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Adaptive Radiotherapy (ART) Using In Vivo Portal Dosimetry Constancy on Halcyon LINAC for Head and Neck Cancer VMAT

Venugopal Sundaram[1,2*], David Khanna[1], P. Mohandass[3], Prabhu R[2], Sathyaraj Palanivel[4], Rekha Arya[2], Nilotpal Chakravarty[2], Anto Vaz S[1,5], Palanivelu D[1,6]

1. Division of Physical Sciences, Karunya Institute of Technology and Sciences, Coimbatore, Tamilnadu, India.
2. Department of Radiation Oncology, Yashoda Super Speciality Hospital and Cancer Institute, Sanjaynagar, Ghaziabad, U.P. India.
3. Department of Radiation Oncology, Fortis Hospital, Mohali, Punjab, India.
4. Department of Radiation Oncology, Kidwai memorial institute of oncology center, Bengaluru, India.
5. Department of Radiation Oncology, Kovai Medical Center and Hospital, Coimbatore, Tamil Nadu, India.
6. Department of Radiation Oncology, Manipal Hospital, Bangalore, India.

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ABSTRACT

Introduction: This study evaluated the potential of the Varian Halcyon LINAC and its associated Portal Dosimetry (PD) software, using in vivo megavoltage portal images, as a tool for in vivo portal dosimetry constancy (IVDc) in head and neck cancer (HNC) patients receiving volumetric modulated arc therapy (VMAT).

Material and Methods: A retrospective study included 100 HNC patients (mean age 58.4 ± 9.2 years; 72 males, 28 females) treated with three arc VMAT plans on the Halcyon LINAC. A prescription dose of 7000 cGy was delivered over 35 fractions to high risk volumes and 6300 cGy to intermediate risk volumes. Portal images from all fractions (3500) and arcs (10,500) were compared to first fraction baselines via gamma analysis with a 3%/2 mm criterion and 95% passing threshold. Phantom tests evaluated sensitivity to thickness changes.

Results: Gamma passing rates exhibited a steady decline over the treatment course (R^2=0.9724), with an average 93.9 ± 3.6% passing rate, dropping below 90% after 25 fractions. Failures correlated with thickness variations exceeding 1 cm, which were detected with high accuracy during phantom tests. Pretreatment patient-specific QA yielded 100% pass rates.

Conclusion: This study demonstrates the potential of the Halcyon LINAC's integrated PD system and Varian PD software for IVDc in HNC patients treated with VMAT. The results confirm the feasibility of using in vivo MV portal images acquired on the Halcyon LINAC to assess dose consistency throughout treatment.

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Introduction

Head and neck cancer (HNC) accounts for 6% of all malignancies, with a substantial portion of patients diagnosed at a locally advanced stage. The current standard of care for these individuals is concurrent chemoradiation, as it has demonstrated a 6.5% improvement in absolute survival rates at the 5 year mark compared to radiation therapy alone [1-3]. It is important to note, however, that the occurrence of both acute and late adverse reactions to treatment is a considerable concern [4]. Due to their capacity to deliver highly conformal dose distributions, intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) are valuable tools. This is particularly relevant given that target volumes in these cases are frequently large and exhibit a concave shape around nearby critical normal tissues, making it possible to improve the therapeutic ratio [5-7].

Anatomical changes during HNC radiotherapy are a common occurrence. These variations, often resulting from weight loss, primary tumor shrinkage, parotid gland volume reduction, and alterations in irradiated normal tissue volumes, can lead to discrepancies between the planned and delivered doses. Such dosimetric variations can impact both target coverage and dose to critical structures, potentially compromising target volume dose coverage while increasing the risk of overdose to organs at risk, such as the parotid glands, and surrounding normal tissues. These dosimetric deviations can ultimately influence treatment response and the incidence of associated toxicities [8-11].

*Corresponding Author: Tel: +91 9080776415; Email: davidkhanna@karunya.edu

Device based pretreatment patient-specific quality assurance (QA) measurements are a widely accepted standard of care [12]. Electronic portal imaging device (EPID) based portal dosimetry (PD) is also employed for this purpose [13-15]. In conventional PD workflows, EPID measurements require an independent portal dose prediction algorithm, thereby introducing additional commissioning and calibration requirements. While EPID-based PD has been applied for in vivo dose verification through both proprietary and custom-developed software, the Halcyon platform streamlines this process by embedding PD within the EPID–Eclipse environment. This integrated approach simplifies and enhances the convenience, effectiveness, and efficiency of portal image dosimetry on Halcyon, as it is a default feature, unlike conventional LINAC based EPID dosimetry. Consequently, in vivo EPID based PD on Halcyon enables efficient daily treatment delivery verification [15-16]. In vivo portal dosimetry (IVD) has been shown to be a useful method for identifying changes in patient anatomy and has been endorsed by multiple review studies [17-19]. When applied under appropriate conditions, EPID-based IVD has demonstrated the capability to detect anatomical variations across a range of treatment sites. In addition, cone-beam CT (CBCT) imaging has been explored as a tool for recognizing both internal and external anatomical changes that may prompt the need for treatment plan adaptation or replanning [20-21].

