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Technical notes

The effect of beam interruption during VMAT delivery on the delivered dose distribution

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ABSTRACT

Purpose: The aim of this study is to investigate the effect of beam interruptions during delivery of volumetric modulated arc therapy (VMAT) on delivered dose distributions.
Methods: Ten prostate and ten head and neck (H&N) VMAT plans were retrospectively selected. Each VMAT plan was delivered using Trilogy™ without beam interruption, and with 4 and 8 intentional beam interruptions per a single arc. Two-dimensional global and local gamma evaluations with a diode array were performed with gamma criteria of 3%/3 mm, 2%/2 mm, 1%/2 mm and 2%/1 mm for each VMAT plan with and without beam interruptions. The VMAT plans were reconstructed with log files recorded during delivery and the dose-volumetric parameters were calculated for each reconstructed plan. The differences among dose-volumetric parameters due to the beam interruptions were calculated.
Results: The changes in global gamma passing rates with various gamma criteria were less than 1.6% on average, while the changes in local gamma passing rates were less than 5.3% on average. The dose-volumetric parameter changes for the target volumes of prostate and H&N VMAT plans due to beam interruptions were less than 0.72% and 1.5% on average, respectively.
Conclusion: The delivered dose distributions with up to 8 beam interruptions per an arc were clinically acceptable, showing minimal changes in both gamma passing rates and dose-volumetric parameters.

Introduction

Volumetric modulated arc therapy (VMAT) is the delivery of intensity-modulated photon beams in a single or multiple arcs [1]. Since VMAT generates steep dose gradients around the target volume, misdelivery of a planned dose distribution could induce low tumor control rates, as well as damage to normal tissues [2]. Moreover, since VMAT modulates beam intensities with simultaneous modulations of multi-leaf collimator (MLC) positions, gantry rotation speed and dose-rate, uncertainties could be potentially larger in VMAT compared to intensity modulated radiation therapy (IMRT), which modulates beam intensities by only modulation of MLC positions [1]. Therefore, pre-treatment quality assurance (QA) for each patient before both IMRT and VMAT is strongly recommended and routinely performed in the clinic to verify that the delivered treatment plan is identical to the intended dose distribution [3–6].

Beam interruptions have the potential to occur during delivery of VMAT to patients in the clinic due to various reasons. The beam delivery of VMAT is interrupted periodically when gated radiation therapy is performed. Temporary failure of linac operation due to malfunction could also result in beam interruption during treatment. Moreover, if there is patient motion during delivery of VMAT, then the beam delivery should be interrupted, with the treatment continuing after the patient is repositioned. Manikandan et al. demonstrated that the discrepancy in gantry angle between treatment plan and actual delivery due to beam interruption was minimal for Synergy® S (Elekta, Stockholm, Sweden) systems [7]. That minimal effect was achieved by a system that upon

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interruption moves the gantry back by several degrees, and then resumes delivery only as the gantry passes the point of interruption. Although, the C-series linacs, such as Trilogy™ (Varian Medical systems, Palo Alto, CA) do not adopt such a mechanism, several studies demonstrated the minimal dosimetric effect of VMAT delivery during respiratory gating [8,9].

In this study, we investigated the clinical relevance of beam interruptions during VMAT on the delivered dose distributions by analyzing the changes in dose-volumetric parameters between original plan and the plans reconstructed with log files recorded during beam delivery. We also analyzed changes in the planar gamma passing rates due to beam interruptions.

Materials and methods

Ten VMAT plans for prostate cancer and 10 VMAT plans for head and neck (H&N) cancer which were used for patient treatment were retrospectively selected for this study. All VMAT plans were generated in the Eclipse™ (Varian Medical Systems, Palo Alto, CA) system with 6 MV photon beams of Trilogy™ with a single, or two full arcs. The progressive resolution optimizer 3 (PRO3, ver.10, Varian Medical Systems, Palo Alto, CA) and the anisotropic analytic algorithm (AAA. ver.10, Varian Medical Systems, Palo Alto, CA) was used for optimization and dose calculation, respectively. For prostate plans, a primary plan and a boost plan were generated for each patient. Only primary plans were selected for this study (50.4 Gy with a daily dose of 1.8 Gy). For H&N plans, the simultaneous integrated boost (SIB) technique with a total of three target volumes was used. The prescription dose to target 1, target 2 and target 3 were 67.5 Gy (daily 2.25 Gy), 54 Gy (daily 1.8 Gy), and 48 Gy (daily 1.6 Gy), respectively. To evaluate modulation degree of prostate and H&N VMAT plans, modulation index was calculated for each VMAT plan [10].

Planar dose distributions were measured with a MapCHECK2™ detector array (Sun Nuclear Corporation, Melbourne, FL). Both global and local gamma evaluations with 3%/3 mm, 2%/2 mm, 1%/2 mm, and 2%/1 mm were performed.

