Validation of Delivery Consistency for Intensity-Modulated Radiation Therapy and Volumetric-Modulated Arc Therapy Plans

Wui Ann Woon1,2, Paul B. Ravindran2,3, Piyasiri Ekayanake2, Yivonne Yih Fang Lim1

1Department of Radiation Oncology, The Brunei Cancer Center, 2Applied Physics Program, Faculty of Science, Universiti Brunei Darussalam, Bandar Seri Begawan, Brunei Darussalam, 3Department of Radiation Oncology, Christian Medical College and Hospital, Vellore, Tamil Nadu, India

Abstract

The delivery consistency of a Varian Edge linear accelerator over the entire course of treatment for nasopharynx carcinoma (NPC) and prostate cancer intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) treatment plans was investigated using four different approaches. Three NPCs and three prostate plans were delivered in 34 and 29 consecutive days, respectively, using a Varian Edge equipped with a 120 high-definition (HD) multileaf collimator (MLC). All deliveries were measured with an electronic portal imaging device (EPID), and MapCheck2 and ArcCheck commercial systems with gamma analysis used to compare the results of all daily measurements against the pretreatment patient-specific quality assurance. The daily log files generated were also assessed for differences between the actual and planned doses using an in-house program to replace the original values in the DICOM plan files with the delivered parameter values from the log file, and then exporting the plans back to the treatment planning system for reconstruction of the actual dose delivered. The trajectory log file and EPID methods showed very good agreement, with minimal deviations between the daily delivered and reference doses. However, comparisons of the MapCheck2 and ArcCheck with the EPID revealed statistically significant differences ($P < 0.001$, one-tailed) with greater daily fluctuations, raising concerns over the performance, and reliability of the MapCheck2 and ArcCheck systems when being used to identify IMRT and VMAT plans with poor dosimetric accuracy. We conclude that the Varian Edge linear accelerator equipped with a 120 HD MLC can consistently deliver IMRT and VMAT plans over the entire treatment course.

Keywords: Dosimetry, intensity-modulated radiation therapy, quality assurance, volumetric-modulated arc therapy

Received on: 11-09-2017 Review completed on: 02-05-2018 Accepted on: 05-05-2018

INTRODUCTION

Radiation therapy (RT) is one of the most important modalities for cancer treatment, accounting for approximately 50% of all cancer patients. The principal behind daily fractionated RT is that high-energy ionizing radiation is used to damage genetic material in the cancer cell beyond repair, thereby resulting in cell death. However, in RT, it is not possible to avoid depositing a radiation dose in healthy tissue or organs at risk (OAR) surrounding the cancer cells, and therefore, toxicity and side effect arises such as cervical subcutaneous fibrosis, hearing loss, skin dystrophy, xerostomia, trismus, temporal lobe injury, cranial nerve damage, cataaract, and brain stem injury for treatment of the head-and-neck cancer. Furthermore, the severity of late toxicities ranging from Grade 1-4 was observed depending on the dose to critical organs. Technological advancements in radiotherapy machines, with techniques such as intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) permit the delivery of much higher doses to the cancer cells than are possible with conventional RT treatment, while also minimizing dose to the OAR and healthy tissue. This results in reduced toxicity, and improvements to local control

Address for correspondence: Mr. Wui Ann Woon, Department of Radiation Oncology, The Brunei Cancer Center, Bandar Seri Begawan, BG3122, Brunei Darussalam. E-mail: wwa143@gmail.com

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: reprints@medknow.com

How to cite this article: Woon WA, Ravindran PB, Ekayanake P, Lim YY. Validation of delivery consistency for intensity-modulated radiation therapy and volumetric-modulated arc therapy plans. J Med Phys 2018;43:119-28.
rate, survival rate, and disease-free survival rates.\[5-7\] This delivery of higher doses is made possible by the multileaf collimator (MLC), which is capable of generating a very steep dose gradient and nonuniform dose during treatment delivery with a field shape that is constantly changing in the IMRT technique,\[8\] and with the further addition of a constantly moving gantry in the VMAT technique.\[9\]