This study evaluated the potential of the Varian Halcyon LINAC and its associated PD software, using in vivo megavoltage portal images, as a tool for in vivo portal dosimetry constancy (IVDc) in HNC patients receiving VMAT delivery.

Materials and Methods

Patient selection and target delineation

This study included 100 HNC patients treated on a Halcyon LINAC (Varian Medical Systems, Palo Alto, CA, USA). A retrospective analysis was conducted from January 2024 to December 2024 on 35 fractions per patient, totaling 3500 fractions. Patient demographics are summarized in Table 1. With each patient receiving 3 arcs per fraction, a total of 10,500 individual VMAT arc fields evaluated for this study. Target volumes were delineated on CT images, with clinical target volume (CTV1) encompassing high risk regions (gross tumor volumes and involved nodes) and CTV2 encompassing intermediate risk elective nodal regions. A 3 mm planning target volume (PTV) margin was applied to account for setup uncertainties. Organs at risk (OARs), including ipsilateral and contralateral parotids, mandible, larynx, spinal canal, and brainstem (as clinically relevant), were contoured. A prescription dose of 7000 cGy (200 cGy per fraction) was delivered to PTV1 over 35 fractions, while PTV2 received 6300 cGy (180 cGy per fraction) over the same 35 fractions. Plan quality was assessed by evaluating target coverage, conformity index (CI), homogeneity index (HI), and OAR doses. Patients were tightly immobilized with a 5 clamp mask and secured by five clamps on the base plate.

Table 1. Patient Demographics (n=100 HNC patients)

S.No	Characteristic	Value
1	Number of patients	100
2	Mean age ± SD (years)	58.4 ± 9.2
3	Age range (years)	41-78
4	Male:Female	72:28 (72%)
5	Tumor stage (AJCC)	
	Stage III	28 (28%)
	Stage IV A	52 (52%)
	Stage IV B	20 (20%)
6	Primary tumor site	
	Oropharynx	42 (42%)
	Larynx	28 (28%)
	Oral cavity	18 (18%)
	Hypopharynx	12 (12%)

Halcyon Clinical VMAT radiation plans

Three arcs, single isocenter VMAT plans were generated in the Eclipse treatment planning system (TPS) v15.6 (Varian Medical Systems, Palo Alto, CA, USA) for all 100 HNC patients. Collimator angles of 45°, 30°, and 285° were employed to optimize target conformity and minimize dose to organs at risk (OARs). Target dose objectives aimed for a D95% (dose to 95% of the target volume) ≥95% of the prescribed dose (7000 cGy to PTV1 and 6300 cGy to PTV2), with maximum doses ≤107%. Parotids, mandible, larynx, spinal cord, and brainstem were included as OARs in the optimization process, with dose constraints adhering to QUANTEC guidelines.

Clinical VMAT plans were optimized using the Photon Optimizer (PO) algorithm [22], with final dose calculations performed using the AcurosXB algorithm (Varian Eclipse TPS, version 15.6) on 2.5 mm grid 3D planning CT images [23]. The Halcyon couch was incorporated into the final dose calculation. A dose to medium reporting mode [23] and plan objectives were employed to achieve optimal target coverage and homogeneity, minimize low and intermediate dose spillage, and reduce OAR dose. kV-iCBCT was used for daily image guidance and parameters shown in Figure 1.

Halcyon LINAC and imaging system specifications

The Varian Halcyon V2.0, specifically the Elite model, is a recently introduced fast rotating; coplanar O-ring linear accelerator (LINAC) designed for conventionally fractionated image guided radiation therapy (IGRT) [24-26]. This system is optimized for IMRT and VMAT due to several key features: rapid delivery at 4 RPM with a single 6 MV flattening filter-free (FFF) beam and a dose rate of 800 MU/s; inherent FFF beam operation; specialized multi-leaf collimator (MLC) characteristics; and an automated daily IGRT workflow [24]. Reliable IMRT and VMAT dose calculation and delivery depend on thorough commissioning of the treatment planning system, which

is critically influenced by accurate beam data measurement and modeling. In the Halcyon LINAC, Eclipse uses a factory-defined reference beam model that is fixed and not open to user adjustment [25-26].

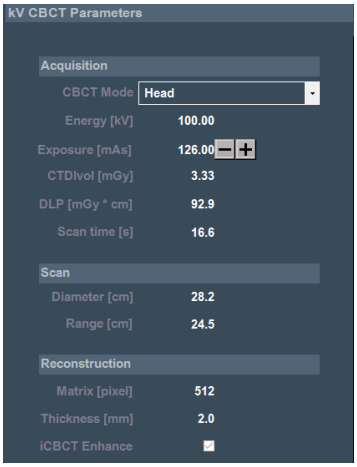

Figure 1. Halcyon Elite kV - iCBCT Enhance parameters for Head and Neck scan acquisition

