Evaluation of Delta 4 system in patient specific QA for VMAT technique: Retrospective lung VMAT cases

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Abstract. The objective of this study was to evaluate the Delta 4 system for lung VMAT technique. The standard fields and VMAT plans were generated into the homogeneous and heterogeneous phantoms and were evaluated using 2%/2 mm criterion to validate the Delta 4 system. For retrospective study, five lung VMAT plans were evaluated using 2%/2 mm criterion. The point dose was measured to ensure the accuracy of beam delivery. Moreover, the 1.0 mm MLC position error was introduced into the VMAT plan of homogeneous phantom and was evaluated using 2%/2 mm and 1%/1 mm criteria to evaluate the small error detection. The range of percentage gamma passing rate for standard fields and VMAT in both phantom was 94.6% to 99.8%. For five retrospective lung VMAT plans, the range of percentage gamma passing rate was 96.6% to 99.5%. The point dose differences were within ± 3%. For 1.0 mm MLC position error, the percentage gamma passing rate for 2%/2 mm and 1%/1 mm were 99.1% and 83.6%, respectively. In conclusion, the Delta 4 system can be used in patient specific QA for lung VMAT cases using 2%/2 mm criterion. The error magnitude 1.0 mm can be detected by 1%/1 mm criterion.

1. Introduction
The volumetric modulated arc therapy (VMAT) is one of the advanced techniques which is achieved intensity modulation volumetrically by variation of dose rate, MLC position and gantry speed [1]. These increased complexities of treatment technique require the patient specific QA for dose verification before treatment. The Delta 4 system is the QA system which can be performed for dose distribution evaluation with Gamma (γ) dose evaluation.

At present, Gamma (γ) dose evaluation is widely used in dose distribution evaluation. This method was introduced by Low et al. [2] They proposed dose evaluation method which used the comparison between planned and measured dose distribution in terms of distance to agreement (DTA) and dose difference (DD). The distant to agreement (DTA) is the distance between a measured data point and the nearest planned data point that represents the same dose. The dose difference (DD) is the difference of dose between a measured data point and the planned data point that represents the same location. The result of dose evaluation can be represented in terms of percentage gamma passing rate.
Before clinical use, the percentage gamma passing rate of the Delta 4 system should be evaluated for VMAT technique including in homogeneous phantom, heterogeneous phantom and retrospective cases. In addition, the ability of small error detection should be investigated before use.

2. Materials and methods

2.1 Homogeneous phantom

The structures of multi targets were mimicked into the solid water phantom. Each cylindrical target has a diameter of 4 cm and length of 4 cm approximately [3]. They were stacked along the axis. The standard fields and VMAT plan were created into the homogeneous phantom. The detail of standard fields is shown in table 1. The 10 cm × 10 cm field size with 45° gantry angle was used instead of 0° gantry angle due to the detector position can lead to data insufficiency for dose interpolation. The dose goals of the VMAT plan followed the AAPM TG 119 [3]. The superior, central and inferior targets receive the different doses. The central target receive the largest dose per fraction. The superior and inferior targets received 50% and 25% of dose per fraction, respectively.

| Standard plans | Gantry angle | Field size     | Prescribed dose |
|---------------|--------------|----------------|-----------------|
| 10 cm × 10 cm field | 45°          | 10 cm × 10 cm  | 200 cGy         |
| Four fields   | 45°          | 10 cm × 15 cm  | 200 cGy         |
|               | 135°         | 8 cm × 15 cm   |                 |
|               | 225°         | 10 cm × 15 cm  |                 |
|               | 315°         | 8 cm × 15 cm   |                 |

Each plan was duplicated the fluence into the Delta 4 phantom and was recalculated by the AAA algorithm. Then each verification plan was exported to the treatment unit and was delivered for patient specific QA. The ionization chambers (semiflex 0.125 cc and Farmer 0.6 cc) were inserted to ensure the accuracy of dose delivery from Linac machine. The dose difference was defined in equation (1) where $D_{measured}$ is the measured dose and $D_{planned}$ is the planned dose in Eclipse TPS.

