Error detection sensitivity test using complex errors on three patient-specific VMAT QA systems

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Abstract. The purpose of this study was to investigate error detection sensitivity for three patient-specific volumetric modulated arc therapy (VMAT) quality assurance (QA) systems (Delta4, EPID-based dosimetry, and log file) with three possible scenarios. Ten patient-specific VMAT QA were randomly selected to test their error detection sensitivities. Artificial complex errors were introduced to the original plans then the QA tests were repeated. These errors were simulated into three possible scenarios: uncertainty, miss-calibration, and worst-case scenario. For uncertainty scenario, the random errors (σ) of multi-leaf collimators (MLC) at ± 2.0 mm and gantry angle at ± 2.0 degree were introduced. The systematic errors of +2MU, and the random errors of MLC and gantry angle at ± 2.0 mm and ± 2.0 degree were applied as a miss-calibration scenario. For worst case scenario, errors were integrated between systematic and random variation of MLC and gantry angle at ±0.5 mm and ±0.5 degree, respectively. The dosimetric agreements between QA tests on original versus artificial error plans were determined to investigate error detection sensitivity used gamma analysis with 3%, 3 mm criteria. EPID-based dosimetry showed the most sensitive QA tool to detect three possible scenarios. Log file was the second best method, whereas Delta4 was the worst method to detect three possible scenario errors.

1. Introduction

Since the advanced radiation therapy (Intensity Modulated Radiation Therapy: IMRT, Volumetric Modulated Arc Therapy: VMAT, Stereotactic Body Radiation Therapy: SBRT, Stereotactic Radiosurgery: SRS, Stereotactic Radiotherapy: SRT) are introduced to the clinic, the beam complexity are also increased [1-5]. VMAT is the current technique used for treatment delivery that allowed variation of three parameters during treatment delivery: gantry rotation speed, multi-leaf collimators (MLC) speed, and dose rate [6]. Hence, plan accuracy needs to be investigated. Patient-specific quality assurance (QA) process is performed to detect the discrepancy between TPS and beam delivery [7, 8]. The main purpose of patient-specific QA is to verify the correct data transfers, the discrepancy between treatment delivery and planned dose should be within specified tolerance, and accuracy of planned dose [9]. Patient-specific QA can be categorized in three methods [10]: first is a measurement-based with phantom such as the commercial products of Delta4 (ScandiDos AB, Uppsala, Sweden), ArcCheck (Sun Nuclear, Melbourne, FL), OCTAVIOUS (PTW, Freiburg, Germany), and Matrixx (IBA Dosimetry, Bartlett, TN), second is an Electronics Portal Imaging Devices (EPIDs), third is log file method. In
advanced radiation therapy, patient-specific QA was expected to detect systematic and random errors. The common error in VMAT can be categorized in two types [11, 12]: systematic errors such as a missed calibration of MLC positions, a missed calibration of gantry angle, and a missed calibration of machine output, and random errors such as the gravitational sagging of MLC during gantry rotation. According to different characteristics of QA tools such as a detector resolution, a phantom shape, the sensitivity of QA to detect errors can be different [13]. To verify the performance of QA, the sensitivity to detect errors needs to be investigated. Several studies have investigated the sensitivity to detect error in various types of QA tools. Hauri et al. [14] investigated the sensitivity of Delta4 to detect gantry error in VMAT plans, and they found the gantry error related to gravitational sagging of gantry. Liang et al. [15] investigated the sensitivity of three VMAT QA systems (ArcCheck, Delta4, in-house developed EPID technique) to machine errors, and they found that ArcCheck is more sensitive to detect gantry error, Delta4 is more sensitive to detect MLC error, and EPID technique has a same sensitivity to detect both of MLC and gantry errors by adjusting the extra angle-to-agreement parameters. Defoor et al. [16] investigated the capability of three QA methods (Delta4, MU-EPID, Dynalog QA) to detect gantry angle, MLC position, and MU errors, and they found that the errors were detected at a rate of 60, 27, and 47% for Delta4, MU-EPID, and Dynalog QA, respectively. However, there are no research investigate the error detection with classifying different type of errors. In our study, artificial complex errors were classified in the three possible scenarios: uncertainty, miss-calibration, and worst-case scenario. The errors were introduced to original plan to investigate error detection sensitivity for the three patient-specific VMAT QA systems (Delta4, EPID-based dosimetry, and log file).

2. Material and methods

TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA) was used to perform VMAT patient-specific QA. Dose calculation was performed using Eclipse TPS version 13.6 (Varian Medical Systems, Palo Alto, CA).