The effective photon beam energy of the Halcyon system is approximately 1.3 MeV, with the maximum dose occurring at a depth of about 1.3 cm. These beam characteristics closely resemble those of the 6 MV FFF beam produced by the TrueBeam LINAC, which exhibits a mean energy near 1.4 MeV and a depth of dose maximum around 1.5 cm [27]. A key distinction between the Halcyon and Truebeam platforms lies in the MLC design. The Halcyon features newly designed double stacked and staggered 1 cm wide MLC layers [28]. These proximal and distal layers are offset by 5 mm, yielding a projected 5 mm effective MLC width at the isocenter, comparable to a VMAT dedicated Truebeam LINAC. The jawless Halcyon LINAC has a maximum field size of 28 x 28 cm². Furthermore, the Halcyon's MLC leaves exhibit twice the speed of the standard Millennium 120 MLC, and their stacked/staggered configuration results in very low MLC leakage and transmission of less than 0.5% [28-29]. The Halcyon also offers improved penumbra characteristics, with a smaller dosimetric leaf gap (DLG) of 0.1 mm [28]. Apart from megavoltage cone beam computed tomography (MV CBCT), the Halcyon Elite LINAC offers fast onboard imaging with integrated kV cone-beam CT capability. The system leverages an iterative CBCT reconstruction algorithm to achieve rapid image acquisition times of about 15 seconds, enhancing workflow efficiency and image quality for IGRT [30-31].

kV-iCBCT protocol

Figure 2 displays axial, coronal, and sagittal views, along with a dose-volume histogram (DVH), of the 25th fraction's Halcyon kV-iCBCT images registered to the planning CT. These images depict the anatomy and planned dose distribution for image-guided head and neck VMAT on the Halcyon system. Figure 3 presents a comparison of image registration and dose distribution. The left panel shows axial, coronal, and sagittal views of the first fraction's Halcyon kV-iCBCT co-registered with the planning CT for image guided VMAT. The right panel displays the dose distribution overlaid on the co-registered iCBCT from the 28th fraction, illustrating the PTV and dose extending beyond the patient's body contour. kV-iCBCT were acquired in the treatment position and registered to the planning CT using a 3D rigid registration, refined manually. The planning isocenter (P) and CBCT acquisition isocenter (A) are indicated.

Patient-Specific QA: Pretreatment Measurements

Pretreatment patient-specific quality assurance (QA) was performed for each plan before treatment delivery, without the patient present, for verification. Dosimetric verification was performed using PD measurements as part of the QA procedure for each plan before treatment delivery. A gamma evaluation criterion of >95% area gamma passing rate with a 3%/2mm dose to difference (DD), distance-to-agreement (DTA) and a 10% low-dose threshold was used based on the guidelines of AAPM Task Group (TG) 218 [12]. Measurements were acquired using the aS1200 flat panel detector (Varian Medical Systems, Palo Alto, CA, USA), the Halcyon's integrated digital megavoltage imager (DMI) [24]. This detector features a 43 x 43 cm active area, a 1280 x 1280 high resolution pixel array (0.34 mm pixel size, equivalent to 0.22 mm/pixel at the isoplane), and is fixed to a beam stopper at a nominal 152 cm source to imager distance. The DMI incorporates enhanced backscatter reduction and acquires 16 bit images at up to 20 frames per second.

Phantom sensitivity and thickness verification

Sensitivity testing was performed using an ARCCHECK phantom (Sun Nuclear Corporation, Melbourne, FL, USA). Gel boluses of different thicknesses (0, 0.5, 1.0, and 1.5 cm) were placed directly on the ARCCHECK phantom, and scans were acquired. This setup was used for the sensitivity testing. ARCCHECK phantom measurements were taken directly, followed by PD measurements with sequentially inserted gel boluses of varying thicknesses (0, 0.5, 1.0, and 1.5 cm) to assess the sensitivity of the system.

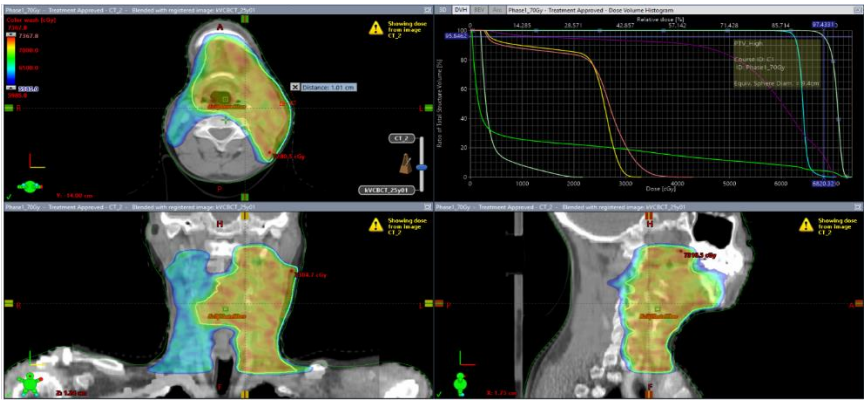

Figure 2. Dose distribution on the 25th fraction iCBCT blended with reference planning images

Figure 3. Dose distribution on 1st and 25th fraction iCBCT blended with reference planning images

In vivo portal dosimetry: Recording and evaluating daily treatment exit dose

Each fraction's portal image for each treatment field was reviewed and evaluated separately. Baseline images were established using the 1st of each patient's treatment. Subsequent treatment deliveries (from the 2nd onward) were compared to these reference baseline images (1st) using planar dose image gamma analysis. The evaluation criteria for individual fields were 3%/2 mm (dose difference/distance to agreement criterion) and a 95% area gamma passing rate. An automated dose constancy check compared each measured portal dose image to a previously acquired baseline portal dose image. The workflow for this dose constancy check was identical to the standard dose analysis workflow (comparison against the predicted dose), except the comparison was made against the baseline image.

