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Dose Evaluation of Head and Neck Cancer IMRT Treatment Planning Based on Gamma Index Analysis of Varian Halcyon 2.0 Linac

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ABSTRACT

Varian Halcyon 2.0 linear accelerator was launched and became available for clinical use in 2018. Therefore, it is necessary to evaluate the accuracy of exit fluence of the Halcyon 2.0 for quality assurance (QA) of head and neck cancer treatment planning, pretreatment, and treatment. The accuracy of the exit fluence for twenty treatment plannings has been evaluated by conducting gamma analysis for QA pretreatment and treatment in each field and composite field by using criteria for gamma index 3 %/3 mm and 2 %/2 mm. The QA pretreatment results are in the average value for each criterion for each field and composite fields on actual gantry angle and null gantry angle with gamma passing rate (GPR) of over 99 % (range 99.78 %-99.95 %) The total treatments consisted of 2717 fractions. The analysis results of GPR for fields were 99.32 % and 97.74 % for gamma indexes of 3 %/3 mm and 2 %/2 mm, respectively. In addition, the analysis results of GPR for composites were 95.46 % and 81.38 % for gamma indexes of 3 %/3 mm and 2 %/2 mm, respectively. Based on this result, the average GPRs of QA pretreatment are ≈ 99 % of the total pixels. This means the prediction dose of Varian Halcyon 2.0 is accurate. The average GPRs of treatment is nearly > 90 %, showing that Varian Halcyon 2.0 is effective for creating treatment plans for complex cases.

INTRODUCTION

Treatment planning for head and neck cancer is quite complex because of its complicated shape and configuration, and the position of cancer close to organs-at-risk (OARs) such as the spinal cord, brain stem, and salivary glands. In Indonesia, the number of recent head and neck cancer cases reached 19 943 patients by 2020 [1]. Intensity-modulated radiation therapy (IMRT) techniques with medical linear accelerator (linac) have been widely used for head and neck treatment planning and have become the standard of nasopharyngeal cancer (NPC) treatment based on National Comprehensive Cancer Network (NCCN) guidelines category 2A [2]. The IMRT technique provides a delivery beam that conforms more closely to tumor targets even with concave contours [3,4].

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Varian Medical Systems launched Halcyon Linac in 2017. In July 2018, Halcyon 2.0 was launched with enhanced features. The Halcyon system, a fast-rotating O-ring, was designed to be friendly for IMRT and volumetric modulated arc therapy (VMAT) techniques. The accuracy and precision of IMRT/VMAT planning and delivery depend on the quality of the treatment planning system (TPS) commissioning and multileaf collimator (MLC) [5-7]. The preconfiguration of Halcyon is built into the Eclipse TPS, and the users are unable to modify it. Halcyon's reference beam model which relates to small fields has shown good reference values on Halcyon 1.0. However, the small beam makes it challenging to commission the Halcyon for IMRT/VMAT [8-10].

Dose evaluations on QA pretreatment and treatment based on gamma index analysis using Halcyon 2.0 were carried out by Kim et al. [11] and Jin et al. [12] in 2019. The objects of the study by

Kim et al. are gynecological cancers with gamma indexes of 4 %/4 mm and various comparisons per field, interfraction, and composite. Meanwhile, Jin et al. conducted a study on the objects of the head and neck, brain, breast, prostate, and pelvis with a gamma index of 3 %/3 mm and used only composite comparison. Therefore, its necessary to do further studies per field and interfraction. In this study, the gamma index analysis will focus on the case of head and neck with the specific object of NPC because it is one of the most commonly occurring cancer types in Indonesia. The criteria used are 3 %/3 mm and 2 %/2 mm with the same comparison variation as Kim et al.

Moreover, by using gamma index analysis and gamma passing rate (GPR), this study resulted in two more findings. First, the dose prediction of QA pretreatment was very accurate. Second, the comparison of the baseline (first fraction) and other fractions in a treatment can detect accuracy and clinical errors.

EQUIPMENT AND METHODS

Equipment specification/features

Halcyon 2.0 has many features like imaging visualization capabilities by optimizing three-dimensional cone-beam computed tomography (3D CBCT) and kV (kilovoltage) CBCT, high image quality due to statistical reconstruction iterative CBCT (iCBCT) algorithm, high resolution due to its 5 mm MLC, a broad field-of-view (FOV), and a 36 cm maximum length treatment attained using multiple isocenters, and provision of dynamic beam flattening sequences for conformal 3D planning. In addition, it is equipped with other features such as multileaf collimator (MLC) characteristics (high leaf speed of 5 cm/s, reducing the transmission and the interleaf leakage), electronic portal imaging device (EPID) with portal dosimetry, maintenance flow, hardware, and beam data/modelling. Furthermore, Halcyon 2.0 features such as hardware, MLC characteristics (dimensions, transmission, interleaf leak, gap dosimetry), EPID with portal dosimetry, maintenance flow, and beam data/modeling are equal to Halcyon 1.0 [11,13-15].