With such complexity in the treatment delivery, pretreatment patient-specific quality assurance (QA) is mandatory for every treatment plan optimized with the IMRT and VMAT techniques, as this will assess whether the dose delivered to the patient is in agreement with the calculated plan.\[10\] Gamma analysis is a widely accepted technique to quantitatively evaluate IMRT and VMAT plans that was developed by Low \textit{et al.},\[11\] which compares the treatment planning system (TPS) calculated dose distribution against the measured dose distribution. Furthermore, the differences between the calculated and measured dose distribution can be analyzed using the absolute gamma criteria of 3\% dose difference (%DD) and 3-mm distance to agreement (DTA) with 90\% of gamma passing rate (%GP), and action limit recommended by AAPM TG119.\[12\]

Many authors have reported on the pretreatment verification of IMRT and VMAT QA, including the use of a variety of devices such as film, ionization chambers, diode detector arrays, ion chamber arrays, and electronic portal imaging devices (EPID).\[13-19\] However, recent studies have shown that performing patient-specific QA with QA metrics recommended by AAPM TG119 for IMRT and VMAT plans does not guarantee clinically relevant dosimetric accuracy.\[20-23\] This has become an important issue, as one study has shown that introduction of a systematic error of only 0.5 mm into the MLCs of a VMAT plan for spine treatment could increase the volume of spinal cord receiving 10 Gy by 58.9\% (it should be <10\%),\[23\] which may lead to a Grade 3+ myelitis or worse, if the errors are not detected by QA. Alternative methods to assess the accuracy of the dose delivered by the IMRT and VMAT techniques have been proposed, including generating a dose volume histogram (DVH) of the patient from a measured dose distribution recorded using ArcCheck or COMPASS.\[22,24-27\] In addition, Nelms \textit{et al.}\[28\] suggested that the DTA of 3\%/3 mm is insensitive, as modern radiotherapy machines are equipped with MLCs capable of modulating the radiation beam to within the order of 1 mm. Furthermore, Yan \textit{et al.}\[17\] also suggested the use of a much tighter gamma criterion, to improve the sensitivity for detecting potential errors in IMRT, and VMAT QA.

Much effort has been expended attempting to find alternative methods, or on improving the pretreatment patient-specific QA, to accurately separate erroneous plans from good quality plans.\[29\] However, to the best of our knowledge, very few studies have attempted to validate whether passing the patient-specific QA for IMRT or VMAT plans is sufficient to assume that the actual daily delivery can maintain its consistency over the entire course of the treatment.

In this work, we investigated the capability of a Varian Edge (Varian Medical Systems, Palo Alto, CA, USA) linear accelerator equipped with a 120 high-definition (HD) MLC to consistently deliver nasopharynx carcinoma (NPC) and prostate cancer plans over the entire course of treatment using four different approaches as follows: (1) trajectory log files generated during the actual delivery, (2) measurements performed using EPID, (3) MapCheck2, and 4) ArcCheck.

**Materials and Methods**

**Patient plan selection and treatment planning**

Three clinical head-and-neck cases and three prostate cases were selected from our database for this study. All cases were generated with the EclipseTM planning system (version 13, Varian Medical Systems, Palo Alto, CA, USA) and were clinically approved and treated using a nine-field simultaneous integrated boost IMRT on a Varian Edge linear accelerator equipped with a HD120-leaf MLC (Varian Medical Systems, Palo Alto, CA, USA). The HDMLC transmission factor is 0.0125, and dosimetric leaf gap is 0.0292 cm for 6 MV photon beam.\[30\] To develop real-world clinical examples, each of the clinical plans was copied and reoptimized with the same planning objectives using the dose volume optimizer and progressive resolution optimizer (version 13.0.26, Varian Medical Systems, Palo Alto, CA, USA) to generate the IMRT and VMAT plans, respectively. The final volume dose was calculated using the anisotropic analytic algorithm (version 13.0.26, Varian Medical Systems, Palo Alto, CA, USA) with a grid size of 1 mm × 1 mm × 1 mm and heterogeneity correction.