2.1 Plan population and error detection

Five patient-specific VMAT QA were randomly selected to test their error detection sensitivities. Artificial complex errors were introduced to the original plans then repeated the QA tests. These errors were simulated into the three possible scenarios: uncertainty, miss-calibration, and worst case. Three possible errors were selected to simulate errors because it is normally occurred in a clinical situation. For uncertainty scenario, the random errors of MLC at ± 2.0 mm and gantry angle at ± 2.0 degree were introduced. For miss-calibration scenario, the systematic error of +2 MU and random errors of MLC at ± 2.0 mm and gantry angle at ± 2.0 degree were applied. For worst case scenario, errors were integrated between systematic and random variation of MLC and gantry angle at ±0.5 mm and ±0.5 degree, respectively. The dosimetric agreements between QA tests on original versus artificial error plans were determined to investigate error detection sensitivity using gamma analysis with 3%, 3 mm criteria, and a cut-off threshold at 10%. The capability to detect error was determined with drop ratio which is ratio between gamma passing rates (GPR) of original and introduced error plans.

2.2 QA tools

2.2.1. Delta4PT. Delta4PT (ScandiDos AB, Uppsala, Sweden) was prior calibrated following a manual guide [17] before performance of the VMAT patient-specific QA. Delta4PT contains 1,069 p-type diodes placed at x-cross plane inserted inside a cylindrical phantom made from polymethylmethacrylate (PMMA). A phantom position error was corrected by Delta4PT software after measurement. Three dimension dose distributions were calculated to other plane with interpolation method.

2.2.2. EPID-based dosimetry. An amorphous silicon (a-Si) 1000 EPID was used to acquire image for VMAT patient-specific QA with spatial resolution of 1024×768 pixels. In this study, EPID images were converted to absorbed dose at 10 cm-depth in water using our model that includes four parameters as
follows: linearity of dose response with MU, beam profile correction, collimator scatter, and scatter kernel. The model was described by Tehovnik et al. [18].

2.2.3 Log file. Dynalog [19] software was used to extract log file to fluence map. Log file data contains information of MU, MLC position, dose rate, and gantry angle, which are related to each control point. The dose agreement was determined by comparing between delivery fluence map and planned fluence map.

3. Results
Table 1 shows the average gamma pass-rates (gamma criteria of 3%, 3mm) ± 1SD for all scenarios. EPID has the lowest % gamma pass-rates, whereas Delta 4 has the highest % gamma pass-rates for all error scenarios.

| Scenario            | Delta4  | EPID    | Log file |
|---------------------|---------|---------|----------|
| Original plans      | 99.33±0.58 | 94.14±1.82 | 96.76±0.87 |
| Uncertainties       | 97.53±1.11 | 84.94±2.21 | 92.42±0.56 |
| Miss-calibration    | 94.12±0.78 | 82.05±1.53 | 89.59±0.67 |
| Worst case          | 90.71±0.93 | 77.51±1.26 | 86.87±1.21 |

Figure 1 shows gamma pass-rate drop from original plan for all scenarios. EPID has the highest sensitivity to detect the uncertainty, miss-calibration, and worst-case scenarios with largest gamma pass-rate drop from original plan. Delta4 and log file QA has a similar sensitivity on error detection in worst-case scenario. However, log file had more error detection sensitivity than Delta4 on miss-calibration scenario.

![Figure 1. Gamma pass-rate drop from original plan for all scenarios.](image)

Figure 2 shows the example of patient-specific VMAT QA results in three QA systems (log file, EPID-based dosimetry, and Delta4) for miss-calibration scenario.
Figure 2. Example of patient-specific VMAT QA results in three QA systems (a) Log file, (b) EPID-based dosimetry, and (c) Delta4 for miss-calibration scenario.

4. Discussion
Uncertainty scenario has a small effect to error detection when compared to miss-calibration scenario. This may imply that random errors have less effect than systematic errors. Worst case scenario showed largest effect to error detection because random and systematic errors were integrated together. Woon et al. [20] reported that the sensitivity to detect errors depend on spatial resolution of detectors. According to high spatial resolution of EPID (1024×768 pixels), EPID-based dosimetry showed higher sensitivity to detect error than Delta4 (1,069 diodes). Zhang et al. [21] reported that 3D analyses are sensitive to detect error less than 2D plane. In this study, EPID-based dosimetry and log file were analyzed with 2D plane, whereas Delta4 was analyzed with 3D interpolation. In case of low spatial...
resolution detectors, AAPM task group no.218 [22] recommended that error detection sensitivity can be increased by reducing gamma criteria.

5. Conclusions
From the three patient-specific QA systems investigated in this work, EPID-based dosimetry was the most sensitive QA tool to detect the three possible scenarios (uncertainty, miss-calibration, and worst-case scenario) in patient-specific VMAT QA. Log file was the second best method, whereas Delta4 was the worst method to detect the three possible scenario errors.

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