The Halcyon with single-energy 6 MV flattening filter-free (FFF) beam and 800 MU/min cause IMRT/VMAT achievable for more patients. Delivery of IMRT/VMAT techniques allows more precisely with automated daily IGRT and faster with 4 RPM gantry speed, 2 RPM for VMAT delivery, and fast MLC motion [11].

Portal dosimetry is an effective system for verification of IMRT/VMAT because of its fast setup, easy data acquisition, and high spatial resolution [16,17]. A Varian portal dosimetry system consists of such components as the Portal Dose Image Prediction (PDIP) software package, the Portal Dose Prediction (PDP) module, the Portal Dose Image Calculation (PDIC) module, the portal imager (aS1000 and aS500 amorphous silicon portal imagers), and the ARIA Portal Dosimetry Review workspace. The portal imager is used to acquire the image. The ARIA Portal Dosimetry Review workspace is used to evaluate how close the predicted and measured images are to each other. The portal dosimetry uses Calibrated Units (CU) to manage complex processes where 1 CU corresponds to 100 MU [17-19].

Methods

Patient-selected classification

Twenty treatment plans for head and neck cancer patients were selected with NPC diagnoses and prescription doses of 65-70 Gy. In this study, the selection of patient treatment planning was not differentiated by their gender. This study used the therapy planning in 2020 with TPS Eclipse v15.6. The therapy planning had been completed with 32-35 fractions, 5-12 fields, and IMRT techniques.

Planning and measuring QA pretreatment

The pretreatment planning QA measurements were conducted with two different gantry angles, namely the actual gantry angle and the null gantry angle. The measurement of the exit beam of Halcyon 2.0 linac was conducted by using the EPID integrated with the Halcyon 2.0 gantry. The ratio of single-field dose prediction with file output in vivo Portal dosimetry with gamma indexes on the different dose/distance to agreement (DD/DTA) criteria were 3 %/3 mm and 2 %/2 mm for $\geq$ 95 % total pixels. Then, all the fields were combined to get an image on a composite field with a threshold of 10 %. The composite field was analyzed with the same DD/DTA criteria at $\geq$ 90 % of the total pixels [20,21].

Review of treatment planning doses by gamma index using in-vivo portal dosimetry

The doses were reviewed by gamma indexes of 3 %/3 mm and 2 %/2 mm of total pixels for each fraction, treatment field, and composite field. The first fraction was reference field or baseline.

RESULTS AND DISCUSSION

Varian Halcyon linacs are available in Indonesia and are used in clinical therapy for cancer with IMRT/VMAT technique. The NPC is one of the cancer types that are often treated with the Halcyon. Therefore, this study investigated the distribution of fluences and evaluated several set-up parameters of the treatments that had been planned and delivered. It was expected that this study would assist the implementation of clinical setting of Halcyon 2.0 in our institution.

The results of QA pretreatment with EPID-Portal Dosimetry from 20 treatment plans are shown in Table 1. The average value of GPR for each gamma index (3 %/3 mm and 2 %/2 mm) for each field and composite fields on actual gantry angle and null gantry angle was ≈ 99 % (range 99.40 %-99.98 %). The average ± standard deviation (SD) value of GPR for actual gantry angle for each field comparison was 99.81 % ± 0.64 % for the gamma index of 3 %/3 mm and 99.75 % ± 0.59 % for the gamma index of 2 %/2 mm, while the GPR for composite field comparisons was 99.76 % ± 0.58 % for the gamma index of 3 %/3 mm and 99.40 % ± 0.22 % for the gamma index of 2 %/2 mm. The average ± SD value of GPR for null gantry angle for each field compared with the same criteria was 99.90 % ± 0.49 % for the gamma index of 3 %/3 mm and 99.89 % for the gamma index of 2 %/2 mm, while the GPR for composite comparison was 99.98 % ± 0.11 % for the gamma index of 3 %/3 mm and 99.74 % ± 0.19 % for the gamma index of 2 %/2 mm.