A coplanar two-arc VMAT and a coplanar 9-field IMRT plans were generated using 6 MV photon beams with a 600 MU/min dose rate with the following prescription for NPC cases as follows: 70 Gy for primary tumors including gross lymph nodes, 59.4 Gy for high-risk nodes, and 54 Gy for low-risk nodes, all to be delivered in 33 fractions. Furthermore, the prescription for prostate cases was 73.8 Gy for the primary tumor, to be delivered in 28 fractions. In addition, a collimator angle of 330° and 30° was used for two-arc VMAT plans and 0° collimator angle for 9-field in IMRT plans.

The main objectives used during the optimization of the IMRT and VMAT plans included that at least 95\% of the prescription dose should be delivered to 100\% of the target volume and that the maximum dose in the plan should not exceed 107\% of the prescription dose. For the planning risk volumes, a 5-mm margin was added around critical organs such as the spinal cord and brainstem to account for the geometric uncertainties of the organ. The maximum doses to these organs were kept to <45 Gy and <54 Gy, respectively. It is important to note that only the OARs listed in Table 1 were analyzed in this study. In addition, the constraints used with regard to the OARs are listed in Table 1, with the total number of monitor units (MUs) generated for each plan during optimization being shown in Table 2. Despite the limited number of OARs analyzed in this study, many other normal structures, such as the parotid glands (left-L, right-R), the mandibular and
temporal mandibular joints, the optic chiasm and the optic nerves, femoral head, and the small bowel were included in the optimization process.

The NPC and prostate plans were delivered in 34 and 29 consecutive days, respectively (including the first measurement as a reference). All measurements were obtained using EPID, MapCheck2, and ArcCheck. Furthermore, the results of all daily measurements were compared to the results of the pretreatment patient-specific QA (first measurement) using gamma analysis. In addition, the daily log files generated were assessed for differences between the actual and planned doses, to investigate whether pretreatment patient-specific QA is sufficient to assume that the actual daily delivery can maintain its constancy over the entire course of the treatment.

**Trajectory log file description**

The trajectory log files come in a binary format capable of recording at 50 Hz intervals (20 ms) the important machine parameters that were actually used during the treatment delivery, such as MLC position, dose rate, jaw position, and gantry angle sampling until treatment is completed. At the end of each treatment, these files were transferred to an external computer containing an in-house program. All IMRT and VMAT treatment plans were also exported in DICOM format to the same external computer for plan modification as shown in Figure 1. The in-house program can insert the actual delivery parameter values from the log file into the DICOM plan files to replace the original values found in the DICOM RT plan file. A total of 2013 trajectory log files generated from daily treatments with 366 copied plans underwent modifications using the in-house program. The differences in each of the DVH metrics between the original and modified plans were then evaluated.

An in-house software to convert the information of actual delivery parameters from the trajectory log files have been developed. Each field of an IMRT plan consisted of 166 control points, and each full arc of a VMAT plan consisted of 177 control points. Each control point consisted of a sub-field that contained several important parameters, such as the position of each leaf in the MLC, gantry angle, jaw position, and cumulative dose index. Therefore, this software written in Python programming language (The Scientific Python Development Environment, Version 2.7+, The Spyder Development Team, http://www.python.org/) is capable of modifying the parameters at each control point. As shown in Figure 2, to locate and access the directory of a control point sequence, the following code (300a, 0111) should be followed by the control point number (1–166) to access each control point. A “For” loop is used to automate the process so that by using a mathematical operation, an automated process will proceed from one control point to the next (for example, for r in range [0, 166, 1]). The same mathematical operation is also used to automate the process for accessing each leaf position, therefore, resulting in an automated replacement of the actual treatment delivery position from the trajectory log files to the original values found in the DICOM RT plan file.

