Method and technology

The angular dependence of a 2-dimensional diode array and the feasibility of its application in verifying the composite dose distribution of intensity-modulated radiation therapy

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Abstract

Background and Objective: The planning dose distribution of intensity-modulated radiation therapy (IMRT) has to be verified before clinical implementation. The commonly used verification method is to measure the beam fluency at 0 degree (0°) gantry angle with a 2-dimensional (2D) detector array, but not the composite dose distribution of the real delivery in the planned gantry angles. This study was to investigate the angular dependence of a 2D diode array (2D array) and the feasibility of using it to verify the composite dose distribution of IMRT. Methods: Angular response of the central detector in the 2D array was measured for 8 MV X-ray, 10 cm × 10 cm field and 100 cm source axis distance (SAD) in different depths. With the beam incidence angle of 0°–60°, at intervals of 10°, and inherent buildup of the 2D array (2 g/cm²), the array was irradiated and the readings of the central diode were compared with the measurement of thimble ionization chamber. Using a combined 30 cm × 30 cm × 30 cm phantom which consisted of solid water slabs on top and underlying the 2D array, with the diode detectors placed at 8 g/cm² depth, measurements were taken for beam angles of 0°–180° at intervals of 10° and compared with the calculation of treatment planning system (TPS) that pre-verified with ion chamber measuring. Results: Differences between the array detector and thimble chamber measurements were greater than 1% and 3.5% when the beam angle was larger than 30° and 60°, respectively. The measurements in the combined phantom were different from the calculation as high as 20% for 90° beam angle, 2% at 90° ± 5° and less than 1% for all the other beam angles. Conclusions: The 2D diode array is capable of being used in composite dose verification of IMRT when the beam angles of 90° ± 5° and 270° ± 5° are avoided.

Key words: 2-Dimensional diode array, angular dependence, intensity-modulated radiation therapy, dose verification

The accurate irradiation technology, such as intensity-modulated radiation therapy (IMRT), has becoming more and more popular in China since 2000. One of the biggest challenges in the clinical application of IMRT is how to verify the implement dose distribution of the treatment plan. The dose distribution of the treatment plan from the treatment planning system (TPS) must be verified before clinical implementation. The commonly used method is to obtain the dose distribution of the patient-specific, quality assure (QA) plan with dosimetric films in a phantom, compare the measurements with the calculated dose distribution of TPS and evaluate the results carefully1–4. However, a large amount of factors can diminish the accuracy of the film verification, such as the complicity of film processing steps, the high demanding for quality control of film processing, and so on. In addition, the disadvantages in film processing, such as the great deal of time consumed and high cost (the films are unrecyclable), also limits the clinical application of the film. In order to avoid those problems mentioned above, the two-dimensional matrix-detector (diodes or ionization chambers, 2D array) has been widely used in recent years5–7. With 2D array, it has become easier to acquire and manage real-time dose images which allow more rapid checks of the IMRT plan dosimetry, albeit with a lower spatial resolution. The 2D array was originally designed for measuring the beam fluency at 0 degree (0°) gantry angle but not the composite dose distribution of real delivery in the planned gantry angles. The angular dependence of the 2D array from its own design and

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characteristics, which would affect the accuracy of its measurements, is probably the main reason for it. This study was to investigate the angular dependence of a commercialized 2D diode array and the feasibility of using it to verify the composite dose distribution of IMRT.

Materials and Methods

The diode-relative-sensitivity calibration of the 2D array

The Mapcheck 1175 2D array (Sun Nuclear, Melbourne, FL), which consists of 445 N-type diodes that are in a 22 cm × 22 cm 2D area with diode intervals of 0.707 cm in the central 10 cm × 10 cm area and 1.414 cm in the outer area, was used. There were intrinsic 2 g/cm² (1.35 cm physical thickness) buildup phantom above the diode plane and 2.7 g/cm² (1.97 cm physical thickness) material phantom below the plane. The sensitivity calibration was performed by a built-in software according to the recommendation of the manufacturer and there would be six steps. The plane of the 2D array diodes was perpendicular to the beam central axis of linear accelerator (Primus, Siemens Co.). The irradiation conditions were the chosen 6 MV beam energy, source-to-surface distance of 100 cm, a 26 cm × 26 cm field. The gantry was at 0° and aligned the axes of 2D array to the beam axes with the +Y axis of 2D array away from the gantry. The central diode was at the beam center and a number of monitor units (MU) was delivered. The following step was that 2D array was turned 90° and 180° clockwisely around the beam center and the same number of MU was delivered each time. Then the 2D array was moved and three specific diodes were placed at the beam center respectively and the same number of MU was delivered each time. An automatic computation will be done by the built-in software and a matrix of the sensitivity of each diode with respect to the central diode was generated and recorded as a file and applied to the following measurements.