Results

Table 2 summarizes the Halcyon V2 Elite model kV-iCBCT characteristics for CBCT imaging. Table 3 summarizes the target coverage, OAR doses for all plans. As shown in Figure 4, the inter-fractional in vivo dose variation decreased linearly across all 100 patients with increasing fractionation. The graph clearly depicts a decreasing linear trend, with a linear regression analysis R^2 value of 0.9724 averaged across all 100 patients. The in vivo dosimetry QA results are presented in the Table 4. A gradual reduction in gamma passing rates was observed after 10 to 15 treatment fractions, with an overall average passing rate of 93.90% ± 3.6% across all patients and fractions.

The in vivo dosimetry QA results (10,500 fields) are summarized in Table 4. Gamma passing rates showed a gradual decline with fractionation (R=0.9724; Figure 4), with overall mean 93.9 ± 3.6%. At key fractions 1,5,10,15,20,25,30,35: Arc 1 = 99.94 ± 0.14%, 98.21±3.34%, 97.34±4.99%, 95.90±6.31%, 94.81±7.25%, 91.59±12.39%, 90.00±11.14%, 88.19±12.05%; Arc 2 = 99.90±0.14%, 98.43±2.83%, 97.34±4.99%, 95.90±6.40%, 94.95±6.96%, 91.89±9.39%, 90.12±10.18%, 87.89±12.88%; Arc 3 = 98.97±8.96%, 97.92±3.57%, 96.77±5.51%, 95.45±6.41%, 94.12±8.18%, 91.06±10.31%, 89.18±11.06%, 87.09±12.90% (all Table 4). Stability held through Fraction 10 (>97%), with consistent decline after Fraction 15 and >68% of fields <90% beyond Fraction 25, correlating with anatomical changes >1 cm thickness. Pretreatment patient specific quality assurance (QA) results were evaluated and are presented in Table 4. Portal dosimetry gamma evaluation yielded a mean passing rate of 100% for all patients.

ARCCHECK phantom sensitivity testing, using 2%/2 mm criteria, detected dose changes for thickness variations

above 1.0 cm at a rate of 95.60% and noticeable dose variations for changes below 0.5 cm at a rate of 69.10% using 1%/1mm criteria. PD sensitivity testing detected dose changes for 1.5 cm thickness variations at rates of 87.10 and 91.20% using 2%/2 mm criteria. PD sensitivity testing also detected dose changes for 1.5 cm thickness variations at rates of 90.9% and 94.2% using 3%/2 mm criteria. The ARCCHECK and PD sensitivity test results are shown in Figures 5 and 6 respectively.

Table 2. Halcyon V2 Elite model - KV iCBCT characteristics

S.No	Characteristics	KV iCBCT - details
1	Energy	80–140 kVp
2	Modes	11 clinical protocols
3	CBCT Scan time	From 16.6 s (Head and neck, Breast and Thorax modes) to 40.6 s (Pelvis modes)
4	Scan diameter	49.1 cm
5	Scan range	24.5 cm
6	Imager offset	17.5-cm lateral offset
7	Bow-tie filters	Half bow tie/titanium filters
8	Pixel resolution	1280 x 1280 (Maximum: 43 cm x 43 cm DMI panel)
9	Reconstruction thickness	2-mm slice thickness
10	Reconstruction algorithm	Conventional FDK (CBCT), iterative process (iCBCT; nonlinear/statistical) New algorithm (iterative statistical reconstruction) added: Designed to remove noise and enhance image quality with high resolution.

Table 3. Evaluation of PTV coverage and OAR dose's for 100 HNC VMAT patient plans. Prescription dose PTV1 was 7000 cGy and PTV2 was 6300 cGy in 35#.