**Measurement with EPID**

The EPID, as shown in Figure 3b, was an aS1200 digital megavoltage imager (DMI) consisting of 1280 × 1280 pixels with a sensitive area of 43 cm × 43 cm and a resolution of 0.336 mm. Before any measurement was taken in this study, a calibration was performed to yield the most accurate readings. A 10 cm × 10 cm field size using a 6 MV photon beams with a dose rate of 600 MU/min and 100 MUs was delivered to the DMI panel at a focus (target) to detector distance (FDD) of 100 cm, such that 1 Gy was equivalent to 0.9994 ± 0.00143

| Case   | OAR                | Dose constraint |
|--------|--------------------|-----------------|
| NPC    | Spinal cord        | D_{max} <45 Gy  |
|        | Brainstem          | D_{max} <54 Gy  |
| Prostate | Rectum            | V40 G<35%       |
|         |                    | V65 G<17%       |
|         |                    | V75 G<10%       |
|         | Bladder            | V40 G<50%       |
|         |                    | V50 G<50%       |
|         |                    | V65 G<25%       |

OAR: Organs at risk

| Case | Total MUs |
|------|-----------|
|      | IMRT      | VMAT      |
| NPC  | 1         | 1877      | 889      |
|      | 2         | 1496      | 1077     |
|      | 3         | 1472      | 864      |
| Prostate | 1    | 1018      | 629      |
|        | 2         | 783       | 565      |
|        | 3         | 767       | 587      |

MU: Monitor units, IMRT: Intensity-modulated radiation therapy, VMAT: Volumetric-modulated arc therapy, NPC: Nasopharynx carcinoma

Figure 1: Workflow of the patient-specific dose volume histogram-based quality assurance using trajectory log files
calibrated unit in portal dosimetry (version 13.0.26, Varian Medical Systems, Palo Alto, CA, USA). All daily measurements, including pretreatment patient-specific QA, were performed at an FDD of 100 cm with the fluences generated from each field in the IMRT and VMAT plans recorded and converted to a two-dimensional (2D) dose distribution for analysis.

**Measurement with MapCheck2**

Mapcheck2 (Sun Nuclear Corporation, Melbourne, FL, USA) as shown in Figure 3a, is a 2D diode array detector that contains 1527 n-type SunPoint® diode detectors capable of measuring a field size of 32 (length) × 26 (width) cm² with a 7.07-mm uniform detector spacing. For accurate measurements, the array detectors are calibrated to correct for the relative differences between the detectors, and in addition, the responses from each detector are calibrated such that 1 MU is equivalent to 1 cGy using a 10 cm × 10 cm field size for a beam of 6 MV photons at a 95.8 cm focus (target) to surface distance (FSD) with a 3-cm buildup. All calculated plane doses from the Eclipse TPS were exported from the MapCheck2 phantom to an external computer containing the dosimetry software SNC Patient™ version. 6.6.2 (Sun Nuclear Corporation, Melbourne, FL, USA), to make comparisons with all the other measurement data. As diode detectors have a directional dependence, MapCheck2 was used only on the IMRT plan with the radiation field perpendicular to the array detectors.

**Measurements with ArcCheck**

ArcCheck (Sun Nuclear Corporation, Melbourne, FL, USA) as shown in Figure 3c, is a cylindrical detector with a 21-cm diameter and a 21-cm length. It is capable of measuring fluences with a continuous gantry rotation during treatment delivery, and was designed for the purpose of measuring VMAT deliveries. The ArcCheck detector contains 1386 n-type SunPoint® diode detectors arranged in a helical grid geometry at a 2.9-cm depth, with 1-cm detector spacing. For accurate measurements, the array detectors and dose calibration are performed at an FSD of 86.7 cm, with the same 10 cm × 10 cm field size and 6 MV photon beam. Furthermore, the density of ArcCheck was corrected with measurements obtained on a standard 0.6 cc Farmer ionization chamber (PTW 30013, Germany) inserted into the central cavity of the phantom using a Sun Nuclear PC electrometer, such that a correct 3D dose distribution could be calculated by the TPS and exported to the dosimetry software SNC Patient™ version. 6.6.2 (Sun Nuclear Corporation, Melbourne, FL, USA) for analysis.

**Data analysis**

The following DVH metrics were selected to quantitatively analyze the differences in DVH between the original and modified plans using the trajectory log file method: mean dose (Dmean), minimum dose (Dmin), and maximum dose (Dmax) of the planning target volume (PTV) and OAR, thus allowing the relative differences in the DVH to be calculated according to the following equation:

\[
\text{Dose Error(%) = } \frac{(\text{Modified plan dose (cGy)} - \text{Original plan dose (cGy)})}{\text{Original plan dose (cGy)}} \times 100
\]

The average dose errors of three NPC and three prostate cases were calculated with respect to each DVH metric, and were plotted against the number of fractions delivered.

