Evaluation of Planar and Cylindrical Diode Arrays for IMRT and VMAT Plan Verification

P.Laojunun, P.Iampongpaiboon, C.Kakanaporn, L.Tuntipumimorn and Y.Chansilpa

Department of Radiology, Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand

Abstract—Complex radiation therapy treatment plans such as intensity-modulated radiation therapy (IMRT) and recently developed volumetric modulated arc therapy (VMAT) require dosimetric verification before clinical delivery. The aim of the study was to evaluate the use of the planar and cylindrical diode arrays for IMRT and VMAT plans verification.

Two diode detector arrays were compared for their use in the patient-specific quality assurance of IMRT and VMAT treatment plans: one diode arrays is a flat panel of diodes (MapCHECK 2) positioned with MapPHAN phantom while the other is a cylindrical phantom with diodes placed in a spiral array (ArcCHECK). Both devices were tested for the dose linearity over a range of 20–400 MU and the dose rate over the range of 100 to 600 MU/min of 6 and 10 MV photons delivered. The dependence of the response of detectors on field size was measured and compared with Farmer-type ionization chamber. The short-term and long-term reproducibility and the array calibration were also examined to understand the stability and uncertainty of the systems. The performance of the dosimeter system was then evaluated using IMRT and VMAT plans. The study included the planning of 8 coplanar plans (pelvic, head and neck, abdominal region) and 3 non-coplanar plans (brain) with IMRT and VMAT which were performed using a Varian ClinacX. These plans were calculated using Eclipse version 8.60. The measured doses were compared to the TPS dose and analyzed using gamma analysis with criteria of 3%/3 mm. No dose rate or field size dependence was observed within the range of the field sizes and dose rate used in the study for both photon energies. Both detector arrays showed linearity with dose and a stable short-term and long-term reproducibility. For IMRT plans delivered at planned angles, MapCHECK 2 results showed lower average gamma passing rate (93.2%) compared to measurements (97.7%) delivered at fix 0 degree gantry angles. The ArcCHECK results showed average differences between measured and calculated of 92.7%. For VMAT plans, average passing rate was 99.0% and 97.6% using MapCHECK 2 and ArcCHECK respectively. The measured differences between IMRT and VMAT QA results for non-coplanar were small, except the MapCHECK 2 results showed averages of 63.9% for the IMRT plans delivered at planned angle.

The ArcCHECK is an efficient and valuable tool for both IMRT and VMAT QA.it achieved above 90% pass rate using gamma criteria of 3%/3mm. For a planar diode array (MapCHECK 2) an excellent agreement was observed between the measurement and the verification dose for VMAT QA and also for IMRT QA when measured at gantry zero degree.

Key word— IMRT, VMAT, treatment verification, quality assurance, diode array

I. INTRODUCTION

The routine clinical use of complex radiotherapy treatment delivery technologies such as intensity modulated radiation therapy (IMRT) has increased rapidly over the past decade. IMRT is generally delivered from several fixed beam angles in order to create a more conformal dose distribution in order to spare surrounding healthy tissue through the use of multileaf collimators (MLC)[1]. Volumetric modulated arc therapy (VMAT) is a method of delivering intensity modulated fields that is currently gaining widespread use. VMAT [2] is distinguished from fixed-beam IMRT in that the radiation is delivered while the gantry rotates around the patient. The dose is shaped using three variables: MLC shape, gantry rotation speed, and dose rate can be continuously varied to deliver the prescribed dose to the planning target volume. IMRT and VMAT treatments are considerably more complex than traditional treatments, and have a greater potential for delivery errors.

Quality assurance (QA) in radiation therapy is the method used to ensure that the correct amount of radiation is being delivered to the correct location. The necessity for an easy-to-use and reliable QA system to ensure the accuracy of dose delivery before clinical use is required. In the past, IMRT QA was performed with film or ion chamber point dose measurements [3], but in recent years, most clinics have moved to a 2D-dosimetric phantom for their measurements. 2D arrays of electronic detectors have become available and have been studied in some detail: the Sun Nuclear MapCHECK diode array Model 1175 [4] and two commercial models of the ionization chamber array IBA MatriXX[5] and PTW seven29[6]. These 2D plane of detectors which work fine for fixed gantry IMRT, but may be less well suited for rotational IMRT. Recently, there have
been attempts to extend electronic detector systems for use with VMAT verification such as the ScanditodosDelta4 phantom [7] has 1069 p-type silicon diodes in a crossed array inside a cylindrical polymethylmethacrylate (PMMA) phantom and the cylindrical phantom, AcCHECK[8] with 1386 diodes embedded in it.

In this study, we aim to evaluate and compare the dosimetric performance of MapCHECK 2 and ArcCHECK. Sun Nuclear Corporation, Melbourne, FL). The evaluation of these dosimetric systems was applied to IMRT and Rapid Arc and deliveries using a Varian iX linear accelerator with plans generated using the Varian Eclipse (ver. 8.6) treatment planning system.

