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Control Point Analysis comparison for 3 different treatment planning and delivery complexity levels using a commercial 3-dimensional diode array

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ABSTRACT

To investigate the use of "Control Point Analysis" (Sun Nuclear Corporation, Melbourne, FL) to analyze and compare delivered volumetric-modulated arc therapy (VMAT) plans for 3 different treatment planning complexity levels. A total of 30 patients were chosen and fully anonymized for the purpose of this study. Overall, 10 lung stereotactic body radiotherapy (SBRT), 10 head-and-neck (H&N), and 10 prostate VMAT plans were generated on Pinnacle^3 and delivered on a Varian linear accelerator (LINAC). The delivered dose was measured using ArcCHECK (Sun Nuclear Corporation, Melbourne, FL). Each plan was analyzed using "Sun Nuclear Corporation (SNC) Patient 6" and "Control Point Analysis." Gamma passing percentage was used to assess the differences between the measured and planned dose distributions and to assess the role of various control point binning combinations. Of the different sites considered, the prostate cases reported the highest gamma passing percentages calculated with "SNC Patient 6" (97.5% to 99.2% for the 3%, 3 mm) and "Control Point Analysis" (95.4% to 98.3% for the 3%, 3 mm). The mean percentage of passing control point sectors for the prostate cases increased from 51.8 ± 7.8% for individual control points to 70.6 ± 10.5% for 5 control points binned together to 87.8 ± 11.0% for 10 control points binned together (2%, 2-mm passing criteria). Overall, there was an increasing trend in the percentage of sectors passing gamma analysis with an increase in the number of control points binned together in a sector for both the gamma passing criteria (2%, 2 mm and 3%, 3 mm). Although many plans passed the clinical quality assurance criteria, plans involving the delivery of high Monitor Unit (MU)/control point (SBRT) and plans involving high degree of modulation (H&N) showed less delivery accuracy per control point compared with plans with low MU/control point and low degree of modulation (prostate).

Introduction

Verification of treatment delivery, or quality assurance (QA), is a crucial stage in the radiation therapy treatment process.[1] In the last decade, several tools were developed and applied for delivery QA, including film[2]; diode arrays, such as MapCHECK (Sun Nuclear Corporation, Melbourne, FL)[3]; and ion chamber arrays, such as the PTW 2D-array seven29.[4] Three-dimensional (3D) phantoms and dosimeters, such as 3D diode arrays, solid gels,[5] and spiral-pattern radiographic films,[6] have also been developed and studied recently. A new 3D diode array called ArcCHECK (Sun Nuclear Corporation, Melbourne, FL) was implemented for delivery QA. A recent study[7] evaluated ArcCHECK and showed consistency of response of the individual diodes and minimal field size dependence.

The demand for better QA systems continues to increase. With the development of new treatment techniques and new radiation delivery systems, more intricate QA metrics and tools must be created. The most accepted metric that is currently used clinically in delivery QA is gamma passing percentage, which is based on the definition of gamma introduced by Low *et al.*[8] However, recent studies[9–12] showed a lack of correlation between gamma passing percentage and dose differences in regions of interest.

Volumetric-modulated arc therapy (VMAT) is a modern treatment technique[13,14] that requires more sophisticated QA tools. In VMAT, dose delivery is spread over an arc or a subarc. Each arc is divided, during optimization, into a number of control points, each

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of which has its own multileaf collimator (MLC) pattern and dose weight. During delivery, it is extremely important to verify that the dose delivered per control point matches with that of the plan. Poor agreement between the dose delivered per control point and that of the plan might translate into poor agreement in clinical outcomes. This problem might be overlooked when comparing the composite delivered dose with the planned dose.[15] Varian electronic portal imaging devices (Varian Medical Systems, Palo Alto, CA) have been used for VMAT QA.[16,17] Sun Nuclear (Sun Nuclear Corporation, Melbourne, FL) recently developed a new tool called "Control Point Analysis" that allows the verification of the dose delivered per control point. It is the first available QA tool that has this capability.

In this study, we used the "Control Point Analysis" tool to analyze and compare delivered plans for 3 different treatment planning complexity levels: (1) high MU per control point (MU per control point $\geq$ 15)—(L1); (2) high degree of modulation (the average open area difference between 2 consecutive control points is more than 3.5 cm^2 for the whole plan)—(L2); and (3) low MU per control point (MU per control point $\leq$ 5) plus low degree of modulation (the average open area difference between two consecutive control points is less than 1.5 cm^2 for the whole plan)—(L3). The consistency of the "Control Point Analysis" tool was examined by comparing its conventional passing percentage of gamma analysis with the "Sun Nuclear Corporation (SNC) Patient 6" results for the 3 treatment planning complexity levels defined earlier. The goal of this work is to study the effect of individual control point QA *vs* the traditional full arc VMAT QA for the 3 different treatment planning complexity levels.