The angular dependence measurements of the 2D array central diode with intrinsic buildup

A nominal 6 MV X-ray, provided by a Siemens Primus linear accelerator, was used in this study. The plane of diodes was at 100 cm from the accelerator radiation source and the 2D array was irradiated by a 10 cm × 10 cm open field with the central diode at the isocenter of the linac (Figure 1). The selected range of beam incidence angles was 0°–60° for the irradiation area because the field would go beyond the 2D array when the gantry angle was 70°. The 2D array was irradiated by 100 MU every 10° and the readings of the central diode were recorded.

A thimble 0.65 cm³ ion-chamber, model FC65-G, with the dosimeter Dose 1 (IBA company), calibrated in Guangzhou Institute of Measuring and Testing Technology, were used. In a stack of solid water (RW3, IBA company), the ion-chamber was placed at 2 cm depth to the surface and also at the isocenter of the linac. According to the same irradiation parameters mentioned above, the readings of the chamber were recorded.

The thimble ion-chamber has excellent angular dependence. The two results mentioned above were compared in order to evaluate the angular dependence of the 2D array central diode.

Measurements in combined phantom

A combined 30 cm × 30 cm × 30 cm phantom consisted of the 2D array and slabs of solid water (Figure 2) was prepared and the diodes were at a radiological depth of 8 g/cm² to the supine surface of the phantom.

With the same X-ray energy, field size and the same number of MU delivered as that in the above subsection, the 2D array was irradiated every 10° gantry angle within an extent of 0°–180° and the central diode was at the isocenter of the linac. The 2D array was also irradiated at two beam incidence angles of 90° ± 5° for a better understanding of the maximum angular dependence of the 2D array. The readings of the central diode were recorded.

The 2D array was upside down when it was irradiated at the gantry angles of 120°–180° in order to avoid the impact by the couch. The slabs of solid water above the 2D array were decreased and the central diode was still at the radiological depth of 8 g/cm² to the supine surface of the combined phantom.

The thimble ion-chamber was place at 8 cm depth to the supine surface of the 30 cm × 30 cm × 30 cm phantom.
consisted of slabs of solid water. With the same irradiation parameters as that mentioned above, the thimble ion-chamber was taken as the beam isocenter and was irradiated. The readings were recorded and were compared with that of the central diode.

**Dose calculation of TPS**

The combined phantoms mentioned above and the thimble ion-chamber with slabs of solid water were undergone the computed tomography (CT) scan (Somatom, Siemens company). Then the images were input into the TPS (Pinnacle 8.0, Philips company) as the QA phantom. With irradiation conditions as that in the above subsection, the doses at the 2D array central diode and the center of the thimble ion-chamber were calculated and compared with that of the two corresponding measurements in the above subsection.

**Results**

**Comparison between measurements of the thimble chamber and the central diode of the 2D array in different radiological depths**

The central diode was at 2 g/cm² radiological depth without solid water on the top of the 2D array and at 8 g/cm² radiological depth when the 2D array was in the combined phantom. When the two detectors (the central diode and the thimble ion-chamber) were at 2 g/cm² radiological depth, the differences of the measurements between the detectors were larger than 1% when the beam incidence angle was 30°; almost 4% when the beam incidence angle was 60°; when the two detectors were at 8 g/cm² radiological depth, the differences of the two measurements were reduced clearly: the difference was slightly larger than 2% when the beam was 60° (Table 1).

![Figure 3](image-url)  
**Figure 3** The comparison among measurements of the central diode of 2D array (Dd), the farmer chamber (Dc) and the calculations of TPS

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Detector</th>
<th>Incidence angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D_center</td>
<td>0°</td>
</tr>
<tr>
<td>1</td>
<td>D_center</td>
<td>103.80</td>
</tr>
<tr>
<td>2</td>
<td>D_center</td>
<td>104.50</td>
</tr>
<tr>
<td>Δ_D(%)</td>
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<td>-0.186</td>
</tr>
<tr>
<td>3</td>
<td>D_center</td>
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</tr>
<tr>
<td>4</td>
<td>D_center</td>
<td>84.61</td>
</tr>
<tr>
<td>Δ_D(%)</td>
<td>-0.118</td>
<td>0.202</td>
</tr>
</tbody>
</table>

**Measurements and calculations within the combined phantom**

The differences between the calculated values of the TPS and the measurements of the thimble ion-chamber were less than 1% at all beam incidence angles; the difference was only 0.79% at 90° beam incidence angle (Table 2). The differences between the calculated values of the TPS and the measurements of the 2D array central diode varied greatly: the differences were up to 20.67% at 90° beam incidence angle, larger than 2% at 90° ± 5° and less than 1% at the other beam incidence angles (Table 3). The two curves (the calculated values of TPS vs. the measurements of thimble ion-chamber, the calculated values of TPS vs. the measurements of the 2D array central diode) showed that the differences were significant when the beam incidence angles were within 90° ± 5° and were rather small at other incidence angles (Figure 3).