$$\text{%Dose difference} = \left(\frac{D_{measured} - D_{planned}}{D_{planned}}\right) \times 100\%$$ (1)

Then, each plan was evaluated by Gamma ($\gamma$) dose evaluation with global normalization, 10% low dose threshold and $\gamma$ index ≤ 1 as the passing criterion. Two gamma criteria (2%/2 mm and 1%/1 mm) were used in this study. The 1%/1 mm criterion was used to investigate the ability of small error detection in VMAT plan. The schematic of framework is shown in figure 1.

2.2 Heterogeneous phantom

The Quasar phantom was used to represent the lung region of the human body. The peripheral sphere was chosen to represent the peripheral lung lesion. The standard fields and VMAT plan were created into the Quasar phantom. The detail of the standard fields in heterogeneous phantom is shown in table 1. The RTOG 0915 criteria were followed to create the VMAT plan. The prescribed dose of PTV is 4800 cGy with 60% - 90% of the maximum dose [4]. The fluence of each plan was duplicated into the Delta 4 phantom for patient specific QA with the same step of work with homogeneous phantom study.

2.3 Retrospective cases

Five clinically approved lung 6FFF VMAT treatment plans which verified by another QA tool with 2%/2 mm and percentage gamma passing rate was greater than 95% for patient specific QA were randomized for retrospective study. All treatment plans were created by using the Eclipse treatment planning system with AAA algorithm (version 13.6.23) and 2.5 mm dose grid size were treated by the
EDGE radiosurgery system (Varian Medical Systems, Palo Alto, CA) at Radiosurgery Center, Ramathibodi Hospital. The retrospective cases are shown in table 2.

**Table 2.** Detail of all five retrospective plans.

| Patient no. | Disease     | GTV volume (cm$^3$) | PTV volume (cm$^3$) | Number of arc | Prescribed dose (cGy) | Number of fraction |
|-------------|-------------|---------------------|---------------------|---------------|-----------------------|-------------------|
| 1           | NSCLC       | 26.10               | 78.60               | 4             | 3500                  | 5                 |
| 2           | CA lung     | 46.10               | 71.00               | 3             | 5000                  | 5                 |
| 3           | Lung metastasis | 39.70             | 64.20               | 4             | 4500                  | 5                 |
| 4           | NSCLC       | 3.60                | 8.40                | 4             | 5000                  | 5                 |
| 5           | CA lung     | 19.40               | 45.90               | 4             | 5000                  | 5                 |

2.4 MLC position error

The known 1.0 mm MLC position error was introduced into the VMAT plan of the homogeneous phantom. Only one field in VMAT plan was changed by manual MLC position changing for 177 control points.

2.5 Treatment machine

The EDGE radiosurgery system is the TrueBeam Varian linac machine with high definition (HD) 120 multileaf collimators. The EDGE machine contains 6MV, 6FFF and 10FFF photon energies. The maximum dose rate of 6MV, 6FFF and 10FFF photon energies are 600, 1400 and 2400 monitor unit per min, respectively. The maximum static field size is 40 cm $\times$ 22 cm. The HD120 MLC consists of 2.5 mm leaf width at central field up until 8 cm $\times$ 8 cm area and 5 mm leaf width outside the central area.

2.6 Delta 4 system (Scandidos, Uppsala, Sweden)

The Delta 4 system consists of two orthogonal detector arrays that placed inside the cylindrical PMMA phantom. The detector array contains 1069 p-type diodes. An area of detector covers 20 cm $\times$ 20 cm. The detectors are spaced at 5 mm intervals in the central 6 cm $\times$ 6 cm area and 10 mm intervals outside the central area. The active volume of the detector is 0.00004 cm$^3$ [5].