This study evaluated gamma index with portal dosimetry on QA pretreatment and treatment measurements. The threshold of this study is defined as the limit within which a process is considered as operating normally. The distribution of exit fluences was mapped on the portal dosimetry with the isodose line and dose color washes as carried out by D.A. Low et al. [22]. Ideally, the comparison should be carried out organ by organ. However, in this study, QA pretreatment and treatment are compared with fluence distribution through portal dosimetry. Therefore, the comparison was carried out image by image. The parameters used by QA pretreatment measurements followed AAPM TG-218, such as DD/DTA criteria of gamma indexes of 3 %/3 mm and 2 %/2 mm with > 95 % of total pixels. In addition, the GPR of gamma index for composite fields is similar for single-field with > 90 % of total pixels by the threshold of 10 % from maximum gamma index to remove noise that impacted calculation [23]. The gamma index concern is < 1 area gamma or DD/DTA. QA pretreatment with actual gantry has been setting of radiation carried out with treatment parameters such as MUs, gantry, collimator, and MLC. The average GPR for all comparisons for gamma indexes of 3 %/3 mm and 2 %/2 mm was ≈ 99 % or > 90 % of total pixels (Table 1). This means that the exit fluence is consistent. Therefore, the dose prediction successfully describes the output files for each field and against composite images. The GPR value of the null gantry angle shows a similar result with a smaller SD value. This prediction is intended to ensure that the quality of exit fluence, EPID conditions, and planning quality so that the dose received by patients is more optimal. The secondary beam factor is not significantly described in the results. Referring to previous results [24,25], it can be seen that the current value QA pretreatment showed that the EPID-Portal Dosimetry, treatment planning, and linac machine still had good performance.

Table 1. Result of GPR for pretreatment QA using EPID-portal dosimetry for variation of gamma index and gantry angle.

Patient	Per-Field Comparison				Composited Comparison			
	3 %/3 mm		2 %/2 mm		3 %/3 mm		2 %/2 mm	
	Actual Angle (%)	Null Angle (%)	Actual Angle (%)	Null Angle (%)	Actual Angle (%)	Null Angle (%)	Actual Angle (%)	Null Angle (%)
1	100.00	100.00	100.00	100.00	100.00	100.00	99.80	99.80
2	99.43	99.77	99.48	99.77	100.00	100.00	99.30	99.70
3	99.97	99.99	99.59	99.80	100.00	100.00	99.80	99.80
4	100.00	100.00	99.98	99.98	100.00	100.00	100.00	100.00
5	99.7	99.98	99.62	99.90	99.60	100.00	99.80	99.90
6	100.00	100.00	100.00	100.00	97.80	100.00	100.00	100.00
7	99.70	100.00	99.74	99.99	100.00	100.00	99.10	100.00
8	100.00	100.00	99.96	100.00	99.90	100.00	100.00	100.00
9	100.00	99.99	99.93	99.97	100.00	100.00	99.80	100.00
10	99.85	99.99	99.94	99.92	100.00	100.00	99.50	99.80
11	100.00	99.80	99.97	99.80	100.00	100.00	99.80	99.70
12	99.67	100.00	99.59	99.96	99.80	100.00	98.50	100.00
13	99.99	99.46	99.94	99.64	100.00	99.90	99.80	98.50
14	99.63	100.00	99.59	99.98	100.00	100.00	99.70	99.90
15	99.86	100.00	99.76	99.97	99.90	100.00	99.80	99.90
16	99.74	100.00	99.92	99.98	100.00	100.00	99.40	100.00
17	99.31	99.07	99.12	99.18	99.90	99.60	98.50	97.70
18	99.90	100.00	99.68	99.99	98.40	100.00	96.50	100.00
19	99.77	100.00	99.78	99.98	100.00	100.00	99.80	100.00
20	99.52	99.99	99.46	99,96	99.90	100.00	99.00	100.00
Average ± SD	99.81 ± 0.64	99.90 ± 0.49	99.75 ± 0.59	99.89 ± 0.40	99.76 ± 0.58	99.98 ± 0.11	99.40 ± 0.22	99.74 ± 0.19

The recent study by Hayeon Kim et al. [11] evaluated QA pretreatment gamma index analysis using Halcyon 2.0 EPID-Portal Dosimetry and the results show gynecological cancer treatment with limited parameters ($n = 12$ treatment plans). The parameters used in that study were a threshold of 10 % and a gamma index of 4 %/4 mm for > 90 % total pixels. The average result of GPR of their study was 100 %. In line with the previous study, the average GPR for this study for QA pretreatment was 99 % for >90 % of total pixels. This result indicates that the Halcyon 2.0 has been implemented to provide a good prediction of dose for treatment planning.

