at 90°, 60°, 30°, 0°, #30°, #60°, and -90° : 0° was vertical to long axial direction of RPLD, and plus and minus were meant clockwise and anti-clockwise, respectively.

Angular dependence was evaluated by the ratio of air kerma measured using the RPLDs to that measured using the chamber (normalized by the ratio at 0°).

3. Comparison of single-slice absorbed dose distribution using CT scanner

1) CT scanner and phantom

A 64-section Light Speed VCT (GE Healthcare, Waukesha, WI) was used in this study.

For the absorbed dose evaluation in a single section, we used the RAN-110 (Phantom Laboratory, Salem, NY) anthropomorphic female abdominal phantom (see Fig. 5 on page 9).

2) Measurement of half-value layers (HVLs)

We measured HVLs at the 80 kV and 120 kV, and estimated the effective energies from the HVLs using equation 1 (see Fig. 6 on page 9).

3) Measurement of absorbed dose distribution

After obtaining localization radiographs, we placed 46 RPLDs (GD-302M and GD-352M by itself) which were calibrated at effective energy shown above at locations that corresponded to soft tissue (26 RPLDs) and skin (20 RPLDs) (see Fig. 7 on page 10). Four RPLDs were used to measure background radiation. After that, the phantom was scanned using the acquisition parameters which were shown in table 2. Each measurement was performed three times to reduce random errors.

The absorbed dose for each tissue was calculated by multiplying the calibrated mean dose values obtained from the reader by the mass energy coefficient ratio of each tissue to air and was united with the CT image using Orign 8 (version 8J, Light Stone, Tokyo, Japan).

Table 2. Acquisition parameter for measurement of absorbed dose distribution.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Eff.mAs</td>
<td>140</td>
<td>400</td>
</tr>
<tr>
<td>Rotation Time (s)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.516</td>
<td>0.516</td>
</tr>
<tr>
<td>Detector Coverage (mm)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Coverage Speed (mm/s)</td>
<td>20.62</td>
<td>20.62</td>
</tr>
<tr>
<td>Coverage Time (s)</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Acquisition Range (mm)</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>CTDIvol (mGy)</td>
<td>20.99</td>
<td>20.21</td>
</tr>
</tbody>
</table>
Fig. 1: (a) Two types of plastic holders: GD-302M (left) and GD-352M (right). A plastic holder of GD-302M was 13.0 mm in length and 2.8 mm in diameter, and that of GD-352M which had low energy compensation filter was 14.5 mm in length and 4.3 mm in diameter. (b) Photograph of RPLD. It had 12.0 mm in length and 1.5 mm in diameter. The same type of RPLD was used for GD-302M and GD-352M.

Fig. 2: Cross sectional view of GD-352M. Tin was used as a filter material and a gap (1.5 mm in length) was made at the reading position.
**Fig. 3:** Experimental layout for energy dependence, dose variation, and angular dependence of RPLDs.

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**Fig. 4:** Direction of irradiated RPLD. 0° was vertical to long axial direction of RPLD.
**Fig. 5:** The anthropomorphic female abdomen phantom used in this study. The entire phantom was cut into transverse sections with grids of holes for placing small dosimeters.
\[
d_{1/2} = \frac{t_b \ln \left( \frac{2E_a}{E_0} \right) - t_a \ln \left( \frac{2E_b}{E_0} \right)}{\ln \left( \frac{E_a}{E_b} \right)} \quad \cdots \text{Eq. 1}
\]

- $d_{1/2}$: HVL
- $E_0$: Dose without absorber
- $E_a$: Slightly higher dose than $E_0$
- $E_b$: Slightly lower dose than $E_0$
- $T_a$: Aluminum thickness which was acquired $E_a$
- $T_b$: Aluminum thickness which was acquired $E_b$

**Fig. 6:** Equation for estimating the effective energy.
**Fig. 7:** Location of RPLDs in a single section of the abdominal phantom.

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Results

1. Basic properties

1) Energy dependence

Fig. 8 on page 14 and Fig. 9 on page 14 indicate the energy dependence of RPLDs.

The dose response of GD-302M was energy dependent, and the dose values showed the highest at approximately 38 keV.

The dose response of GD-352M was better than that of GD-302M. However the relative response of GD-352M was small when low energy X-ray (RQR2 or RQA2) was irradiated.

2) Variation

Fig. 10 on page 15 and Fig. 11 on page 16 indicate the variation of the dose response.

Dose variation of GD-302M was higher than that of GD-352M. The variation of GD-302M and GD-352M were within 3% and 16%, respectively.

The dose variation of GD-352M showed the largest at around 60 keV.

3) Angular dependence

Fig. 12 on page 17 indicates the angular dependence of RPLDs.

The dose response was normalized at 0°

The angular dependence of GD-302M was small from #60° to 60°.

However, the dose responses of GD-352M at 30°, 60°, and 90° irradiated with the beam quality of RQR9 were 14%, #32% and 104%, respectively.

2. Absorbed dose distribution

1) HVLs

The effective energies were 43.0 keV and 52.3 keV at the 80 kV and 120 kV, respectively.
2) Single-slice absorbed dose distribution

Fig. 13 on page 18 indicates absorbed dose distribution in the abdominal section.

The obtained absorbed doses for the GD-352M were lower than those for the GD-302M (p<0.05, paired t-test).

We believe this was because the GD-352M had large angular sepndence and it could not measure the scattered X-ray correctly.
Fig. 8: Energy dependence of the dose response with RQR X-ray beam quality.

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Fig. 9: Energy dependence of the dose response with RQA X-ray beam quality.

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Fig. 10: Variation of the dose response with RQR X-ray beam quality.

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**Fig. 11:** Variation of the dose response with RQA X-ray beam quality.

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Fig. 12: Angular dependence of RPLDs normalized to the response at 0°.

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Fig. 13: Distribution maps of absorbed doses with GD-302M and GD-352M.

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Conclusion

The dose responses of GD-302M and GD-352M depend on beam energy and irradiation angle of X-ray. The dose variation among dosimeters was large with GD-352M. The obtained absorbed doses were lower than those for the GD-302M because the GD-352M cannot measure scattered X-ray correctly due to its angular dependency.

Therefore, we believe the GD-302M is recommended for CT dosimetry.
Personal information

Ayaka HIROSAWA.

Department of Quantum Medical Technology, Graduate School of Medical Science, Kanazawa University, Kanazawa, Japan.

E-mail: ayakhiro@yahoo.co.jp
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