Physica Medica 31 (2015) 1118–1122

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Technical Notes

Gamma-index method sensitivity for gauging plan delivery accuracy of volumetric modulated arc therapy

Jong In Park [a,b], Jong Min Park [b,c,d,e,*], Jung-in Kim [b,c,d,e], So-Yeon Park [b,c,d,f], Sung-Joon Ye [a,b,c,d]

[a] Program in Biomedical Radiation Sciences, Department of Transdisciplinary Studies, Seoul National University Graduates School of Convergence Science and Technology, Seoul, Republic of Korea
[b] Biomedical Research Institute, Seoul National University Hospital, Seoul, Republic of Korea
[c] Department of Radiation Oncology, Seoul National University Hospital, Seoul, Republic of Korea
[d] Institute of Radiation Medicine, Seoul National University Medical Research Center, Seoul, Republic of Korea
[e] Center for Convergence Research on Robotics, Advanced Institutes of Convergence Technology, Suwon, Republic of Korea
[f] Interdisciplinary Program in Radiation Applied Life Science, Seoul National University College of Medicine, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 8 May 2015
Received in revised form 17 August 2015
Accepted 30 August 2015
Available online 1 October 2015

Keywords:
Pre-treatment quality assurance
Volumetric modulated arc therapy
Gamma-index method
Dynamic log file

ABSTRACT

Purpose: The aim of this study was to investigate the sensitivity of the gamma-index method according to various gamma criteria for volumetric modulated arc therapy (VMAT).
Methods: Twenty head and neck (HN) and twenty prostate VMAT plans were retrospectively selected for this study. Both global and local 2D gamma evaluations were performed with criteria of 3%/3 mm, 2%/2 mm, 1%/2 mm and 2%/1 mm. In this study, the global and local gamma-index calculated the differences in doses relative to the maximum dose and the dose at the current measurement point, respectively. Using log files acquired during delivery, the differences in parameters at every control point between the VMAT plans and the log files were acquired. The differences in dose–volumetric parameters between reconstructed VMAT plans using the log files and the original VMAT plans were calculated. The Spearman's rank correlation coefficients (r_s) were calculated between the passing rates and those differences.
Results: Considerable correlations with statistical significances were observed between global 1%/2 mm, local 1%/2 mm and local 2%/1 mm and the MLC position differences (r_s = –0.712, –0.628 and –0.581). The numbers of r_s values with statistical significance between the passing rates and the changes in dose–volumetric parameters were largest in global 2%/2 mm (n = 16), global 2%/1 mm (n = 15) and local 2%/1 mm (n = 13) criteria.
Conclusion: Local gamma-index method with 2%/1 mm generally showed higher sensitivity to detect deviations between a VMAT plan and the delivery of the VMAT plan.

Introduction

Volumetric modulated arc therapy (VMAT) enables the fast delivery of highly conformal prescription doses to target volumes while avoiding normal tissue complications by utilizing beam modulations [1]. Before delivery of a VMAT plan to a patient, pre-treatment quality assurance (QA) is strongly recommended to verify whether the intended dose distribution would be delivered properly to a patient or not. A widely-adopted pre-treatment QA method for VMAT is the delivery of a verification plan, identical to the treatment plan, to a two-dimensional (2D) detector array in order to measure the planar dose distribution [2]. Generally the measured planar dose distribution is compared to the calculated one in the treatment planning system (TPS) using the gamma-index method suggested by Low et al. [3].

Most clinics and previous studies have adopted the gamma-index method with a gamma criterion of 3%/3 mm. However, recent studies have recommended a gamma criterion of 2%/2 mm rather than a 3%/3 mm for VMAT [4]. These studies were performed with VMAT plans with intentional errors resulting in clinically unacceptable changes in dose distributions to evaluate the capability of the gamma-index method to detect unacceptable delivery of the VMAT plans [4]. In those studies, the analyzed gamma criteria were limited to 3%/3 mm and 2%/2 mm. On the other hand, Kim et al. demonstrated that the gamma criterion of 2%/1 mm was suitable to verify VMAT plans for stereotactic ablative radiotherapy (SABR) with high-definition MLC (HD-MLC) [5].

Another approach to the pre-treatment QA method is an analysis of dynamic log files recorded in the linac control system during delivery of a treatment plan. Peng et al. demonstrated the feasibility

* Corresponding author. Department of Radiation Oncology, Seoul National University Hospital, 101 Daehak-ro, Jongno-gu, Seoul 110-744, Republic of Korea. Tel.: +82 2 2072 2527; fax: 82-2-765-3317.
E-mail address: leodavinci@naver.com (J.M. Park).

http://dx.doi.org/10.1016/j.ejmp.2015.08.005
1120-1797/

of dynamic log file analysis as a pre-treatment QA method for VMAT [6]. Using dynamic log files as a pre-treatment QA verification system has some advantages. However it is potentially limited as it is not an independent verification system for VMAT delivery. In other words, pre-treatment QA with dynamic log files verifies the linac performance using the linac control system. To utilize dynamic log files as a pre-treatment QA method, it would be necessary to periodically verify the linac control system with an independent verification system to determine whether or not it is flawed.

