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Technical note

Geometric and dosimetric quality assurance using logfiles and a 3D helical diode detector for Dynamic WaveArc

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ABSTRACT

Purpose: To conduct patient-specific geometric and dosimetric quality assurance (QA) for the Dynamic WaveArc (DWA) using logfiles and ArcCHECK (Sun Nuclear Inc., Melbourne, FL, USA).

Methods: Twenty DWA plans, 10 for pituitary adenoma and 10 for prostate cancer, were created using RayStation version 4.7 (RaySearch Laboratories, Stockholm, Sweden). Root mean square errors (RMSEs) between the actual and planned values in the logfiles were evaluated. Next, the dose distributions were reconstructed based on the logfiles. The differences between dose-volumetric parameters in the reconstructed plans and those in the original plans were calculated. Finally, dose distributions were assessed using ArcCHECK. In addition, the reconstructed dose distributions were compared with planned ones.

Results: The means of RMSEs for the gantry, O-ring, MLC position, and MU for all plans were 0.2°, 0.1°, 0.1 mm, and 0.4 MU, respectively. Absolute means of the change in PTV $D_{99\%}$ were 0.4 ± 0.4% and 0.1 ± 0.1% points between the original and reconstructed plans for pituitary adenoma and prostate cancer, respectively. The mean of the gamma passing rate (3%/3 mm) between the measured and planned dose distributions was 97.7%. In addition, that between the reconstructed and planned dose distributions was 99.6%.

Conclusions: We have demonstrated that the geometric accuracy and gamma passing rates were within AAPM 119 and 142 criteria during DWA. Dose differences in the dose-volumetric parameters using the logfile-based dose reconstruction method were also clinically acceptable in DWA.

1. Introduction

Intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) offer the potential of a clinical benefit in terms of high doses to the target and reduced acute toxicity for organs at risk (OARs) [1,2]. Several studies have shown that non-coplanar IMRT and VMAT irradiation allows significant improvement in the treatment plan quality, especially when trying to spare adjacent OARs [3,4].

The Dynamic WaveArc (DWA) delivery technique is a novel non-coplanar arc delivery technique, involving a dynamic combination of multileaf collimator (MLC) motion and simultaneous gantry, O-ring rotation, and various dose rates [5–10]. DWA delivery techniques represent a fully automated non-coplanar arc delivery technique that does not require rotation of the treatment couch during the delivery process. Currently, DWA is clinically available on Vero4DRT (Mitsubishi Heavy Industries, Ltd., Hiroshima, Japan; and Brainlab AG, Munich, Germany) [9,10].

When a new radiotherapy technology is used, it is important to evaluate the geometric and dosimetric accuracy for patient-specific quality assurance (QA). In general, geometric and dosimetric assessments of the patient-specific QA have been performed using the ionization chamber, film, a three-dimensional (3D) diode array phantom [11,12], and logfiles [13,14]. Burghelea et al. performed patient-specific QA for DWA plans using an ionization chamber, film, and Delta4 diode array phantom (Scandidos, Uppsala, Sweden) as pre-clinical and/or clinical research [8,9].

Nelms et al. reported a low correlation between the gamma passing rate and dose errors in the patient's anatomical regions of interest [15]. Stasi et al. also indicated cases where high gamma passing rates were not in agreement with the patient's anatomic dose metrics [16]. Therefore, in addition to the gamma analysis, assessing dose errors in the patient's anatomy is important, especially for a complex delivery technique.

Recently, the dose reconstruction method based on logfiles has been used to evaluate dose errors in the patient's anatomy. Several

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researchers have demonstrated that dose reconstruction based on log-files was effective for assessing dose distribution in a patient's anatomy for co-planar VMAT [13,17,18].

Thus far, there are no reports assessing the dose distribution in a patient's anatomy using the dose reconstruction method and comparing the gamma passing rates between the reconstructed dose distribution and planned ones for non-coplanar VMAT, such as DWA. The purpose of this study was to assess the geometric and dosimetric accuracy of patient-specific QA for the DWA delivery technique using ArcCHECK (Sun Nuclear Corp (SNC), Melbourne, FL, USA) and logfile. Moreover, the reconstructed dose distributions based on logfiles were evaluated, allowing the comparison of the reconstructed dose distribution with the original treatment plan.

2. Materials and methods

2.1. Patient characteristics

A total of 20 patients, 10 who underwent a stereotactic irradiation for pituitary adenoma and 10 who underwent step-and-shoot IMRT technique for prostate cancer between March 2012 and April 2016, were enrolled in an institutional review board-approved trial (approval number R0470-1). These two treatment sites were determined by radiation oncologists.

2.2. Treatment plans

After CT scanning and contouring (Supplementary materials), 20 DWA plans were created for enrolled patients using the RayStation (version 4.7; RaySearch Laboratories, Stockholm, Sweden) treatment planning system. Fig. 1 presents DWA delivery trajectories for brain and prostate. The plans were performed with a reciprocating motion of ring rotation in the positive or negative direction simultaneously with the gantry rotating from 182° to 178° (clockwise direction). A single arc of continuous non-coplanar trajectory was selected from the list of pre-installed trajectories for both plans to achieve the desired target and OAR objectives. Table 1 summarizes the prescribed dose and dose-volume constraints for pituitary adenoma and prostate cancer cases. Combinations of different dose rates (150–400 monitor unit (MU)/min), gantry rotation speeds (0.1–6.0°/s), O-ring rotation speeds (0.1–2.5°/s), and dynamic MLC leaf velocities (1.0–4.0 cm/s) were applied. The dose calculation algorithm was a collapsed cone dose engine (version 3.1) with heterogeneity correction. The final dose was calculated on a 2.5 × 2.5 × 2.5 mm^3 resolution dose grid based on our institution-specific protocols.

