RESEARCH PAPER

Gamma Index Analysis for Volumetric Modulated Arc Therapy (VMAT) Treatment Planning in the Head and Neck Regions with Ring-Mounted Halcyon Machine

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ABSTRACT

Background

The complexity of dose delivery in "volumetric modulated arc therapy (VMAT) necessitates patient-specific quality assurance (PSQA). This is especially true in head and neck cancer treatments. Portal dosimetry using an electronic portal imaging device (EPID)" is extensively utilized in VMAT dose verification.

Aim

To assess the feasibility of gamma index analysis in VMAT treatment plans for head and neck cancers with a ring-mounted Varian Halcyon linear accelerator using EPID-based portal dosimetry.

Methods

Retrospective analysis was done for 65 head and neck VMAT treatment plans. The plans were prepared using the "Eclipse Treatment Planning System (TPS)" version 16.1 and Varian Halcyon™ linear accelerator. PSQA was performed using Varian aS1200 EPID. Gamma passing rates (GPR) were assessed at 1%/1 mm, 2%/2 mm, 2%/3 mm, 3%/2 mm, and 3%/3 mm criteria. GPR ≥97% was clinically acceptable as per AAPM TG-218 guidelines.

Results

Gamma passing rates improved gradually with relaxation of dose difference and distance-to-agreement criteria. Majority of the treatment plans yielded high GPR values (>99%) at the 2%/3 mm and 3%/3 mm criteria. Central arch cases showed comparatively lower passing rates at stringent criteria due to greater treatment complexity.

Conclusion

EPID-based portal dosimetry with the Varian Halcyon platform proved effective in ensuring VMAT QA. The 2%/3mm threshold was deemed appropriate for clinical purposes when evaluating patients under head and neck RT treatment.

Keywords: Gamma passing rate, EPID, Portal Dosimetry, VMAT, Arcs, PSQA.

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1. Introduction

Previously, they delivered radiation to cancer patients in cobalt-60 (Tele-cobalt) machine and conventional linear accelerator machine which has a limited treatment technology such as conventional, 2-D plan and 3-DCRT (Three dimensionally conformal radiation therapy) [1]. However, these technologies failed to save the normal surrounding tissues and critical organs. "Intensity modulated radiation therapy (IMRT), a volumetric modulated arc therapy (VMAT)" planning method, and the evaluation of technology in radiotherapy treatment optimize the high dosage to the target area while lowering the dose to normal tissue areas. However, intensity-modulated radiation treatment (IMRT) techniques offer more precise radiation dose delivery for treating head and neck region tumours that have significant concavities, uneven surfaces, or may be near

several OARs (Organ at Risk) [2]. Nonetheless, employing too complex IMRT fields presents recognised drawbacks [2, 3]. To reduce the complexity of the treatment plan, current literature has advocated the application of a smoothing penalty during the inverse optimisation process.[4] Extended beam-on durations (elevated monitor unit [MU]/Gy) are necessitated when administering treatment to patients with intricate beams employing small-field segments, hence heightening the risk of patient displacement and augmenting leakage dosages via multi-leaf collimators [2,3]. Moreover, these medicines elevate mechanical stress, hence augmenting the likelihood of errors during therapy administration and intensifying the workload for quality assurance (QA). Volumetric modulated arc treatment (VMAT) is an innovative technique designed to address these issues by manipulating gantry speed, dose rate (DR), and multi-leaf collimator (MLC) movements to create fluence non-uniformity [5]. VMAT requires less time for administration compared to intensity-modulated radiation treatment (IMRT). IMRT employs many static fields (five or more) to administer treatment, hence minimizing the likelihood of intra-fractional errors [5]. The intricacy of the treatment plan is increased by the process of adjusting the fluence utilizing the previously described factors. As a result, there is also more unpredictability in the delivery of treatment. "The treatment planning system's (TPS)" dosage computation accuracy and the mechanical limits of the delivery apparatus take the blame for these uncertainties in dose administration [7]. To confirm the accuracy of the planned delivery, "patient-specific quality assurance (PSQA)" is strongly advised [6]. The Gamma index is frequently used to verify doses in two or three dimensions (2-D or 3-D) [8, 9]. Pre-treatment QA additionally makes advantage of linear accelerator (LINAC) treatment log files [10]. These approaches do, however, offer benefits and drawbacks.