**Gamma analysis**

Absolute gamma analyses were used to compare all measurements performed using EPID, MapCheck2, and ArcCheck with the calculated dose generated by the TPS. Global normalization with a stringent gamma criterion of 3%/1 mm was used to improve the sensitivity for detecting potential errors. A low-dose threshold of 10% was applied to reduce noise effects, and an action level of 90% GP rate was set to differentiate between good and poor-quality plans. Furthermore, to quantitatively analyze the differences between daily measurements and pretreatment patient-specific QA, the following calculation was used:

\[
\text{Gamma Difference(%) = } \frac{\%GP_{\text{daily measurement}} - \%GP_{\text{first measurement}}}{\text{Dose Error(%)}}
\]

The resulting gamma differences with respect to each case were plotted against the number of fractions delivered.

**Results**

**Dose-volume histogram analysis**

The average dose error (%) and standard deviations of the three NPC cases and three prostate cases optimized with the IMRT and VMAT technique are illustrated in Figures 4 and 5, respectively, for each of the DVH metrics. For the analysis of delivery consistency, the daily dose errors (%) between the original plans and the modified plans with the actual delivery parameters were subtracted from a reference dose error (%), with respect to each DVH metric generated from the first measurement. For IMRT of the prostate, no deviation was observed in any of the DVH metrics over the entire 28 fractions, except for Dmin of PTV, where a minimal deviation of 0.00 ± 0.01% dose error was observed between the first and daily measurements. The analysis of VMAT prostate cases showed a minimal deviation in dose error (%) in all DVH metrics, except for Dmin of the rectum, with the observed deviation ranging from 0.00 ± 0.01% to 0.03 ± 0.05% dose error. Both IMRT and VMAT NPC cases showed similar results, with deviation being observed in Dmax of both the brainstem and spinal cord, and an additional deviation also being observed in the Dmax of the PTV for IMRT NPC. The observed deviations ranged from 0.00 ± 0.02% to 0.03 ± 0.03% dose error.

**Portal dosimetry analysis**

Fluences measured daily using the EPID from each field of the IMRT, and VMAT plans were compared to fluences calculated using gamma analysis of the portal dosimetry, with the resulting average %GP rates being subtracted from a reference %GP for both prostate and NPC cases, as shown in Figures 6 and 7, respectively. In IMRT of the prostate, the average gamma differences (%) between the daily %GP and reference %GP were 0.30 ± 0.22%, 0.10 ± 0.21%, and 0.05 ± 0.25%,
respectively, for cases 1, 2, and 3, whereas for VMAT, they were 0.15 ± 0.09%, 0.23 ± 0.09%, and 0.61 ± 0.14%, respectively, as shown in Table 3. For IMRT NPC cases 1, 2, and 3, the average gamma differences (%) were 0.04 ± 0.29%, −0.31 ± 0.45%, and −0.25 ± 0.32%, respectively, whereas in VMAT NPC, they were 0.19 ± 0.15%, 0.06 ± 0.33%, and −0.17 ± 0.30%, respectively, as shown in Table 4.

**Gamma analysis using MapCheck and ArcCheck**

The gamma differences (%) between daily %GP and reference %GP for IMRT and VMAT are shown in Figure 6 for prostate cases and Figure 7 for NPC cases. In the analysis of prostate cases, a slightly larger standard deviation was observed in VMAT plans than in IMRT plans, with VMAT plans ranging from −0.9 ± 2.47% to 1.87 ± 2.56%, and IMRT plans ranging from −0.59 ± 1.42% to 1.76 ± 1.43% as shown in Table 5. Similar results were found in NPC cases, with a slightly larger standard deviation again being observed in VMAT plans than in IMRT plans, with VMAT plans ranging from −1.47 ± 1.76% to −0.75 ± 0.84%, and IMRT plans ranging from 0.11 ± 0.63% to 0.54 ± 0.60% as shown in Table 6.