2.3. Logfile analysis

The logfiles, which were acquired at the time of QA using ArcCHECK, were analyzed to evaluate machine accuracy. The Vero4DRT components including gantry, O-ring angle, MLC position, and MU were recorded as a function of time at a sampling rate of 20 Hz using the outputs of rotary of encoders. The logfiles were written in the two comma-separated value format: the control log and the MLC log. Root mean square errors (RMSEs) between the actual and planned values in the logfiles were calculated for gantry angle, O-ring angle, moving MLC position, and MU in acquired data at 50-ms intervals.

2.4. Reconstruction of dose distribution based on logfiles

Based on the acquired logfiles, dose distributions were reconstructed [13,17,18]. In-house software written in C# loaded an original DICOM-RT plan file and logfiles. The software searched the gantry position, corresponding to the planned position for 90 control points, replaced the planned values of the O-ring position and MLC position, and delivered MU with the corresponding control values from logfiles. When the actual gantry position did not match the planned one at each control point, linear interpolation was performed from adjacent actual values compared to extracted values.

Finally, a reconstructed DICOM-RT plan file was exported and then imported into RayStation. Dose distributions were recalculated on the planned CT images. The following dose-volumetric parameters were recorded: the dose was received based on 99% volume ($D_{99\%}$) of the planning target volume (PTV), $D_{2\%}$ of the chiasm and optic nerve, and the volume received more than 70 Gy ($V_{70\ Gy}$) for the rectal and bladder wall. The differences between dose-volumetric parameters in the

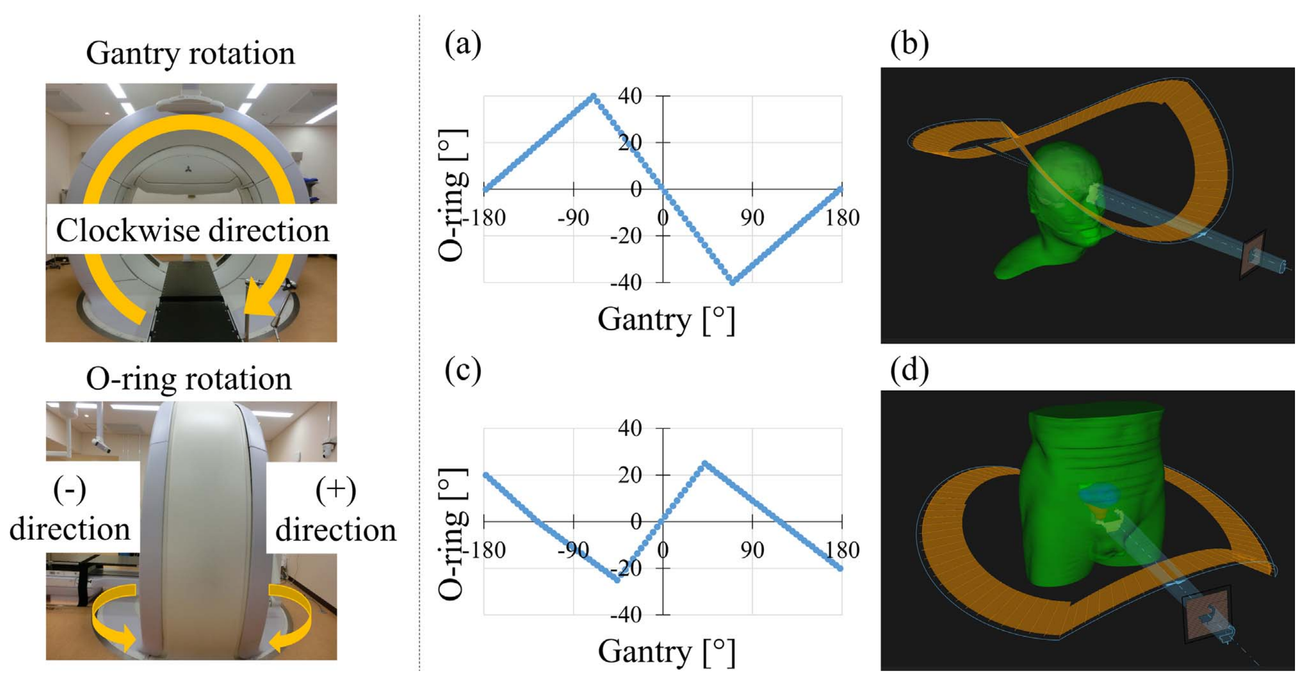

Fig. 1. Gantry and O-ring rotation direction, as well as DWA delivery trajectory: (a) the control point and (b) actual delivery trajectory for brain; (c) the control point and (d) actual delivery trajectory for prostate. The delivery plans of pituitary adenoma and prostate cancer were performed with reciprocating motion of O-ring rotation in the positive or negative direction simultaneously with the gantry rotating from 182° to 178° (clockwise direction). A single arc of DWA trajectory was generated for each plan in RayStation.