Because of the complex planning and delivery procedures, patient-specific quality assurance "(PSQA) is a crucial clinical technique for ensuring treatment safety. PSQA for VMAT typically involves comparing the calculated and measured dose distributions using a detector array before beginning treatment [11].

The gamma index is a frequently used statistic that evaluates the degree of agreement between two distributions by considering both the percentage dose difference (DD) and the distance-to-agreement (DTA) [12]. The gamma passing rate (GPR), which can be computed using choices like global or local normalization [13], various dosage discrepancies, and DTA criteria like 3%/3 mm, is the percentage of measurement points that meet the condition of a gamma index <1. 90% GPR with 3%/3 mm was first recommended by AAPM Task Group 119 as sufficient for clinical approval of the IMRT (intensity modulated)"/VMAT plans [14]. But since more Reliable software and detectors come to accessible, and AAPM has p revised their values in TG 218 guidelines that impose more stringent parameters, like 3%/2 mm and a 95% GPR [15]. There are a few distinct sources of uncertainty and mistakes that contribute to the reduced gamma analysis passing rates. Previous studies have shown that these issues may include phantom setup, detector resolution, and calibration. [16-18] Other factors include the intrinsic complexity of treatment regimens, difficulties with beam modelling, and variations During the measurement day, in the beam profile and output.

This complex treatment modality must be thoroughly verified before being delivered to the patient, without fail to avoid the radiation dose misadministration [19-21]. The aim of this study is to analyse PSQA (patient specific quality assurance) for VMAT plans of each patient treated in Varian Halcyon Bolt Linear accelerator and to verify all criteria as per AAPM TG-218. This give the GPR pass or fail results [22]. The optimization and verification of VMAT plans are enhanced by the precision of the appropriate dosimetric measures. The goal is to increase the efficacy and reliability of the VMAT treatment delivery and planning processes [23].

A few studies have been carried out to assess patient-specific quality assurance of VMAT treatment with conventional detector arrays, but there is not much literature available on EPID based portal dosimetry for complex cases of head/neck cancer in the ring mounted Halcyon system [24]. This study evaluates gamma index performance in a large set of 65 head and neck VMAT plans for various criteria of dose difference and DTA [25]. In addition, this study suggests validating this 2%/3 mm gamma criterion at the institutional level for EPID-based QA with the use of Halcyon technology, providing clinically relevant data to enhance the VMAT treatment verification workflow.

2. Materials and Methods

In this study, computed tomography (CT) simulation images of 65 patients with head and neck cancer were analyzed. The patient group consisted of various anatomical sites including tongue, buccal mucosa, alveolus, base of tongue (BOT), post-cricoid region, oropharynx, hypopharynx, larynx, lip, hard palate, tonsil and parotid gland, with 5 patients per disease site. A 16-slice Toshiba Alexion CT scanner was used to

do a computer simulation. "Images from all CTs were imported to the Eclipse Treatment Planning System (TPS) version 16.1 (Varian Medical Systems, Palo Alto, CA, USA) via the Digital Imaging and Communications in Medicine (DICOM)" protocol.

2.1 Study Design

In this retrospective, observational study, 65 head and neck cancer patients with volumetric modulated arc therapy "(VMAT) (Varian Halcyon™ linear accelerator (Varian Medical Systems, Palo Alto, CA, USA))" treatment plans were analyzed. The purpose of this study was to investigate (PSQA) for VMAT treatment verification, through EPID based portal dosimetry and gamma index analysis.