Target volume	Parameters	HNC VMAT Plans
PTV1	$PTVD_{95}$ (%)	99.56 ± 0.49 (99.97-97.74)
	Mean	7022.65 ± 24.51 (7060-6966)
	HI	0.05 ± 0.01 (0.08-0.04)
	CI	1.18 ± 0.07 (1.32-1.06)
PTV2	$PTVD_{95}$ (%)	99.70 ± 0.41 (99.97-98.00)
Total MUs	Monitor units	692.94 ± 53.29 (777.5-603.2)
Dose to OAR	Parameters	HNC VMAT Plans
Brain stem (cGy)	Dmax	2813.00 ± 10.68 (4022.0-425.0)
Brain stem PRV (cGy)	Dmax	3318.12 ± 11.55 (4235.1-685.9)
Spinal cord (cGy)	Dmax	3446.03 ± 1.42 (3743.2-321.1)
Spinal cord PRV (cGy)	Dmax	4441.11 ± 3.29 (5008.1-3778.2)
Mandible (cGy)	Dmax	7160.25 ± 1.66(7345.2-6517.5)
LT Parotid (cGy)	Dmean	2592.45 ± 6.42 (3768.1-1106.8)
RT Parotid (cGy)	Dmean	2384.55 ± 3.57 (3125.4-1495.6)
Larynx (cGy)	Dmean	2679.36 ± 7.21 (4261.5-1478.8)

Note: Values are reported as Mean ± SD (range).

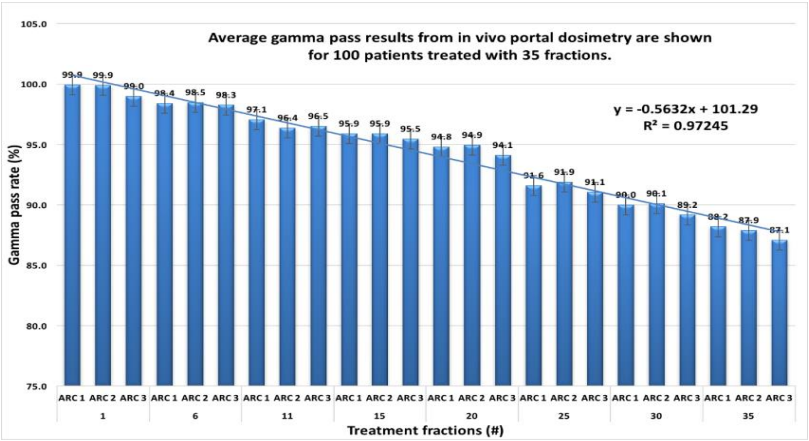

Figure 4. Inter fractional exit dose change using in vivo portal dosimetry

Table 4. In vivo gamma passing rates (Mean ± SD, %) for 3 VMAT arcs across 35 fractions (n=100 patients, 10, 500 fields total) 3%/2mm criterion, baseline=Fraction 1.

Fractions No.	Arc 1 (%)	Arc 2 (%)	Arc 3 (%)
Pretreatment QA	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
1 (Baseline)	99.94 ± 0.14	99.90 ± 0.14	98.97 ± 8.96
5	98.21 ± 3.34	98.43 ± 2.83	97.92 ± 3.57
10	97.34 ± 4.99	97.31 ± 5.23	96.77 ± 5.51
15	95.90 ± 6.31	95.90 ± 6.40	95.45 ± 6.41
20	94.81 ± 7.25	94.95 ± 6.96	94.12 ± 8.18
25	91.59 ± 12.39	91.89 ± 9.39	91.06 ± 10.31
30	90.00 ± 11.14	90.12 ± 10.18	89.18 ± 11.06
35	88.19 ± 12.05	87.89 ± 12.88	87.09 ± 12.90

Note: Values are reported as rates (Mean ± SD, %), Beyond fraction 25, 68% of fields (Arcs 1-3) fell <90%.