**Discussion**

The ability of the Varian Edge linear accelerator to consistently deliver three NPC and three prostate plans optimized for IMRT and VMAT techniques over the entire treatment course has been validated using four different methods. The first method involved using information from the trajectory log files to modify the plan when the dose was being reconstructed in the TPS, and then analyzing the resulting DVHs. An important point to note is that the clinical impact due to dose error (%) in the DVH between the original and modified plans was not studied, as the main aim of this study was to investigate the consistency and reproducibility of the error over the entire course of delivery. Furthermore, the results showed minimal deviations in the daily delivery of IMRT and VMAT plans over the entire course, thus indicating only minimal differences between actual and planned MLC positions, dose rates, gantry angles, MUs, and jaw positions. However, when compared to the EPID method, an increase in deviation was observed between daily and reference measurements. The reason for this was that in the trajectory log file method, the cumulative dose fraction was converted to absolute dose in the TPS, using the beam data collected during commissioning. By contrast, the increased deviations observed in the EPID method were due to the fact that the daily fluctuation of the beam output (absolute
Figure 4: Daily dose errors (%) in Dmin, Dmax, and Dmean of (a) brainstem, (b) spinal cord, and (c) planning target volume, averaged over three nasopharynx carcinoma cases. The error bars indicate one standard deviation.

Table 3: Daily gamma difference (%) observed in all three intensity-modulated radiation therapy and volumetric-modulated arc therapy prostate cases measured with electronic portal imaging device

|          | IMRT_EPID | VMAT_EPID |
|----------|-----------|-----------|
| Prostate Case-1 | [-0.13-0.80] | [-0.20-0.20] |
| Prostate Case-2 | [-0.57-0.37] | [0.00-0.30]  |
| Prostate Case-3 | [-0.36-0.60] | [0.40-0.90]  |
| Range     | 0.30±0.22 | 0.15±0.09  |
| Mean±SD   | 0.10±0.21 | 0.23±0.09  |

Table 4: Daily gamma difference (%) observed in all three intensity-modulated radiation therapy and volumetric-modulated arc therapy nasopharynx carcinoma cases measured with electronic portal imaging device

|          | IMRT_EPID | VMAT_EPID |
|----------|-----------|-----------|
| NPC Case-1 | [-0.13-0.80] | [-0.20-0.20] |
| NPC Case-2 | [-0.57-0.37] | [0.00-0.30]  |
| NPC Case-3 | [-0.36-0.60] | [0.40-0.90]  |
| Range     | 0.24±0.29 | 0.41±0.15  |
| Mean±SD   | -0.31±0.45| 0.06±0.33  |

dose) was taken into consideration with respect to the MUs delivered.

Further analysis on prostate cases with the EPID method showed that the deviation observed was higher in IMRT plans than in VMAT plans, although the difference did not reach statistical significance ($P > 0.05$, one-tailed). This was because the total number of MUs delivered and the number of control points in each IMRT plan was very much higher than in the VMAT plans, and therefore, the deviation observed was higher in IMRT when fluctuations in the beam output (absolute dose) were taken into account. Similar results were observed in NPC cases, with the deviation being
slightly higher than in the prostate cases, due to the high number of MUs in each plan.

Comparisons of the MapCheck2 and ArcCheck methods with the EPID method, as shown in Figures 6 and 7, reveal a statistically significant difference between the results ($P < 0.001$, one-tailed). In addition, the daily fluctuation observed was greater in the MapCheck2 and ArcCheck methods than in the EPID method. This was due to the following reasons such as (1)
random daily setup errors\(^{[31]}\) in the MapCheck2 and ArcCheck methods as opposed to the automated EPID setup, and (2) the poor resolution of MapCheck2 and ArcCheck with detector spacings of 7.07 mm and 1 cm, respectively. This subsequently led to a combination of random setup errors together with undersampling, and therefore, greatly affected the gamma analysis.\(^{[29,32]}\) Unfortunately, data from the MapCheck2 and ArcCheck that are shown in Figures 6 and 7 indicate that the linear accelerator exhibited poor consistency and reproducibility in delivery of the IMRT and VMAT plans, are not true, as
revealed by the trajectory log file and EPID methods. Although the superior EPID detector resolution has been repeatedly made in the literature, it is important to address the drawbacks of such system, for example, (1) no communication of subfields during magna field IMRT, (2) no plan verification, only field verification, and (3) unable to perform field verification on noncoplanar plans without resetting the couch rotation to zero.