2.2 Patient Selection

This study included patients with the following cancer types: tongue carcinoma, buccal mucosa carcinoma, alveolus carcinoma, base of tongue (BOT) carcinoma, post-cricoid carcinoma, oropharyngeal carcinoma, hypopharyngeal carcinoma, laryngeal carcinoma, lip carcinoma, hard palate carcinoma, tonsillar carcinoma and parotid carcinoma. A total of five patients were selected from each site for gamma index evaluation and dosimetric verification.

2.3 CT Simulation and Contouring

A Toshiba Alexion 16-slice CT scanner was used to perform a CT simulation. To reduce set-up uncertainties when imaging and treating all patients were immobilized with thermoplastic head and neck immobilization mask. Images were taken on the CT with a proper slice thickness and then transferred into the Eclipse TPS version 16.1 via DICOM protocol.

The target delineation and contouring were done following institutional radiotherapy protocols. All patients had the following structures contoured:

- Gross Tumor Volume (GTV)
- Clinical Target Volume (CTV)
- Planning Target Volume (PTV)
- Organs at Risk (OARs)

Anatomically specific organs such as the spinal cord, brainstem, parotid glands, oral cavity, and neighbouring healthy tissues were particularly vulnerable.

2.4 Treatment Planning

In Eclipse TPS version 16.1, all patients were to be treated with the method of volumetric modulated arc treatment ("VMAT"). A Varian HalcyonTM linear accelerator (linac) was used to generate treatment plans using 6 MV FFF photon beams.

Each VMAT plan consisted of three treatment arcs:

- Counter-clockwise arc 1 (CCW1)
- Clockwise arc 1 (CW1)
- Counter-clockwise arc 2 (CCW2)

Treatment optimization was done to ensure sufficient coverage of the planning target volume (PTV) when minimizing radiation dose to the surrounding (OARs). The dose constraints for critical structures were followed within the general radiotherapy planning procedure. Optimization parameters used were gantry speed modulation, dose rate modulation, and MLC motion.

2.5 Portal Dosimetry and EPID-Based Quality Assurance

PSQA was carried out with the use of an amorphous silicon (aSi) based "electronic portal imaging device (EPID)", the Varian aS1200 EPID system (Varian Medical Systems, Palo Alto, USA). The detector was located at a source to imager distance (SID) of 154cm and the total pixel matrix was 1280 × 1280 while the active detector area was 43 × 43 cm².

The EPID system was installed alongside the ring mounted Halcyon gantry and used in conjunction with the Eclipse portal dosimetry software. The dose rate, gantry rotation, MLC motion, dose distribution and couch positioning were all the same for all VMAT treatment plans delivered to the EPID.

Figure-1 shows the EPID image and **Table-1** shows Technical of Halcyon linear accelerator.

Fig.1.[19]

Table-1: Technical specification of Varian Halcyon EPID

S No	Specifications	Varian aS1200 (Halcyon/ Ethos)
1	Moveable lateral, sup-inf	No
2	Moveable up-down	No
3	SID (cm)	154
4	Dimensions (cm^2) lateral × superior-inferior	43 × 43
5	Dimensions at isocenter (cm^2)	27.9 × 27.9
6	Pixel size (mm^2)	0.336 × 0.336
7	Frame rate (Hz)	Up to 20
8	DICOM image Format export (including DPS[e])	Yes
9	Dosimetric cine mode acquisition (including DPS[e])	No[j]
10	Support for FFF imaging	Yes

"EPID: Electronic Portal Imaging Device, SID: Source-Imager Distance, DICOM: Digital Imaging and Communications in Medicine", DPS: Dosimetric Pixel Scaling, FFF: Flattening Filter Free.

The treatment planning system used gamma index analysis to anticipate portal dose images, which were compared with the measured EPID dose images. Looked at these gamma assessment criteria:

- "1%/1 mm
- 1%/2 mm
- 1%/3 mm
- 2%/1 mm
- 2%/2 mm
- 2%/3 mm
- 3%/1 mm
- 3%/2 mm
- 3%/3 mm"

All VMAT plans were also assessed and compared with the new AAPM TG-218 recommendation of 3%/2 mm and the conventional TG-119 criterion of 3%/3 mm.