In our study, twenty patients were treated with the IMRT technique and 7-12 gantry angles with 32-35 fractions. The duration of each treatment depends on the prescription dose per fraction and total MU. The total fraction of all treatments was 2717. The results in each field on the gamma index of 3 %/3 mm was 0.68 % or 39 fractions < 90% of total pixels and GPR of 99.32 %. Meanwhile, the gamma index of 2 %/2mm was 2.26 % or 129 fractions < 90 % of the total pixels and GPR of 97.74 %. The average fraction per patient for both criteria can be seen in Figs. 1 and 2. Those pictures show a variation of each treatment. The results in each composite field on the gamma index of 3 %/3 mm was 4.54 % < 90 of total pixels and GPR of 95.46 %, while in the gamma index of 2 %/2 mm was 18.62 % < 90 % of total pixels and GPR of 81.38 %.

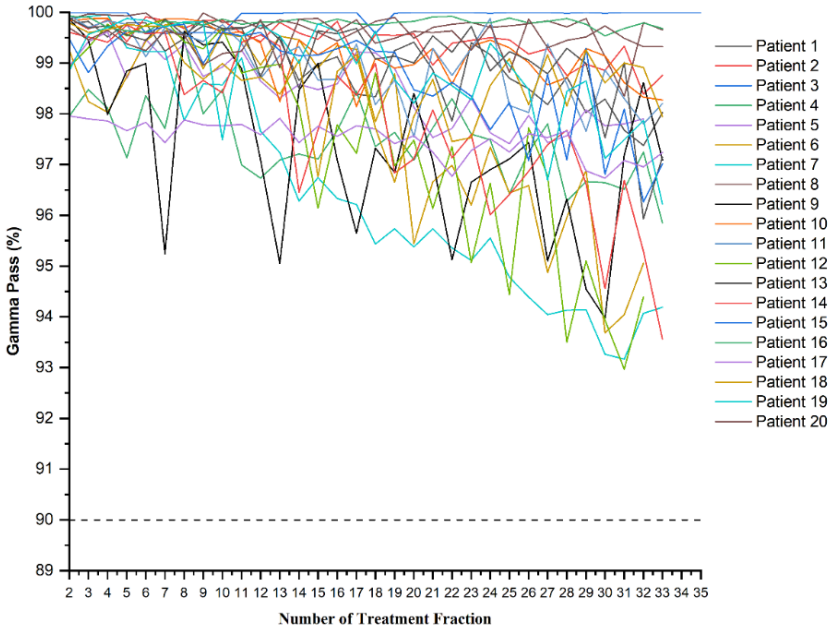

Fig. 1. Comparison of GPR for interfractional treatment with gamma index of 3 %/3 mm.

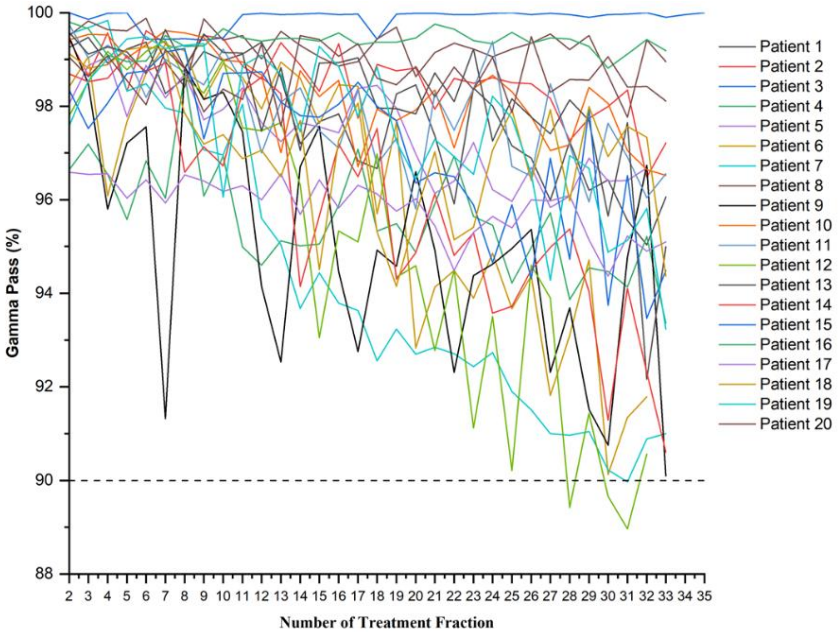

Fig. 2. Comparison of GPR for interfractional treatment with gamma index of 2 %/2 mm.