One of the main limitations of this study was the limited number of patients used to investigate the consistency of IMRT and VMAT delivery by the linac over the entire course of treatment; however, this is a pilot study, and more samples will be included in the future studies.

Finally, this study indicates that when an IMRT or VMAT plan has passed patient-specific QA, it is sufficient to assume that the actual daily delivery can maintain its consistency and reproducibility over the entire course of the treatment, as is evident from the analysis of 2013 trajectory log files and EPID results.

**Conclusion**

This study used four different methods to investigate the consistency of IMRT and VMAT delivery over the entire course of treatment. The trajectory log file and EPID monitoring daily fraction treatment have shown consistency in the delivery of IMRT and VMAT plans. Therefore, we conclude that the Varian Edge linear accelerator equipped with a 120 HD MLC is capable of consistently delivering IMRT and VMAT plans over the entire course of treatment. Furthermore, IMRT and VMAT are more complex in NPC cases than in prostate cases, therefore, there is an increase in deviation observed. In addition, through comparisons with a more stringent gamma index, this work has raised questions over the performance and reliability of MapCheck2 and ArcCheck for use as patient-specific QA to identify IMRT and VMAT plans with poor dosimetric accuracy.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Baskar R, Lee KA, Yeo R, Yeoh KW. Cancer and radiation therapy: Current advances and future directions. Int J Med Sci 2012;9:193-9.
2. Zheng Y, Han F, Xiao W, Xiang Y, Lu L, Deng X, et al. Analysis of late toxicity in nasopharyngeal carcinoma patients treated with intensity modulated radiation therapy. Radiat Oncol 2015;10:17.
3. Zeng L, Tian YM, Sun XM, Chen CY, Han F, Xiao WW, et al. Late toxicities after intensity-modulated radiotherapy for nasopharyngeal carcinoma: Patient and treatment-related risk factors. Br J Cancer 2014;110:49-54.
4. Ghadjar P, Vock J, Vetterli D, Manser P, Bigler R, Tille J, et al. Acute and late toxicity in prostate cancer patients treated by dose escalated intensity modulated radiation therapy and organ tracking. Radiat Oncol 2008;3:35.
5. De Felice F, Galdieri A, Abate G, Bulzonetti N, Musio D, Tombolini V, et al. Definitive intensity-modulated radiotherapy in elderly patients with locally advanced oropharyngeal cancer. In Vivo 2017;31:455-9.
6. Li Y, Xu B, Xu X, Wu H, Han S, Zhang S. Analysis of dosimetry and clinical outcome using intensity modulated radiation therapy for early breast cancer patients after breast conservative surgery. Chin J Radiol Med Prot 2009;29:74-7.
7. De Neve W, De Gerssem W, Madani I. Rational use of intensity-modulated radiation therapy: The importance of clinical outcome. Semin Radiat Oncol 2012;22:40-9.
8. Webb S. The physical basis of IMRT and inverse planning. Br J Radiol 2003;76:678-89.
9. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 2008;35:310-7.
10. Low DA, Moran JM, Dempsey JF, Dong L, Oldham M. Dosimetry tools and techniques for IMRT. Med Phys 2011;38:1313-38.
11. Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. Med Phys 1998;25:656-61.
12. Ezzell GA, Burmeister JW, Dogan N, LoSasso TJ, Mechalakos JG, Mihailidis D, et al. IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. Med Phys 2009;36:5359-73.
13. Hussein M, Rowshanfarzad P, Ebert MA, Nisbet A, Clark CH. A comparison of the gamma index analysis in various commercial IMRT/VMAT QA systems. Radiother Oncol 2013;109:370-6.