2.6 Statistical Analysis

The mean ± standard deviation (SD) was used to express all gamma passing rates. The statistical study was carried out using Excel and SPSS from Microsoft. Comparative evaluation among different gamma criteria was carried out to identify clinically acceptable quality assurance thresholds. A gamma passing rate (GPR) ≥97% was considered clinically acceptable according to institutional quality assurance protocols and recommendations from AAPM TG-218 guidelines.

3. Results and Discussion

The electronic portal imaging device (EPID) mounted on the Varian Halcyon™ linac has been used to deliver and verify all 65 VMAT treatment plans. Patient-specific quality assurance (PSQA) analysis was carried out using an Eclipse Treatment Planning System (TPS) integrated Portal Dosimetry (PD) software package. The study population comprised of head and neck cancer patients with left/right buccal mucosa (Lt/Rt BM), tongue, base of tongue (BOT), alveolus, central arch, lip, post-cricoid, oropharynx, larynx, hypopharynx, hard palate, tonsil and parotid carcinoma, with about 5 patients observed for every anatomical site.

All treatment plans were analyzed using multiple gamma index criteria including "1%/1 mm, 1%/2 mm, 1%/3 mm, 2%/1 mm, 2%/2 mm, 2%/3 mm, 3%/1 mm, 3%/2 mm, and 3%/3 mm. The gamma passing rates (GPR) calculated from measurements using EPID portal dosimetry are shown in Table-2. The dose difference (DD) and distance-to-agreement (DTA)" values were calculated for every treatment arc. The graph in figure-2 shows the graphical representation of the gamma passing rates corresponding to Table-2.

Table-2: 65 (VMAT) patients Gamma index values each value average over 5 patients respectively Lt/Rt BM, Tongue, BOT, Alveolus, Central-arch, Lip, Post-Cricoid, Oropharynx, Larynx, Hypopharynx, Hard-Palate, Tonsil, Parotid.

Cases	**Average Gamma index values for 65 patients respective of each case (%)**								
	1%/1mm	**1%/2mm**	**1%/3mm**	**2%/1mm**	**2%/2mm**	**2%/3mm**	**3%/1mm**	**3%/2mm**	**3%/3mm**
Lt/Rt BM	67.5	75.5	87	96	98.3	99.4	98.6	99.6	99.9
Tongue	79.6	85.7	90.38	97.2	98.6	99.4	98.9	99.6	99.9
BoT	81.6	88.6	91.8	98.5	99.1	99.6	99.5	99.8	99.9
Alveolus	76.7	85.4	96.2	96.5	98.4	99.4	98.5	99.5	99.9
Central arch	71.8	79.6	87	93.1	96.4	98.7	97.1	98.8	99.7
Lip	80.3	86.8	92	95.7	98	99.2	98.1	99.2	99.8
Post cricoid	85.8	91.3	95.1	97.2	98.9	99.7	98.8	99.5	99.9
Oropharynx	83	89.2	93.2	97.2	98.8	99.5	98.9	99.6	99.9
Larynx	83.6	91.1	95.6	96.2	98.8	99.8	98.3	99.6	99.9
Hypo-pharynx	85.6	92	95.5	97.3	99.1	99.7	98.9	99.7	99.9
Hard Palate	74.5	82.5	88.5	94.3	97	99	97.6	99	99.8
Tonsil	78.6	86.8	92.7	95	98	99.5	97.8	99.3	99.9

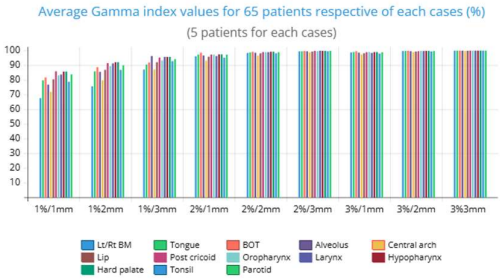
Parotid	83.7	89.9	94.1	97.1	98.8	99.7	98.7	99.6	99.9