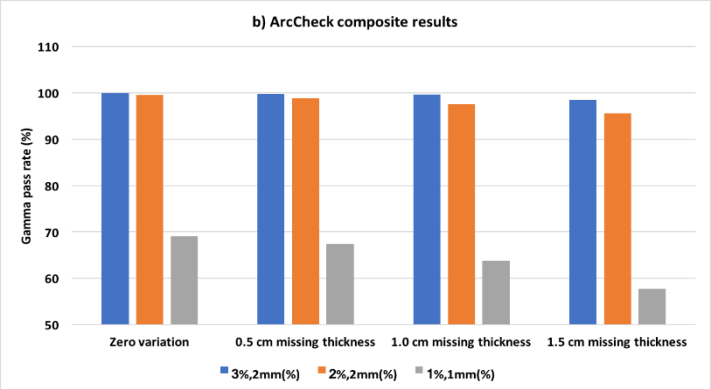

Figure 5. ArcCheck phantom sensitivity test results

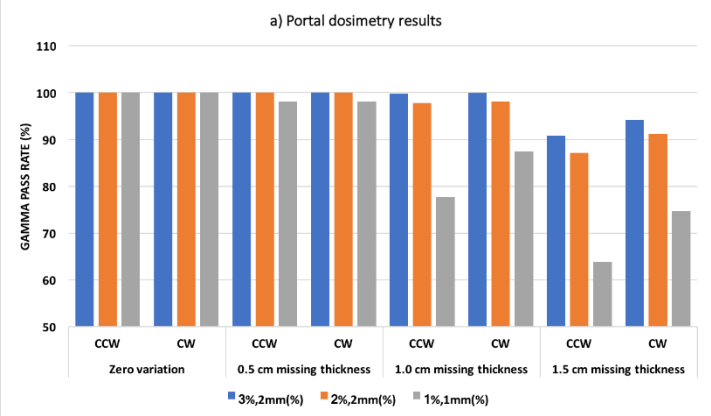

Figure 6. Portal dosimetry sensitivity test results

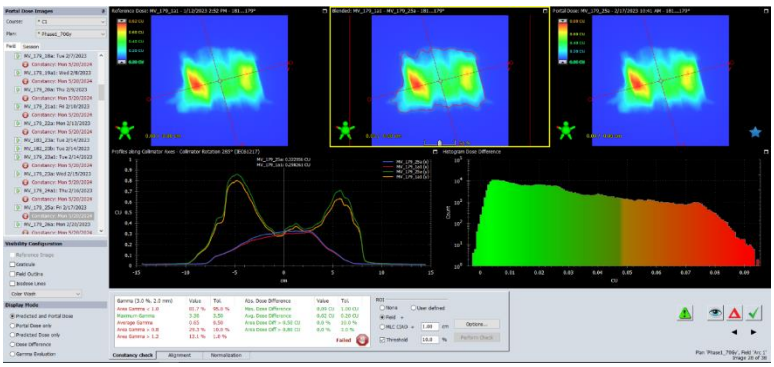

Figure 7. Distributions of patient-specific VMAT portal dosimetry quality assurance (PD-QA) performed for the HNC VMAT patient on the Halcyon

Figure 7 illustrates portal fluence map comparisons and VMAT Portal dosimetry QA results. The left panel shows the EPID fluence map for a single field from the first fraction's Arc 1 (baseline). The right panel shows the corresponding fluence map from the 25th fraction. The top middle panel presents a blended view of these two fluence maps. The bottom graph displays the VMAT Portal dosimetry QA pass rate of 81.7%, calculated using a 3%/2 mm clinical gamma criterion. 3D CBCT was performed before each fraction for setup verification. All patients scanned iterative CBCT (iCBCT) in head mode (parameters shown in Figure 1) with a 360° rotation for every fraction. Reconstruction added 15 seconds to the process. kV-iCBCT was used for daily IGRT due to its superior soft tissue visualization; MV imaging was not employed. The kV-iCBCT dose is not included in Halcyon V2.0 dose calculations. Conversely, the MV imaging dose, if acquired, is incorporated into the final dose calculation and is fixed for the given plan.

Discussion

A retrospective analysis of in vivo dosimetry data was performed for 100 head and neck cancer patients treated across 35 fractions each (10,500 total fields) using a Halcyon LINAC. The in-vivo dosimetry QA results, summarized in Table 4, reveal a clear trend of decreasing gamma passing rates, indicating dose deviations with increasing fractionation as illustrated in Figure 4. The strong linear correlation (R^2 = 0.9724, averaged across all 100 patients) suggests a systematic change occurring throughout treatment. This observed trend aligns with expected anatomical and physiological changes in head and neck cancer patients undergoing radiotherapy, such as weight loss, tumor regression, and parotid gland volume reduction. This gradual decreasing trend in gamma passing rates, starting after 10-15th fractions and falling below 90% by the 25th fraction for individual arc fields, further highlights the significant impact of these changes. The observed dose deviations, averaging 10-15% in the latter 20 fractions, raise concerns about potential clinical implications, especially given the consistent detection of gamma passing rate failures for treatment thickness changes exceeding 1.0 cm.

The sensitivity testing results provide valuable context for interpreting the clinical in vivo dosimetry findings. The ARCCHECK phantom tests demonstrate the system's ability to detect dose changes associated with thickness variations above 1.0 cm with high accuracy (95.6% detection rate using 2%/2mm criteria). While the sensitivity for more minor thickness changes (below 0.5 cm) is lower (69.1% detection rate with 1%/1mm criteria), the trend is still noticeable. The portal dosimetry sensitivity tests corroborate these findings, showing robust detection of dose changes for 1.5 cm thickness variations across both 2%/2mm (87.1% and 91.2% detection rates) and 3%/2mm (90.9% and 94.2% detection rates) criteria. The combined results from the ARCCHECK and PD sensitivity tests suggest that the observed gamma passing rate reductions in the clinical setting are likely attributable to anatomical and/or setup variations occurring throughout the treatment course.

Aland et al. [32] developed an in IVDc tool for pelvic and HNC patients undergoing VMAT. They compared 96 portal dose images from eight patients with planning target volume (PTV) metrics derived from daily CBCT based treatment plan recalculations to assess the IVDc tool's ability to detect inter-fractional anatomical changes. The tool's application was then demonstrated using a separate cohort of 315 portal dose images from 22 patients. Using a 95% (2%/2 mm) IVDc passing criterion, the tool identified all cases in the 96 image cohort exhibiting 2% or more PTV metric changes. Applying the same 95% passing criterion to the 315-image cohort resulted in 74 IVDc failures. Our study's findings are consistent with these published results.