Methods and Materials

Treatment planning and delivery

A total of 30 patients were chosen and fully anonymized for the purpose of this study. Overall, 10 lung stereotactic body radiotherapy (SBRT) plans consisting of 1 arc (360° arc for 8 patients and 215° arc for 2 patients) and a prescription of 54 Gy in 3 fractions (fx) to the planning target volume (PTV) comprised the L1 level and 10 head-and-neck (H&N) cases (prescription of 70 Gy in 35 fx to the PTV) were considered as L2 level. The H&N cases were planned with 2 separate 360° arcs (clockwise and counterclockwise). The L3 level consisted of 10 patients with prostate cancer with a prescription of 76 Gy in 35 fx to the PTV delivered in a 360° arc. Each patient was analyzed using "SNC Patient 6" and "Control Point Analysis." Because of the fact that multiple arcs could not be analyzed using the current version of the "Control Point Analysis" tool, those plans that consisted of 2 arcs were studied by analyzing each arc separately. All the arcs used in this study were created with a 4° control point spacing.

Each plan was optimized using Pinnacle^3 treatment planning system version 9.0 (Philips Radiation Oncology, Fitchburg, WI) and was delivered on a Varian clinical linear accelerator (Clinac iX) with RapidArc delivery capability (Varian Medical Systems, Palo Alto, CA). Each arc was planned with 6-MV photon beams with 120-leaf MLC. Each plan was copied to a computed tomography scan of the ArcCHECK and the dose was recalculated. The radiotherapy (RT) plan, RT dose per control point, and RT dose per prescription DICOM files were exported from Pinnacle^3 and were used for the analysis. Delivered dose was measured using ArcCHECK and was collected using "SNC Patient 6" software (Sun Nuclear Corporation, Melbourne, FL).

Measurement evaluation

The "SNC Patient 6" is a patient-specific QA software package that compares the patient plan dose with the measured plan dose for the same patient using gamma analysis. It measures the composite dose delivered by integrating the dose every 10 ms. The ArcCHECK-measured dose is compared with the ArcCHECK RT plan and RT dose per prescription. The import filter extracts a cylindrical dose plane from the imported 3D volume for direct dose comparison with the measured values. Based on the gamma analysis criteria (dose difference, distance to agreement [DTA], and maximum dose threshold) provided by the user to the software, it will calculate the percentage of points that are passing gamma analysis.

The "Control Point Analysis" tool provides the ability to analyze dose delivery in an arc and identify dose errors down to the individual control point level. The operation of the "Control Point Analysis" tool can be briefly described as follows. After the ArcCHECK measurement is acquired, the ArcCHECK-measured dose is synchronized to the RT plan control points using a function that extracts data from the RT plan file and places a time stamp at each control point. Then, the time-stamped control points are used to integrate dose updates from the ArcCHECK-measured file into ArcCHECK dose for each control point interval.[18] Finally, the integrated measured dose for each control point can be compared with the corresponding RT plan control point using gamma analysis.

In gamma analysis, a global normalization point is used to normalize the dose difference; this point is the measured dose value at the normalization point, which is typically chosen as the maximum dose value in the measurement.[8] In the "Control Point Analysis" tool, a different global normalization point is used for each control point (or sector). This point is chosen to be the maximum measured dose in the control point (or sector) interval, which is, in general, much smaller than the maximum dose from a composite measured dose. The "Control Point Analysis" tool provides a choice between using a weighted or a nonweighted global normalization point for each control point. In the weighted option, the global normalization point is multiplied by a weight function related to the maximum dose from a composite measured dose, making control point dose analysis dependent on the composite measured dose entities. The weight function, F_w, is defined as follows:

$$F_w = \sqrt{\frac{max\ dose\ (beam)}{max\ dose\ (CP_j)}} \quad (1)$$

where max dose (beam) is the maximum dose at a grid point in the composite measurement dose object from a beam, and max dose (CP_j) is the maximum dose at a grid point in the measurement dose object from CP_j (the control point interval). The dose difference comparison equation used in gamma analysis is then defined as follows:

$$\left|D_{m,i} - D_{c,i}\right| \leq p\% \times maxdose(CP_j) \times F_w \quad (2)$$

where $D_{m,i}$ is the dose value at grid point (i) in the measurement dose object, $D_{c,i}$ is the dose value at grid point (i) in the calculation dose object, and p% is the percent difference value used in the analysis. In the nonweighted option, the weight function is not included.[18] As a final extension to the analysis, the difference in results when using the weighted and nonweighted global normalization point in gamma analysis was examined.

The Table lists the required input data needed for "SNC Patient 6" and "Control Point Analysis" tools as well as the output comparison metric between the plan and measurement. We used the "SNC Patient 6" and "Control Point Analysis" built-in tools[19] to calculate the conventional passing percentage of gamma analysis.

For all gamma passing percentage analysis, 2 combinations of thresholds were used, 3% dose difference and 3-mm DTA and 2% dose difference and 2-mm DTA, with 10% of the maximum dose used as our dose threshold. These combinations

Table
A list of the required input data needed for "SNC Patient 6" and "Control Point Analysis" tools, the output comparison metric between the plan and measurement, and the four control point binning combinations analyzed for each patient

	SNC Patient 6	Control Point Analysis
Input	(1) Recorded measurement (2) ArcCHECK RT plan (3) ArcCHECK RT dose per prescription	(1) Recorded measurement (2) ArcCHECK RT plan (3) ArcCHECK RT dose per control point
Output	Gamma passing percentage for the composite plan	Gamma passing percentage for the individual control points, multiple control points binned together in 1 sector and the composite plan
Control point combinations (number of control points binned together/sector)		(1) 1 Control point per sector (2) 5 Control points per sector (3) 10 Control point per sector (4) All the control points per sector (equivalent to the composite plan)