Interpretation:

The results showed that the passing rates of the gamma progressively rose as the distance-to-agreement criterion relaxed and the dose difference criterion relaxed. Significantly more passing rates were found with clinically acceptable criteria "(2%/2 mm, 2%/3 mm, 3%/2 mm and 3%/3 mm) than with stricter ones (1%/1 mm and 1%/2 mm). The gamma passing rates of most anatomical sites were higher than 99% at 2%/3 mm and 3%/3 mm, suggesting a good level of agreement between the predicted and measured dose distributions"

Relaxing dosage difference and distance-to-agreement criteria led to an overall rise in the mean gamma passing rate. A passing rate as low as 1%/1 mm was recorded and the highest passing rate as high as 3%/3 mm was recorded for the lowest and highest criterion parameters, respectively.

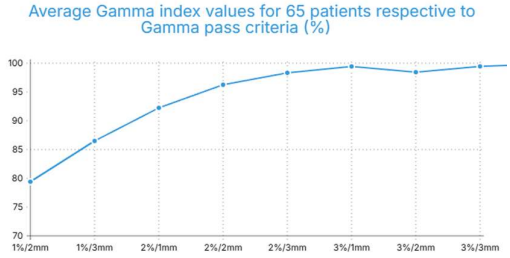
Figure-2: 65 (VMAT) patients Gamma index values each value average over 5 patients in each case respectively Lt/Rt BM, Tongue, BOT, Alveolus, Central-arch, Lip, Post-Cricoid, Oropharynx, Larynx, Hypo-pharynx, Hard-Palate, Tonsil, Parotid. Gamma Index passing rate meets the 1mm/1%, 1mm/2%, 1mm/3%, 2mm/1%, 2mm/2%, 2/3%, 3mm/1%, 3mm/2%, 3mm/3%.



Interpretation:

The gamma index passing rates are shown in Figure-2 for all the anatomical sites at various gamma evaluation criteria. It can be seen from the graphical analysis that the passing rate of the gamma-level was better in the increasing order of the tolerance limits. The stricter criteria (1%/1 mm) had a lower passing rate compared to the other parameters, as VMAT plans are complex to modulate and head and neck radiotherapy have steep dose gradients.

Figure-3: Average Gamma Index values for 65 patients respective to Gamma pass rate criteria (%)



Interpretation:

Overall average gamma index values for all 65 patients for various gamma pass rate criteria are shown in Figure-3. The graph shows an increasing trend in the proportions of pupils achieving a grade 4 in gamma, from the stricter to the more relaxed criteria. The lowest average passing rates were seen for the 1%/1 mm criterion and highest average passing rates were recorded for the 3%/3 mm criterion. This is normal behaviour as tighter DD and DTA criteria are sensitive to small doses and mechanical uncertainties during treatment delivery.

Table-3: 65 (VMAT) patients Gamma index values each value average over 5 patients respectively Lt/Rt BM, Tongue, BoT, Alveolus, Central arch, Lip, Post Cricoid, Oropharynx, Larynx, Hypo pharynx, Hard Palate, Tonsil, Parotid. Gamma Index passing rate meets the 2mm/3% value for individual arc such as CCW1, CW1 and CCW2.

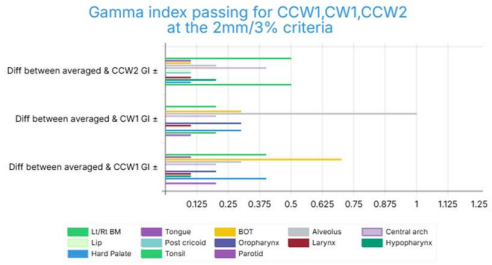
Cases	**CCW1**	**CW1**	**CCW2**	**Difference average & CCW1 GI ±**	**Difference average & CW1 GI ±**	**Difference average & CCW2 GI ±**
	2mm/3%					
Lt/Rt BM	99.8	99.6	98.9	0.4	0.2	0.5
Tongue	99.5	99.4	99.3	0.1	0	0.1
BoT	99.8	99.3	99.7	0.7	0.3	0.1
Alveolus	99.7	99.5	99.2	0.3	1	0.2
Central Arch	98.9	99	98.3	0.2	0.2	0.4
Lip	9	99.2	99.1	0	0	0.1