Although various pre-treatment QA methods have been suggested, most clinics still use the 2D gamma-index method for practical reasons [4]. In this study, we investigated the sensitivity of gamma passing rates with various gamma criteria comparing the information from the dynamic log files as well as changes in clinically-relevant dose–volumetric parameters acquired from VMAT plans reconstructed with those dynamic log files. Since the reliability of dynamic log files has been demonstrated in previous studies, we assumed the differences between a VMAT plan and a dynamic log file is a measure of the VMAT delivery accuracy in this study after verifying the linac control system [6]. Sensitivity evaluation of various gamma criteria were performed using clinically acceptable head and neck (HN) and prostate VMAT plans in order to investigate the sensitivity in the fine resolution of passing rates. To investigate the sensitivity, correlations between the gamma passing rates and the deviations between the original treatment plan and the dynamic log files were analyzed.

Materials and methods

Volumetric modulated arc therapy plans

A total of 40 VMAT plans for HN cancer (20 cases) and prostate cancer (20 cases) were retrospectively selected for this study. For both HN and prostate VMAT planning, Trilogy™ with Millennium™ 120 MLC (Varian Medical Systems, Palo Alto, CA) was used. Every VMAT plan was generated with 6 MV photon beams and 2 full arcs in the Eclipse™ (Varian Medical Systems, Palo Alto, CA) system. The progressive resolution optimizer 3 (PRO3, version 10) and the anisotropic analytic algorithm (AAA, version 10) were used for the optimization and dose calculation, respectively. The dose calculation grid was 2.5 mm for the treatment plans. For HN plans, the simultaneous integrated boost (SIB) technique was used to treat nasopharyngeal cancer. A total of 3 target volumes, target 1, target 2 and target 3, were defined with a margin of 0.3 cm in every direction, which were the primary tumor, high-risk tumor and low-risk nodal area, respectively. Prescription doses to target 1, target 2 and target 3 were 67.5 Gy (2.25 Gy/fraction), 54 Gy (1.8 Gy/fraction) and 48 Gy (1.6 Gy/fraction), respectively. For prostate plans, a primary plan delivering 50.4 Gy (1.8 Gy/fraction) to the primary target volume and a boost plan subsequently delivering 30.6 Gy (1.8 Gy/fraction) to the boost target volume were generated. A primary target volume included both prostate and seminal vesicles while the boost target volumes included only the prostate. Only primary plans were analyzed for this study.

Pre-treatment QA using 2D gamma-index method

Pre-treatment QAs for each VMAT plan were performed using a MapCHECK2™ detector array with MapPHAN™ (Sun Nuclear Corporation, Melbourne, FL). When calculating the reference 2D dose distributions in the Eclipse™ system for gamma evaluation, the calculation grid was 1 mm. Before pre-treatment QA, the absolute dose of the 6 MV photon beam, absolute dose of the array and the relative reading of the array were calibrated. When setting the devices up for measurements, cone beam computed tomography (CBCT) as well as a laser localization system was used for accurate setup of the devices. After pre-treatment QA, the measured 2D dose distributions were compared to the calculated ones using the gamma-index method with SNC patient™ software (version 6.1.2. Sun Nuclear Corporation, Melbourne, FL). Local as well as global gamma evaluations were performed with gamma criteria of 3%/3 mm, 2%/2 mm, 1%/2 mm and 2%/1 mm. The points with doses less than 10% of the maximum dose were ignored to reduce noise [4].

Differences in parameters at each control point (CP) between the planned and delivered treatments

Before acquiring linac log files, MLCs, gantry angles and output were calibrated to ensure the reliability of log files. After that, dynamic log files which are records of actual gantry angles and delivered MUs at each CP, as well as DynaLog files which are records of actual MLC positions were acquired during the delivery of pre-treatment QA using the gamma-index method for VMAT plans. An in-house program was written in MATLAB (version 8.1, Mathworks Inc., Natick, MA) to combine the dynamic log file and DynaLog file and to format the combined file in DICOM-RT format. The differences between each MLC position, gantry angle and MU from the treatment plans and those from the DICOM-RT formatted log files were calculated at each CP. The average values of those differences of each VMAT plan were calculated for MLC positions, gantry angle and MU.

Dose–volumetric differences between the treatment plans and the plans reconstructed with log files

The DICOM-RT formatted log files were imported to the Eclipse™ system and the dose distributions were calculated using the patient CT images which were used for original planning. The same calculation grid as the original treatment plan, 2.5 mm, was used for the calculation of dose distributions. To calculate dose–volumetric parameters for each VMAT plan, identical structures as the original treatment plans were used. For planning target volumes (PTVs), the dose received by 95% of the PTV ($D_{95\%}$), $D_{5\%}$, the mean, maximum, and minimum dose to the PTV were calculated. For HN plans, maximum dose to spinal cord, brain stem, each lens, optic chiasm, and each optic nerve were calculated. For prostate plans, $D_{20\%}$ of rectal wall and bladder, $D_{50\%}$ of femoral head, and mean dose to rectal wall, bladder, and femoral head were calculated. The differences between the dose–volumetric parameters of original treatment plans and those of the reconstructed plans were calculated.

Correlation analysis for evaluation of sensitivity of the gamma-index method with various gamma criteria

Since the data in this study were not normally distributed, those were analyzed with the nonparametric statistics correlation test. Therefore, Spearman's rank correlation coefficients (r_s) and corresponding p values were calculated between the gamma passing rates and the averaged differences in gantry angles, MUs and MLC positions at every CP between the log file and the original treatment plan.

The differences in dose–volumetric parameters of each structure between the original treatment plans and the plans reconstructed with log files were averaged for HN VMAT plans (a total of 20 plans) and prostate VMAT plans (a total of 20 plans), respectively. The values of r_s and corresponding p values were calculated between the gamma passing rates and the averaged dose–volumetric differences for each structure.