II. MATERIALS AND METHODS

A. Description of Diode array

All measurements were performed on Clinac iX linear accelerator with a 120-leaf Millennium MLC (Varian Medical Systems, Palo Alto, CA) with 6 and 10 MV photons. The two devices investigated in this study are the MapCHECK 2 and the ArcCHECK from Sun Nuclear Corporation.

2D diode array measurements were taken using the MapCHECK 2 with MapPHAN. The MapCHECK 2 consists of 1527 n-type solid state diode detectors arranged in a zigzag pattern with uniform detector spacing throughout the array of 0.7 cm. The array covers an area of 32 x 26 cm². The active detector area of each diode is 0.8 x 0.8 mm². The MapPHAN is a water equivalent phantom designed to rigidly hold a MapCHECK with no air gap. The radiological depth is 5 cm from the front and back directions. The 3D diode array, ArcCHECK, Model 1220 consists of 1386 n-type solid state diode detectors that is curved to form a cylindrical surface inside a doughnut-shaped phantom. The phantom has an outer diameter of 26.6 cm and an inner hole diameter of 15.1 cm, with the curved plane of diodes at a distance of 10.4 cm from the center. The diodes form a helical pattern and are positioned 1 cm apart along both the cylindrical length and circumference. The overall device length is 44.3 cm, of which 11.9 cm is taken up by the electronics section and the remaining 32.4 cm is the length of the PMMA phantom. The active area (detector array) length is 21 cm. The PMMA buildup and backscatter is approximately 2.9 cm each (water equivalent depth 3.3 g/cm²).

B. Dosimetric performance tests

B.1 Calibration and reproducibility

The MapCHECK 2 and ArcCHECK were calibrated for array sensitivity to determine the relative sensitivity difference between the detectors in diode array devices according to the calibration process steps designed by the manufacturer and absolute dose calibration before its use for measurement. Dose calibration was performed with 6 and 10 MV photons for 10x10 cm² at 100 cm SAD. Short term and long term reproducibility of response by delivering a 100 MU, 10x10 cm² open field ten times over 2 hours period and ten times over a 4-month period respectively was evaluated by calculating the standard deviation (SD) of the reading. The accelerator output was verified using a Farmer type chamber in a solid phantom at the same time.

B.2 Dose linearity and dose rate response

The linearity with dose delivered was assessed using 10x10 cm² field size with MU varying from 20 MU to 400 MU while dose response with dose rate was determined with a range of dose rate between 100 and 600 MU/min.

B.3 Field size dependence

The response of the detector as a function of field size was studied with field size range from 4x4 cm² to 25x25 cm² and compared with those obtained using a Farmer chamber measurement in the same geometry. All detectors response test performed with 6 MV and 10 MV photon beams.

C. Dosimetric measurement

To evaluate the ability of the detector arrays in measuring planar dose distributions, 8 coplanar plans (pelvic, head and neck and abdominal region) and 3 non-coplanar plans (brain) with IMRT and VMAT which were performed using a Varian ClinacIX. These plans were calculated using Eclipse version 8.60. (Varian Medical System, Palo Alto, CA, USA) All measured doses were compared to the TPS dose and analyzed using gamma analysis with criteria of 3%/3 mm. For MapCHECK 2, MapPHAN measured at gantry angle set to 0° (IEC convention) and actual planned gantry angles whereas ArcCHECK measured at actual planned gantry angle for IMRT verification. For VMAT verification, both detectors measured at the whole arc as planned.
III. Results

The short-term reproducibility of the MapCHECK 2 response was found maximum SD to be 0.12 and the long-term reproducibility to be 1.28 when measured ten times over a 4-month period. For the ArcCHECK, short-term and long-term reproducibility was found maximum SD to be 0.27 and 1.2 respectively.

Dose response linearity of the MapCHECK and ArcCHECK was found to be linear over a range of 20 to 400 MU as shown in Fig. 1, the average of the central five diodes and the average of the central two diodes were correlated with the delivered dose. It should be noted that no saturation dose was observed or expected because the charge generated by the diodes was read and reset between each beam pulse. In addition, no dose rate dependence was observed in the range of 100 MU/min to 600 MU/min, as shown in Fig. 2.

![MapCHECK2](image1)

**Fig.1** Response linearity of the two detector arrays. The absolute dose is plotted as a function of delivered dose from 20 MU to 400 MU in a 6 MV and 10 MV photon beam.

![ArcCHECK](image2)

The response of the detectors as a function of field size for MapCHECK 2 and ArcCHECK are displayed in Figs. 3 and 4, respectively, together with the results using a Farmer chamber in the same geometry. Both the results of the MapCHECK 2 and ArcCHECK are agreed with the Farmer chamber measurement to be within 1.59% for the range of field sizes studied for both photon energy beams.