	9.2					
Post cricoid	99.7	99.7	99.6	0	0	0.1
Oropharynx	99.3	99.8	99.5	0.2	0.3	0
Larynx	99.7	99.9	99.7	0.1	0.1	0.1
Hypo-pharynx	99.8	99.7	99.5	0.1	0	0.2
Hard Palate	99.4	98.7	98.9	0.4	0.3	0.1
Tonsil	99.5	99.7	99	0	0.2	0.5
Parotid	99.5	99.8	99.7	0.2	0.1	0

Interpretation:

Only small variations from the mean gamma index values were seen across the three treatment arcs, reflecting good consistency and stability of the dose delivered for the different gantry rotations. The gamma values averaged for most anatomical sites were negligible both in terms of variation between individual arc measures and the arc measures themselves. However, there was larger variation for the CW1 during the gantry rotation while the case of alveolus carcinoma, the deviation value was 1. This variation could be caused by the greater modulation complexity of the plans and anatomical heterogeneity in the vicinity of critical organs.

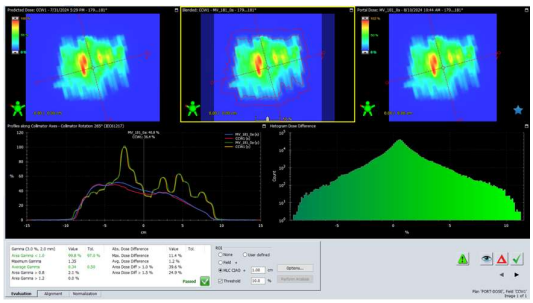
Figure-4: Show the gamma index passing for CCW1, CW1, CCW2 at the 2mm/3% criteria.



Interpretation:

The gamma index differences between CCW1, CW1, and CCW2 are shown in Figure-4 based on the 2%/3 mm criteria. This graphical representation clearly shows that the differences between these three arcs have remained clinically insignificant in most treatment plans, which is an indication of the robustness of the Halcyon delivery system.

Figure-5: Gamma index predicted dose and Portal dose



Interpretation:

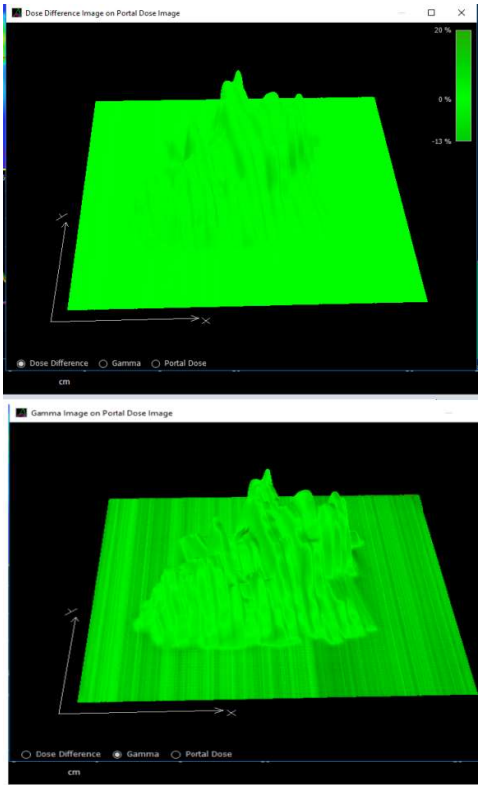
From Fig-5, it is clear that there is high correlation between the expected dose and the measured dose of EPID portal dose in the VMAT plan. Gamma index test was successful, where 99.8% passing rate was recorded, which is higher than the institutional threshold level of 97%. It can be noted from the low mean gamma value and the small dose difference.