When measuring planar dose distributions, VMAT plans were delivered 1) without interruption (*0 times*), 2) with four interruptions per single arc (*4 times*) and 3) with eight interruptions per single arc (*8 times*) to investigate the changes in delivered doses in extreme cases of beam interruption.

During delivery of VMAT plans, the dynamic log files recorded in the linac control system were acquired for each VMAT plan. Simultaneously, DynaLog files, which are a record of MLC positions, were also acquired. Since a dynamic log files is a delivery record of gantry angles and delivered monitor units (MUs) at each control point while a DynaLog file is a record of MLC positions every 0.05 s during delivery, we calculated times between adjacent control points to combine these two kinds of log files. With time information, we generated DICOM-RT formatted files based on the information during delivery using MATLAB (ver.8.1, Mathworks Inc., Natick, MA). The DICOM-RT formatted files of *0 times*, *4 times* and *8 times* were acquired for each VMAT plan. Those files were imported in the Eclipse™ system and the dose distributions delivered through whole fractionations were calculated in the patient CT images. For the target volumes, the dose received by 95% of the planning target volume (PTV) ($D_{95\%}$), $D_{5\%}$, the minimum, maximum, and mean dose to the PTV were acquired. For organs at risk (OARs) of prostate plans, $D_{20\%}$ of rectal wall and bladder, mean dose to the rectal wall, bladder, and femoral head, and $D_{50\%}$ of femoral head were acquired. In the case of H&N plans, the maximum dose to the spinal cord, brain stem, lens, optic chiasm and optic nerves and mean doses to each parotid gland were acquired.

For gamma passing rates, the statistical significances of the differences were analyzed with the Student's t-test between 1) *0 times* vs. *4 times*, 2) *0 times* vs. *8 times* and 3) *4 times* and *8 times*. For changes in dose-volumetric parameters, the differences between 1) original plan vs. *0 times* plan, 2) original plan vs. *4 times* plan, 3) original plan vs. *8 times* plan, 4) *0 times* plan vs. *4 times* plan and 5) *0 times* plan vs. *8 times* plan were calculated and the statistical significances of the differences were also analyzed with the Student's t-test.

Results

The average values of modulation indices of prostate and H&N VMAT plans were 15.4 ± 1.4 and 40.6 ± 8.1, respectively ($p < 0.001$). Therefore, H&N VMAT plans were highly modulated than did the prostate VMAT plans in this study [10].

Tables 1 and 2 show the global and local gamma passing rates of *0 times*, *4 times* and *8 times* of VMAT plans with various gamma criteria, respectively. The differences in global passing rates due to beam interruptions were less than 1.6% for prostate plans and 1.4% for H&N plans. In the cases of local gamma passing rates, those were less than 3.4% and 5.3%, respectively. No tendency of decrease in gamma passing rates as increasing the frequency of beam interruptions was observed.

The differences in dose-volumetric parameters of prostate VMAT plans between original treatment plans and plans reconstructed with log files recorded during beam delivery with and without beam interruptions are shown in Table 3. The largest difference in target volume was observed in the maximum dose to the target volume between the original treatment plans and *8 times* plans (0.73% with $p = 0.007$). In the cases of OARs, the largest difference with statistical significance was observed in the mean dose to rectal wall between original treatment plans and *8 times* plans, which was 0.7% ($p < 0.001$). In the cases of H&N VMAT plans, the differences in dose-volumetric parameters are shown in Table 4.

Table 1
Global gamma passing rate of VMAT plans.

Gamma criterion	0 times (%)	4 times (%)	8 times (%)	*p* (0 times vs. 4 times)	*p* (0 times vs. 8 times)	*p* (4 times vs. 8 times)
Prostate VMAT plans						
3%/3 mm	99.8 ± 0.3	99.9 ± 0.2	99.7 ± 0.6	0.177	0.425	0.343
2%/2 mm	98.2 ± 1.1	98.8 ± 1.1	98.8 ± 0.9	0.008	0.030	0.581
1%/2 mm	93.7 ± 2.3	94.9 ± 1.6	94.9 ± 1.9	0.148	0.056	0.157
2%/1 mm	95.2 ± 2.2	96.6 ± 1.8	96.8 ± 1.5	0.033	0.015	0.041
Head and neck VMAT plans						
3%/3 mm	99.8 ± 0.2	99.8 ± 0.2	99.7 ± 0.3	0.574	0.041	0.181
2%/2 mm	97.4 ± 1.3	97.3 ± 1.2	96.6 ± 1.6	0.597	0.001	0.018
1%/2 mm	90.0 ± 2.4	90.3 ± 2.1	89.0 ± 2.8	0.498	0.009	<0.001
2%/1 mm	94.6 ± 2.1	94.3 ± 1.7	93.2 ± 2.5	0.470	<0.001	0.048

Abbreviations: 0 times, no interruption during delivery; 4 times, 4 times interruptions per arc during delivery; 8 times, 8 times interruptions per arc during delivery.