![Figure 1. Schematic of measurements for homogeneous phantom, heterogeneous phantom and retrospective cases.](image)

3. Results

The range of point dose difference for error-free plan was from 0.14% to 2.96%. The point dose difference for VMAT introduced 1.0 mm MLC position error was up to 8.46%. The dose difference for all plans in this study are shown in table 3.
Table 3. Dose difference for all twelve plans.

| Plans                      | Average measured dose (cGy) (±SD) | Planned dose (cGy) | % Dose difference |
|----------------------------|-----------------------------------|-------------------|-------------------|
| Homogeneous phantom        |                                   |                   |                   |
| 10 × 10 cm (Gantry 45°)    | 279.33 (±0.00)                    | 278.50            | 0.30%             |
| Four fields                | 235.21 (±0.00)                    | 233.30            | 0.82%             |
| VMAT                       | 248.40 (±0.00)                    | 243.20            | 2.14%             |
| VMAT with error 1.0 mm     | 263.77 (±0.00)                    | 243.20            | 8.46%             |
| Heterogeneous phantom      |                                   |                   |                   |
| 10 × 10 cm (Gantry 45°)    | 274.31 (±0.00)                    | 273.50            | 0.30%             |
| Four fields                | 209.23 (±0.00)                    | 207.50            | 0.83%             |
| VMAT                       | 959.51 (±0.00)                    | 932.30            | 2.92%             |
| Retrospective cases        |                                   |                   |                   |
| No.1                       | 734.20 (±0.33)                    | 723.70            | 1.45%             |
| No.2                       | 919.30 (±0.04)                    | 918.00            | 0.14%             |
| No.3                       | 897.45 (±0.10)                    | 871.60            | 2.96%             |
| No.4                       | 1020.00 (±0.11)                   | 993.00            | 2.72%             |
| No.5                       | 1119.26 (±0.01)                   | 1101.20           | 1.64%             |

The percentage passing rate of all VMAT plans was more than 95% with 2%/2 mm criterion. The percentage passing rate was dropped from 86.60% to 83.60% with 1%/1 mm criterion. The detail is shown in Table 4.

Table 4. Percentage gamma passing rate for all twelve plans.

| Plans                      | % Passing rate |
|----------------------------|----------------|
|                            | 2%/2 mm        | 1%/1 mm        |
| Homogeneous phantom        |                |                |
| 10 cm × 10 cm (Gantry 45°) | 94.70%         | -              |
| Four fields                | 94.60%         | -              |
| VMAT                       | 99.80%         | 86.60%         |
| VMAT with error 1.0 mm     | 99.10%         | 83.60%         |
| Heterogeneous phantom      |                |                |
| 10 cm × 10 cm (Gantry 45°) | 94.70%         | -              |
| Four fields                | 95.80%         | -              |
| VMAT                       | 98.50%         | -              |
| Retrospective cases        |                |                |
| No.1                       | 98.30%         | -              |
| No.2                       | 97.40%         | -              |
| No.3                       | 96.60%         | -              |
| No.4                       | 99.50%         | -              |
| No.5                       | 97.90%         | -              |

4. Discussion
The point dose in all twelve plans was measured to ensure the accuracy of delivery dose by Linac machine. For the error free plan, the range of point dose difference was from 0.14% to 2.96%. For
retrospective cases, the largest percentage dose difference was found in patient no.3. Because the treatment plan of this patient contained three different prescribed doses for the different area of PTV (PTV, PTV overlapping with average heart contour and PTV overlapping with maximum intensity projection (MIP) of heart contour). The inhomogeneous treatment plan could lead to the maximum point dose difference. The contours of PTV and dose distribution of patient no.3 are illustrated in figure 2. Moreover, the small treatment field could affect to the measurement. For patient no.4, the $8.4 \text{ cm}^3$ volume of PTV which was the smallest size might lead to the 2.72% of point dose difference. The PTV of patient no.4 is illustrated in figure 3.