Figure-6: Result of Gamma evaluation

Interpretation:

The gamma pass rates for figure-6 are depicted from the analysis done using portal dosimetry based on EPID. The gamma pass rate achieved is 99.8%, surpassing the tolerance level set in the institution of 97% at the 3%/2mm criteria. The mean gamma rate attained is 0.34, suggesting that there is a high degree of accuracy of the planned and delivered doses.

Figure-7: a) Dose Difference map, b) Gamma map



(a) Dose Difference (b) Gamma

Interpretation:

Figure-7 shows the dose difference map and gamma map acquired by EPID-based portal dosimetry analysis. A comparison of the computed and measured dose distributions shows negligible discrepancies on the dose difference map, and many of the examined areas met the gamma acceptance criteria, according to the gamma map. In VMAT methods, low gamma values often mean that the dosage was administered precisely and that the two sets of data were in good agreement.

Most carcinoma patients such as buccal mucosa, tongue, BOT, alveolus, lip, post-cricoid, oropharynx, larynx, hypopharynx, hard palate, tonsil, and parotid passed the 2%/2 mm gamma criterion and had high gamma passing rate than institutional tolerance level of 97%. In contrast, central arch carcinoma had lower gamma passing rate and only met the 2%/3 mm criterion. This is because of the complexity of VMAT optimization, steeper dose gradient, and presence of many nearby critical organs.

Table-2 clearly shows that most treatment plans passed the clinically acceptable gamma passing rate at 2%/3 mm criterion, and there was confidence level of more than 99.5%. Moreover, AAPM TG-218 criteria (3%/2 mm) and TG-119 criteria (3%/3 mm) were successfully attained for most treatment plans.

These relatively poor results of the stricter gamma criteria such as 1%/1 mm and 1%/2 mm may be due to such aspects as high modulation complexity, dose gradient, detector resolution constraints, MLC position uncertainty, and setup variability typically encountered in head and neck VMAT treatment. In other words, extremely stringent gamma criteria do not seem to be required for patient-specific QA assessment.

These results are like the findings of previous research related to EPID-based portal dosimetry. Madhusudhana Sresty et al. used the IBA I'MatriXX system to evaluate the global 2%/3 mm gamma criterion and concluded that adequate QA was achieved in advanced radiotherapy procedures. Likewise, the current research revealed good performance of the Varian Halcyon EPID system for QA based on the 2%/3 mm gamma criterion.

An important feature of the EPID-based portal dosimetry system under study is the absence of any additional external detectors or phantoms. This allows for saving time and increasing efficiency in the QA process. The portal dosimetry software provided a quick, convenient, and accurate assessment of dose delivery quality in head and neck VMAT plans.

"In accordance with AAPM TG-218 guidelines", tolerance criteria for gamma index analysis for EPID-based VMAT QA should be like those for 2D and 3D detectors. Additionally, AAPM TG-307 also suggested the application of "EPID-based QA systems" for pre-treatment and transit QA procedures. Moreover, the results of this study also confirm the utility of the Varian Halcyon EPID and endorse the use of the 2%/3 mm gamma index tolerance criterion for VMAT QA.

4. Study Limitations

This study had several limitations due to its retrospective design as well as the absence of comparison between EPID and other detector-based QA systems, such as ArcCHECK or Delta4. Future multi-center trials using machine learning-based QA prediction models may also prove beneficial for further validation of EPID-based dosimetry system.

5. Conclusion

The purpose of this study was to use EPID-based portal dosimetry to focus on the anticipated and intended dose in the eclipse TPS treatment plan for the head and neck region. Furthermore, the normal tissue region's dose distribution is under control. GPRs of 2%/2mm meet the 97% tolerance criterion for every cancer patient. With a 99.5% confidence level, the global gamma criteria of 3%/2mm has been met. Therefore, the EPID-based portal

dosimetry approach has been demonstrated to be very sensitive and successful in predicting accurate dose delivery to the tumour and reducing the dosage to the healthy tissue.

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Nil

Conflicts of interest

There are no conflicts of interest.

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