**Table 2** Comparison between the thimble chamber measurements and the TPS calculations in different incidence angles

<table>
<thead>
<tr>
<th>Item</th>
<th>0°</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
<th>80°</th>
<th>90°</th>
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<th>110°</th>
<th>120°</th>
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<th>160°</th>
<th>170°</th>
<th>180°</th>
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<tbody>
<tr>
<td>Dc</td>
<td>84.10</td>
<td>83.90</td>
<td>82.60</td>
<td>80.60</td>
<td>76.90</td>
<td>71.30</td>
<td>61.70</td>
<td>62.40</td>
<td>63.70</td>
<td>64.20</td>
<td>64.30</td>
<td>64.20</td>
<td>63.80</td>
<td>63.10</td>
<td>62.50</td>
<td>71.20</td>
<td>77.10</td>
<td>80.70</td>
<td>83.00</td>
</tr>
<tr>
<td>Δ/Dc(%)</td>
<td>-0.17</td>
<td>0.10</td>
<td>-0.12</td>
<td>0.15</td>
<td>-0.06</td>
<td>0.22</td>
<td>-0.24</td>
<td>-0.26</td>
<td>-0.98</td>
<td>-0.96</td>
<td>-0.79</td>
<td>-0.70</td>
<td>-0.76</td>
<td>0.90</td>
<td>0.13</td>
<td>-0.75</td>
<td>-0.13</td>
<td>-0.05</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Discussion**

IMRT is a modern accurate irradiation technology characterized by the highly conformal radiation dose to the planning target volume and great steep dose gradients. The tiny error in the designing or processing of clinical implementation of treatment plan can lead to a comparatively large bias at the final implementation of the plan. This probably diminishes the effect or even results in failure of the treatment. Therefore, every treatment plan of IMRT must be verified before the clinical implementation in order to assure that the plan can be carried out accurately at the treatment machine. The verification should reflect the real implementation of treatment plan well, i.e., the irradiation conditions should be consistent with that in treatment
plan as much as possible.

At present, the diodes of the 2D array used in IMRT verification have angular dependence which would lower the verification accuracy when the 2D array is used in measuring the actual beams of the treatment plan. Consequently, all the beam gantry angles would be modified to 0° for the verification of the IMRT treatment plan.[10–13]. However, the multi-leaf collimator (MLC) assembled in linac would probably have some positioning errors when the gantry angle is not 0° and this tiny error would cause a little discrepancy between the actual dose distribution of the treatment plan and that computed in TPS. This discrepancy cannot be detected by the verification at 0° gantry angle. In addition, the method of verification at 0° gantry angle cannot tell where the error has happened and the impact to the actual implementation of treatment plan. In short, the best verification method of IMRT treatment plan is to measure the composite dose distribution at the real irradiation conditions.

Wolff et al.[14] had reported that the angular dependence of an improved N-type diode was less than 1%, which was similar to the results of this study at the certain range of beam incidence angles and greater depth of measurement. The variation in angular dependence of the 2D array central diode was less than 1% in the ranges of 0°–80° and 100°–180° when the diode was measuring at 8 g/cm² radiological depth. When comparing with the thimble ion-chamber whose variation in angular dependence was less than 0.5%[8], the variation in angular dependence of the central diode decreased with the increasing measurement depth, and increased with the increasing beam incidence angle. When comparing with the calculation of TPS whose variation from the measurement of the thimble ion-chamber was less than 1%, the differences between the measurements of the central diode and the calculated values of TPS were less than 1% except that the beam incidence angles were in the range of 90°±5°. When beam incidence angle was 90°, the measurement value of the central diode was about 20% higher than the calculated value of TPS. The reason may be that when the beam incidence angle is 90°, the X-ray would go through a series of diodes whose density is beyond the scope of the CT number to relative electronic density conversion. Furthermore, there are irregular air gaps (whose density is zero) between the diodes, which would result in the inaccuracy of density corrections of TPS. The structural inhomogeneity of the 2D array is also reflected by the comparison of measurements between the central diode and the thimble ion-chamber. It can be seen from Table 1 that with the increasing depth of the central diode, the differences caused by material inhomogeneity were decreasing.

Our results suggest that the 2D array can be used in the verification of the composite dose distribution of IMRT treatment plan if enough solid water slabs are attached around the 2D array and the beam incidence angles are not in the range of 90° (270°) ±5°. The fields with beam incidence angles in this range should be verified separately and the rest fields can undergo the verification of composite dose distribution. For the verification of intensity-modulated arc therapy treatment plan, since the percent of the fields with beam incidence angles around 90° and 270° is rather small, whether this 2D array could be used or not requires further studies to testify.

References