The comparison of GPR for interfractional treatments with a little limitation is shown in Fig. 1 and Fig. 2 for gamma indexes of 3 %/3 mm and 2 %/2 mm, respectively. The limit used is by setting the first fraction as a baseline or reference compared to the following fraction although the first fraction as baseline is not an ideal or a consistent condition. This is due to the limitation of the dosimetry portal for predicting fluence mapping from treatment. If the predictions are available, we can count them as a reference and compare them with all fractions. The figures show the variants of the flow line fraction of each treatment plan might be caused by some other contributing factors. The first factor is anatomical changes caused by organ motion or changes in target size. The biggest contributing factor to interfractional GPR is the anatomical changes during treatment. The second factor is a positioning error by the organ motion or the patient movement. A low GPR caused by positioning error due to organ motion is shown for the 9th treatment plan and several other plans. In order to minimize positioning error, we must follow every part of the rules before starting the treatment. Prior to treatment, the position of the patient should be verified by matching between the kV image and DRR (digitally reconstructed radiograph) image to ensure that a shift in the patient's position by planning within the limits of tolerance. Then, during treatment, the patient wore a mask to limit movement, but the target organ is a part of the breathing organ as suggested by P. Sukumar et al. [25]. According to D. J. Noble et al. [26] and P. Jin et al. [12], gamma analysis due to changes in target size also leads to a decrease gradually. The decrease can be caused by the change of size of the target that receive a radiation dose after several treatments. Figures 1 and 2 show that the increasing fraction of treatment will induce decreasing the GPR. If the GPR < 90 % or lower than the criterion, clinicians have to evaluate the treatment planning as suggested by P. Jin et al. [12]. The third factor is MLC motion and backscattering. The MLC motion is one of the main of IMRT planning quality [10]. Mechanical errors of the MLC might stop the treatment temporarily then the system requests a follow-up or repeated treatment order as suggested by T. Li et al. [15], W. Woon et al. [27], and C. J. A. Wolfs [28]. Many images are formed in portal dosimetry if it is compared to the baseline. The results decrease on the 12th treatment planning and some fractions of other patient treatments. A backscattering x-ray is formed as interaction between the primary x-ray and the target. The backscattering is one of the factors that contribute to fluence mapping. As the backscattering is probabilistic in nature, there is no ideal prediction of the backscattering values on each treatment. Therefore, the results from fraction to a fraction are different. The gamma index of 2 %/2 mm is more sensitive with error factors than 3 %/3 mm. The results of composite fields with the same criteria for interfractional results in a considerable discrepancy rate of 4.54 % for the gamma index of 3 %/3 mm and 18.62 % for gamma index of 2 %/2 mm. This discrepancy rate increases in evaluation in the composite field which combines several images to be an image with a direction of view.

Another recent study by Jin et al. [12] evaluated head and neck cancer treatment planning using EPID-Portal Dosimetry Halcyon 2.0 and IMRT/VMAT technique treatment (n = 19 plans). Their parameter limitation was a 5 % threshold with a gamma index of 3 %/3 mm. Their results showed that the average GPR ate was 99.04 % ± 1.67 % for > 90 % total pixels (n = 19 plans). The GPR increased to 99.58 % ± 0.32 % for > 90 % total pixels (n = 17 plans). The errors detected in their study were anatomical changes from the MVCBCT image. Anatomical changes were observed in the 17th fraction, indicating with a decreased in result. In line with the previous study, GPR result in this study with a gamma index of 3 %/3 mm was 95.46 %. The decrease in GPR is due to the increase in treatment fraction.

CONCLUSION

The average of all GPRs of comparisons, QA pretreatment and treatment, on the gamma index of 3 %/3 mm is > 90 % of total pixels for all and on the gamma index of 2 %/2 mm is nearly all > 90 % of total pixels but composite comparison. The GPR of the dose prediction and the QA-pretreatment measurement is ≈ 99 % or > 90 % of total pixels. This means that the prediction of exit fluence is accurate. Accurate dose prediction can improve efficient treatment. The evaluation results show that Halcyon 2.0 is effective for creating treatment plans for complex cases like the NPC. One potential concern is the error factors during treatment, because it can be a contributor to additional doses to patients or fluence mapping errors by EPID which can increase discrepancy rate of the dose.

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AUTHOR CONTRIBUTION

W. Purwanti collected and analyzed the data, wrote the first draft of the manuscript, F. Suhaimi assists collecting the data, W. E. Wibowo and S. A. Pawiro conceived the idea and supervised the work, and all authors were involved in discussing and revising it. All authors read and approved the final version of the paper.

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