Aland et al. [32] reported 74/315 (23.4%) IVDc failures (95%/2%, 2 mm criteria) in a mixed cohort (pelvic and HNC) of 22 patients, higher than Kim et al.'s 2.7% in gynecological cases using less stringent criteria [16]. In Aland's pelvic subset (n=179), only 8/179 (4.5%) failed, aligning with Kim et al. after criteria adjustment. Our HNC cohort showed higher late-fraction failures (e.g., 11-15% below 90% post-fraction 25, Table 4), attributable to greater anatomical changes like weight loss and tumor shrinkage versus pelvic stability.

Figure 2 illustrates anatomical changes and corresponding dose distribution variations during treatment. The co-registered 25th fraction kV-iCBCT and planning CT images reveal anatomical shifts, and the overlaid dose distribution demonstrates the potential impact on target coverage and OAR sparing. The observed extension of the PTV outside the body in later fractions, coupled with the associated dose distribution changes, emphasizes the importance of adaptive radiation therapy strategies in HNC treatment.

Recent AAPM TG 218 recommendations [12] outline IMRT QA methodologies and tolerances. The true composite (TC) method, delivering all beams to a measurement device using actual patient geometry, is considered the most clinically relevant. Field by field (FF) analysis aids in identifying subtle errors within individual, highly modulated fields. EPID based portal dosimetry offers a convenient and efficient approach for both TC and FF analyses compared to other device-based methods. These findings highlight the utility of in vivo dosimetry for treatment monitoring and identifying patients potentially requiring plan adaptation.

This study has several limitations. Primarily, the IVDc tool, by comparing results of the day 1 data, cannot detect anatomical changes occurring between simulation and the start of treatment, limiting its scope to changes arising during treatment. Furthermore, the first treatment fraction's in vivo portal dose image served as the reference due to the inability to calculate the predicted portal dose image from the treatment planning system. While using the expected portal dose

as a reference would allow for tolerance criteria validation as in pretreatment QA and improve quantitative evaluation of daily EPID based treatment verification on the Halcyon, this study's focus on inter-fractional in vivo dose variation was effectively addressed by using the first fraction as a baseline to verify delivery consistency. Finally, while intra fractional motion was not investigated, existing research suggests it does not significantly impact dosimetry for HNC treatments under 10 minutes.

Conclusion

This study demonstrates the potential of the Halcyon LINAC's integrated PD system and Varian PD software for IVDc in HNC patients treated with VMAT. The results confirm the feasibility of using in vivo MV portal images acquired on the Halcyon O-ring LINAC to assess dose consistency throughout treatment. This convenient and efficient method facilitates treatment monitoring and identification of patients who may benefit from adaptive strategies, potentially leading to improved patient outcomes.

References

1. Zhang S, Zeng N, Yang J, He J, Zhu F, Liao W, et al. Advancements of radiotherapy for recurrent head and neck cancer in modern era. Radiat Oncol. 2023;18(1):166.
2. Grégoire V, Langendijk JA, Nuyts S. Advances in radiotherapy for head and neck cancer. J Clin Oncol. 2015;33(29):3277-84.
3. Anderson G, Ebadi M, Vo K, Novak J, Govindarajan A, Amini A. An updated review on head and neck cancer treatment with radiation therapy. Cancers (Basel). 2021;13(19):4912.
4. Alterio D, Marvaso G, Ferrari A, Volpe S, Orecchia R, Jereczek-Fossa BA. Modern radiotherapy for head and neck cancer. Semin Oncol. 2019;46(3):233-45.
5. Teoh M, Clark CH, Wood K, Whitaker S, Nisbet A. Volumetric modulated arc therapy: a review of current literature and clinical use in practice. Br J Radiol. 2011;84(1007):967-96.
6. Hunte SO, Clark CH, Zyuzikov N, Nisbet A. Volumetric modulated arc therapy (VMAT): a review of clinical outcomes—what is the clinical evidence for the most effective implementation? Br J Radiol. 2022;95(1136):20201289.
7. Buciuman N, Marcu LG. Dosimetric justification for the use of volumetric modulated arc therapy in head and neck cancer—a systematic review of the literature. Laryngoscope Investig Otolaryngol. 2021;6(5):999-1007.
8. Buciuman N, Marcu LG. Adaptive radiotherapy in head and neck cancer using volumetric modulated arc therapy. J Pers Med. 2022;12(5):668.
9. Sreejeev AT, Joseph D, Krishnan AS, Pasricha R, Gupta S, Ahuja R, et al. Weekly assessment of volumetric and dosimetric changes during volumetric modulated arc therapy of locally advanced head and neck carcinoma: implications for adaptive radiation therapy—a prospective study. Head Neck. 2024;46(7):1547-56.
10. Maheshwari G, Dhanawat A, Kumar HS, Sharma N, Jakhar SL. Clinical and dosimetric impact of adaptive intensity-modulated radiotherapy in locally advanced head-and-neck cancer. J Cancer Res Ther. 2020;16(3):600-4.
11. Burela N, Soni TP, Patni N, Natarajan T. Adaptive intensity-modulated radiotherapy in head-and-neck cancer: a volumetric and dosimetric study. J Cancer Res Ther. 2019;15(3):533-8.
12. Miften M, Olch A, Mihailidis D, Moran J, Pawlicki T, Molineu A, et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: recommendations of AAPM Task Group No. 218. Med Phys. 2018;45(4):e53-83.
13. Bojechko C, Phillips M, Kalet A, Ford EC. A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy. Med Phys. 2015;42(9):5363-9.
14. Min S, Choi YE, Kwak J, Cho B. Practical approach for pretreatment verification of IMRT with flattening filter-free (FFF) beams using Varian portal dosimetry. J Appl Clin Med Phys. 2015;16(1):40-50.
15. Nailon WH, Welsh D, McDonald K, Burns D, Forsyth J, Cooke G, et al. EPID-based in vivo dosimetry using Dosimetry Check®: overview and clinical experience in a 5-yr study including breast, lung, prostate, and head and neck cancer patients. J Appl Clin Med Phys. 2019;20(1):6-16.
16. Kim H, Huq MS, Lalonde R, Houser CJ, Beriwal S, Heron DE. Early clinical experience with Varian Halcyon V2 linear accelerator: dual-isocenter IMRT planning and delivery with portal dosimetry for gynecological cancer treatments. J Appl Clin Med Phys. 2019;20(11):111-20.
17. MacDougall ND, Graveling M, Hansen VN, Brownsword K, Morgan A. In vivo dosimetry in UK external beam radiotherapy: current and future usage. Br J Radiol. 2017;90(1072):20160915.
18. Olaciregui-Ruiz I, Beddar S, Greer P, Jornet N, McCurdy B, Paiva-Fonseca G, et al. In vivo dosimetry in external beam photon radiotherapy: requirements and future directions for research, development, and clinical practice. Phys Imaging Radiat Oncol. 2020;15:108-16.
19. Mijnheer B, Beddar S, Izewska J, Reft C. In vivo dosimetry in external beam radiotherapy. Med Phys. 2013;40(7):070903.
20. Gros SA, Xu W, Roeske JC, Choi M, Emami B, Surucu M. A novel surrogate to identify anatomical changes during radiotherapy of head and neck cancer patients. Med Phys. 2017;44(3):924-34.
21. Esteyrie V, Gleyzolle B, Lusque A, Graff P, Modesto A, Rives M, et al. The GIRAFE phase II trial on MVCT-based volumes of the day and dose of the day addresses when and how to implement adaptive radiotherapy for locally advanced head and neck cancer. Clin Transl Radiat Oncol. 2019;16:34-9.
22. Sundaram V, Khanna D, Mohandass P, Vasudeva T. Comparison of Progressive Resolution Optimizer and Photon Optimizer algorithms in RapidArc delivery for head and neck SIB treatments. Rep Pract Oncol Radiother. 2023;28(5):623-35.