![Dose rate dependence of MapCHECK2 VS ArcCHECK](image3)

**Fig.2** Relative dose as a function of dose rate for the 6 MV and 10 MV photon beam measured with the MapCHECK 2 and ArcCHECK. The dose rate varied from 100 MU/min to 600 MU/min with a fixed field size 10x10cm², SAD 100 cm.

![Output factor of MapCHECK2(MC)](image4)

**Fig.3** Relative output as a function of field size for the 6 MV and 10 MV photon beam measured with the MapCHECK 2 and compared with the measurement using a Farmer-type ion chamber. Measurement was done in a solid water phantom at 100 cm source to detector distance (SDD). Field size varied from 4x4 cm² to 25x25 cm².

![Output factor of ArcCHECK(AC)](image5)

**Fig.4** Relative output as a function of field size for the 6 MV and 10 MV photon beam measured with the ArcCHECK and compared with the measurement using a Farmer-type ion chamber. Measurement was done in a solid water phantom at 100 cm source to detector distance (SDD). Field size varied from 4x4 cm² to 25x25 cm².

For evaluation of both detectors in IMRT and VMAT treatment plans, the passing rates between the MapCHECK 2 and TPS calculated dose distributions and
between the ArcCHECK and TPS calculated dose distributions for 8 coplanar plans (pelvic, head and neck and abdominal region) and 3 non-coplanar plans (brain) are summarized in Table 1.

<table>
<thead>
<tr>
<th>Plan</th>
<th>Plan type</th>
<th>MapCHECK 2</th>
<th>ArcCHECK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMRT</td>
<td>VMAT</td>
<td>IMRT</td>
</tr>
<tr>
<td></td>
<td>Gantry 0 Actual gantry</td>
<td>Actual gantry</td>
<td>Actual gantry</td>
</tr>
<tr>
<td>H&amp;N</td>
<td>97.3 91.9 96.7</td>
<td>85.1 96.4</td>
<td></td>
</tr>
<tr>
<td>H&amp;N</td>
<td>97.1 94.0 99.8</td>
<td>94.8 98.4</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>90.9 89.8 97.7</td>
<td>90.3 97.5</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>99.5 97.5 99.8</td>
<td>93.1 98.5</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>98.7 94.1 99.6</td>
<td>96.0 96.7</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>98.2 89.9 98.3</td>
<td>86.9 99.6</td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>100 96.0 99.8</td>
<td>98.7 97.6</td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>100 92.5 100</td>
<td>96.9 96.2</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>97.7 93.2 99.0</td>
<td>92.7 97.6</td>
<td></td>
</tr>
<tr>
<td>Non-coplanar</td>
<td>99.2 52.0 97.8</td>
<td>98.8 96.8</td>
<td></td>
</tr>
<tr>
<td>Non-coplanar</td>
<td>100 55.6 99.5</td>
<td>99.1 95.1</td>
<td></td>
</tr>
<tr>
<td>Non-coplanar</td>
<td>97.4 84.2 99.2</td>
<td>97.5 91.6</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>98.9 63.9 98.8</td>
<td>98.5 94.5</td>
<td></td>
</tr>
</tbody>
</table>

For IMRT plans verification using MapCHECK 2, the result showed that all comparisons achieved better than 90.9% passing rates, at fix 0 degree gantry angles. But at the planned gantry angles set-up, the passing rates reduced in the range of 89.8% to 97.5% for coplanar plans and 52.0% to 84.2% for non-coplanar plans. The ArcCHECK’s results are shown in the range 85.1% to 99.1% when measured at the planned gantry angles. For IMRT plans verification, both detector showed all comparisons achieved better than 91.6% passing rates.

IV. DISCUSSION AND CONCLUSIONS

The performance tests carried out in this study show that the basic behaviors of both the planar diode array MapCHECK 2 and the cylindrical diode array ArcCHECK are accurate.

Both diode detector arrays also were examined for their use in the quality assurance of patient-specific IMRT and VMAT treatment plans. For the plan comparisons, the gamma analyses are in reasonable correlation. Following these comparative measurements, we found that the ArcCHECK is an efficient and valuable tool for both IMRT and VMAT QA. For the VMAT plan verification and IMRT QA that measured at zero degree gantry, the excellent agreement was observed. But this application of a 2D planar array to planned gantry angle IMRT QA requires careful considerations; it may indicate the loss of QA information in the composite.

ACKNOWLEDGEMENTS

The study was performed at Department of Radiology, Faculty of Medicine, Siriraj Hospital, Mahidol University. We would like to thank the physicist team at Division of Radiation Oncology for providing to use the IMRT and VMAT treatment planning plans and instrument for this study.

REFERENCES


Address of the corresponding author:
Author: Mr.Pornpimolaojunun
Institute: Mahidol University
Street: Rama VI
City: Bangkok
Country: Thailand
Email:pornpimol78@hotmail.com