14. van Elmpt W, McDermott L, Nijsten W, Welling M, Lambin P, Mijnheer B, et al. A literature review of electronic portal imaging for radiotherapy dosimetry. Radiother Oncol 2008;88:289-309.
15. Van Esch A, Depuydt T, Huyskens DP. The use of an aSi-based EPID for routine absolute dosimetric pre-treatment verification of dynamic IMRT fields. Radiother Oncol 2004;71:223-34.
16. Li JG, Dempsey JF, Ding L, Liu C, Palta JR. Validation of dynamic MLC-controller log files using a two-dimensional diode array; Med Phys 2003;30:799-805.
17. Yan G, Liu C, Simon TA, Peng LC, Fox C, Li JG, et al. On the sensitivity of patient-specific IMRT QA to MLC positioning errors. J Appl Clin Med Phys 2009;10:2915.
18. Dong L, Antolak J, Salehpour M, Forster K, O’Neill L, Kendall R, et al. Patient-specific point dose measurement for IMRT monitor unit verification. Int J Radiat Oncol Biol Phys 2003;56:867-77.
19. Sathiyanan S, Ravikumar M, Varatharaaj C, Supe SS, Keshava SL. IMRT implementation and patient specific dose verification with film and ion chamber array detectors. Gulf J Oncolog 2010;8:20-7.
20. Kruse JJ. On the insensitivity of single field planar dosimetry to IMRT inaccuracies. Med Phys 2010;37:2516-24.
21. Nelms BE, Zhen H, Tomé WA. Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors. Med Phys 2011;38:1037-44.
22. Jin X, Yan H, Han C, Zhou Y, Yi J, Xie C, et al. Correlation between gamma index passing rate and clinical dosimetric difference for pre-treatment 2D and 3D volumetric modulated arc therapy dosimetric verification. Br J Radiol 2015;88:20140577.
23. Kim JJ, Park SY, Kim HJ, Kim JH, Ye SJ, Park JM, et al. The sensitivity of gamma-index method to the positioning errors of high-definition MLC in patient-specific VMAT QA for SBRT. Radiat Oncol 2014;9:167.
24. Yi J, Han C, Zheng X, Zhou Y, Deng Z, Xie C, et al. Individual volume-based 3D gamma indices for pretreatment VMAT QA. J Appl Clin Med Phys 2017;18:28-36.
25. Stasi M, Bresciani S, Miranti A, Maggio A, Sapino V, Gabriele P, et al. Pretreatment patient-specific IMRT quality assurance: A correlation study between gamma index and patient clinical dose volume histogram. Med Phys 2012;39:7626-34.
26. Zhen H, Nelms BE, Tome WA. Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA. Med Phys 2011;38:5477-89.
27. Kadoya N, Saito M, Ogasawara M, Fujita Y, Ito K, Sato K, et al. Evaluation of patient DVH-based QA metrics for prostate VMAT: Correlation between accuracy of estimated 3D patient dose and magnitude of MLC misalignment. J Appl Clin Med Phys 2015;16:5251.
28. Nelms BE, Chan MF, Jarry G, Lemire M, Lowden J, Hampton C, et al. Evaluating IMRT and VMAT dose accuracy: Practical examples
of failure to detect systematic errors when applying a commonly used metric and action levels. Med Phys 2013;40:111722.

29. Woon W, Ravindran PB, Ekayanake P, Subramani V, Lim YY, Khalid J, et al. A study on the effect of detector resolution on gamma index passing rate for VMAT and IMRT QA. J Appl Clin Med Phys 2018;19:230-48.

30. Yao W, Farr JB. Determining the optimal dosimetric leaf gap setting for rounded leaf-end multileaf collimator systems by simple test fields. J Appl Clin Med Phys 2015;16:65-77.

31. Chandraraj V, Stathakis S, Manickam R, Esquivel C, Supe SS, Papanikolaou N, et al. Consistency and reproducibility of the VMAT plan delivery using three independent validation methods. J Appl Clin Med Phys 2010;12:3373.

32. Bailey DW, Nelms BE, Attwood K, Kumaraswamy L, Podgorsak MB. Statistical variability and confidence intervals for planar dose QA pass rates. Med Phys 2011;38:6053-64.