23. Miyasaka R, Cho S, Hiraoka T, Chiba K, Kawachi T, Katayose T, et al. Investigation of Halcyon multileaf collimator model in Eclipse treatment planning system: a focus on the VMAT dose calculation with the Acuros XB algorithm. J Appl Clin Med Phys. 2022;23(3):e13519.
24. Varian Halcyon Linac. Customer user manual. 2019.
25. Fogliata A, Cayez R, Garcia R, Khamphan C, Reggiori G, Scorsetti M, et al. Flattening filter free beams from Halcyon linac: evaluation of the profile parameters for quality assurance. Med Phys. 2020;47(8):3669-74.
26. Gao S, Netherton T, Chetvertkov MA, Li Y, Court LE, Simon WE, et al. Acceptance and verification of the Halcyon-Eclipse linear accelerator-treatment planning system without 3D water scanning system. J Appl Clin Med Phys. 2019;20(10):111-7.
27. Glide-Hurst CK, Bellon M, Foster R, Altunbas C, Speiser M, Altman M, et al. Commissioning of the Varian TrueBeam linear accelerator: a multi-institutional study. Med Phys. 2013;40(3):031719.
28. Lim TY, Dragojević I, Hoffman D, Flores-Martinez E, Kim GY. Characterization of the Halcyon™ multileaf collimator system. J Appl Clin Med Phys. 2019;20(4):106-14.
29. Miyasaka R, Cho S, Hiraoka T, Chiba K, Kawachi T, Katayose T, et al. Investigation of Halcyon multileaf collimator model in Eclipse treatment planning system: a focus on the VMAT dose calculation with the Acuros XB algorithm. J Appl Clin Med Phys. 2022;23(3):e13519.
30. Jarema T, Aland T. Using the iterative kV CBCT reconstruction on the Varian Halcyon linear accelerator for radiation therapy planning for pelvis patients. Phys Med. 2019;68:112-6.
31. Cai B, Laugeman E, Mazur TR, Park JC, Henke LE, Kim H, et al. Characterization of a prototype rapid kilovoltage x-ray image guidance system designed for a ring shape radiation therapy unit. Med Phys. 2019;46(3):1355-70.
32. Aland T, Jarema T, Spalding M, Kairn T, Trapp J. Use of in vivo transit portal images to detect gross inter-fraction patient geometry changes on an O-ring type linear accelerator for pelvis and head-neck patients. Biomed Phys Eng Express. 2021;7(6):065036.