![Figure 2](image2.png)

**Figure 2.** The contour of PTV and dose distribution of patient no.3 in (a) inferosuperior, (b) anteroposterior and (c) lateral views.

![Figure 3](image3.png)

**Figure 3.** The PTV of patient no.4 in (a) inferosuperior, (b) anteroposterior and (c) lateral views.

Dong et al. [6] reported that the complicated intensity pattern, inhomogeneous plan and very small treatment field could lead to significant uncertainty of the position of ionization chamber relative to the non-uniform dose distribution. Consequently, it could give rise to considerable point dose difference.

In early stage, the percentage passing rates of $10 \times 10 \text{ cm}$ field size with $0^\circ$ gantry angle were lower than 95% for 3%/3 mm, 3%/2 mm and 2%/2 mm criteria. Consequently, the $10 \times 10 \text{ cm}$ field size with $45^\circ$ gantry angle was applied instead of $0^\circ$ gantry angle. The results are shown in table 5.

| Plan                      | % Passing rate |
|---------------------------|----------------|
|                           | 3%/3 mm | 3%/2 mm | 2%/2 mm |
| $10 \times 10 \text{ cm}$ (Gantry 0°) | 89.90%  | 84.80%  | 76.10%  |
| $10 \times 10 \text{ cm}$ (Gantry 45°) | 98.60%  | 98.50%  | 94.70%  |

![Figure 4](image4.png)

**Figure 4.** The plus-shaped diode array configuration in the Delta 4 phantom.

This situation may be affected by data insufficiency for dose interpolation with $0^\circ$ gantry angle due to plus-shaped diode array configuration. Only, one of two planes diode array is faced to the irradiation
with perpendicular direction when using 0° gantry angle while the dose data from both detector planes are used to interpolate the measured dose when using 45° gantry angle. The shape of the biplanar diode in the Delta 4 phantom is illustrated in figure 4.

The percentage gamma passing rates of the two phantoms were investigated for the baseline comparison. The standard fields were used to represent the non-complexity plan. The VMAT plans were used to represent the more complex plan. The range of percentage gamma passing rate of 2%/2 mm gamma criterion was from 94.6% to 99.8% for all plans. The percentage gamma passing rate of all VMAT plans was more than 95% with 2%/2 mm criterion. The percentage gamma passing rates of standard fields are less than the VMAT plans due to the insignificant errors were compromised in VMAT plan.

In addition, the small MLC position error could be detected by using the 1%/1 mm criterion meanwhile it could not be detected by using the 2%/2 mm criterion. In accordance with the Saito et al. [5] study, they reported that the loose criteria could not detect the small MLC position error for lung treatment plan. For VMAT introduced 1.0 mm MLC position error, the percentage gamma passing rate was dropped from 86.60% to 83.60% while the point dose difference was up to 8.46%. In other word, the 1.0 mm MLC position error in VMAT plan can be detected by point dose verification. Therefore, the point dose verification can be used to confirm the results when the percentage gamma passing rate decrease less than 85.00% with 1%/1 mm criterion. However, the percentage gamma passing rate was slightly decreased from 99.80% to 99.10% for 2%/2 mm criterion while the dose difference was up to 8.46%.

The global percentage gamma passing rates of all five retrospective plans are more than 95% for 2%/2 mm criterion. The limitations of this study were its small sample size of the retrospective cases and only one type of error was introduced. It does not represent the all of error types in clinical situation. The patient anatomy-based (DVH based) method which is the other application for dose distribution evaluation in the Delta 4 system will be explored in further work.

5. Conclusion
In conclusion, the Delta 4 system can be used in patient specific QA for lung VMAT case by using 2%/2 mm criterion with at least 95% gamma passing rate. We have to realize that this criterion might not detect the 1.0 mm of MLC position error unless other verification are applied. However, the 1.0 mm of MLC position error can be detected by 1%/1 mm criterion and point dose verification.

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